



EARTHTIME

Educators Guide

How do we measure time?



DENVER MUSEUM OF
NATURE & SCIENCE

How Do We Measure Time?

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Overview

Time is fleeting, if not instantaneous for most students. Our fast paced world seems to be one reason it is hard for students to understand the vast amount of time Earth has been in existence. However, being able to comprehend the enormity of Earth's history is difficult, even for adults. It is hard for most of us to comprehend that Earth has been around for about 4.567 billion years. A major goal of the EARTHTIME Education Project is to develop a better understanding of Earth's history or "deep time." The *How Do We Measure Time?* Curricula (Grades 5-8 and 9-10) provide teachers with thoughtfully sequenced activities, investigations, video chapters, and readings to help students on their journey to understanding how Earth's history has changed over billions of years. Dr. Kirk Johnson, Chief Curator and Vice President of Research and Collections at the Denver Museum of Nature & Science, and Dr. Samuel Bowring of the EARTHTIME Project at the Massachusetts Institute of Technology, are the scientists that students connect with as they work to develop the concepts of relative and absolute age.

Deep time is easy for geoscientists to understand since it is the framework of their science. But, in order for our students to have a better understanding of Earth and how it changes, from climate change, to extinction, to the evolution of plant and animal species (all National Science Education Standards [NSES]), it is necessary for them to have exposure in meaningful ways to Earth's history.

Research shows that students come to us with preconceptions about the Earth. Therefore, students need multiple opportunities to explore difficult concepts if they are to integrate new learning into their knowledge framework. Students also need opportunities to explore new concepts, or they may fail to learn them.

How People Learn (NRC, 2000) provides us with three important implications for teaching. First, we need to uncover students' preexisting understandings and work with them based on that information. More specifically, research has identified many difficult concepts and preconceptions regarding Earth's history. Some of those preconceptions include:

- Dinosaurs all lived at the same time (Smithsonian National Museum of Natural History, 2007).
- Cavemen lived during the time of dinosaurs (Operation Physics, 1998).
- Sedimentary layers in an outcrop are caused by rivers running through an area resulting in a bathtub ring phenomenon (FOSS Earth History, 2001).
- The planet Earth and complex life on Earth originated at the same time (Comins, 1993).
- Soil has always been in its present form (Operation Physics, 1998).
- Mountain ranges form rapidly (Operation Physics, 1998).
- Every plant and animal species from the past has been fossilized. (Matthews, 1996).
- Most fossils that are found are complete. (Matthews, 1996).
- Humans are responsible for the extinction of dinosaurs (Operation Physics, 1998).
- The number "one billion" is a very abstract concept for students (Llewellyn, 2005).



- Students may “clump” ideas about events in Earth’s history according to their present understandings (e.g., young, old, really old) (Trend, 2001)
- A student’s spatial ability may need further development in order to understand deep time (Abell & Lederman, 2006).

Secondly, students need to have multiple experiences around a concept to develop good understanding. The curriculum provided for you is only a beginning point for your students. Multiple classes in high school should further the development of the concept of the vastness of Earth’s history including earth science, biology, and chemistry.

Metacognition, learning to think about one’s thinking and learning, is the last principle addressing student learning. Writing about one’s learning and sharing one’s thinking are two easy ways to incorporate this principle into the science classroom. The lessons in the *How Do We Measure Earth Time?* include questions for discussion and writing prompts to help students process their learning.

Another goal of the EARTHTIME Project is for students to realize that scientists cannot work alone. The fieldwork done by Dr. Kirk Johnson involves a team of scientists, as well as the work done by Dr. Samuel Bowring at the MIT EARTHTIME Lab. It is important for students to see the collaboration between the groups and understand the number of people involved in establishing a rock sample’s age. Activities in the curricula depend on group work for the collection and analysis of data, modeling the real-life cooperative work of scientists.

The curriculum was developed using the National Science Education Standards. The middle school curriculum (intended for Grades 5-8) focuses on developing the Principles of Superposition and Horizontality through the relative dating of the Earth and an introduction to absolute dating. The high school curriculum (intended for Grades 9-10) addresses the same concepts but with an additional focus on radiometric dating.

Each curriculum takes a little more than one week to complete all activities and investigations. One difficulty in teaching earth science is that a crucial part of the science is making observations in the field. We know that geology fieldtrips are not easily accomplished at many middle schools and high schools, although they are extremely helpful. The models, investigations, and activities included in this curriculum are intended for use in the classroom.

The How Do We Measure Time? Curriculum uses the 5E instructional model developed by the Biological Sciences Curriculum Study (BSCS). It is hoped that teachers spend the time needed for each phase: Engage, Explore, Explain, Elaborate, and Evaluate. Recommendations for a “shorter version” are included in this manual, as well as optional activities to further understanding.



Understanding the 5E Model

The “5 Es” are phases of a model that strategically develops conceptual understanding. What does this mean for the classroom teacher? It means that when followed, the 5E learning cycle addresses how students learn. The 5E Model can be used in a lesson, a unit, or in curriculum programs. The summary below explains how a classroom teacher can implement the model.

Summary of the BSCS 5E Instructional Model

Phase	Summary
Engagement	The teacher, or a curriculum task, accesses the learners’ prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students’ thinking toward the learning outcomes of current activities.
Exploration	Exploration experiences provide students with a common base of activities within which current concepts (i.e. preconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and/or design and conduct a preliminary investigation.
Explanation	The explanation phase focuses students’ attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.
Elaboration	Teachers challenge and extend students’ conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.
Evaluation	The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

The summary is an excerpt from *The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications* written by Rodger W. Bybee, Joseph A. Taylor, April Gardner, Pamela Van Scotter, Janet Carlson Powell, Anne Westbrook, and Nancy Landes as an Executive Summary in 2006.



National Science Education Standards

The following National Science Education Content Standards, along with fundamental concepts and principles that underlie each standard, are listed according to grade level groups:

Science as Inquiry – Content Standard A

As a result of activities in grades 5-8 and grades 9-12, all students should develop:

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Grades 5-8 abilities necessary to do scientific inquiry:

- Identify questions that can be answered through scientific investigations.
- Design and conduct a scientific investigation.
- Use appropriate tools and technology to gather, analyze, and interpret data.
- Develop descriptions, explanations, predictions, and models using evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate scientific procedures and explanations.
- Use mathematics in all aspects of scientific inquiry.

Grades 5-8 understandings about scientific inquiry:

- Different kinds of question suggest different kinds of scientific investigations.
- Current scientific knowledge and understanding guide scientific investigations.
- Mathematics is important in all aspects of scientific inquiry.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- Science advances through legitimate skepticism.
- Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data.
- Identify questions and concepts that guide scientific investigations.



Grades 9-12 abilities necessary to do scientific inquiry:

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument.

Grades 9-12 understandings about scientific inquiry:

- Scientists usually inquire about how physical, living, or designed systems function.
- Scientists conduct investigations for a wide variety of reasons.
- Scientists rely on technology to enhance the gathering and manipulation of data.
- Mathematics is essential in scientific inquiry.
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.
- Results of scientific inquiry - new knowledge and methods - emerge from different types of investigations and public communication among scientists.

Physical Science - Content Standard B

As a result of their activities in grades 5-8, all students should develop and understanding of:

- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

Fundamental concepts and principles that underlie this standard in grades 5-8 include:

- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.
- In most chemical and nuclear reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might be involved in such transfers.



As a result of their activities in grades 9-12, all students should develop and understanding of:

- Structure of atoms
- Structure and properties of matter

Fundamental concepts and principles that underlie this standard in grades 9-12 include:

- Most elements have two or more isotopes (i.e., atoms that differ in the number of neutrons in the nucleus); although the number of neutrons has little effect on how the atom interacts with others, it does affect the mass and stability of the nucleus.
- Radioactive isotopes can be used to estimate the age of materials that contain them because radioactive isotopes undergo spontaneous nuclear reactions and emit particles and/or wavelike radiation; the decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate, which can be used to estimate the material's age.

Life Science – Content Standard C

As a result of their activities in grades 9-12, all students should develop an understanding of:

- Biological evolution

Fundamental concepts and principles that underlie this standard in grades 9-12 include:

- The great diversity of organisms is the result of more than 3.5 billion years of evolution that has filled every available niche with life forms.

Earth and Space Science – Content Standard D

As a result of their activities in grades 5-8, all students should develop an understanding of:

- Structure of the Earth system
- Earth's history
- Earth in the solar system

Fundamental concepts and principles that underlie this standard in grades 5-8 include:

- The Earth processes we see today, including erosion, movement of lithospheric plates, and changes in atmospheric composition, are similar to those that occurred in the past, Earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet.
- Fossils provide important evidence of how life and environmental conditions have changed.



As a result of their activities in grades 9-12, all students should develop an understanding of:

- Energy in the Earth system
- Geochemical cycles
- Origin and evolution of the Earth system
- Origin and evolution of the universe

Fundamental concepts and principles that underlie this standard in grades 9-12 include:

- Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates of radioactive isotopes present in rocks to measure the time since the rock was formed.
- Interactions among the solid Earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the Earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take over hundreds of millions of years.

History and Nature of Science – Content Standard G

As a result of the activities in grades 5-8 and 9-12, all students should develop an understanding of:

- Science as a human endeavor
- Nature of scientific understanding
- Historical perspectives

Fundamental concepts and principles that underlie this standard in grades 5-8 include:

- Science requires different abilities, depending upon such factors as the field of study and type of inquiry.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- Tracing the history of science can show how difficult it was for scientific innovations to break through the accepted ideas of their time to reach the conclusions that we currently take for granted.

Fundamental concepts and principles that underlie this standard in grades 9-12 include:

- Individuals and teams have contributed to and will continue to the scientific enterprise.
- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available.
- Usually, changes in science occur as small modification in extant knowledge.



EARTHTIME DVD Outline

Introduction - EARTHTIME

- Gould's metaphor of the arm
- Sagan's metaphor of the yearly calendar

Chapter 1 – Determining the Age of Things

- Comparison of Human to Earth with times
- Compare tree rings to layers of Earth
- Introduction that volcanic ash layers can help date rock layers

Chapter 2 – Zircon Time Capsules

- Volcanic ash is found in layers of rock all over the world and occurred and occurs at various times in Earth's history
- Zircon crystals are time capsules found in volcanic ash
- Overview of dating rock layers

Chapter 3 – Scientific Process: Observation, Hypothesis, and Prediction

- Two Groups of Scientists That Solve Age Problems
 - Field scientists – paleontologists and geologists
 - Lab scientists – geochronologists
- Why they collaborate

Chapter 4 – Half-Life: Atomic Decay

- What it is
- Why zircon is a good crystal to use to date rocks

Chapter 5 Scientific Process: In the Field – Data Collection and Collaboration

- What paleontologists/geologists do know from fieldwork
- How rock samples are collected for the lab

Chapter 6 – Scientific Process: In the Lab Testing and Data Analysis

- Breaking down rock samples
- Separating crystals
- Use of mass spectrometer
- Use of computer to calculate precise age



Chapter 7 - The Future

- Continued collaborative effort
- Type of scientists needed for work

Data Cast

- Question and Answer Period – Students ask Dr. Kirk Johnson and Dr. Sam Bowring questions about dating rock layers.

Vocabulary Development

There are ultimately three goals from learning vocabulary in science. One is to be better prepared to read and understand science texts. The second is to develop understanding of science concepts. Finally, the third is to be able to communicate science understanding through speaking and writing.

Science text tends to be dense. The number of new words introduced and concepts covered can be mind boggling to our students. Each content area in our students' day has its own language. Our students' minds click back and forth depending on the content they are engaged with at any given time. When students come to the science classroom, they need to be science language specialists. When students move on to math class, they need to become proficient communicators of mathematics. What we must do as science teachers is make our language meaningful to our students.

There are some easy ways to do that:

1. When appropriate, use the words often in class. Do not introduce a term until after students have had an experience with the term or concept.
2. Provide examples of terms used. This can be done orally, pictorially, or even with realia. There is nothing wrong with labeling rocks and having them on display in the classroom, hanging pictures of uplifted land features, or drawing pictures of concepts.
3. Though the vocabulary list is long in this curriculum, focus only on words you have identified as important for your students.
4. For this curriculum, use the following 3 Column Strategy when you have students write vocabulary in their science notebooks:
 - a. Divide the paper into three columns.
 - b. Students write the word in the first column.
 - c. Students draw a picture of the term in the second column. (The use of nonlinguistic representations is one of Marzano's Ten Best Practices.)
 - d. Students give examples or create their own definition in the third column.

By processing the term in a number of ways, students have a better chance of understanding it and using the word in class.



Literature Resources

For the teacher:

Johnson, K. R., & Reynolds, R. (2006). Ancient Denvers Scenes from the past 300 Million Years of the Colorado Front Range. Golden, CO: Fulcrum Pub.

Johnson, K. R., & Stucky, R. K. (2006). Prehistoric Journey: a History of Life on Earth. Golden, CO: Fulcrum Pub. , 144 p.

Johnson, K. R., & Troll, R. (2007). Cruisin' the Fossil Freeway: an Epoch Tale of a Scientist and an Artist on the Ultimate 5,000-mile Paleo Road Trip. Golden, CO: Fulcrum Pub., 204 p.

Mathez, E. A., & Webster, J. D. (2004). The Earth Machine: the Science of a Dynamic Planet. New York: Columbia University Press.

Tarbuck, E. J., & Lutgens, F. K. (2003). Earth Science. Upper Saddle River, NJ: Prentice Hall.

For the student:

Johnson, K. R., & Reynolds, R. (2006). Ancient Denvers Scenes from the past 300 Million Years of the Colorado Front Range. Golden, CO: Fulcrum Pub.

Johnson, K. R., & Stucky, R. K. (2006). Prehistoric Journey: a History of Life on Earth. Golden, CO: Fulcrum Pub. , 144 p.

Web Resources

To visit the EARTHTIME website or download a copy of this curriculum, visit www.EARTHTIME.org

More sites for the teacher:

Age of the Earth – United States Geological Survey article about determining the age of rocks
<http://wrgis.wr.usgs.gov/docs/parks/gtime/ageofearth.html>

Ancient Denvers
www.dmnh.org/main/minisites/ancientDenvers/index.html

Introduction to Cyanobacteria
<http://www.ucmp.berkeley.edu/bacteria/cyanointro.html>

Date a Rock: Finding the Ages of Rocks and Fossils – Teacher lessons
<http://www.indiana.edu/~ensiweb/lessons/deep.les.html>

Deep Time: Finding the Ages of Rocks and Fossils – Teacher lessons
<http://www.indiana.edu/~ensiweb/lessons/deep.les.html>



Earth Science: On the Origin of the Earth
<http://scienceweek.com/2004/sa040319-1.htm>

Fossils
http://www.seismo.berkeley.edu/seismo/istat/9th/index_fossils.html

Fossils, Rock, and Time (an online book)
<http://pubs.usgs.gov/gip/fossils/contents.html>

Geological Society of America
<http://www.geosociety.org/educate/>

Nova: A Brief History of Life-Interactive Geologic Time Scale
<http://www.pbs.org/wgbh/nova/origins/life.html>

Nova: Origins: Earth is Born (for Teachers)
http://www.pbs.org/wgbh/nova/teachers/programs/3111_origins.html

Nova: Origins Game – an interactive game about research done about Earth and life’s origins
<http://www.pbs.org/wgbh/nova/origins/earth.html>

Plate Tectonics
<http://www.ucmp.berkeley.edu/geology/tectonics.html>

Saving Your Ears and Dating the Earth – a radio talk by Dr. Sam Bowring with the American Museum of Natural History
http://www.mos.org/topics/earth_and_space_sciences?events_activities/podcasts&d=1510

Science Mission Directorate
http://www.earth.nasa.gov/flash_top.html

Sedimental Journey: Fossils in the Context of Geological Time – a tour of the fossil history of Earth
<http://www.flmnh.ufl.edu/fhc/sedjourn1.htm>

Time Machine – Teacher lesson
<http://www.indiana.edu/~ensiweb/lessons/time.mac.html>

Tree of Life Web Project
<http://tolweb.org/tree/phylogeny.html>

Tour of Geologic Time – Online exhibit introductory page
www.ucmp.berkeley.edu/exhibits/geologictime.php

United States Geological Survey – A Tapestry of Time and Terrain, the union of two types of maps
 geologic and topographic
<http://tapestry.usgs.gov/>



United States Geological Survey – Map of Geologic Time

<http://pubs.usgs.gov/gip/geotime/time.html>

University of California Museum of Paleontology (Online Exhibits)

www.ucmp.berkeley.edu/exhibits/index.php

Virtual Age Dating – a tutorial on dating rocks

<http://www.sciencecourseware.org/VirtualDatingDemo/index.html>

Web Time Machine – Geologic time scale with links for each time interval

<http://www.ucmp.berkeley.edu/help/timeform.html>

Who's on First? A Relative Dating Activity

<http://www.ucmp.berkeley.edu/fosrec/BarBar.html>

Zircon Chronology – an excerpt from the book, Earth Inside and Out

http://www.amnh.org/education/resources/rfl/web/essaybooks/earth/cs_zircon_chronolgy.html

Student Web Sites (High School Appropriate)

Ancient Denvers

www.dmnh.org/main/minisites/ancientDenvers/index.html

Nova: A Brief History of Life-Interactive Geologic Time Scale

<http://www.pbs.org/wgbh/nova/origins/life.html>

Nova: Origins Game – an interactive game about research done about Earth's and life's origins

<http://www.pbs.org/wgbh/nova/origins/earth.html>

Sedimental Journey – a tour of the fossil history of Earth

<http://www.flmnh.ufl.edu/fhc/sedjourn1.htm>

Tour of Geologic Time – Online exhibit introductory page

www.ucmp.berkeley.edu/exhibits/geologictime.php

United States Geological Survey – A Tapestry of Time and Terrain, the union of two types of maps
geologic and topographic

<http://tapestry.usgs.gov/>

University of California Museum of Paleontology (Online Exhibits)

www.ucmp.berkeley.edu/exhibits/index.php

Web Time Machine – Geologic time scale with links for each time interval

<http://www.ucmp.berkeley.edu/help/timeform.html>



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- Manzo, A. V., Manzo, U. C., & Estes, T. (2001). Content area literacy interactive teaching for active learning. New York: Wiley.
- Marzano, R. J., Pickering, D., & Pollock, J. E. (2001). Classroom instruction that works research-based strategies for increasing student achievement. Alexandria, Va: Association for Supervision and Curriculum Development.
- Matthews, C. (1996). Fossil Finds. *Science Scope*, 19, 13-16.
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- Plait, P. C. (2002). Bad astronomy misconceptions and misuses revealed, from astrology to the moon landing 'hoax'. New York: Wiley.
- Russell, T., Bell, D., Longden, K., & McGuigan, L. (1993). L. Rocks, Soil, and Weather: Primary SPACE Project Research Report (Rep.). Liverpool, U.K.: Liverpool University Press.
- Smithsonian Institution. Dinosaurs. Retrieved October 12, 2007, from <http://paleobiology.si.edu/dinosaurs/>



Middle School Curriculum

Middle School Prior Knowledge

Success with this curriculum is based on students having some prior knowledge of geology. Students should know what a sedimentary rock is and how sedimentary rocks are formed (lithification). They should also have a basic understanding of erosion and deposition, including the actions causing them. Last, students should also have an understanding of fossils, what they are and how they are formed. With this background, students should be able to better comprehend and enjoy the activities in *How Do We Measure Time?*

Stages of Learning

Engage: How Old is the Earth?

- A. How Old is Old? Student Quick Write
- B. Show EARTHTIME DVD: Introduction and Chapter 1
- C. Numerical Time – Creating a geologic timeline

Explore: The Denver Basin – Relative Time through Core Samples, Understanding Formations,

Explain: Reading on Relative Time

Elaborate: Absolute Dating

- A. EARTHTIME DVD; Chapters 2-6
- B. Poster Reading Activity

Evaluate:

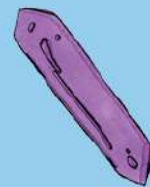
- A. Embedded assessments in activities
- B. GSI – Geology Scene Investigation



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5E MODEL

Engage

GRADE LEVEL

Middle School

NSES STANDARDS

A, D

PREPARATION

Estimated Preparation: 45 min.

Estimated Activity: 1 class period

MATERIALS

DVD - EarthTime

Rock or fossil

How Old is the Earth? – Part One

Learning Goals/Objectives

To help students gain an understanding of the vastness of Earth's history

Activity Overview

Teachers use the Quick Write strategy (Stephens and Brown, 2000) to determine their students' prior knowledge about how scientists date rocks. Students view the Introduction and first chapter of the DVD to create interest in the subject of Earth's time and to provide the teacher with more information about their students' background knowledge about the history of Earth.

Teacher Background

It is hard for students to grasp large numbers. Research shows that many factors make it hard for students to understand the vastness of Earth's history. One factor is exposure to the concept (Trend, 2001). Very little time is spent on Earth's history in most earth science programs at both the middle and high school level. Repeated experiences on the topic can help develop understanding. Another factor is spatial ability and understanding. Research shows that students with strong spatial ability do much better at grasping the concept of deep time (Black, 2005). When spatial experiences and problems were presented over time, student understanding of Earth's history increased. In Part Two of this introductory lesson, students physically create their own timeline of Earth history as a way to address this issue. The third factor is cognitive development. If students are not in the formal operational stage of cognitive development, it will be hard for them to understand abstract concepts (Pressley & McCormick, 2006). However, exposure to these concepts can develop an awareness and interest in the subject matter. Last is field experience. Students with actual experience doing fieldwork develop a better conceptual understanding of geologic time (Kusnick, 2002). Opportunities for geologic fieldtrips are not always available to middle school students during their earth science studies.

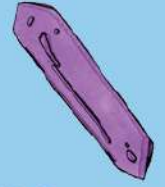
Analogies are used to try to make sense of Earth's history in the DVD. Stephen Jay Gould compared a human arm's length to the history of the universe. Carl Sagan's Cosmic Calendar is another analogy used to explain Earth history on the video. In his book, *Dragons of Eden* (1977), and on his TV show *Cosmos* (1978-79), Sagan explained the history of the universe using a one-year calendar. Using his cosmic calendar,



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Teacher Background continued...

a month equals 1.25 billion years, 1 day equals 40 million years, and each second equals 500 years. In Sagan's pre-December calendar, these events occurred:

- Big Bang - January 1
- Origin of Milky Way Galaxy – May 1
- Origin of the solar system – September 9
- Formation of the Earth – September 14
- Formation of the oldest rocks known on Earth – September 25
- Origin of life on Earth – October 2
- Date of oldest fossils (bacteria and blue-green algae) – October 9
- Invention of sex (by microorganisms) – November 1
- Oldest fossil photosynthetic plants – November 12
- Eukaryotes (first cells with nuclei) flourish – November 15

The month of December contains these important events:

- First worms – December 16
- Invertebrates flourish; Paleozoic Era begins – December 17
- Trilobites flourish – December 18
- First fish – December 19
- First vascular plants – December 20
- First insects, first land animals – December 21
- First amphibians, first winged insects – December 22
- First trees, first reptiles – December 23
- First dinosaurs – December 24
- Paleozoic Era ends, Mesozoic Era begins – December 25
- First mammals – December 26
- First birds – December 27
- First flowers – December 28
- End of Mesozoic Era, dinosaurs become extinct, beginning of Cenozoic Era, first primates – December 29
- First hominids – December 31

On December 31st, each minute equals 30,000 years according to Sagan and some notable events are as follow:

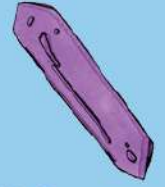
- First humans – 10:30 p.m.
- Widespread use of stone tools – 11:00 p.m.
- Domestication of fire by Peking man – 11:46 p.m.
- Invention of agriculture – 11:59:20 p.m.
- Neolithic civilization; first cities – 11:59:35 p.m.
- Present time – 11:59:59 p.m.



EARTHTIME

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How do we measure time?



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NATURE & SCIENCE

Teacher Background continued...

Some event placements have been updated on more recent Cosmic Calendars. Since Sagan's calendar is used in the video, it has been referenced in this section.

Advance Preparation

Find one rock or fossil that you can share with the class.

Arrange to show DVD – EARTHTIME: Introduction and Chapter One. Student Handout *Major Divisions in Geologic Time*. Make a copy for each student in the class.

Classroom Activity

1. Tell students that they are starting a new unit in science and that they will be doing a quick write (Stephens & Brown, 2000). Ask students if they know how to do a quick write. Teach or review the strategy with the class:
 - a. The teacher poses a question or a statement on a topic.
 - b. Students quickly write down their ideas, phrases, and/or sentences about the topic for two-five minutes.
 - c. Students are specifically told that they should not be concerned about the mechanics of their writing. You are concerned about their thoughts and ideas.
 - d. Students share their thoughts with at least one other student.
 - e. The teacher then invites students to share their quick writes or portions of what they have written.

Note to the teacher: Quick writes are easy to use when starting a lesson or unit. They are not graded, but can be used as an informal assessment. Quick writes can also be used for reflection at the end of a unit.

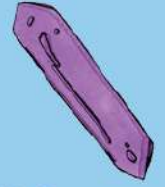
2. Hold up a rock or fossil to show to the class. Ask students the following question and tell them that the question is the focus of their "quick write" today. The question is: "How do you think a scientist could figure out how old a rock/fossil is?"
3. Tell students that they have five minutes to write about this question.
4. At the end of five minutes, have students stop writing. Inform them that they must share their ideas with a teammate.
5. Tell students that they need to decide who will share their ideas first. Give the first student two minutes to share.



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Classroom Activity continued...

6. Ask students to switch and let the other student share his/her ideas for two minutes.
7. Ask students to share some of their ideas with the class.
8. Let students know that they will be learning about the ways that scientists figure out the age of rocks and events in Earth's history.
9. Inform students that they will next view parts of a DVD and that it covers information about the age of planet Earth.
10. Show the Introduction to EARTHTIME.

After viewing the Introduction:

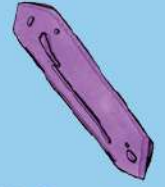
- A. Ask students if it is hard to envision a million of something, or even larger, a billion of something. Some students may have tried to count a million of something in math during elementary school. Tell your students that it is hard, even for adults, to conceptualize a billion.
 - B. Ask students if the analogies (Gould's arm and Sagan's calendar) helped them to understand: (a) how long the Earth has been around and (b) the length of time that humans have been around in relation to Earth's existence. *Answers will vary.* Explain to the class that it usually takes a lot of experiences thinking and working with Earth's history to get a better grasp of its time.
11. Show Chapter 1: Determining the Age of Things.
After viewing Chapter 1:
 - A. Ask students if relating Earth's age to their time and human life on the planet gave them any better idea of the amount of time Earth has been around. If not, remind students that it's okay.
 - B. Ask students if they have ever counted the rings in a cross-section of a tree (Some students may know these as tree cookies or wood cookies.) What did they find out? *Possible answers: The dark and light rings together make up a year's growth. They found out how old a tree was when it was cut down. The oldest ring is in the center of the tree and the outermost ring is the youngest. (Point out that these growth rings were added on top of the original center/first year of growth and that this is not unlike how layers are added to the Earth's crust).*
 - C. Ask students how layers of the Earth can help us determine what has happened in its past.



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Classroom Activity continued...

12. Explain to students that they will learn about the volcanic layers and how they date these rocks later in this unit. At this point in time, they are going to do some activities to help them understand all of Earth's entire history and some of the work that Dr. Johnson has done in the Denver area to learn about its many layers.

Resources

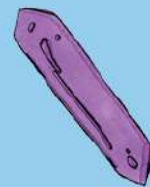
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- The Shores of the Cosmic Ocean [Television series episode]. (1980, September 28). In *Cosmos*. PBS.
- Stephens, E. C., and Brown, J. E. (2000). *A handbook of content literacy strategies: 75 practical reading and writing ideas*. Norwood, MA: Christopher-Gordon. 33-34.
- Trend, R. (2001). Deep time framework: a preliminary study of U.K. primary teachers' conceptions of geological time and perceptions of geoscience. *Journal of Research in Science Teaching*, 38, 191-221.



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5E MODEL

Engage

GRADE LEVEL

Middle School

NSES STANDARDS

A, D

PREPARATION

Estimated Preparation: 45 min.

Estimated Activity: 1 class period

MATERIALS

Meter sticks

4 different colors of yarn or string

First color – 4 meters

Second through fourth color – one meter each

Preprinted events on $\frac{1}{2}$ " x $1\frac{3}{4}$ " mailing labels or as copies that students can cut out as strips and tape onto the timeline.

Tape (stronger than scotch)

Rolls of scotch tape (if not using labels) – enough for students to share

Markers – enough for students to share

Scissors – enough for students to share

How Old is the Earth? – Part Two

An adaptation of *Geologic Time in Living Color - A Visual Representation of the Geologic Timescale*, activity by Sharon Unkart, Denver Museum of Nature & Science

Learning Goals/Objectives

1. To understand the immense length of time in the geologic record
2. To explore changes in the Earth and Earth's history through geologic time

Activity Overview

Each student or student team builds a scale model of the geologic time scale using colored yarn or string. The visual is taped to the wall to show the vertical representation of EARTHTIME. Important geologic events are then attached to their appropriate place on the timeline to provide visual representation of the span of these events. The time scale is revisited in the next activity when events from the Denver Basin are added to the model.

Teacher Background

Students have just been exposed to Earth's history through the video using Stephen Jay Gould's and Carl Sagan's Earth history analogies. Since it is difficult to visualize or conceptualize immense amounts of time, the physical task of creating a large timeline using millimeters to represent a million years is one way to begin building understanding of Earth's time and how it is measured. The purpose of this activity is for students to see the length of time Earth has been in existence and the major divisions of time. Though the major divisions of geologic time are important to understanding how geologists categorize Earth's history, it is not the focus of this activity. At the EARTHTIME Web site, you can find more information on the history of geologic timescales, as well as the different accepted geologic timescales that are used by scientists. Visit www.EARTHTIME.org and click on timescales.

The physical representation of Earth's time is important for students to experience. Only when students have the hands-on experience of creating a time scale can they begin to deal with the immensity of 4.567 billion years. After figuring out which fossils belong to which formation, students return to this timeline adding information from the Denver Basin and seeing how life is very recent in Earth time.

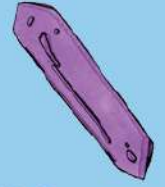
See the following list for most currently accepted dates for geologic events. Starred events are used with students in the activity.



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Event	Years Ago
Origin of the Earth	4,567,000,000*
Precambrian Era	4,567,000,000 – 542,000,000
Paleozoic Era	542,000,000 – 251,000,000
	Age of Ancient Life*
Mesozoic Era	251,000,000 - 65.5,000,000
	Age of Reptiles/Age of Dinosaurs*
Cenozoic	65.5,000,000 to Present
	Age of Recent Life/Age of Mammals*
Oldest dated zircon grains	4,400,000,000
Oldest dated crustal rocks	4,030,000,000
Oldest evidence for life	3,800,000,000*
Oldest Metazoan fossil	578,000,000
Oldest fossil fish	510,000,000
First land plants	458,000,000
Amphibians evolve	375,000,000
Mass extinction at the end of Permian Period	251,000,000
First mammals	200,000,000
Atlantic Ocean begins to open	200,000,000
First birds	160,000,000
Angiosperms (flowering plants) appear	130,000,000
Dinosaurs go extinct at the Cretaceous-Tertiary Boundary	65,500,000
Ice begins to form on Antarctica	34,000,000
Age of Australopithecus afarensis (Lucy) fossils from Ethiopia (One of the first Human species)	3,400,000
Pleistocene (Ice Age) begins	1,800,000
First Homo erectus (Early Man) fossils from Ethiopia	600,000
Homo sapiens (Modern man) appears in the fossil record	160,000*
Last ice sheet retreats from northern United States	11,500

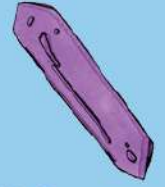
Source: Earth Science Week.
Geologic Time Scale Analogy
http://www.earthsciweek.org/forteachers/geotime_cont.html
(with DMNS corrections and additions)



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Advance Preparation

1. Gather and cut the required colors and lengths of yarn or string.
2. Use the Teacher Handout to create labels for each student or student team. The information about geologic events can be cut and pasted into a label format or copied for student use.
3. Copy *Major Divisions of Geologic Time* for each student.
4. Gather scissors and tape if students are cutting out strips with geologic history information

Classroom Activity

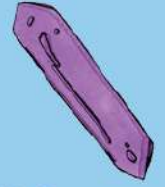
1. Explain to students that they will be building a visual representation of the history of the planet Earth, from its very beginning as a molten ball to the present.
2. Provide students with the handout *Major Divisions of Geologic Time*. It provides information about the length of time represented by the four major divisions in geologic time.
3. Once students read about the span of time represented by each Era, assign them their scale for this activity: 1mm = 1 million years.
4. Provide yarn or string to represent each of the major divisions in geologic time (Precambrian Era, Paleozoic Era, Mesozoic Era, and Cenozoic Era). Students should figure out that the 4-meter length represents the Precambrian Era.
5. Students now measure and cut their yarn/string to the required length. With markers, they mark their string and label each length with the name of their era and its length of time from beginning to end **with the beginning year at the bottom and the ending year at the top**. Note: If students are tying knots in their yarn/string, make sure that they mark the beginning and end of each era with the marker and leave extra string to tie knots when they put the eras together in their timelines.
6. Once all students have finished measuring, marking, and cutting their yarn/string, starting with the Cenozoic Era, they need to tape or knot the sections to each other in succession to create one, large, continuous timeline.
7. Discuss what has been created. Look for surprise and/or disbelief.
8. As a class, place a few of the important geologic events that are on mailing labels (or on strips of paper) in the correct position on the timeline. Students will find they cannot place all of the labels that



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Classroom Activity continued...

- they have in the Cenozoic Era. Suggest that they place a sheet of paper behind the top of the timeline and add the labels to the paper. They can then draw lines to where the events fit on the string.
9. Discuss what they notice about where certain events were placed. Ask what new understandings they now have about Earth's history.
 10. Hang timelines, from youngest era to oldest, from the top of the ceiling to emphasize length and scale.
 11. Ask students about deposition and different ways that earth materials are moved and deposited to help students see that processes of long ago are the same as today. (*Methods of deposition: flowing water, ice, wind, gravity, decayed organic material, and chemical deposits from water.*)
 12. Ask students about erosion and different ways earth materials are broken down to help students see that processes of long ago are the same as today. (*Methods of erosion: flowing water, gravity, wind, ice.*)
 13. Ask students if they ever wondered how scientists knew how old dinosaurs were, or how old mammoths were? How do they know how old something is? Explain that it has only been since the mid-1900s that scientists were able to place more accurate estimates of time on to major geologic events on the timescale. Before that, scientists used what they could observe to order events relative to each other in time. And, that's exactly what students will be doing – placing events relative to each other in relative time. Later on, they will address the numerical ages.
 14. Review the major divisions between the eras and how those divisions were created from the article.
 15. Ask students to write using the 3-2-1 Strategy. They need to list three things that they learned, two things they found interesting, and one question they still have.

Extensions

1. Have students draw a picture of the timeline they created as a class in their Science Journals.
2. Have them discuss any surprises or list questions they did not get the answer to during the activity.



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Resources

Denver Museum Of Nature & Science. (2005). Earth-Time [Computer software]. Denver, CO: Denver Museum of Nature & Science.

Johnson, K. R., & Stucky, R. K. (2006). Prehistoric journey a history of life on Earth. Golden, CO: Fulcrum Pub.

Source: Earth Science Week: Geologic Time Scale Analogy. Retrieved from http://www.earthsciweek.org/forteachers/geotime_cont.html



How Old is the Earth?

Major Divisions of Geologic Time

The Precambrian Era was an enormous expanse of time ranging from the beginning of Earth over 4,567,000,000 years ago up to 542,000,000 years ago. At the beginning of this time, Earth was liquid and cooling to form rock. Around 4.4 billion years ago, the first continents began to form. Evidence of microscopic life appeared in the fossil record by 3.4 billion years ago. New types of organisms evolved about 2.5 billion years ago. These organisms had cells that had a nucleus inside of them. Finally, about 578 million years ago, animals you could see without a microscope appeared.

The Paleozoic Era lasted almost 300 million years. It began 542 million years ago and ended 251 million years ago. An interesting episode of explosive evolutionary radiation occurred just after the start of this era. It was an explosion of many different kinds of shelled animals in the seas. Fossils of shelled animals have been found from this time period all over the world. The most famous fossils of this time were the bug-like trilobites.

Around 510 million years ago, the first fish appeared. Amphibians showed up on land and the first forests formed. At the end of this era, a great extinction occurred wiping out over 90% of the ocean life.

The Mesozoic Era was the Age of Reptiles. It began 251 million years ago and ended 65.5 million years ago. All of the major reptiles – lizards, turtles, crocodiles, dinosaurs, pterosaurs, and marine reptiles – appeared during this era. Evidence of the first mammals occurred 225 millions years ago. Birds appeared after mammals. Dinosaurs were incredibly successful and ranged the planet from 230 million years ago to 65.5 million years ago when a major asteroid wiped them out.

The Cenozoic Era is known as the Age of Modern Mammals. It started 65.5 million years ago and continues today. Mammals became diverse after the extinction of the dinosaurs. Flowering plants, birds, insects, fish, and reptiles also became more diverse. The first human ancestors were found during the Cenozoic Era about 7 million years ago.

Reference: Prehistoric Journey

Origin of the Earth - 4,567,000,000 YA		Origin of the Earth - 4,567,000,000 YA		Origin of the Earth - 4,567,000,000 YA		Origin of the Earth - 4,567,000,000 YA
Oldest Dated Crustal Rocks- 4,030,000,000 YA		Oldest Dated Crustal Rocks- 4,030,000,000 YA		Oldest Dated Crustal Rocks- 4,030,000,000 YA		Oldest Dated Crustal Rocks- 4,030,000,000 YA
Oldest Evidence for Life- 3,800,000,000 YA		Oldest Evidence for Life- 3,800,000,000 YA		Oldest Evidence for Life- 3,800,000,000 YA		Oldest Evidence for Life- 3,800,000,000 YA
Oldest Fossil Fish - 510,000,000 YA		Oldest Fossil Fish - 510,000,000 YA		Oldest Fossil Fish - 510,000,000 YA		Oldest Fossil Fish - 510,000,000 YA
First Land Plants - 458,000,000 YA		First Land Plants - 458,000,000 YA		First Land Plants - 458,000,000 YA		First Land Plants - 458,000,000 YA
First Amphibians (animals moving to land) - 375,000,000 YA		First Amphibians (animals moving to land) - 375,000,000 YA		First Amphibians (animals moving to land) - 375,000,000 YA		First Amphibians (animals moving to land) - 375,000,000 YA
Mass Extinction at End of Permian Period 251,000,000 YA		Mass Extinction at End of Permian Period 251,000,000 YA		Mass Extinction at End of Permian Period 251,000,000 YA		Mass Extinction at End of Permian Period 251,000,000 YA
First Mammals – 225,000,000 YA		First Mammals – 225,000,000 YA		First Mammals – 225,000,000 YA		First Mammals – 225,000,000 YA
First Birds –160,000,000 YA		First Birds –160,000,000 YA		First Birds –160,000,000 YA		First Birds –160,000,000 YA
Atlantic Ocean first opens - 200,000,000 YA		Atlantic Ocean first opens - 200,000,000 YA		Atlantic Ocean first opens - 200,000,000 YA		Atlantic Ocean first opens - 200,000,000 YA
Flowering Plants appear - 130,000,000 YA		Flowering Plants appear - 130,000,000 YA		Flowering Plants appear - 130,000,000 YA		Flowering Plants appear - 130,000,000 YA
Dinosaurs Go Extinct - 65,500,000 YA		Dinosaurs Go Extinct - 65,500,000 YA		Dinosaurs Go Extinct - 65,500,000 YA		Dinosaurs Go Extinct - 65,500,000 YA
Close of the Mesozoic Era/ Beginning of the Cenozoic Era – 65,500,000 YA		Close of the Mesozoic Era/ Beginning of the Cenozoic Era – 65,500,000 YA		Close of the Mesozoic Era/ Beginning of the Cenozoic Era – 65,500,000 YA		Close of the Mesozoic Era/ Beginning of the Cenozoic Era – 65,500,000 YA
Evidence of one of first Hominids (Lucy) - 3,400,000		Evidence of one of first Hominids (Lucy) - 3,400,000		Evidence of one of first Hominids (Lucy) - 3,400,000		Evidence of one of first Hominids (Lucy) - 3,400,000
Pleistocene Ice Age begins 1,800,000 YA		Pleistocene Ice Age begins 1,800,000 YA		Pleistocene Ice Age begins 1,800,000 YA		Pleistocene Ice Age begins 1,800,000 YA
Age of Homo erectus (Early Man) fossils - 600,000 YA		Age of Homo erectus (Early Man) fossils - 600,000 YA		Age of Homo erectus (Early Man) fossils - 600,000 YA		Age of Homo erectus (Early Man) fossils - 600,000 YA
Homo sapiens (Modern man) 160,000 YA		Homo sapiens (Modern man) 160,000 YA		Homo sapiens (Modern man) 160,000 YA		Homo sapiens (Modern man) 160,000 YA
Last ice sheet retreats from northern United States 11,600 YA		Last ice sheet retreats from northern United States 11,600 YA		Last ice sheet retreats from northern United States 11,600 YA		Last ice sheet retreats from northern United States 11,600 YA



EARTHTIME

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How do we measure time?



DENVER MUSEUM OF
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5E MODEL

Explore

GRADE LEVEL

Middle School

NSES STANDARDS

A, D, G

PREPARATION

Estimated Preparation: 1 hour
plus

Estimated Activity: 1 class period

MATERIALS

See Advanced Preparation
Section

Core Sample Storytelling

Learning Goals/Objectives

1. To introduce students to the Denver Basin
2. To introduce or review and provide students with an opportunity to apply their knowledge of basic geologic principles
3. To create a cross-section map from clay core samples

Activity Overview

In this Explore stage lesson, students are introduced to and apply their knowledge of the Principles of Superposition, Horizontality, Lateral Continuity, and relative age by “drilling core samples” in a Play dough model of the sedimentary layers of the Denver Basin and then aligning the samples to determine a cross-section view of the layers.

Note: This lesson is an adaptation of a lesson titled Layers of Rock.

The source of this lesson is *Windows to the Universe*, at <http://www.windows.ucar.edu/> at the University Corporation for Atmospheric Research (UCAR). @1995-1999, 2000 The Regents of the University of Michigan; @2000-2006 University Corporation for Atmospheric Research.

Teacher Background

Geologists often drill and retrieve core samples from Earth layers where there are no rock outcroppings or to determine what is beneath the surface layer of rock. Drilling these cores helps geologists understand what they can't see at the surface and informs them about their specific purpose(s) for drilling; possibly, the feasibility of building on a certain site, location of groundwater resources, location of oil and gas resources, or the geologic history of an area.

In 1999, the Denver Museum of Nature & Science drilled a 2,256-foot-deep well in Kiowa, Colorado, which is near the center of the Denver Basin. The hole was drilled to better understand the sequence and age of the extinct Colorado landscapes and to understand the nature of the groundwater resource and the rocks that host the water. The core from the well-provided samples were subjected to a battery of tests that dated the layers and tested their capacity to hold groundwater...the shape of the ancient and extinct landscapes controls the distribution of water that is so precious to the growing population of Colorado's high plains.¹

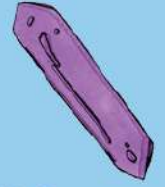
Johnson, Kirk R., and Robert G. Raynolds. *Ancient Denvers*. Denver: Denver



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Vocabulary to be Introduced during Instruction

Core sample – earth and rock that is collected in the layers that they occur in a hollow steel tube by drilling down into the earth

Principle of Original Horizontality – the principle that states that sedimentary and igneous rocks are usually laid down in horizontal layers

Principle of Lateral Continuity – sedimentary and volcanic rock layers are usually much greater in the area that they cover rather than the thickness of the layers

Principle of Superposition – the principle that states that younger sedimentary rocks are deposited on top of older sedimentary rocks

Principle of Uniformitarianism – the principle that states that Earth processes that happen today most likely happened in the past

Relative Dating – determining which rock layers are older and younger using basic geologic principles

Strata – rock layers

Uplift – when land slowly rises (as in mountain building)

Advance Preparation

Note: You will need to make the models ahead of time. It is important to refrigerate the models for a few hours before class if you are using Play Dough. Depending on your budget, Play Dough may be purchased or made. A recommended recipe is listed below to lessen costs for this activity.

Teacher decisions to be made in preparation for the activity

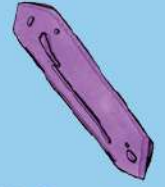
- *Be aware that because of the amount of air in the clay, Play Dough compresses in the clear straw core sample and does not provide an accurate picture of the depth of the layers. However, the samples do show the layering in the core. Modeling clay is denser and provides a more accurate amount of clay for each layer in the core sample. However, it is more costly and harder to “drill.”*
- *The thickness of your layers will depend on the amount of clay you have available to create the Denver Basin. Do not make layers too thin. If a layer is too thin and you are using Play Dough, it will be hard to see when the clay is compressed in the straw.*
- *It is recommended that only the Denver Basin design of the sedimentary layer model be used for each container. This is so that class discussions about the layering use common reference points.*



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Advance Preparation continued...

- *The number of models that you need will depend on the number of classes that you have during the day. Models can be used more than once. New holes that are drilled should be placed near the original set of nine holes.*

Materials needed to make models

- Small plastic containers with straight sides, one for each group of four students (small, clear, disposable, Gladware-type square containers work well because of their straight sides and affordability).
- Play dough or plasticene modeling clay: multiple colors
- Rolling pin
- Flour

Other materials needed for class

- Colored pencils (if you are providing this item)
- Roll of painters' tape
- Clear 10 – inch, 0.25 diameter drinking straws – enough so each group has ten pieces when straws are cut in half
- Permanent marking pen
- Pictures of the Boulder Flatirons and horizontal sedimentary rock outcrop (in curriculum guide)
- Small ½" x 1 ¾" mailing sticker labels (each group will need 18)
- Box of straight pins
- Eight small self-sealing baggies
- White copy paper
- *Core Sample Storytelling* student handouts, one for each student
- *Front Range Denver Basin Cross-section Map* handouts, one for each team

Making models beforehand:

1. Gather multiple colors of play dough or modeling clay, flour, and enough plastic containers so that there will be one for every four students.
2. Sprinkle a small amount of flour on the bottom of each container. (This helps cores to be retrieved more easily.)
3. Create layers of dough similar to the diagram of a cross-section of the Denver Basin. The lowest three layers can be fairly thin. They go $\frac{3}{4}$ of the way across the container. The next layer in actuality is over a mile



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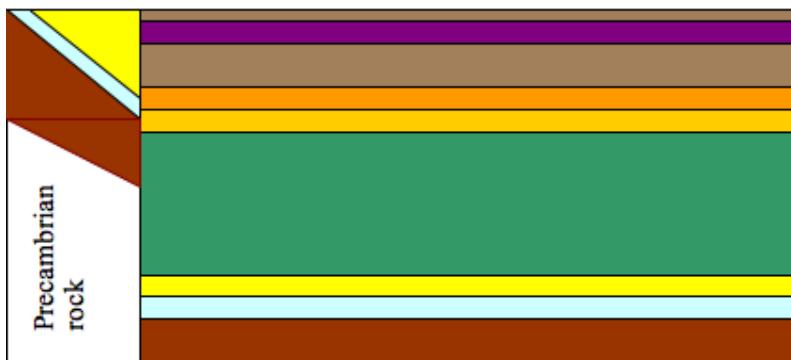
DENVER MUSEUM OF
NATURE & SCIENCE

Advance Preparation continued...

thick. Make this your thickest layer. The next five layers should curve slightly upwards. The top layer should be a thin layer of clay that covers the entire container.

4. The Denver Basin has also been faulted, tilted, and uplifted near the Rocky Mountains. This area should show the bottom three layers of the Denver Basin tilted and near the surface. Below those three layers is Precambrian igneous and metamorphic rocks.
5. Cover the outside of the container with painters' tape so that students cannot see the layers from the side.
6. Label the sides A, B, C, and D with a permanent marker on the plastic where there is no tape.

Cross-section of how layers should be constructed in container



Note: If it is not possible to create a model with this many layers, create a version with layers that can be correlated to the Denver Basin map.

7. Put the lids on the containers and store them in a refrigerator until time to use. This only needs to be done for Play dough models. Refrigerating helps the cores come out more easily and lessens the compression of the clay in the straw. It is not necessary to do if you have used modeling clay.

Materials needed for each team of four:

- One sedimentary rock layer model with cover
- Five clear 10-inch, 0.25 diameter drinking straws, cut in half
- One sheet of white paper
- Colored pencils
- Nine straight pins
- One self-sealing baggie



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Advance Preparation continued...

- Eighteen small self-sticking mailing labels
- Four sets of student handouts: *Core Sample Storytelling*
- One copy of handout: *Front Range Denver Basin Cross-section Map*
- Colored pencils

Classroom Activity

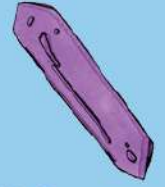
1. Explain that we can't see the layers of sedimentary rock if the land surface is relatively flat. Geologists often collect core samples when wells are drilled to get detailed information about the layers of rock below the surface. Explain that they find out what types of rocks there are, the order in which they were deposited, and any changes that happened to the original deposits of sediment that were made.
2. Provide each group of four students with a plastic container than contains the dough layers. Explain that this is a model of layers of part of the Denver Basin. The one layer that they can see is at the surface. Inform the class that they are not to remove the tape from the sides of the container.
3. Supply each group with ten clear straw pieces, nine straight pins, eighteen labels, and their worksheets.
4. Demonstrate how to take a core using the straw. Hold the straw vertically and turn it as you slowly push straight down. Make sure the straw touches the bottom of the box. Keep turning the straw around and wiggle it back and forth to make sure it has cut through the bottom layer and is free from the dough. Hold a finger over the top of the straw and pull the core up out of the container. Repeat the process for one more "drill hole."
5. Show students how to number their core holes and number their core samples.
6. Read and discuss the directions for the first part of the activity on the worksheets. Monitor and assist students as they work on Part A.
7. Upon completion of the first part of the activity, hold a class discussion. Questions to ask:
 - ☐ How hard was it to collect core samples? Did anyone have any unsuccessful cores?
 - ☐ What kind of information did you get from the rock layers?
 - ☐ What layer did you determine to be the oldest layer? *Students should be able to determine from the colors that the oldest layer is that under the bottom three layers that covers most of*



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Classroom Activity continued...

the container. Which layer is the youngest layer? *The top layer is the youngest.* How do you know this? How did you apply your knowledge of how sediment is deposited when you looked at this model of Denver's past? *Introduce or review the Law of Superposition. Explain that it might seem simple that new material is deposited on top of older materials. However, it is a basic principle in geology. It gives an order to what happened over time and this is called the relative age of a rock.*

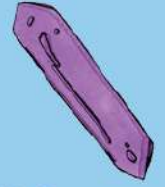
8. Did you find layers that did not match up to other layers? *Yes.* Where in other parts of the cross-section do these layers exist? *The top three layers of one area of the model are the bottom three layers for most of the model. Explain to students that when today's Rocky Mountains formed, they were uplifted (slowly rose). The old rock layers were then tilted and exposed.*
9. Have students lay their samples out on a sheet of paper. Read and discuss the directions for the second half of the activity.
10. Illustrate on the board or overhead projector how to draw the core samples on their worksheets.
11. Direct students to connect lines between core samples and color their cross-section maps.
12. Let students remove the tape to compare their maps with the actual sedimentary dough cross-sections on sides A, B, C, and D.
13. Hold a class discussion using the following questions:
 - How close were your pictures to the actual layering of the dough sediments?
 - How does mapping the core samples provide a better picture of what is under the surface layer? *It provides a picture of the layers on a particular side of the container.*
 - (If using Play dough) How did the compression of the clay impact your maps of each side of the container? *This will depend upon how forceful students were when pushing into the clay.*
 - Why is it important to get core samples from multiple locations? *Geologic layers can change over an area or layers can be the same over an area.*
 - How is your picture of the order of "rock layers" enhanced by cross-section maps? *Answers may vary. Point out to students that much of the layering was the same across the container. Introduce the Principles of Horizontality and Lateral Continuity. Explain to*



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Classroom Activity continued...

students that many people don't realize that layers can extend for hundreds or thousands of miles beneath the surface of the Earth. This is also an appropriate time to explain that most sedimentary and many igneous materials are deposited on a horizontal plane.

- Consider that this model was an actual area where you collected core samples. In order to better understand the timeframe; would it be helpful to know the numerical dates for the material that was deposited? *Yes. Why? It provides more information and gives a time reference to work with. Inform your students that in a future lesson they will see how scientists are able to determine the age in years for Earth materials millions and billions of years old.*
- 14. Have students reflect in writing about their understanding of relative time. How has it changed? What problems occur with it?
- 15. Have the class clean up the materials:
 - Remove straight pins with numbers from the model and place the straight pins in the self-sealing baggie.
 - Dispose of core samples.
 - Turn in models and pins.
 - Put away color pencils.
 - Hand in worksheets.
- 16. Reuse or reconstruct models for the next class.

Extensions

Further student reading about the Denver Basin and the Denver area can be done at these websites:

Ancient Denvers

<http://www.dmnh.org/main/minisites/ancientDenvers/index.html>

Red Rocks and Dinosaur Ridge

http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17126



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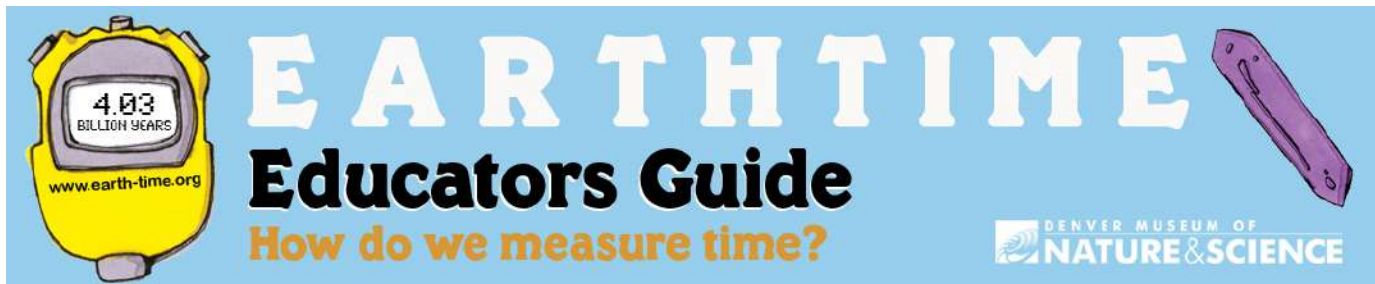
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Resources

Johnson, K.R., & Raynolds, R. G. (2002) Ancient Denvers. Denver: Denver Museum of Nature & Science.

Johnson, K. R., & Stucky, R. K. (2006). Prehistoric journey a history of life on Earth. Golden, CO: Fulcrum Pub.

Windows to the Universe, at <http://www.windows.ucar.edu/> at the University Corporation for Atmospheric Research (UCAR). @1995-1999, 2000 The Regents of the University of Michigan; @2000-2006 University Corporation for Atmospheric Research.



Name _____ Date _____

Core Sample Storytelling Student Worksheet

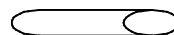
Geologists and other scientists wanted to better understand the layers of rocks and their ancient environments in the Denver Basin. These scientists knew that over the very long history of Earth, mountains and oceans came and went in the area. Earth materials eroded from the mountains and ended in this area. Materials were also deposited from the ancient seas. Only part of the Denver Basin’s past history is evident above the ground around the region.

Drilling wells and removing samples from the earth can tell scientists *what* happened to Earth in the past. These samples can also tell scientists when events occurred. In the center of the Denver Basin, the Denver Museum of Nature & Science drilled a 2,256-foot-deep well. From this well, scientists collected core samples.* These core samples were collected and studied. Much more was learned about the Denver Basin region’s past from these samples.

Purpose of Activity

You will investigate a model that represents a small area of the Denver Basin. By collecting “cores” from this model, you will find the relative ages of the layers of the Denver Basin, as well as what happened to these rock layers. You should get an idea of the depth of some of the formations based on the core samples that you collect.

*Core samples are sections of Earth materials collected in metal tubes when drilling is done.
The samples are removed from the tubes and analyzed in a lab.



Materials

- One sedimentary layer model (container with layers of clay)
- Eighteen ½” x 1 ¾” mailing labels
- Nine straight pins
- Nine clear plastic drinking straw pieces
- Colored pencils
- One sheet of white paper

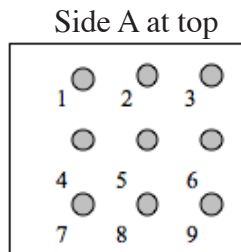


Diagram A

Number across as you take samples.

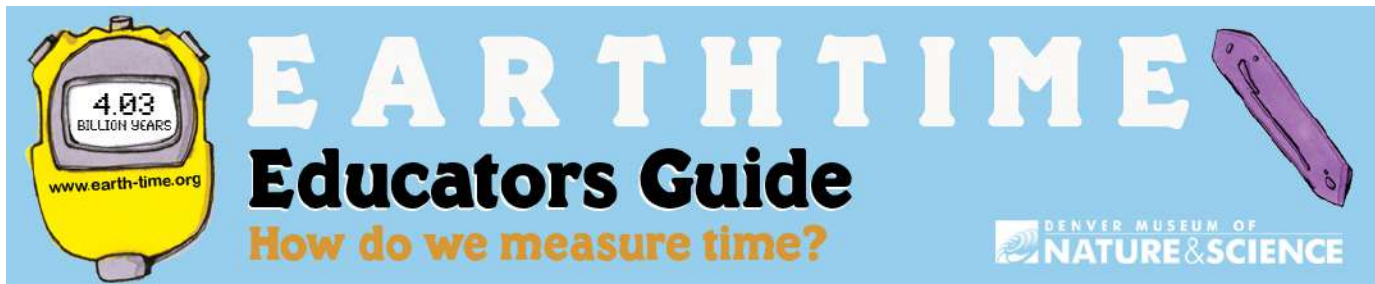


Diagram B

Tape the corresponding number label onto the core sample.

Directions

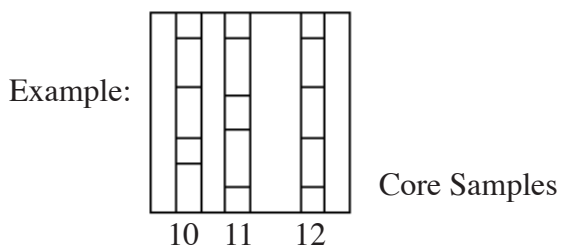
1. In order to figure out what lies beneath the surface of your clay model, you will need to take nine core samples across the entire surface. Make sure your nine cores represent most of the surface of the model. You will need to collect these core samples in three lines across the model. You will need to label your site and core samples as shown below (Diagram A).
2. Make two sets of labels numbered 1 to 9. Write each number on one end of the label (See Diagram B).
3. To collect a sample, hold a straw vertically and slowly turn the straw in the clay. Slowly push down while you turn the straw until it touches the bottom of the box.
4. Once your straw touches bottom, continue to turn and wiggle the straw to free it from the rest of the dough.
5. Cover the top end of the straw with your thumb and slowly bring the core sample to the surface. Because your Denver Basin is made of Play dough, it will be compressed. You should still have the same layers, just thinner.
6. Once you have the sample, label the straw filled with core with the correct sample number on it. (Don't cover the end of the straw that has the dough in it. See Diagram B)
 - Some cores are not always successful.
 - If a core of Play dough does not come out with the straw, try "drilling" again in another spot close to the original hole.
7. Find the same sample number on another label and attach it to a straight pin. Place the pin next to the hole on the dough.
8. Repeat the process until you have taken nine core samples and have nine locations marked on the clay surface.
9. Put all of your cores against a sheet of white paper so that everyone in the group can see them. How many different colored layers did you find? Which "rock layer" is the oldest? Which layer is the youngest? Do all team members agree?
10. Because the Earth moves and tilts layers of sedimentary rocks, not all layers are found in all locations. Identify which layers are found in each location you cored.
11. Participate in the class discussion about your findings.



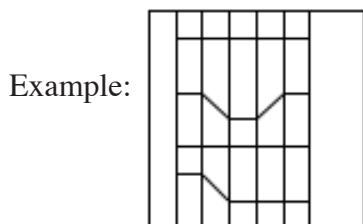
Part 2

Core samples provide scientists with a picture of what lies beneath their feet. In fact, they can create a map that tells the story of what happened over time. You will also create maps of your findings.

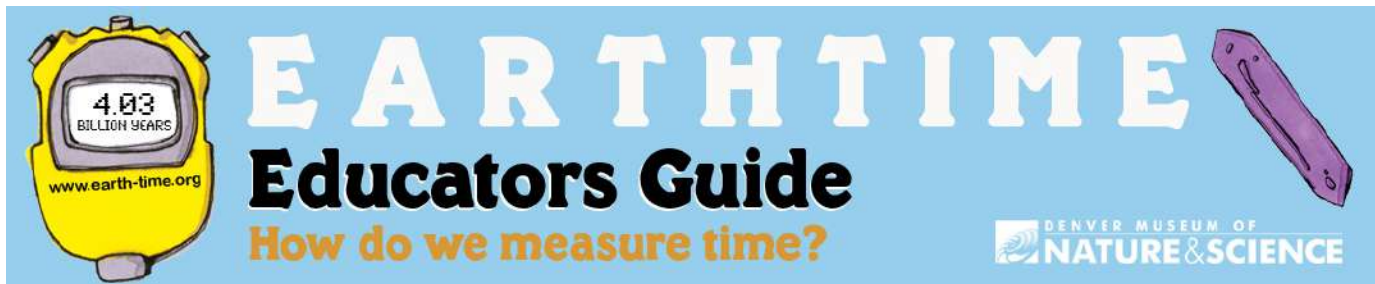
1. Each team member needs to record data and create a map for one side of the box.
2. Each side has three cores that you are responsible for; record these on the diagram.
3. Line the samples up in the order of the numbers for each side.
4. Based on your cores, what do you think Side A looks like? Side B? Side C? Side D?
Discuss your ideas with your teammates.
5. Draw the layers of each core sample on the diagram in the order listed.
These drawings do not need to be to scale, but should show the relative sizes of the layers.



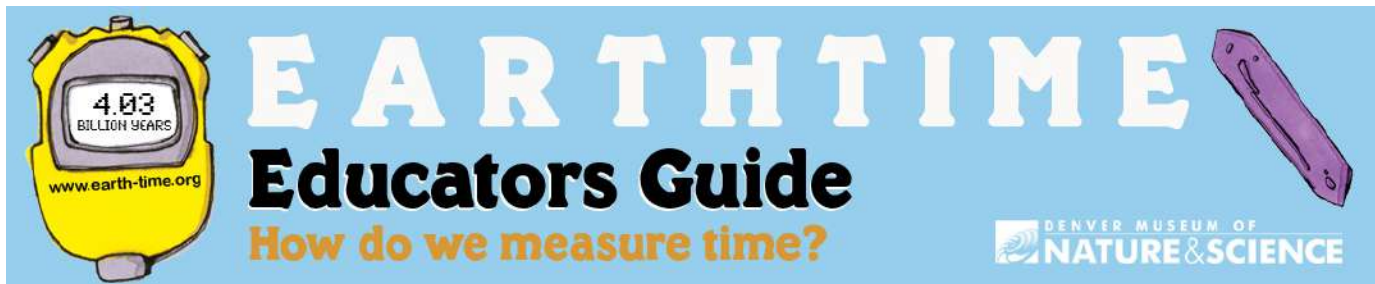
6. Connect the same layers in each sample with lines to create a cross-section map.



7. Color each layer of your map.
8. Look at each team member's cross-section map. Do you think that your maps will look like the sides of the container?
9. Take the tape off of the container. Compare your maps to the actual side views (cross-sections) of the container.
10. Answer the following in your science notebook or on a sheet of paper:
 - How closely did your maps look like the actual cross-sections of layers (sides of container)? Describe the similarities and differences.



- If you used Play dough, did the compressed (squished) clay in the core samples cause any problems with making an accurate map?
 - What other problems occurred in drawing and mapping?
11. Tell the story of your container.
- Write what “rock” layers were deposited first, second, third, etc.
 - Did any other events occur in your model? What were they like? When did they occur?
12. Compare your maps with the Front Range Denver Basin Cross-section map. Think about the following questions and be prepared to share your ideas:
- How many layers/formations are represented on the map?
 - How many of these layers are similar to those in your container?
 - What span of time do you think occurred from the uninterrupted layers that occur after the Precambrian to the ending layer at the surface?
13. Clean up your area according to your teacher’s directions.
14. Participate in the class discussion.



Name _____ Date _____

**Core Sample Storytelling
Student Worksheet**

- Below the diagram, number the core samples for the side you are drawing.
Your side will be numbered as one of the following:
 - 1, 2, 3
 - 1, 4, 7
 - 3, 6, 9
 - 7, 8, 9
- Draw the layers of each core sample. These layers do not need to be the exact size of the layers in the straw. They do need to show relative size.
- Connect the lines between the samples for each layer. (If a certain layer is not in the other core samples, it will not have lines connecting to it.)
- Color your map.
- Compare your map to your teammates' maps.

Core Sample Map Side _____

Core Samples:

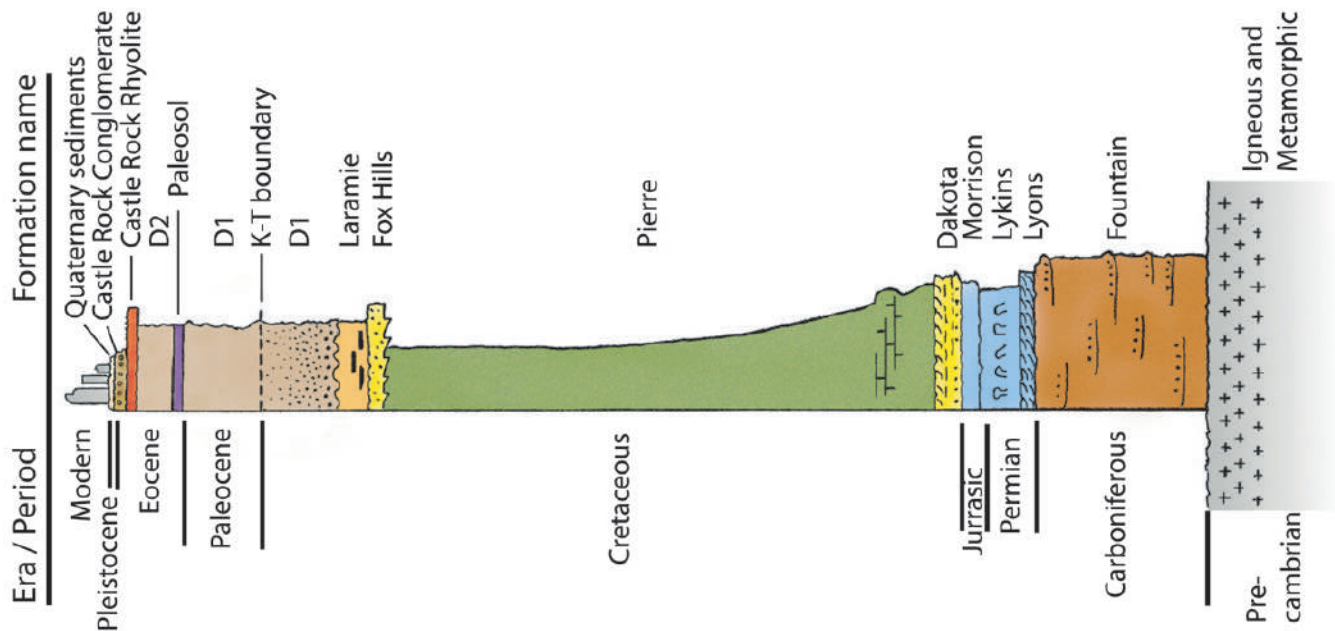
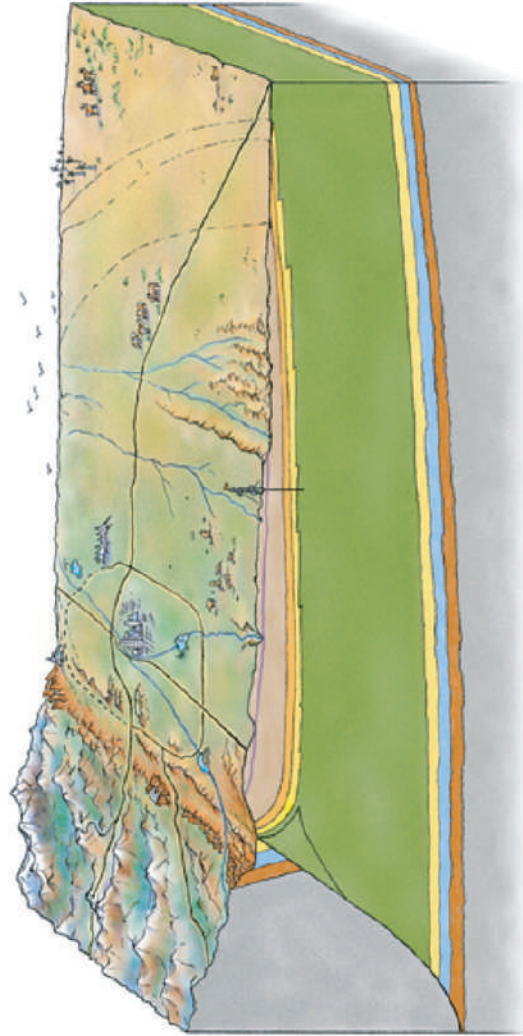
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The Denver Basin Stratigraphic Column

The image below shows a block diagram of the Denver Basin. It shows what you would see if you took a giant knife and cut a giant east-west slice 14,000 feet into the earth. The different colors represent different rock formations. By looking at the composition of the rock and the types of fossils found within the rock, scientists can interpret what past environments may have looked like.

The diagram to the left is called a stratigraphic column. It shows the same rock formations but this time, they represent the rocks that would be encountered by digging a well in the center of the basin. Denver's 700' tall Wells Fargo Center (the "cash register building") is drawn to scale, showing how thick the layers are. Since these layers come to the surface around the edge of the Denver Basin, this stratigraphic column will be used to create a geologic map of the surface of the Denver Basin.

The colors of your map will match the colors of the stratigraphic column. By "digging holes" in the basin and looking at the data that comes from each site, you will be able to piece together the geologic map in the same way that scientists piece together data to inform our understanding of the rock record and ancient history of the planet.





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Boulder, Colorado Flatirons – Fountain Formation
Shows uplift and tilting

TEACHER PAGE



Horizontally layered rock - Lykins Formation

TEACHER PAGE



Homemade Play Dough (Flour Clay) Recipes

Classroom teachers have provided all of these recipes.
All recipes can be increased to make larger batches.

Recipe #1

This recipe has a somewhat oily consistency and compacts like commercial Play dough.

Ingredients:

4 cups flour
1 cup salt
4 cups water
4 tablespoons oil
1/2-cup cream of tartar
Food coloring

1. Mix all of the ingredients in a saucepan.
2. Add food coloring at this time.
3. Cook and stir over low/medium heat until play dough is completely formed and no longer sticky.
4. Cool before storing in an airtight container or Ziploc bag.

Recipe #2

Ingredients:

3 cups Flour
1 1/2 cups Salt
3 cups Water
2 Tbs. Vegetable Oil
1 Tbs. Cream of tartar
Food coloring – Add a few drops to each batch to create the colors you need

1. Mix ALL of the ingredients in a large saucepan.
2. Cook over medium low heat, until the dough comes away from the edges of the pan and it becomes difficult to move the spoon.
3. Remove from heat. Cool until it can be handled.
4. Place on wax paper knead 3-4 times.
5. Store in Ziploc bags.



Homemade Play Dough (Flour Clay) Recipes continued...

Recipe #3

This recipe is more dough-like and compresses less than the others when taking a core sample. It may dry out before the others due to less oil in the recipe.

Ingredients:

- 1 cup flour
- 1 cup warm water
- 2 teaspoons cream of tartar
- 1 teaspoon oil
- 1/4-cup salt
- Food coloring of choice

1. Mix all the ingredients, adding the food coloring last.
2. Stir over medium heat until play dough has a smooth consistency and comes off the sides of the pan.
3. Remove play dough from the pan and cool.
4. Knead until smooth.
5. Place in a self-sealing plastic bag or airtight container to keep it soft.



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5E MODEL

Explore

GRADE LEVEL

Middle School

NSES STANDARDS

A, C, D

PREPARATION

Estimated Preparation: 30+ min.

Estimated Activity: 1-2 class periods

MATERIALS

- Copies of Animal Fossil Cards for each team
- Copies of Denver Basin rock formation cards for each team
- Envelopes for Animal Fossil Cards
- Copy of Geologic Time Scale and the Denver Basin Handout for each student
- Student Science Notebooks or paper
- Copies of mailing labels with Denver Basin Formations, one per student or team

OPTIONAL MATERIALS

- Reference materials from school library
- Johnson, Kirk R., and Robert G. Reynolds. Ancient Denvers. Denver: Denver Museum of Nature and Science. 2003.
- Websites:
Denver Museum of Nature and Science: Ancient Denvers
<http://www.dmnh.org/main/minisites/ancientDenvers/index.html>
Earth-Time: Geologic timescales
<http://www.earth-time.org/timescale.html>
MS L4 ~ Page 1

Geologic Time Scale and the Denver Basin Activity

Learning Goals/Objectives

To determine how the fossil record changes over geologic time.

To understand that earth's history is influenced by catastrophes.

To discover that earth processes can take millions of years to occur.

Activity Overview

Fossil evidence helps geologists and paleontologists determine the relative age of a rock formation. Students in this activity read about the makeup and history of rock formations in the Denver Basin. Students then analyze fossil cards to determine the specific rock formation(s) to which the rocks belong. After determining this information, students finally analyze and reflect on how life changed over millions of years in the Denver Basin. Without years connected to the amount of time and fossil evidence, student will see the need for radiometric dating to help delineate the dates and rates of time for geologic events, including the formation of rock layers.

Teacher Background

Students have already been introduced to the Principles of Superposition and Horizontality. In this activity, relative positions of rock formations, rock composition and the fossils found in various formations provide information about the Denver Basin's past. Students are introduced to the Principle of Fossil Succession during this activity.

Denver is part of what is known as the Front Range. The Front Range is where the eastern edge of the Rocky Mountains meets the High Plains in Colorado from its northern borders to the south central part of the state. It includes Denver and its metropolitan area.

With mountains, buttes, cliffs, foothills, mesas, and layered rock formations, scientists have long known that the area has undergone many changes over hundreds of millions of years in Earth's history.

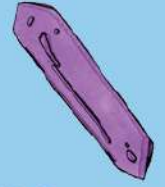
In the early 1990s, there were some very interesting fossil discoveries in the Denver area. When building a new airport (Denver International Airport) on the plains east of Denver, fossils of ancient palm trees were found. South of Denver in a town called Castle Rock, fossil evidence of an ancient rainforest was discovered. And under the Colorado Rockies' baseball field, dinosaur bones were found.



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Teacher Background continued...

Scientists wanted to know just how old rocks were in the Denver Basin. Dr. Kirk Johnson and other scientists from the museum drilled a 2,256-foot core of continuous rock near Kiowa, Colorado. Using the findings (evidence), from this core and evidence from other locations around the area, the museum staff and other scientists created a map of the Denver Basin. They learned and continue to learn more about Earth-time on the Front Range.

Dr. Johnson was also able to find the Cretaceous-Tertiary boundary at multiple locations in the Denver Basin region. The Cretaceous-Tertiary boundary, also known as the K-T boundary, is a thin ash rock layer that separates the Cretaceous time period from the Tertiary time period (the term Tertiary is no longer used by geologists). It also separates the Mesozoic Era from the Cenozoic Era. What does this mean? It means that major environmental changes occurred at the time of the formation of this rock band. A major asteroid impact occurred in the ocean off the Yucatan Peninsula in Mexico. Dinosaur fossils are found below this rock layer, but not above it. Many scientists are convinced that this impact is the cause of the extinction of the dinosaurs, as well as other organisms and ecosystems.

As a paleobotanist, Dr. Johnson researches the plant fossils he has uncovered at many sites in the Denver Basin. The clues provided in the fossils he finds help him reconstruct the environments of the Earth's past. He hopes to further understand past environments with each new discovery that is made.

The ancient plants, animals, rock composition, and rock formations in this lesson will help your students construct a picture of different environments and how the Denver Basin has changed over *millions* of years. From information that is gathered and organized, students should also be able to determine when the dinosaurs became extinct.

Vocabulary to Introduce

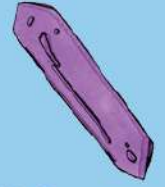
Principle of Fossil Succession – fossils change in a definite order and time periods and can be identified by the fossil content



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Advance Preparation

Note: It is optimal for the sets of these materials to be reproduced in color. It is easiest to preserve the color copies by laminating them or placing them in plastic sheet protectors. The expense of color copies may be beyond your classroom budget. The pictures were selected to provide good black and white copies. You should check the black and white copies from your school copy machine before running off multiple copies. You may need to adjust the light/dark setting to get the best possible copies.

1. Prepare a set of animal fossil cards for each team.
 - a. Cut the animal fossil cards in half and mix up the cards.
 - b. Place them in a large envelope.
2. Prepare a set of Formation Fact Sheets for each team. Mix up the numbered pages.

Classroom Activity

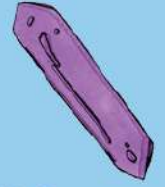
1. Read and discuss the information section of the student handout with your class.
2. Explain to the students that they will be finding out information about each of the formations in the Denver Basin and that this information will help them place animal fossil cards that belong in each of the specific formations.
3. Hand out the cards on each of the formations. Explain that they will find clues in the information provided on the cards.
4. Have students read about each of the formations. Ask students what they thought was most important about each formation. What did they learn? Were there any animals, plants, or environmental information that seemed unique to the formation?
5. Hand out the animal fossil cards. Explain that each animal comes from a specific rock formation. They should be able to analyze and correlate the information on the animal fossil card to a rock formation. Some of the formations have more than one animal fossil that is related to it. All formations have at least one animal fossil card.
6. Explain that once they have found where each animal fossil belongs, they need to stack or “deposit” their fossil and rock formation cards, from oldest to youngest, using the numbers on the Formation Fact Sheets. Ask the class what they think the numbers on the formation fact sheets mean. (#1 is the oldest formation, #2 is the next oldest, #13 is the youngest formation, etc.)



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Classroom Activity continued...

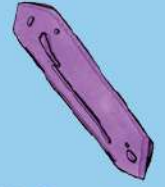
7. Student teams should then check with another team to see if they placed fossils in the same formations. If there are differences, teams should discuss why they thought a fossil belonged with a certain formation. Changes should then be made.
8. When teams have completed checking their answers with another team, provide them with a cross-section diagram of the Denver Basin that has numerical dates for each of the different formations.
9. The following questions are on the student worksheet. These questions can be used as a focus for a class discussion or assigned as written work. Use the answers to these questions to determine student understanding of relative time and fossil succession.
 1. Which fossil(s) are the oldest? *The oldest fossils found in the Denver Basin were found in the Fountain Formation: Scale trees, giant relative of the horsetail rush, small amphibians, fish, protomammals, giant cockroaches, millipedes, and dragonflies.*
 2. In which formation were these fossils found? *Fountain Formation.*
 3. Which fossils were the youngest? *Mammoths and camels.*
 4. In which formation were these fossils found? *Quaternary Sediments.*
 5. In how many of the formations were dinosaurs found? What were these formations? *Morrison, Dakota Sandstone, Pierre Shale, and Denver Formation.*
 6. What does the fact that different types of dinosaurs were found in different formations prove about their existence? *Possible answers: Different dinosaurs lived at different times. Dinosaurs lived over a long period of time. Different climates and ecosystems allowed different types of dinosaurs to evolve.*
 7. What types of fossils were found after the dinosaurs became extinct? *Small mammals, birds, fish, crocodiles, turtles.*
 8. Based on the information that you have, what dinosaurs were first to inhabit the Denver Basin? *According to the information given, sauropods.*
 9. Which dinosaurs were the last to inhabit the Denver Basin? *Common dinosaurs that existed in the Denver Basin were Tyrannosaurus rex and Triceratops. Many other dinosaurs lived at this time, but these are two that lived in the Denver Basin at this time.*



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Classroom Activity continued...

10. What problems exist with relative dating of rocks? *Possible answers: There are no numeric dates associated with the rock formations. Fossil evidence needs to be correlated to other known information.*
11. Why do you think geologists use absolute dating with the relative dating of rocks? *Numerical dates further define the information found from relative dating. Numerical dates don't provide a complete picture of a particular area; it's only one piece of information.*
12. How do the types of fossils change as the rock layers become younger and younger? What kind of changes do you see in the fossils over time? *Expect a variety of answers. Students should notice, at the very least, that the types of animals change with the ages, and plants and animals change with different environments.*
10. Refer middle school students to their geologic timelines. Tell students that they will next add the formations from the Denver Basin to their timelines.
11. Give middle school students prepared sticker labels or have students prepare their own labels. If labels are prepared ahead of time, ask students to write one animal or plant fossil representative of the formation and time period.
12. Allow time for students to add the labels to their string/yarn timeline. As they are working, ask your students to think about where most of the labels are being placed. *(Most labels will be placed in the upper portion of their timelines.)*
13. Have students add other important event labels to their timelines. *(These can be obtained from the How Old is the Earth? – Part Two Lesson.)*

Resources

Johnson, Kirk R., and Raynolds. Robert G. (2006). Ancient Denvers. Denver Museum of Nature and Science. Denver.

Johnson, Kirk R. (2007) Interviews. Denver Museum of Nature and History. Denver.



Data Card Answer Key

Card no	Data	Formation Name
1	Apatosaurus	Morrison
2	T-rex	KD1
3	Lycopod tree trunk	Fountain
4	Ripple marks	Dakota
5	Triceratops	KD1
6	Triceratops	Laramie
7	Ammonite	Pierre
8	Stromatolite	Lykins
9	Protomammal trackway	Lyons
10	Sauropod footprint	Morrison
11	Ankylosaur scute	Fox Hills
12	Lion jaw bone	Quaternary sediments
13	Pterosaur bones	Pierre
14	Mosasaur tooth	Pierre
15	Coryphodon tooth	D2
16	Titanothere	CR Conglomerate
17	Mammoth tusk	Quaternary sediments
18	Volcanic rock	CR Rhyolite
19	Mudstone and rock	KT boundary
20	Bison jaw	Quaternary



Precambrian igneous and metamorphic rocks

Description of the rocks:

These rocks, formed in high-temperature, high-pressure environments deep in the Earth, are very hard, making them more difficult to erode. Much of the Front Range that we see today is exposed Precambrian rock, including the sparkling Pikes Peak granite. Formed about 1.0 billion years ago, this granite and the other rocks in the unit are all that is left after the younger softer upper portions of the Rocky Mountains eroded away. In the center of the Denver Basin, the Precambrian rocks are about 2 miles below us.

Ancient Environment:

Landscape: none (sub-surface)

Plants: none

Animals: none

What it looks like today:



© Kirk Johnson



Fountain Formation

Description of the rocks:

This formation contains over a thousand feet of reddish sandstone, mudstone, and conglomerate, originally laid down by rivers draining off the Ancestral Rockies during the Pennsylvanian and Permian periods. Coarse pieces of quartz and granite within the sandstone are a good clue that a mountain range was eroding somewhere upstream. The name for this formation comes from Fountain Creek in Colorado Springs.

Ancient Environment:

Landscape: Mountainous with early forests.

Plants: *Lycopod* and *Sphenopsid* trees (100' tall, relative of horsetail rush, all parts of the tree were photosynthetic, including the trunk!)

Animals: Small amphibians, fish, protomammals, giant cockroaches, and dragonflies

What it looks like today:



© Kirk Johnson



Lyons Sandstone

Description of the rocks:

This reddish-orange colored sandstone is the remnant of giant sand dunes and rivers which formed along the edge of the ancestral Rocky Mountains. The sand grains are blown up one side of the dune and slip down the other. Stacks of sand were eventually buried and cemented to form fossilized sand dunes. The structure of the dunes, called cross-beds, is still visible in some places. Today, this rock is quarried in sheets which are broken into smaller pieces to make flagstone. Occasionally, footprints and impressions of ancient raindrops are preserved in the stone!

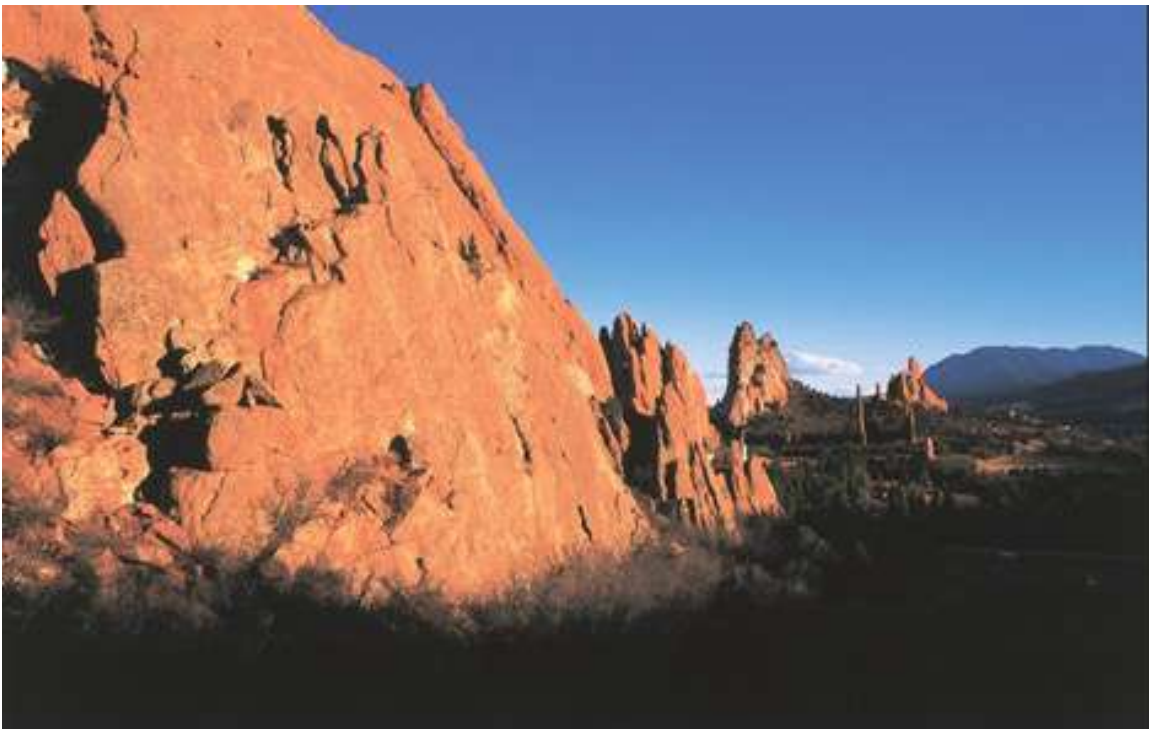
Ancient Environment:

Landscape: Dry and seasonal climate, immense sand dunes.

Plants: Early conifers and cycads.

Animals: somewhat larger protomammals (the size of dogs with squat-bodies) that ate plants.

What it looks like today:



© Kirk Johnson



Lykins Formation

Description of the rocks:

The Lykins formation is a series of cream-colored layers of wavy limestone amid thick piles of brick red mudstone. The mudstone is extremely soft and weathers so quickly that it is rarely exposed at the surface. The limestone was created by stromatolites, which are formed by cyanobacteria (algae and bacteria that live together). These odiferous, slimy mounds live in shallow salty pools.

Ancient Environment:

Landscape: Subtropical with humid, stinky, swampy tidal flats.

Plants: algae

Animals: not preserved as fossils

What it looks like today:



© Kirk Johnson



Morrison Formation

Description of the rocks:

The famous Morrison Formation is named after the small town of Morrison, just west of Denver. It is composed primarily of mudstone layers, with some fluvial sandstones and limestone pond deposits in between. This formation stretches into Wyoming and Utah, its characteristic purple and red colors make it instantly recognizable. About 400 feet thick, the Jurassic Morrison is loaded with dinosaur fossils. They've been quarried in well-known spots such as Wyoming's Como Bluff, Garden Park in Cañon City, and Dinosaur National Monument in Utah. At Dinosaur Ridge, along Alameda Parkway, visitors can see fossilized dinosaur bones and cross-sections of dinosaur footprints still in the rock. The very first *Apatosaurus* was described from this layer in 1877 by O. C. Marsh.

Ancient Environment:

Landscape: Monotonous flat landscape with lazy rivers

Plants: Ferns, conifers and cycads dominate the landscape

Animals: Large plant-eating dinosaurs such as sauropods, and meat-eating dinosaurs such as *Stegosaurus* and *Allosaurus*

What it looks like today:



© Kirk Johnson



Dakota Sandstone

Description of the rocks:

The best exposures of this sandstone formation are found along the Dakota Hogback, a ridge that runs for miles along the eastern front of the Rocky Mountains. The sandstone of this now-uplifted layer comes from the flat shore that was here 100 million years ago, during the Cretaceous, deposited just before the Western Interior Seaway covered the area. Ripple marks in this sandstone are evidence of the water's edge.

Ancient Environment:

Landscape: Beach

Plants: herbaceous ferns, broadleaf flowering trees, conifers

Animals: Dinosaurs such as *Iguanodon*, shrimp (known from burrows)

What it looks like today:



© Kirk Johnson



Pierre Shale

Description of the rocks:

This soft, dark grey rock was created by layers of marine mud that fell to the bottom of a shallow seaway, which split North America in half from North to South near the end of the Cretaceous period.

Ancient Environment:

Landscape: Saltwater sea, 600' deep.

Plants: (none fossilized)

Animals: Pterosaurs, mosasaurs, ammonites, Baculites, fish, giant clams

What it looks like today:



© Kirk Johnson



Fox Hills Sandstone

Description of the rocks:

These light colored, sandstone rocks mark the retreat (regression) of the interior seaway by preserving the beach. Few fossils are preserved in this sandy environment.

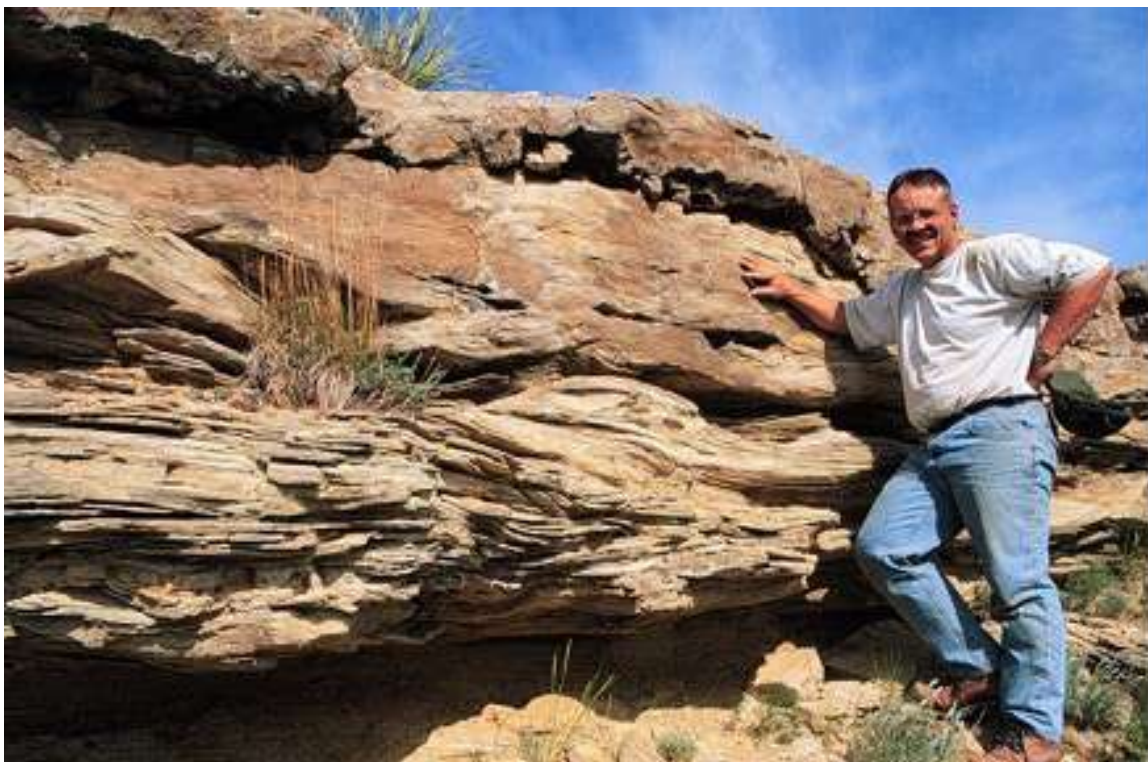
Ancient Environment:

Landscape: Beach along the retreating interior seaway

Plants: Ferns, conifers, broadleaf trees

Animals: *Ankylosaur*, turtles, crocodiles, shrimp (known from burrows)

What it looks like today:



© Kirk Johnson



Laramie Formation

Description of the rocks:

As the Western Interior Seaway continued to retreat, its western edge was characterized by vegetated coastal swamps of estuaries, which deposited in this yellowish to brown rock layer. Coal beds are frequently found in the lower part of this Cretaceous formation. About 200-400 feet thick in the middle of the Denver Basin, the Laramie is around 2100 feet below the surface. There is an unconformity between this formation and the one above it, the Arapahoe Conglomerate. This means that there is a period of time unaccounted for in the rock record.

Ancient Environment:

Landscape: Warm, swampy and fairly flat with closed-canopy forests

Plants: Palms, broadleaf trees, ferns

Animals: Dinosaurs such as *Triceratops* and *Tyrannosaurus rex*, crocodiles, early mammals

What it looks like today:



© Kirk Johnson



D1 (Arapahoe Conglomerate, Denver Formations, and Dawson Arkose)

Description of the rocks:

The Front Range, our local Rocky Mountains, arose at two times during the Laramide Orogeny. As the tops of these new mountains eventually began to erode, their sediments added more layers to the Denver Basin. These sediments never completely solidified, leaving layers that are much more like soil than they are like rock. From oldest to youngest, they are the Arapahoe Conglomerate, the Denver Formation, and part of the Dawson Arkose. About 2000 feet thick in the center of the Basin, these rocks include most of the aquifers supplying groundwater to the Denver metro area.

Ancient Environment:

Landscape: Very warm and wet (tropical), large forests grew along the base of the newly rising Rocky Mountains.

Plants: Broadleaf trees, ferns, cycads, palm, conifers and gingers.

Animals: Dinosaurs such as *Triceratops* and *Tyrannosaurus rex*, crocodiles, early mammals

What it looks like today:



© Kirk Johnson



K-T boundary

Description of the rocks:

The K-T boundary marks the global mass-extinction when the dinosaurs became extinct. It occurred when an asteroid crashed into the ocean near Mexico. Although this was not the largest mass-extinction that our Earth has experienced, it was the most recent. The K-T boundary occurred in the middle of the D1 formation and often appears as ~3 cm thick whitish clay between layers of coal or mudstone. This layer is hard to spot with your eye but can be measured in the lab because it contains a much higher concentration of iridium (a very rare element), shocked quartz (crystals that were blown into the air during the asteroid impact) and an increase in fern spores just above it.

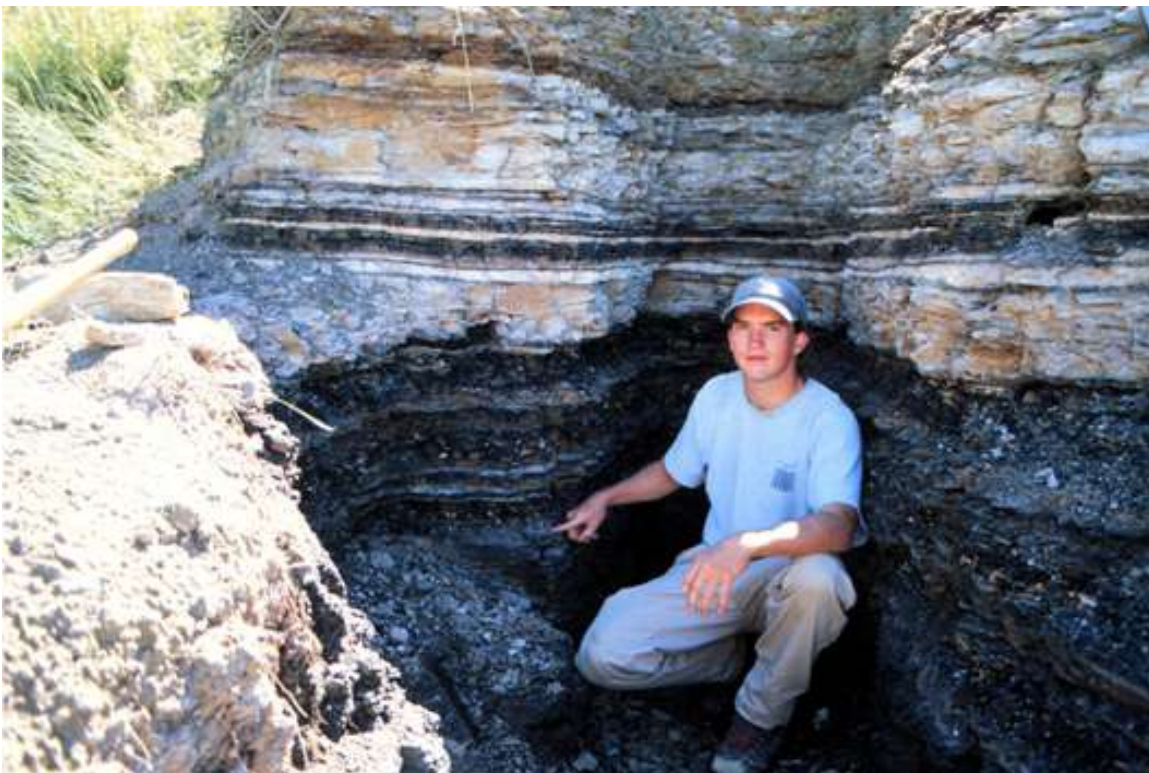
Ancient Environment:

Landscape: Fires burn much of the landscape, ferns are the first plants to come back

Plants: At least 30% of plants go extinct

Animals: All of the dinosaurs and ammonites go extinct at this point in time; turtles, crocodiles and small mammals survive

What it looks like today:



© Kirk Johnson



Denver Basin Paleosol

Description of the rocks:

Paleosol is the remains of a soil that formed beneath a tropical forest. This particular soil in the Denver Basin is a brilliant red, orange, and/or purplish clay layer at the base of the D2 sequence. On your map, it will look like a thin line. The original soil, similar to the rich red soils of modern Georgia and the Amazon Basin, was exposed and weathered for several million years. Averaging 20 feet thick, today the paleosol clay is mined for brick making.

Ancient Environment:

Landscape: Hot, dry, forested

Plants: Forests of broadleaf trees

Animals: Mammals like *Coryphodon*, turtles, crocodiles

What it looks like today:



© Kirk Johnson



D2 (Dawson Arkose)

Description of the rocks:

The layer represented by the second phase of the Laramide uplift is called the D2 sequence and contains the upper part of the Dawson Arkose. This white sandstone is composed of pieces of Pikes Peak granite, deposited across the basin by rivers during the Eocene. Fossil leaves and petrified wood have been found in this layer. Mammal bones and teeth, better known from Eocene rocks in Wyoming and other places, are rare during this time in the Denver Basin. The D2 sequence can be several hundred feet thick and contains shallow groundwater aquifers. Ponderosa pines frequently grow on this material today, a good clue when you're looking for this layer.

Ancient Environment:

Landscape: Hot, dry, forested

Plants: Forests of broadleaf trees

Animals: Mammals like *Coryphodon*, turtles, crocodiles

What it looks like today:



© Kirk Johnson



Castle Rock Rhyolite

Description of the rocks:

This rock was formed when a volcano, located in the Rocky Mountains, erupted and spewed a cloud of superheated airborne rock into the air. This superheated ash cloud welded together as it blanketed the ground and killed everything that it covered. In some places, this rock is 20 feet thick and it is now used as building stone.

Ancient Environment:

Landscape: Hot, dry

Plants: (not fossilized)

Animals: Large mammals like *Brontotheres* and rhinoceroses

What it looks like today:



© Kirk Johnson



Castle Rock Conglomerate

Description of the rocks:

This rock is the remnant of a catastrophic flood that rushed down the canyons of Castle Rock Rhyolite. It contains angular, refrigerator-sized pieces of Castle Rock Rhyolite as well as the bones of large animals that were swept into its wake. Although this rock was once at the bottom of a river, it is now a high cap rock topping buttes in the town of Castle Rock.

Ancient Environment:

Landscape: Warm, dryer, still recovering from the volcanic event

Plants: Palm trees, broadleaf trees, giant Sequoias

Animals: Large mammals like *Titanotheres* and rhinoceroses

What it looks like today:



© Kirk Johnson



Quaternary Sediments

Description of the rocks:

Quaternary sediments are bits of dirt and rock that eroded from the Rocky Mountains over the past few hundred thousand years, but have not yet formed rocks. These bits of sediment often contain bones of animals that lived during the Ice Age and record the arrival of people to this part of the planet.

Ancient Environment:

Landscape: Seasonal, cool, mix of open prairies and woodlands

Plants: Grasses, conifers

Animals: Mammoths, mastodon, camels, lions, bison, cheetahs, giant ground sloths

What it looks like today:



© Kirk Johnson



Geologic Time Scale and the Denver Basin Student Handout

Information

Denver is part of what is known as the Front Range. The Front Range is where the eastern edge of the Rocky Mountains meets the High Plains in Colorado from its northern borders to the south central part of the state. It includes Denver and its metropolitan area.

With mountains, buttes, cliffs, mesas, and layered rock formations, scientists have long known that the area has undergone many changes over hundreds of millions of years in Earth's history.

In the early 1990s, there were some very interesting discoveries in the Denver area. When building a new airport on the plains east of Denver, fossils of ancient palm trees were found. South of Denver in a town called Castle Rock, fossil evidence of an ancient rainforest was discovered. And under the Colorado Rockies' baseball field, dinosaur bones were found.

Scientists wanted to know just how old rocks were underneath the Denver Basin. Dr. Kirk Johnson and other scientists from the museum drilled a 2,256-foot core of continuous rock near Kiowa, Colorado. Using the findings (evidence), from this core and evidence from around the area, the museum staff and other scientists created a map of the Denver Basin. They learned and continue to learn more about Earth time (geologic history) on the Front Range.

Dr. Johnson was also able to locate the Cretaceous-Tertiary boundary at multiple locations in the Denver Basin region. The Cretaceous-Tertiary boundary, also known as the K-T boundary, is a thin ash rock layer that separates the Cretaceous time period from the Tertiary time period. It also separates the Mesozoic Era from the Cenozoic Era. What does this mean? It means that major environmental changes occurred at the time of the formation of this rock band. A major asteroid impact occurred in the ocean off the Yucatan Peninsula in Mexico. Dinosaur fossils are found before this rock band, but not after it. This impact is believed to have caused the extinction of the dinosaurs, as well as other organisms and ecosystems.

As a paleobotanist, Dr. Johnson has researched the plant fossils he has uncovered at many sites in the Denver Basin. The clues provided in the fossils he finds help him reconstruct environments of the Earth's past. With each find, he hopes to further understand these past environments.

The ancient plants and animals, as well as rock formations you will learn about in this lesson will help you construct a picture of different environments and how the area has changed over *millions* of years. And from the information you put together, you will also be able to determine when and where the dinosaurs became extinct.

Purpose:

1. To show how rock layers and fossils can be used to give relative dates to Earth's history
2. To apply your knowledge of the Principle of Superposition and relative dating to determine the order of fossils in these layers

**Materials:**

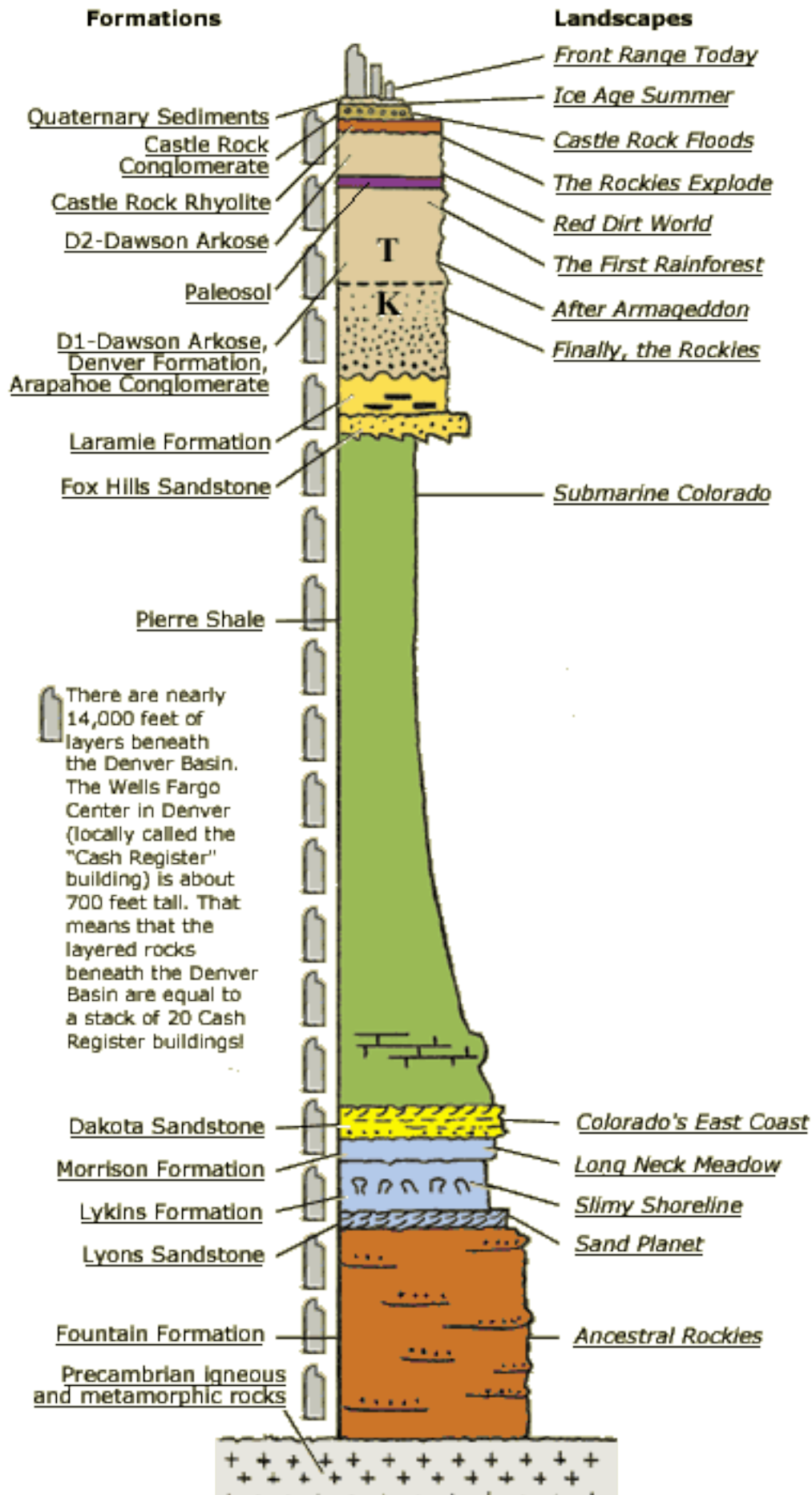
- One Geologic Time and the Denver Basin handout per person
- One set of fossil cards per team
- One set of rock formation cards per team

Procedure:

1. You and your teammates will be given a cross-section of the rock formations of the Denver Basin with information about each of these rock layers.
2. You will also be given a set of animal fossil cards. The fossil cards include information that provides clues to which rock formation the animal fossils belong.
3. Carefully read about each rock formation. Plant information, plant fossils, and environmental conditions that existed at each particular formation's time in Earth's history will help you make connections to the clues given on the animal fossil cards.
4. Carefully examine the fossil picture and read the fossil information on each card. Clues are given that should help you determine where they fit in the Denver Basin formations. Evidence for where each fossil fits in geologic time can be found in the rock types, plants, and other fossils.
5. Once you feel you have found the correct formation for each of your fossil pictures, arrange your animal fossil pictures and rock formation cards from oldest to youngest.
6. Discuss your results with another team. Do they agree with where you placed the animal fossils?
7. Ask your teacher for a copy of the Denver Basin cross-section diagram showing numerical ages for the formations.
8. Answer the following questions in your science notebooks. Be ready to discuss the questions with your class.

Questions for Discussion or Notebooks:

1. Which fossil(s) are the oldest?
2. Where were these fossils found?
3. Which fossils were the youngest?
4. Where were these fossils found?
5. Over how many formations were dinosaurs found? What were these formations?
6. What does the fact that different types of dinosaurs were found in different formations tell you about their existence?
7. What type of fossils were found after the dinosaurs became extinct?
8. Which dinosaurs were the first to inhabit Earth?
9. Which dinosaurs were the last to inhabit Earth?
10. What problems exist with relative dating of rocks?
11. Why do you think geologists use absolute dating along with relative dating of rocks?
12. How do the types of fossils change as the rock layers become younger and younger? What kind of changes do you see in the fossils over time?



Fountain Formation 300,000,000 YA		Ancestral Rockies		Fountain Formation 300,000,000 YA		Ancestral Rockies
Lyons Sandstone 280,000,000 YA		Sand Planet		Lyons Sandstone 280,000,000 YA		Sand Planet
Lykins Formation 250,000,000 YA		Slimy Shoreline		Lykins Formation 250,000,000 YA		Slimy Shoreline
Morrison Formation 150,000,000 YA		Long Neck Meadow		Morrison Formation 150,000,000 YA		Long Neck Meadow
Dakota Sandstone 100,000,000 YA		Colorado's East Coast Iguanodons		Dakota Sandstone 100,000,000 YA		Colorado's East Coast Iguanodons
Pierre Shale 70,000,000 YA		Cretaceous Western Inte- rior Seaway		Pierre Shale 70,000,000 YA		Cretaceous Western Interior Seaway
Denver Formation 66,000,000 YA		Rocky Mountains form again		Denver Formation 66,000,000 YA		Rocky Mountains form again
Denver Formation 65,000,000 YA		Extinction of Dinosaurs		Denver Formation 65,000,000 YA		Extinction of Dinosaurs
Denver Formation 64,000,000 YA		Castle Rock Rainforest		Denver Formation 64,000,000 YA		Castle Rock Rainforest
Paleosol-Dawson Arkose 55,000,000 YA				Paleosol-Dawson Arkose 55,000,000 YA		
Castle Rock Rhyolite 37,000,000 YA		Catastrophic volcanic events		Castle Rock Rhyolite 37,000,000 YA		Catastrophic volcanic events
Castle Rock Conglomer- ate 34,000,000 YA		Major Floods		Castle Rock Conglomer- ate 34,000,000 YA		Major Floods
Quaternary Sediments 16,000 YA		End of the Last Ice Age		Quaternary Sediments 16,000 YA		End of the Last Ice Age
Fountain Formation 300,000,000 YA		Ancestral Rockies		Denver Formation 65,000,000 YA		Extinction of Dinosaurs
Lyons Sandstone 280,000,000 YA		Sand Planet		Denver Formation 64,000,000 YA		Castle Rock Rainforest
Lykins Formation 250,000,000 YA		Slimy Shoreline		Paleosol-Dawson Arkose 55,000,000 YA		
Morrison Formation 150,000,000 YA		Long Neck Meadow		Castle Rock Rhyolite 37,000,000 YA		Catastrophic volcanic events
Dakota Sandstone 100,000,000 YA		Colorado's East Coast Iguanodons		Castle Rock Conglomer- ate 34,000,000 YA		Major Floods
Pierre Shale 70,000,000 YA		Cretaceous Western Inte- rior Seaway		Quaternary Sediments 16,000 YA		End of the Last Ice Age
Denver Formation 66,000,000 YA		Rocky Mountains form again		«Next Record»		«Next Record»



Rock description: Mudstone, ranging in color from light green to purplish red

Data found: Large dinosaur bones from a sauropod



Rock description: Mustard yellow to brown colored mudstone formed in very slow-moving to still water

Data found: *Tyrannosaurus rex* leg bone



Rock description: Coarse reddish rock with chunks of quartz and granite.

Data found: Trunk of a large *Sphenopsis* tree



Rock description: Light brown sandstone

Data found: Ripple marks in the rock made by water moving back and forth



Rock description: Orange-brown sand and mudstone, poorly consolidated; more like soil than rock

Data found: *Triceratops* skull



Rock description: Yellowish to brown sand and mudstone, poorly consolidated

Data found: *Triceratops*, a large Cretaceous dinosaur that probably ate cycads and other plants, had a three-horned skull that made up a third of its body. The horns were probably used for protection and mating rituals.



Rock description: Dark grey, brittle rock that looks like dirt on the surface. Thin layers peel off.

Data found: Ammonites, shelled marine organisms that were most likely related to squid and octopi



Rock description: Cream-colored limestone sandwiched between layers of red mudstone.

Data found: Stromatolite (a mound of photosynthetic bacteria and algae found in marine environments)



Rock description: Reddish-orange colored sandstone

Data found: Footprints of a protomammals



Rock description: Mudstone with green, red and purplish colored stripes

Data found: Footprint of a large sauropod



Rock description: White sandstone formed from beach sand

Data found: *Ankylosaur* scutes



Rock description: Unconsolidated soil

Data found: Lion jaw bone



Rock description: Dark grey, crumbly rock

Data found: *Pterosaur* bones

13



Rock description: Dark grey, shale

Data found: *Mosasaur* tooth

14



Rock description: White sandstone

Data found: *Coryphodon* tooth



Rock description: Conglomerate of cobbles containing some large chunks of volcanic rock

Data found: *Titanotherium* bones



Rock description: Sediments that have not yet formed rock

Data found: Mammoth tusk



Rock description: Pink, welded volcanic rock

Data found: Very few fossils are found



Rock description: Layers of mudstone and coal

Data found: An ash layer with high concentrations of iridium



Rock description: Unconsolidated dirt and rock

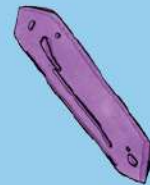
Data found: Bison jaw



EARTH TIME

Educators Guide

How do we measure time?



DENVER MUSEUM OF
NATURE & SCIENCE

5E MODEL

Explain

GRADE LEVEL

Middle School

NSES STANDARDS

D, E

PREPARATION

Estimated Preparation: 30 min.

Estimated Activity: 30-45 min.

MATERIALS

Student Handouts:

- Solving Geologic Puzzles
- Anticipation Guide

Solving Geologic Puzzles

Learning Goals/Objectives

To develop the concept of relative time through furthering student understanding of the Principles of Fossil Succession, Horizontality and Superposition

Activity Overview

Students review the principles of geology that they have been exploring in previous activities. Through the use of the Anticipation Guide reading strategy, students show their understanding of the Principles of Superposition, Horizontality, and Fossil Succession, as well as the concept of angular unconformities.

Teacher Background

Science reading is successfully done when students make meaning from personal experiences, the experiences of people they are connected to. This is the reason for the placement of the reading selection after the activities and the introduction to the scientists in this curriculum. Students also have a reason to read if they have prior experiences with the content of the reading.

The Anticipation Guide strategy (Herber, 1978) is a fun, effective strategy for developing understanding since it allows students to self-correct and not be penalized for mistakes. It often helps students solidify their understandings about certain concepts.

What it is: Students are given a set of four to six statements based on the reading selection. Students determine whether or not the statements provided are true prior to reading the selection. They provide reasons for their choices in a class discussion before reading. While reading, and after reading, the article, students reinforce knowledge when they confirm their answers and they are able to change their understandings when statements are different from what they thought they would be. A class discussion held after students have completed their anticipation guides reinforces the correct understanding of material.

Advance Preparation

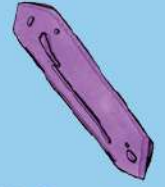
- Copies of Handout: Solving Geologic Puzzles, one per student
- Copies of Anticipation Guide, one per student



EARTHTIME

Educators Guide

How do we measure time?



DENVER MUSEUM OF
NATURE & SCIENCE

Classroom Activity

1. Provide students with the anticipation guide handout. Explain to students that they will be reading a selection that reviews concepts and ideas that they explored in their activities.
2. Ask students to read the statements provided on the handout. Explain that they will write “A” if they agree with a statement or “D” if they disagree with a statement. Ask students to mark an A or D for each statement in the *Before Reading* column.
3. Provide the students with the Solving Geologic Puzzles handout. Assign the reading to your students. You may choose to have your students read with a partner if you feel the selection’s reading level is high for your students.
4. Students then read the selection. After reading the selection, they respond once again to the statements, but this time in the “*After Reading*” column. Note: Many students do not like to be wrong. They will often go back and change “*Before Reading*” answers. Emphasize that you are only concerned with their final answers in the “*After Reading*” column.
5. Lead a discussion about the statements. Which ones were true? Where did they find evidence to support the statement? Which statements were not true? Where did they find evidence to disconfirm the statement?
6. Determine student understanding of relative time while you hold the class discussion.

Resources

Herber, H. (1978). Teaching reading in the content areas (2nd ed.). Englewood Cliffs, NJ: Prentice Hall.

Mathez, E. A., & Webster, J. D. (2004). The earth machine the science of a dynamic planet. New York: Columbia University Press.

Tarbuck, E. J., & Lutgens, F. K. (2003). Earth science (10th ed.). Upper Saddle River, NJ: Prentice Hall.

Waggoner, B. University of California Museum of Paleontology. Retrieved October 12, 2007, from <http://www.ucmp.berkeley.edu/history/steno.html>



Solving Geologic Puzzles

In the last activity, you put together pieces of a puzzle to learn about the Denver Basin. You found out how life and the Earth changed over time in this particular region. At the end of the activity, you were given years to put with the rock formations of the Denver Basin. The years added to your understanding of what you were able to figure out. Now it's time to think about what you have learned so far.

You learned and applied some principles of geology that are very old. In fact, they may seem like common sense. The principles *are* common sense. They happen to be hundreds of years old. When these principles were developed, they were new ideas. What was learned in the past helps geologists interpret rock layers today. Let's review some of these principles.

The Principle of Superposition. It wasn't until the 1600's that someone (Nicolaus Steno) came up with this idea. He basically said that if you find sedimentary rock layers that haven't been disturbed, the younger rock material would always be deposited on top of older rock material. Think of how this played out in your activities. It seems so simple and it definitely makes sense. It's a good principle to know.

The Principle of Original Horizontality. In the 1600's, Steno also came up with another easy principle that is still used today. In simple terms, it says that rock material is usually deposited horizontally. If rock layers are flat, they haven't been disturbed. They have their original horizontality. If rock layers are tilted or changed, the tilting and other changes occurred after the rock material was deposited. Geologists use the principle to help decide the order of events for rock layers.

The Principle of Lateral Continuity. This was another one of Steno's principles. When sediment is deposited in an area, it is usually deposited in all directions. Eventually, because sediment is spread out as it is deposited, the layer will become thinner and eventually end.

Angular Unconformities. It has a big name, but it is an easy concept to understand. (The term comes from the 1700's!) You need to know that it is not the only unconformity. But, this is the most easily recognized unconformity. You figured out angular unconformities when you collected core samples and drew cross-sections of your sedimentary model. Angular unconformities are tilted or folded sedimentary rocks where younger flat-lying materials cover these rocks. (Those tilted layers do not have original horizontality!)

Geologists use these principles (and some others) to figure out how layers of rock were deposited, when they were deposited, and where the layers formed. Geologists determine the proper sequence of the rocks according to what they find.

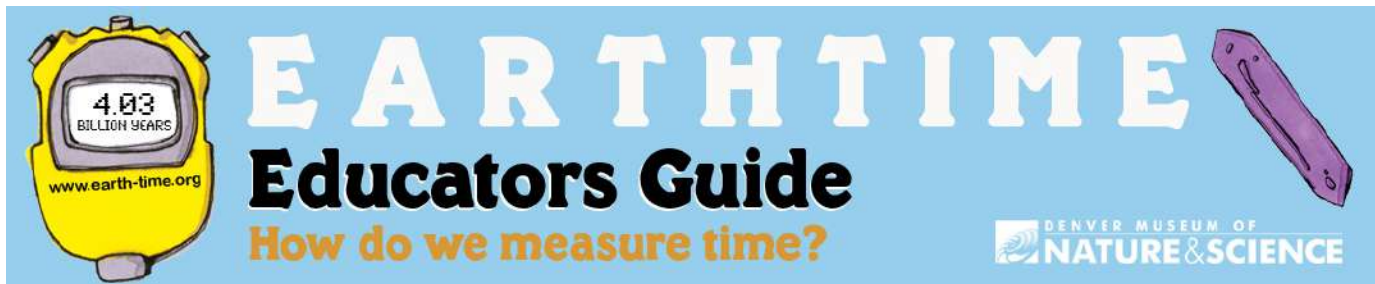
Fossils help complete the picture. Fossils are defined as the remains or traces of prehistoric life found in the earth. Knowing what fossils live in which formations adds another piece to the puzzle. Fossils tell us what past environments were like. They tell us where in geologic time they existed. In fact, an English canal builder in the early 1800's discovered that fossils follow a definite order in rock layers. He saw that periods of time in Earth history could be recognized by their fossil content. These observations became the **Principle of Fossil Succession.** You observed the changes of plants and animals over time in your Denver Basin activity. You also saw that many plants and animals that lived millions of years ago look similar to plants and animals of today.



Solving Geologic Puzzles continued...

All of these pieces together give us a pretty good picture of Earth's time. But, we're still missing "years"...

For hundreds of years in *human* history, there wasn't a good way to find out exactly when rocks were formed. There were a lot of good guesses for time based on observations and creative ideas, but they weren't very accurate. Putting accurate dates on rock layers came after the discovery of radioactive elements. In the 1950's scientists came up with a way to use these elements to date material. Geologists could now date rocks. In the next lesson, you will find out how this is done.



Name _____ Date _____

Solving Geologic Puzzles

Anticipation Guide

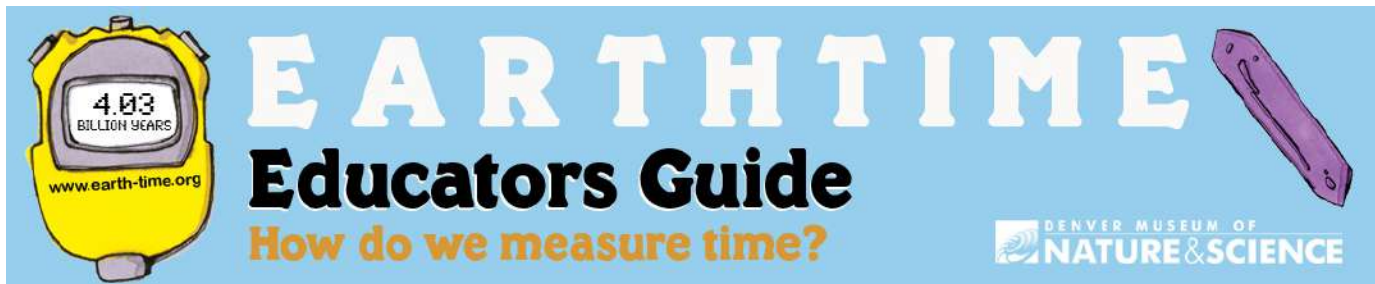
Directions:

1. Read each statement below.
2. In the **Before Reading** column, write an “A” if you agree with the statement. Write a “D” if you disagree with the statement.
3. Read *Solving Geologic Puzzles*. Some of your responses may change as you read. That’s okay.
4. Reread each statement.
5. In the **After Reading** column, you will need to respond again. If you agree with the statement, write an “A.” If you disagree with a statement, write a “D.”
6. Be ready to provide evidence in the reading for your answers.

*Before
Reading*

*After
Reading*

- | | |
|------------------------------------------------------------------------------------------------------------------|-------|
| _____ 1. In sedimentary rock layers, older materials are found on top of younger materials. | _____ |
| _____ 2. Most sediments are deposited horizontally. | _____ |
| _____ 3. Tilting and uplifting happens after the layers of rock material have been deposited. | _____ |
| _____ 4. Angular unconformities are tilted or folded rocks where younger flat-lying materials cover these rocks. | _____ |
| _____ 5. Fossils help scientists determine geologic time periods. | _____ |
| _____ 6. Relative dating of rock layers uses numerical years. | _____ |



Name TEACHER KEY Date _____

Solving Geologic Puzzles

Anticipation Guide

Directions:

1. Read each statement below.
2. In the **Before Reading** column, write an “A” if you agree with the statement. Write a “D” if you disagree with the statement.
3. Read *Solving Geologic Puzzles*. Some of your responses may change as you read. That’s okay.
4. Reread each statement.
5. In the **After Reading** column, you will need to respond again. If you agree with the statement, write an “A.” If you disagree with a statement, write a “D.”
6. Be ready to provide evidence in the reading for your answers.

*Before
Reading*

*After
Reading*

- | | |
|------------------------------------------------------------------------------------------------------------------|---------|
| _____ 1. In sedimentary rock layers, older materials are found on top of younger materials. | ___D___ |
| _____ 2. Most sediments are deposited horizontally. | ___A___ |
| _____ 3. Tilting and uplifting happens after the layers of rock material have been deposited. | ___A___ |
| _____ 4. Angular unconformities are tilted or folded rocks where younger flat-lying materials cover these rocks. | ___A___ |
| _____ 5. Fossils help scientists determine geologic time periods. | ___A___ |
| _____ 6. Relative dating of rock layers uses numerical years. | ___D___ |



EARTHTIME

Educators Guide

How do we measure time?



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5E MODEL

Elaborate

GRADE LEVEL

Middle School

NSES STANDARDS

A, D, E, G

PREPARATION

Preparation Time: 20-30 minutes

Activity Time: 1+ class period

MATERIALS

- EARTHTIME DVD
- TV
- Handout: *How Do We Measure Time?* Poster (6 pages)
- Handout: *About-Point Worksheet*

Absolute Dating of Rocks

Learning Goals/Objectives

1. To introduce middle school students to how scientists work together to find the absolute age of rocks
2. To create awareness of the process using radioactive elements to date rocks

Activity Overview

Students view the video to learn how Dr. Kirk Johnson works with Dr. Sam Bowring to date rocks using radiometric techniques. They learn the steps in the process and are made aware of the complexities of the process through the video. Students then review and clarify the steps through a reading about zircon crystals.

Teacher Background

See “How Do Scientists Date Fossils?” in the introductory section of *How Do We Measure Time?* Curriculum. It provides extensive information about the radiometric dating of ash layers.

Advance Preparation

- DVD EARTHTIME: Chapters 2-6
- Copies of the backside of the *How Do We Measure Time?* Poster; Steps 1-6 (six pages) for class; also downloadable online at www.EARTHTIME.org in PDF format

Classroom Activity

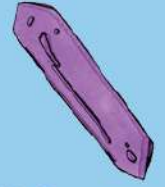
1. Remind students of when you asked them the questions about how they knew long ago dinosaurs or mammoths lived. Explain to students that geologists have found an accurate way to date rocks and by doing this they can tell when animals and plants lived in the past. The scientists that do this work are called geochronologists. These are the scientists that are able to put “years” on rock layers. Tell students that they will watch a video that takes them through the process of the precise dating of volcanic ash layers.
2. It is recommended that you pose the following questions *before* viewing the DVD chapter (segment). Middle school students need a focus and a reason for viewing videos that we show them. Before showing Chapter 2, explain to students that they will be learning



EARTH TIME

Educators Guide

How do we measure time?



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Classroom Activity continued...

about a very important crystal called zircon. Pose the following questions to your students to focus their viewing:

- How are zircon crystals formed?
- Why are zircon crystals called time capsules?

Discuss the answers to these questions *after* watching the video segment.

3. Before Chapter 3, pose the following questions and ask students to look for the answers as they watch the video:

- What are two things that paleontologists and geologists are good at doing?
- What does a geochronologist do?

Dr. Kirk Johnson compares regional ancient rainforest plants to other ancient rainforest plants around the world. Why does he want to know the exact age of his rocks?

Discuss the answers that your students found to the questions.

4. Before Chapter 4, pose the following questions and ask students to look for the answers as they watch the video:

- Why are zircon crystals important for determining the age of rocks?
- How long does it take for half of the ^{238}U in a zircon crystal to change to lead?

5. Before Chapter 5, pose the following questions and ask students to look for the answers as they watch the video:

- How are volcanic ash beds collected?
- How are zircons separated from these ash samples?
- Why is it necessary to collect such large quantities of rock for the lab?

Discuss the answers to the questions after viewing the DVD segment.

6. Before Chapter 6, pose the following question and ask students to look for the answer as they watch the video:

- What are some of the laboratory steps used to date zircon crystals?

Discuss students' answers and ask for clarification on the steps that they mention.

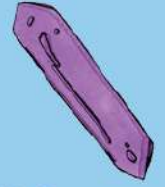
- *Please do not hesitate to use your own questions. The types of questions asked will depend on the age and background of your students.*



EARTH TIME

Educators Guide

How do we measure time?



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Classroom Activity continued...

7. Provide your students with copies of *How Do We Measure Time?* Explain that the pages were created to further explain the process of dating zircon crystals. Pair up students to read *How Do We Measure Time?* using the About-Point reading strategy. At the end of each section, ask students to complete this phrase:

This section is about _____; and the point is _____.

About-Point statements can be written in science notebooks or on the handout for this activity.

8. Use the following procedure to teach students how to use the strategy:
- Have students read first section.
 - Put three “about” statements up and instruct students to choose the best “about” statement for the section they just read. Explain to your class that the titles of the sections cannot be used for as the “about” part of the statement.

Possible “About” statements:

- This section is about zircon crystals.
- This section is about how zircon crystals can be stable and how they can contain unstable uranium.

- Put up three “point” statements and do the same. Discuss student answers.

Possible “point” statements:

- And the point is that zircon can withstand time, but the uranium in it decays to lead.
- And the point is that it is really strong and durable, but the uranium in it changes over time.
- And the point is that it helps scientists read time because it has uranium in it.

- Ask student pairs to read the next section.
- Ask students for possible “about” statements and choose as a class the best “about” statement.
- Repeat the same process for the “point” statement.
- Students read the rest of the selection and pause after each section to write their own about-point statements.

9. Discuss the rest of the students’ statements.



EARTHTIME

Educators Guide

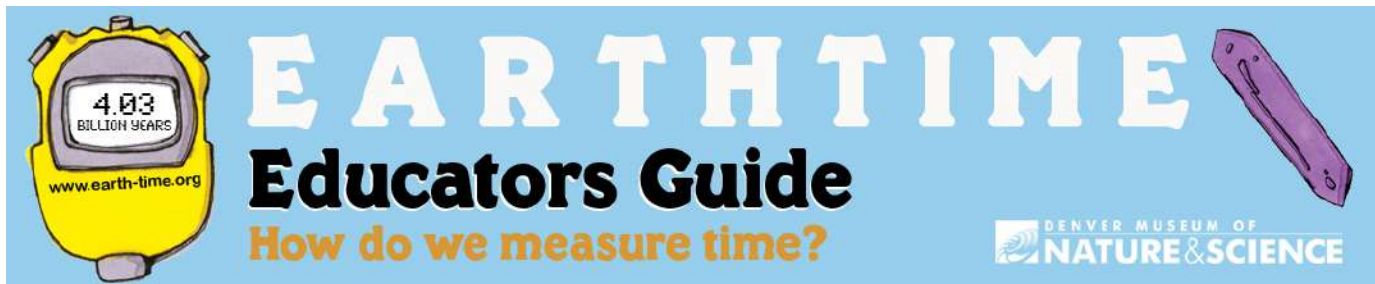
How do we measure time?



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Resources

Manzo, A. Manzo, U. and Estes, T. H. (2001). Content Area Reading: A Heuristic Approach. Columbus, OH: Merrill Publishing Co. 115-116.



Name _____ Date _____

Absolute Dating of Rocks Student Worksheet

Directions: After reading each section, write an “About-Point” statement. Make sure you do not use the title of each section in your “About” phrase. It should reflect the entire section of reading. The “point” phrase should include important information from the section. Your teacher will help you with your first two “About-Point” statements.

Write your statements in the following format:

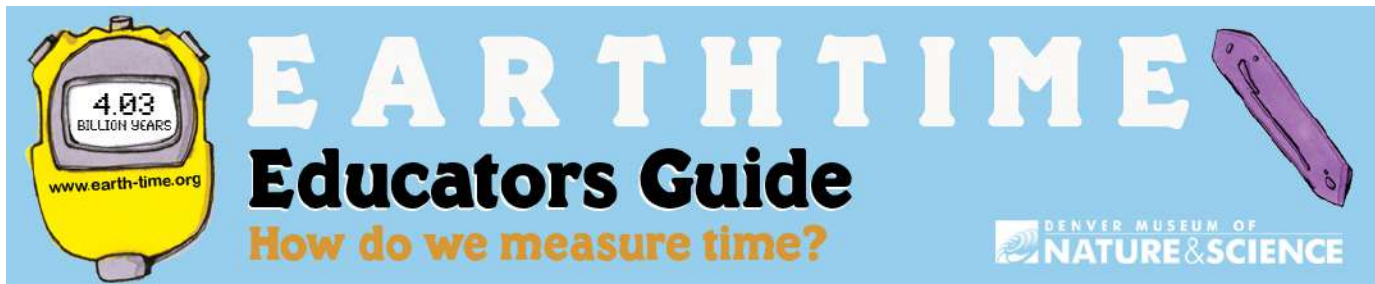
This section is about _____; and the point is _____ .

Section 1 - Stability vs. Instability

Section 2 - Formation

Section 3 - Deposition

Section 4 - Erosion and Discovery



Section 5 - Concentration

Section 6 - Reading the Stopwatch

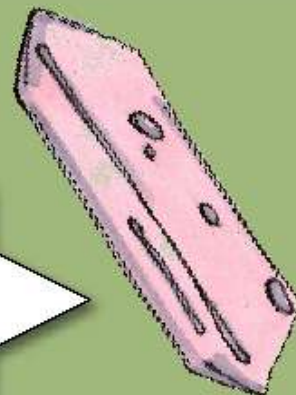
1 STABILITY vs. INSTABILITY

How can studying zircon help us understand time? Its combination of stability and instability makes it the perfect big time problem solver.



STABILITY

From the moment a zircon forms, it is one tough crystal. Zircon is dense, inert, and non-magnetic. It also resists weathering, withstands temperature extremes, and strongly rejects lead when it forms. In these ways, Zircon is incredibly stable.

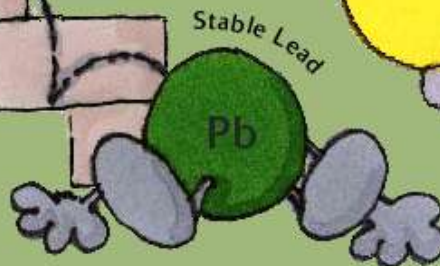


INSTABILITY

Within this tough crystal, however, there is a useful instability. Zircon contains unstable, or radioactive, uranium. From the moment a zircon crystal forms, unstable uranium begins to decay into stable lead. Over time, the amount of uranium decreases and the amount of lead increases.

When scientists study a zircon crystal and measure the ratio of uranium to lead, it is like a very precise stopwatch, one that can date events from a few hundred thousand years ago to several billion years ago.

It takes 4.468 billion years for the half of the Uranium-238 to change to Lead-206.



2 FORMATION



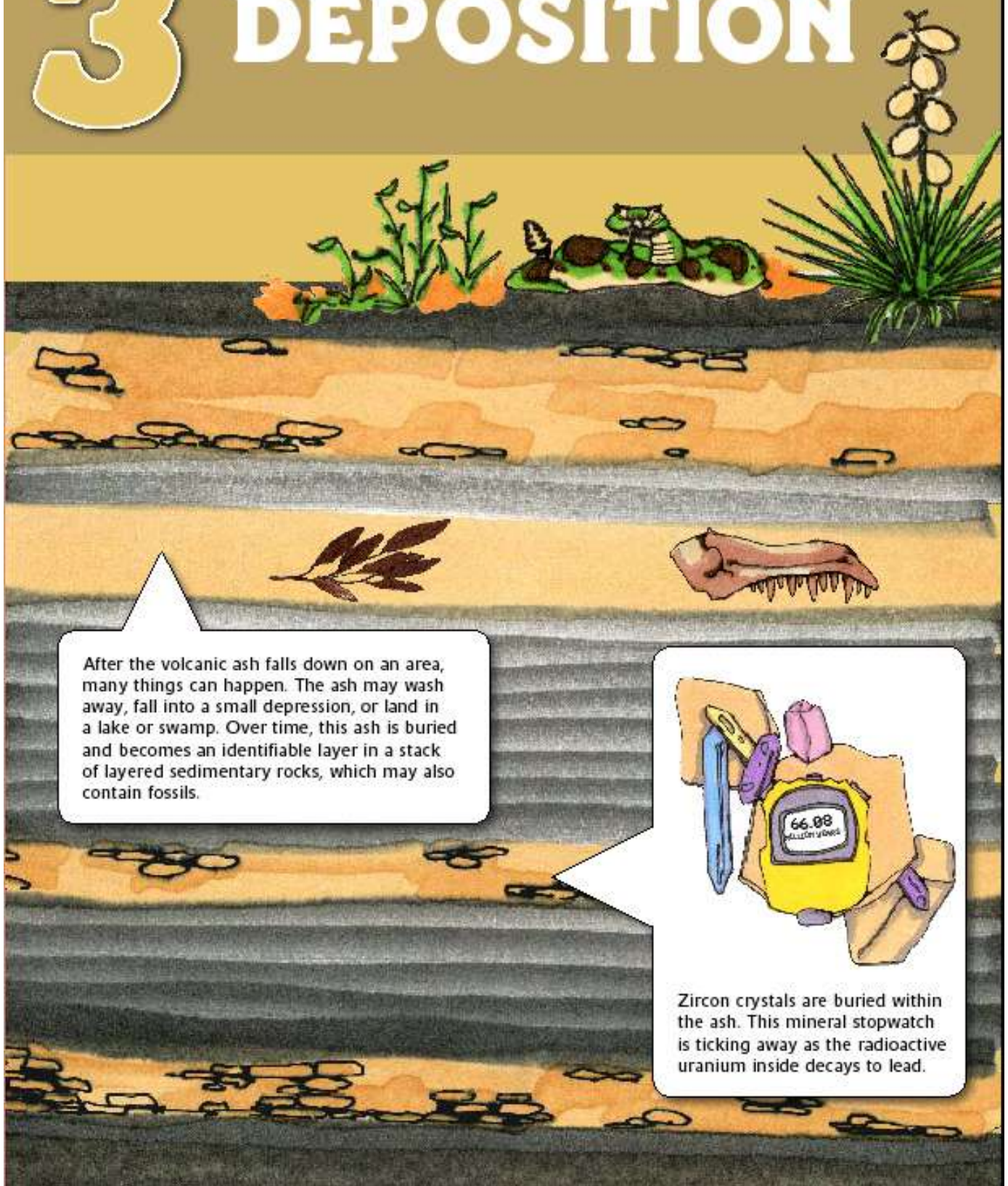
When a volcano erupts, gases originally dissolved in the magma form bubbles so quickly that they explosively shred magma into microscopic glass shards and mineral crystals. This is volcanic ash. Common minerals found in volcanic ash are feldspar, quartz, mica, and zircon. While zircon is formed in the same way as the rest of the minerals, it is unique because it is extremely durable and contains radioactive uranium, but no lead.



Crystals in close-up of volcanic ash

3

DEPOSITION

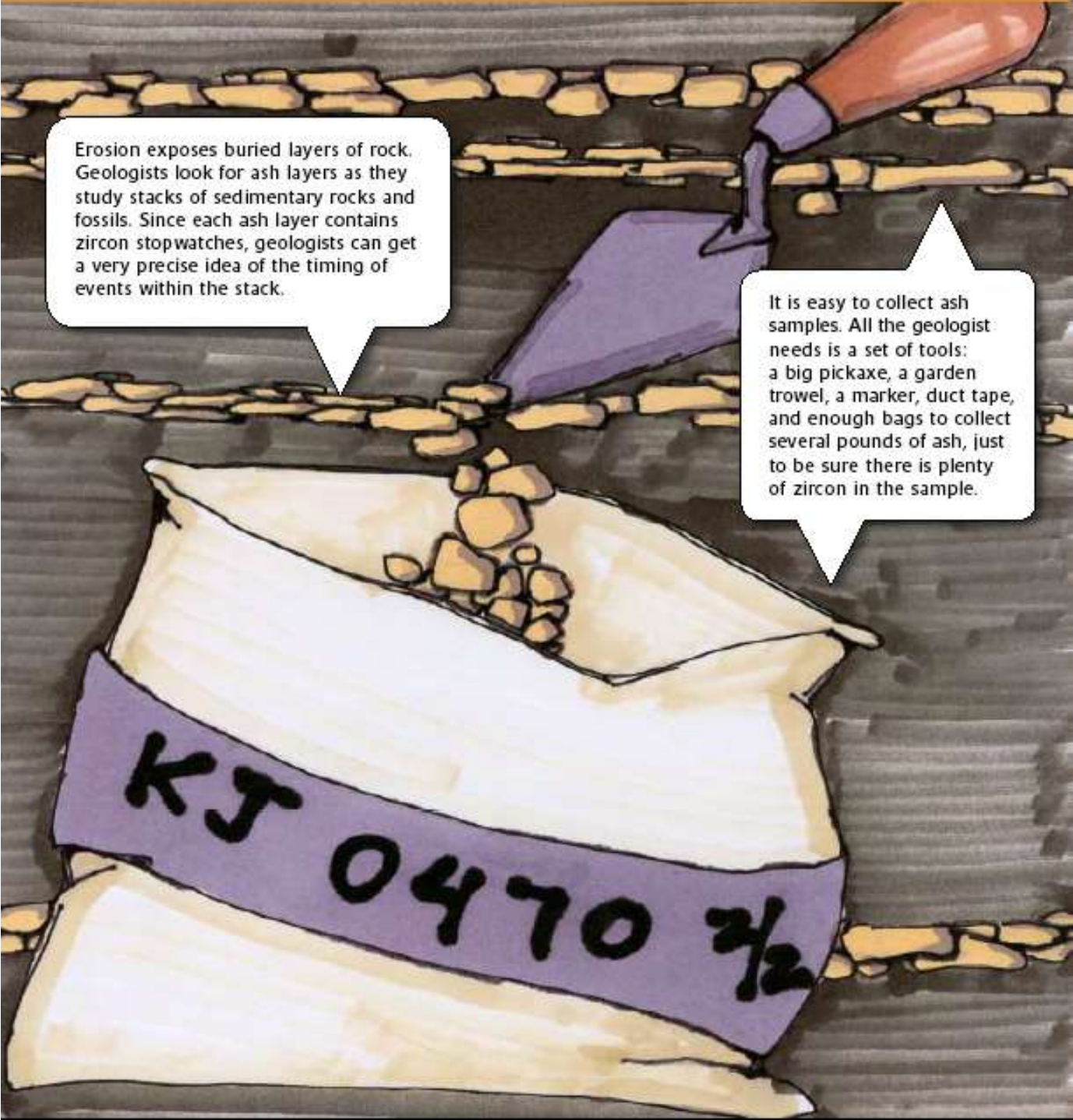


After the volcanic ash falls down on an area, many things can happen. The ash may wash away, fall into a small depression, or land in a lake or swamp. Over time, this ash is buried and becomes an identifiable layer in a stack of layered sedimentary rocks, which may also contain fossils.



Zircon crystals are buried within the ash. This mineral stopwatch is ticking away as the radioactive uranium inside decays to lead.

4 EROSION & DISCOVERY



Erosion exposes buried layers of rock. Geologists look for ash layers as they study stacks of sedimentary rocks and fossils. Since each ash layer contains zircon stopwatches, geologists can get a very precise idea of the timing of events within the stack.

It is easy to collect ash samples. All the geologist needs is a set of tools: a big pickaxe, a garden trowel, a marker, duct tape, and enough bags to collect several pounds of ash, just to be sure there is plenty of zircon in the sample.

5 CONCENTRATION



In the lab, geologists crush the ash sample and wash away all the fine dust and clay.

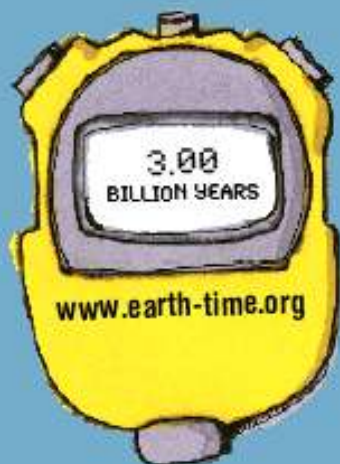
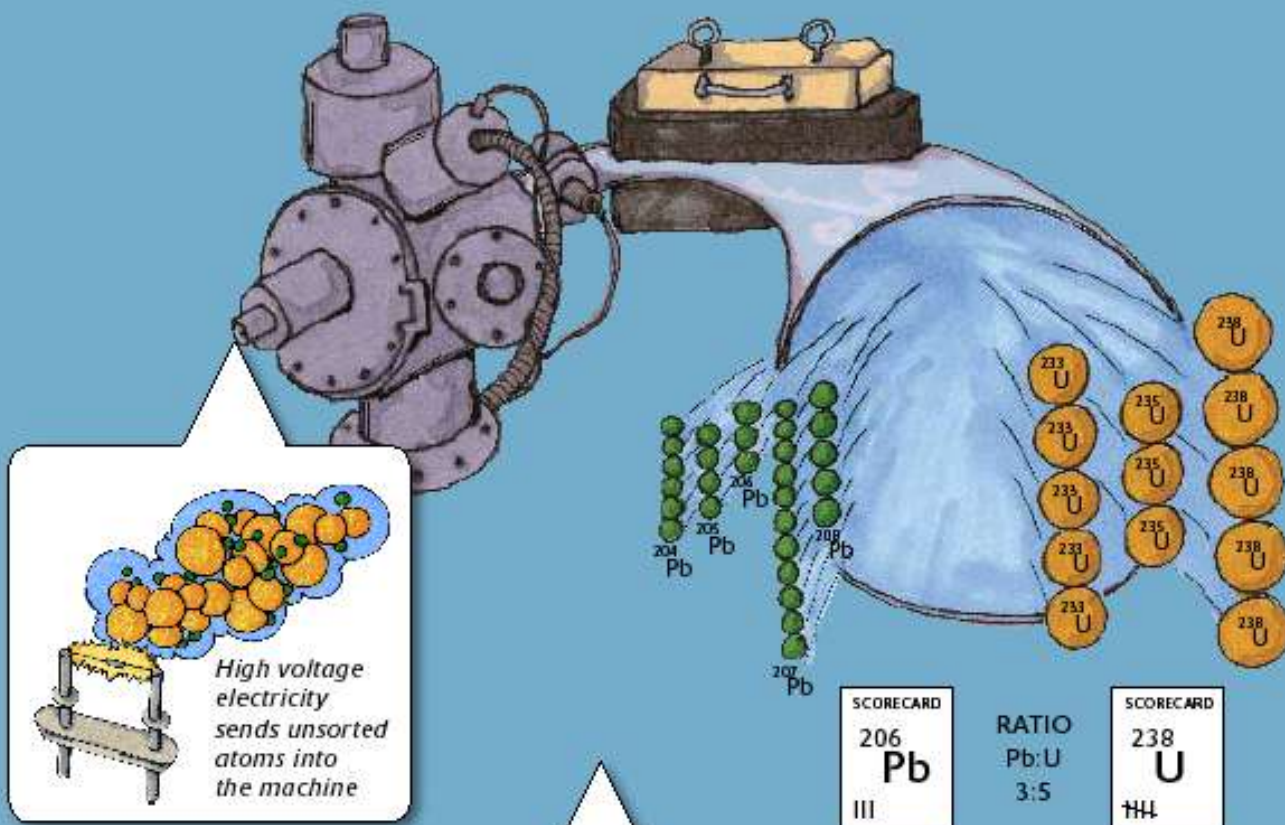


Zircon's unique properties make it possible to separate it from all other ingredients in the ash sample. Zircon is dense but not magnetic, so geologists first use a large magnet to get rid of the magnetic minerals.



Next, they separate the zircon crystals from the remaining minerals using heavy (high density) liquids. The zircon crystals are so dense that they sink to the bottom while the lower density crystals float in the heavy liquid.

6 READING THE STOPWATCH



After removing the zircon from the heavy liquid, scientists dissolve the individual tiny zircon crystals and separate the uranium and lead from all the other elements in the zircon. To read the stopwatch, the uranium and lead are put in a mass spectrometer, a machine that separates and counts individual atoms. The ratio of uranium to lead atoms allows scientists to calculate how many years have passed since the volcano erupted and the lead atoms started to accumulate in the zircon crystals.

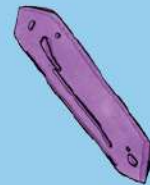
So, if a scientist wants to solve a big time problem, like the age of a mountain range, the answer just might be inside a zircon crystal.



EARTH TIME

Educators Guide

How do we measure time?



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5E MODEL

Evaluate

GRADE LEVEL

Middle School

NSES STANDARDS

A, C, D, G

PREPARATION

Preparation Time: 20 minutes

Activity Time: 30 minutes

MATERIALS

Handout of rock outcrop

Handout: GSI: Geologic Scene Investigation

GSI – Geologic Scene Investigations

Learning Goals/Objectives

To provide an opportunity to explain understanding of geologic time

To use evidence to support answers

To apply understanding of geologic time in another setting

Activity Overview

Students are given an imaginary Denver Basin outcrop cross-section diagram to analyze. Students use the diagram and their knowledge of geologic time to answer a series of questions.

Teacher Background

Students should be able to apply their understanding of relative time and absolute time in the *GSI: Geologic Scene Investigation* activity. This activity has been developed to both evaluate student understanding of learning and to replicate the types of items used on many of the state assessments. Multiple choice and short answer constructed response items were chosen, as they are the most common types of items used on the state assessments.

Advance Preparation

Run-off copies of handouts for each student:

Rock Outcrop

GSI: Geologic Scene Investigation

Classroom Activity

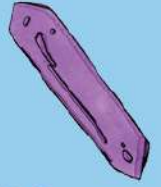
1. Provide students with copies of the handouts.
2. Let students know that this activity is an opportunity to show their understanding of the material in this module. Their job is one of geologists: to interpret information from a rock and fossil record. They are geology detectives.
3. Explain to students that they have been given an imaginary outcrop of a location in the Denver Basin. Ask students to look at the picture. Explain the following:
 - MYA stands for million years ago. Reinforce this idea by explaining that 64 mya is really 64,000,000 years ago. It may be helpful to write out the zeroes on the board or overhead projector.



EARTHTIME

Educators Guide

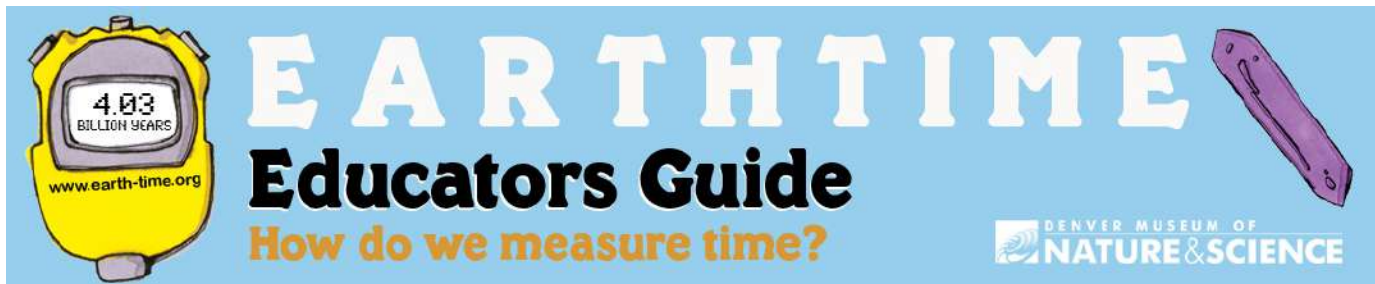
How do we measure time?



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Classroom Activity continued...

- The numbered thin layers represent volcanic ash layers that have been dated radiometrically.
4. The worksheet has questions for them to answer and they should base their answers on the information given to them in the rock and fossil record.
 5. Allow the time needed for students to complete the activity.
 6. Discuss the answers to the questions with the class.



Student Name _____ Date _____

GSI: Geologic Scene Investigation

Look at the cross-section diagram of an outcrop of the Denver Basin. The numbers listed on the diagram identify the volcanic ash layers. These ash layers have been radiometrically dated. Use the information from the outcrop diagram and the dating of the volcanic ash layers to answer these questions.



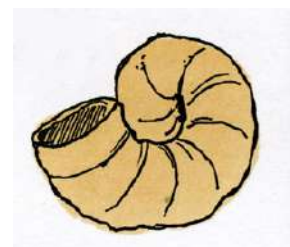
1. A triceratops skull was found in one of the layers of this outcrop. When did this Triceratops live?
 - a. From 66 – 64 million years ago
 - b. From 68 – 65.5 million years ago
 - c. From 65.5 - 63 million years ago
 - d. From 68 – 66 million years ago

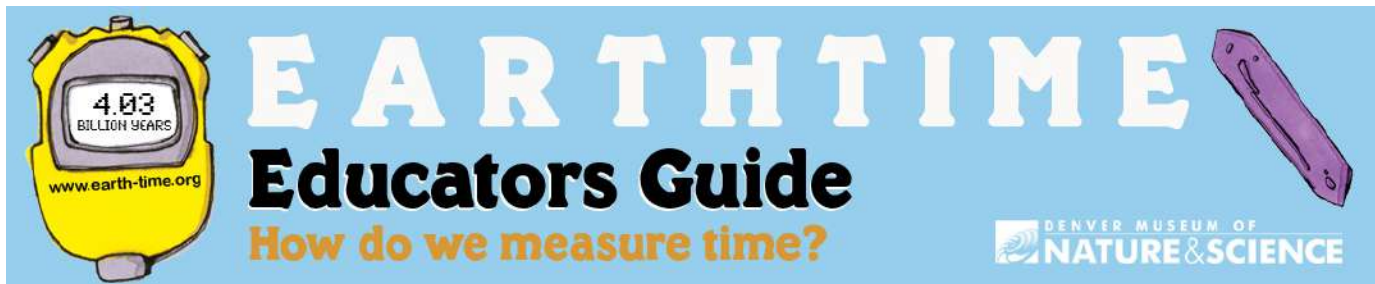
2. Which ash layer would best help you date the K-T (Cretaceous-Tertiary) boundary and the extinction of the dinosaurs? (Select the number representing the ash layer).
 - a. 2
 - b. 3
 - c. 4
 - d. 5

3. What evidence is there in this outcrop to support your answer?

4. What is the range of time represented by ammonite fossils in this outcrop?

- a. 70 – 65.5 million years ago
- b. 70 – 69.1 million years ago
- c. 70 – 64 million years ago
- d. 70 – 63 million years ago

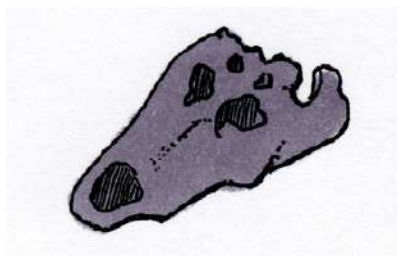




5. What might be the reason for the disappearance of the ammonites from this fossil record?

6. During what time span was the crocodile fossil found in the Denver Basin?

- a. 69 -68 million years ago
- b. 68 – 66 million years ago
- c. 66 – 65.5 million years ago
- d. 69.1 – 54 million years ago



7. This fossilized jaw bone belonged to an early placental mammal. Looking at where it is placed in the fossil record, what would you determine to be its age?

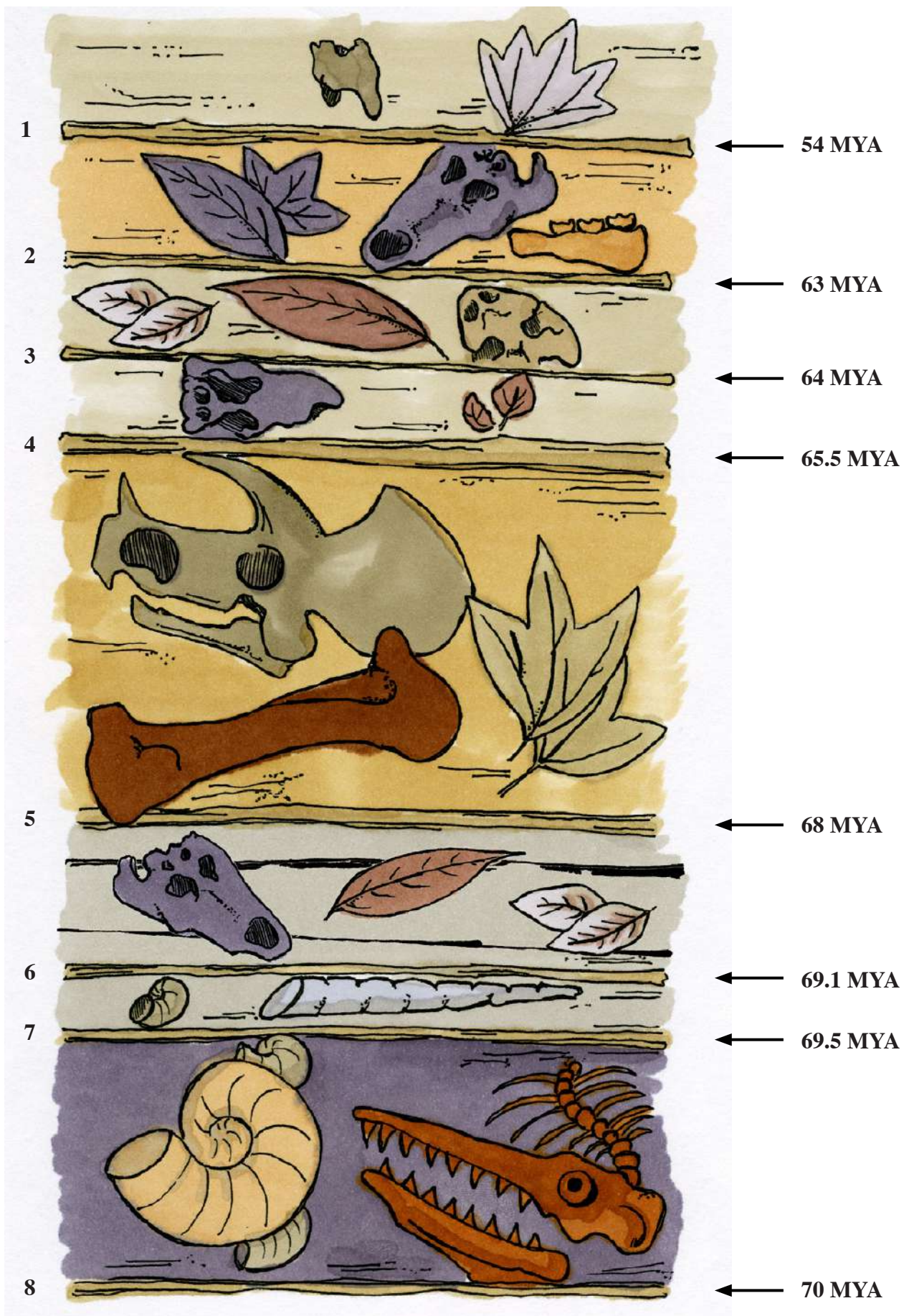
- a. between 63 and 54 million years old
- b. younger than 54 million years old
- c. 60 million years old
- d. 63 million years old



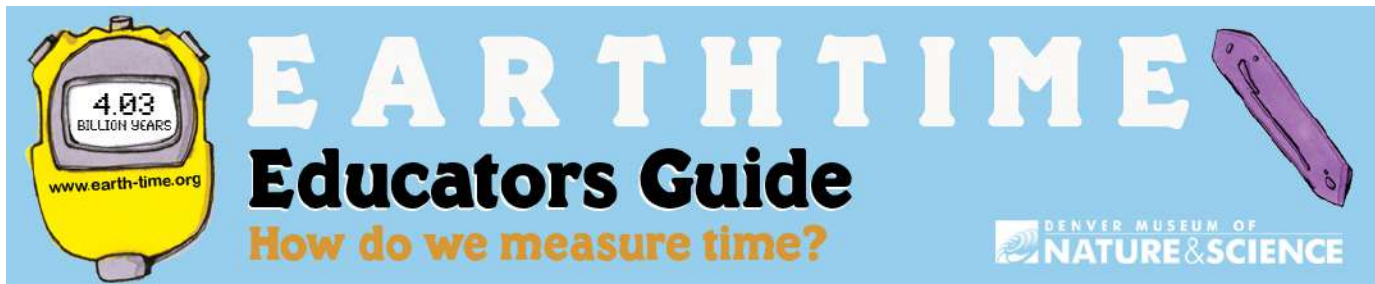
8. What information did you use to determine the age of the jaw bone?

9. All of the layers shown are horizontal. What does this tell you about the geography of the area?

- a. There was a volcano.
- b It was once mountainous.
- c. It was flat when the sediments were deposited.
- d. Everything has eroded away from this area.



MYA = million years ago



TEACHER KEY _____ Date _____

GSI: Geologic Scene Investigation

Look at the cross-section diagram of an outcrop of the Denver Basin. The numbers listed on the diagram identify the volcanic ash layers. These ash layers have been radiometrically dated. Use the information from the outcrop diagram and the dating of the volcanic ash layers to answer these questions.



1. A triceratops skull was found in one of the layers of this outcrop. When did this Triceratops live?
 - a. From 66 – 64 million years ago
 - b. From 68 – 65.5 million years ago***
 - c. From 65.5 - 63 million years ago
 - d. From 68 – 66 million years ago

2. Which ash layer represents the K-T (Cretaceous-Tertiary) boundary and the extinction of the dinosaurs? (Select the number representing the ash layer).
 - a. 2
 - b. 3
 - c. 4***
 - d. 5

3. What evidence is there in this outcrop to support your answer?

There are no dinosaur fossils above layer number four.

4. What is the range of time represented by ammonite fossils in this outcrop?

- a. 70 – 65.5 million years ago
- b. 70 – 69.1 million years ago***
- c. 70 – 64 million years ago
- d. 70 – 63 million years ago



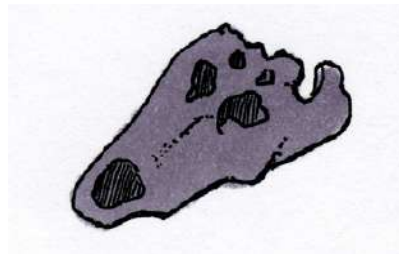


5. What might be the reason for the disappearance of the ammonites from this fossil record?

Globally, the ammonites became extinct after the major asteroid impact as did many species of animals. Students should at least mention that the ammonites disappear after the K-T boundary. In the Denver Basin, however, the marine conditions disappeared 69 million years ago, leading to the ammonites' extinction in this area.

6. During what time span was the crocodile fossil found in the Denver Basin?

- a. 69 -68 million years ago
- b. 68 – 66 million years ago
- c. 66 – 65.5 million years ago
- d. 69.1 – 54 million years ago***



7. This fossilized jaw bone belonged to an early placental mammal. Looking at where it is placed in the fossil record, what would you determine to be its age?

- a. between 63 and 54 million years old***
- b. younger than 54 million years old
- c. 60 million years old
- d. 63 million years old



8. What information did you use to determine the age of the jaw bone?

The jaw bone was found below the 54 million year old volcanic ash layer, so it must be more than 54 million years old. It was found above the 63 million year old ash layer, so it must be younger than 63 million years old. However, because the layer in which the fossil lies has not been precisely dated, there is no way to assign a precise date to its existence. Its age can only be determined within the range of the two precisely date ash layers.

9. All of the layers shown are horizontal. What does this tell you about the geography of the area?

- a. There was a volcano.
- b It was once mountainous.
- c. It was flat when the sediments were deposited.***
- d. Everything has eroded away from this area.



High School Curriculum

High School Prior Knowledge

Radiometric dating is addressed in a variety of courses in high school. Students may encounter the subject in biology, chemistry, physical science, earth science, or geology. Your school district should have made its own decision on where this topic is taught in high school science courses. The curriculum presented in the next pages focuses on the use of radiometric dating in geology.

Students need the following prerequisite knowledge to be successful with this curriculum:

- Students need to have some knowledge of atoms and atomic structure. (A quick review or introduction is provided for teachers that know their students need this background knowledge.) Knowing that atoms bond together in molecules should also be a prior understanding.
- Students should have background in the basic principles of geology and sedimentation.
- An understanding of erosion and deposition on a large scale is also required for success.
- Students should have access to the Internet and have some familiarity with Google Earth. There is an online tutorial that students can use to learn how to navigate the site.

Stages of Learning

Engage: EARTHTIME DVD: Show Introduction & Chapter One
How Old Is It? Student Activity

Explore: EARTHTIME DVD: Show Chapters 2 and 4
Zircon Crystals and Radioactive Decay Activity
Volcanic Mineral Activity
Penny Isotope Experiment

Explain: EARTHTIME Video: Show Chapters 3, 5, and 6
Reading: Introduction to the Scientists and the Science behind EARTHTIME: A Brief Guide to Uranium-Lead Radiometric Dating and the Geologic Time Scale, or *How Do You Measure Time?* Poster Pages

Elaborate /Evaluate: Denver Basin: Putting It All Together: Relative and Radiometric Time
Google Earth: Seeing the sites in 3-D

Evaluate: Optional: Quiz

Extend: EARTHTIME DVD: Show Datacast Broadcast



EARTHTIME

Educators Guide

How do we measure time?



DENVER MUSEUM OF
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5E MODEL

Engage

GRADE LEVEL

High School

NSES STANDARDS

A,D

PREPARATION

Estimated Preparation Time: 5 minutes

Estimated Activity Time: Less than 30 minutes

MATERIALS

DVD player and television
or

Computer with Projector
EarthTime DVD

How Old Is It?

Learning Goals/Objectives

To assess prior student understanding of EARTHTIME

To motivate student interest in understanding geologic time

Activity Overview and Teacher Background

It is hard for students to grasp large numbers. Research shows that many factors make it hard for students to understand the vastness of Earth's history. One factor is exposure to the concept (Trend, 2001). Very little time is spent on Earth's history in most earth science programs at both the middle and high school level. Repeated experiences on the topic can help develop understanding. Another factor is spatial ability and understanding. Research shows that students with strong spatial ability do much better at grasping the concept of deep time (Black, 2005). When spatial experiences and problems were presented over time, student understanding of Earth's time increased. In this introductory lesson, students physically create their own timeline of Earth history as a way to address this issue. The third factor is cognitive development. If students are not in the formal operational stage of cognitive development, it will be hard for them to understand abstract concepts (Pressley & McCormick, 2006). However, exposure to these concepts can develop an awareness and interest in the subject matter. Last is field experience. Students with actual experience doing fieldwork develop a better conceptual understanding of geologic time (Kusnick, 2002). Opportunities for geologic fieldtrips are not always available to middle school students during their earth science studies.

Analogies are used to try to make sense of Earth time in the DVD. Stephen Jay Gould compared a human arm's length to the history of the universe. Carl Sagan's Cosmic Calendar is another analogy used to explain Earth Time on the video. In his book, *Dragons of Eden* (1977), and on his TV show *Cosmos* (1978-79), Sagan explained the history of the universe using a one-year calendar. Using his cosmic calendar, a month equals 1.25 billion years, 1 day equals 40 million years, and each second equals 500 years.

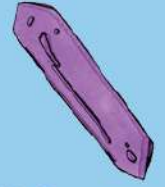
The following dates are from the Discovery School Education website. "The Universe in One Year" (2008) is an updated version of Sagan's



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Teacher Background continued...

original “Cosmic Calendar.” (<http://school.discoveryeducation.com/schooladventures/universe/itsawesome/cosmiccalendar/page2.html>)

Big Bang – January 1
Origin of Milky Way Galaxy – March
Sun and Planets Form – August
Oldest Known Life (Single Celled Organisms) – September
First Multi-cellular Organisms – November
Cambrian Explosion – December 15
First Vertebrates – December 17
Early Land Plants – December 18
First four-limbed animals – December 20
Insects flourish – December 21
First Dinosaurs – December 24
First Mammals – December 25
First Birds – December 27
Dinosaurs Become Extinct – December 29

December 31st

Apes appear 10:15 A.M.
First human ancestors walk upright 9:24 P.M.
10:48 P.M., Homo erectus appears
11:54 P.M., modern humans appear
11:59:59 P.M., voyage of Christopher Columbus

Classroom Activity

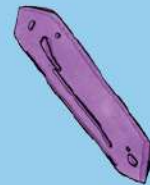
1. Start class by showing the EARTHTIME video. Show the Introduction and the first part of Chapter 1 up to where it is mentioned that the Earth does not have a birth certificate.
2. Say to students:
 - You were just asked to think about how long Earth has been around.
 - You heard two analogies describing Earth from its origins to your time on Earth.
 - How do scientists know how old the planet Earth is?
 - Did you ever wonder how a museum knows a Tyrannosaurus rex is 66 million years old? How do they know this?
 - Take two minutes to write down your ideas about how scientists figure out time and the age of things.
 - Share your ideas with a teammate. Share those ideas with another team.



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Classroom Activity continued...

- Write down what you think are the best ideas.
 - Appoint a spokesperson and share these ideas with the class.
3. Ask student spokespeople to share their best ideas. You may have some students whose religious viewpoints will not agree with the times determined by scientists and also challenge other student responses. This is okay. State that as a class you will be learning about how scientists date rocks and why they feel these dates are accurate. Explain that they will be looking at how scientists working in an area known as the Denver Basin have been able to find accurate dates for rock layers.
 4. Continue showing the rest of Chapter One on the EARTHTIME DVD.
 5. Continue class discussion after viewing the DVD.

Extensions

1. Ask students to come up with their own analogies for the history of Earth.
2. Encourage students to view Carl Sagan's segment on the Cosmic Calendar from Cosmos. It is in the first episode.

Resources

- Black, A. A. (2005). Spatial ability and earth science conceptual understanding. *Journal of Geoscience Education*, 1-19. Retrieved December 17, 2007, from http://findarticles.com/p/articles/mi_qa4089/is_200509/ai_n15668072
- Discovery Education. (2008). The Universe in One Year. <http://school.discoveryeducation.com/schooladventures/universe/itsawesome/cosmiccalendar/page2.html>
- Kusnick, J. (2002). Growing pebbles and conceptual prisms: Understanding the source of student misconceptions about rock formations. *Journal of Geoscience Education*, 50, 31-39.
- Pressley, M. & McCormick, K. (2006). *Child and adolescent education for educators*. New York: Guilford Press.



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Resources continued...

Sagan, C. (1977). The dragons of Eden speculations on the evolution of human intelligence. New York: Random House.

The Shores of the Cosmic Ocean [Television series episode]. (1978, September 28). In Cosmos. PBS.

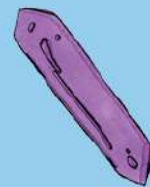
Trend, R. (2001). Deep Time Framework: A preliminary study of U.K. primary teachers' conceptions of geological time and perceptions of geoscience. Journal of Research in Science Teaching, 38, 191-221.



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5E MODEL

Explore

GRADE LEVEL

High School

NSES STANDARDS

A,B, D

PREPARATION

Estimated Preparation: 1-2
hours (one time preparation)

Estimated Activity: 1 class period

MATERIALS

12 small Styrofoam balls

12 large Styrofoam balls

A container of BBs

12 large Baggies for sets of "Styrofoam atoms"

Pencil (sharp)

Knife

6-8 balances to mass nuclei

Amazing Atoms and Interesting Isotopes – Activity

Learning Goals/Objectives

To know that matter has characteristic properties; to explore or review the basic structure of the atom; and to understand the characteristics of isotopes.

Activity Overview

In Part 1, students review the concept of an atom through a short reading. In Part 2, students observe Styrofoam nuclei to explore the concept of an isotope. By comparing 3 similar, yet different Styrofoam balls, students come up with critical attributes of isotopes. One Styrofoam ball is very unstable and represents a radioactive isotope.

Advance Preparation

The Styrofoam balls will need to be prepared as atomic nuclei.

1. Cut a small hole in each Styrofoam ball creating small, dime size lids that will be replaced on the ball at completion of preparation.
2. Use a thin sharp pencil or pointed similar object to make a narrow cavity in the Styrofoam ball. Make sure that you do not push the pencil all the way through the ball.
3. To make a set of three for each group
 - a. Place five to six BBs in one ball and ten to twelve BBs in another ball of the same size. Make sure that there is a noticeable difference in the weights of the Styrofoam balls as BBs can vary in weight depending on their composition.
 - b. Leave one same-sized ball empty.
 - c. Place the lids back on each of the balls. If necessary, glue the lids back onto the ball. Make sure that the BBs cannot be heard inside the balls.
 - d. Using a permanent marker, mark the set of three Styrofoam balls with the same number or letter. This makes a set of the same atom.
 - e. Prepare the other sets the same way. Just give sets different numbers or letters.

(Some teachers have decided to use different symbols: stars, flowers, squares, etc., so they do not confuse their students with symbols for elements or atomic numbers. You will need to decide



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Advance Preparation continued...

on how to identify your sets.)

- f. You may want to use different amounts of BBs in the other sets so student teams have different data.

Teacher Background

This lesson is meant to be a quick review or introduction to atoms and isotopes. It helps build student understanding of the properties of elements. In order to develop an understanding of radioactive decay, students need to have at least a basic understanding of atoms and isotopes.

According to the research studied by the American Association for the Advancement of Science's *Benchmarks for Science Literacy* (1993):

"Students may at first take isotopes to be something in addition to atoms or as only the unusual, unstable nuclides. The most important features of isotopes (with respect to general scientific literacy) are their nearly identical chemical behavior and their different nuclear stabilities. Insisting on the rigorous use of isotope and nuclide is probably not worthwhile, and the latter term can be ignored."

The activities used and the activities listed in the extensions should help your students develop an understanding of the important features of isotopes.

<http://galileo.phys.virginia.edu/Education/outreach/8thgradesol/BackgroundAtom.htm>

Atomic Structure History and Introduction

Democritus of Abdera, a Greek who lived during the fourth century B.C, first suggested atoms. His ideas, however, were not based on any experimental evidence. John Dalton, in the late 1700s is credited with first relating observed chemical phenomena to the idea of individual atoms. His theory stemmed from his study of combining substances through chemical reactions to make new substances. He found substances combined in fixed and predictable proportions, which led to his theory that:

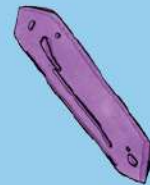
1. All elements are composed of tiny indivisible particles called



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Teacher Background continued...

atoms.

2. Atoms of the same element are identical. The atoms of any one element are different from those of any other element.
3. Atoms of different elements can combine with one another in simple whole number ratios to form compounds.
4. Chemical reactions occur when atoms are separated, joined, or rearranged. However, atoms of one element are not changed into atoms of another by a chemical reaction.

Much of Dalton's theory remains accepted; however, further study led scientists to understand that atoms are in fact composed of smaller sub-atomic particles and not all atoms of the same element are identical. Even more recent experimentation has revealed fundamental particles beyond electrons, protons, and neutrons.

Electrons were first discovered by scientists that were more interested in electricity than atomic structure. Sir Joseph J. Thomson (1856-1940) was one of these scientists. In 1897, he found cathode rays could be deflected by magnets or electrically charged plates. A cathode ray is a beam of particles that travels from the cathode (negatively charged plate) to the anode (positively charged plate) inside a glass tube with a vacuum or low-pressure gas. Through his experiment, Thomson showed cathode rays are collections of small negatively charged particles, which he named electrons. He further found they were nearly 2000 times lighter than a hydrogen atom, the lightest element. Because he found that all cathode rays were composed of electrons, he concluded that electrons must be a fundamental part of the atom. He formulated a model, which he named the "Plum Pudding Model", to describe what he felt the atom must be like. In the model, electrons were distributed throughout an atomic material much like the fruit in a plum pudding or chocolate chips in a cookie.

Atoms are normally electrically neutral. Because the electrons were found as negatively charged, scientists deduced that some positive charge source must be present to offset the negative. Experimental evidence soon led to the discovery of the proton, which is a positively charged subatomic particle that is approximately 1840 times heavier than an electron. It was not until 1932 that Sir James Chadwick found and confirmed evidence of the neutron, or the electrically neutral subatomic particle.



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Teacher Background continued...

The discovery of the nucleus is one example of an ingenious indirect measurement technique that students can readily appreciate. Ernest Rutherford (1871-1937) wanted to test the accepted structure of an atom at the time. To test this theory, Rutherford set up what came to be known as the “Gold Foil Experiment” where he directed a beam of alpha particles (helium ions which are positively charged, relatively heavy, and fast moving) at a very thin sheet of gold. A fluorescent screen was positioned around the gold foil set-up. The expected result was that the alpha particles would travel through the gold foil unabated, strike the screen, and cause a bright dot to appear at the point of impact. To Rutherford’s surprise, however, some of the alpha particles were actually scattered by the gold foil.

Rutherford’s results led him to conclude that the atom contained some dense and positively charged region that he termed the nucleus. He proposed that the remainder of the atom must be empty space containing the much smaller electrons. Later experiments led scientists to discover a third subatomic particle, the neutron, located in the nucleus with the protons.

Niels Bohr (1885-1962) was a young associate of Rutherford. In 1913, he proposed another model of the atom where electrons are arranged in circular paths about the nucleus. His model closely related to the movement of the planets around the sun and is sometimes referred to as the “Planetary Model.” In this model, electrons in a particular path (or radius) contain a fixed amount of energy that corresponds to that path. As long as an electron continues to have that energy, it would remain in that path or energy level. (Energy level is a region around the nucleus where an electron is likely to be moving.) From experiments, he knew that atoms could under some circumstances absorb energy; under other conditions, atoms can emit energy. Emitted energy was in the form of light of discrete and predictable frequencies seen as colors. He deduced then, that when energy was added, electrons were pushed to new and higher energy levels that were discrete like rungs on a ladder. He concluded that electrons could not exist at just any level within the atom—only at the defined energy levels, which, unlike a ladder, were not evenly spaced around the nucleus. He termed these packets of energy “quanta” (singular quantum or the amount of energy required to move an electron from its present energy level to the next higher one).



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Teacher Background continued...

Thirteen years after Bohr developed his model, Austrian Erwin Schrodinger went another step in the development of atomic models with the quantum mechanical model. Where the earlier models were physical in nature, Schrodinger's model was very mathematical. Like the Bohr model, the quantum model includes quantized energy levels for the electrons, but it does not define exact paths for the electrons. Instead, the model includes the likely path or probable path of an electron about the nucleus – like a blurry cloud of negative charge. It is also analogous to locating the position of a single fan blade when it is rotating. At a given instant, the fan blade is at a certain location but there are many possible locations available to it. Over a period of time, these positions all blend to form a blur where there is a high probability of finding the fan blade. The electron cloud is similarly a time-averaged view of the electron. The model further reveals information about the arrangement of electrons within the energy levels. Within the first energy level closest to the nucleus, two electrons can be located. In the second energy level, up to eight electrons can be found. The third level can hold up to eighteen electrons, and the fourth can hold up to thirty-two. The atomic orbitals are more complicated than this description implies, but this offers a glimpse at their arrangement.

All atoms follow the basic arrangement, yet atoms of different substances are different. Scientists currently know of approximately 118 different atoms. Each is unique chemically and physically. Elements are identified by the number of protons in the nucleus, which is given as the atomic number on the **periodic table**. Neutral atoms contain an equal number of electrons around the nucleus as protons in the nucleus. The electrons are arranged in energy levels as described in the quantum model. As one moves across the periodic table of elements, one finds a single proton and a single electron are added to the preceding atom. The number of neutrons is not always as straightforward as the number of protons. In a single atom, the number of neutrons is found by subtracting the atomic number from the atomic mass. Usually, atomic masses on the periodic table are not integral values because the reported values are weighted averages of all known isotopes or forms of the atom. (*Isotopes* : atoms of the same element with different numbers of neutrons in the nucleus.)



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Classroom Activity

Part 1 – Amazing Atoms

1. Explain to your students that knowing about atoms and isotopes will help them understand how absolute dates are put on volcanic ash layers. Let them know that putting years on rocks has a lot to do with chemistry and the chemical structure of certain elements found in minerals. Ask students what they know or remember about atoms.
2. Inform students that they will do a quick reading about atoms to jog their memories or provide them with a background about atoms.
3. Ask students to read the article and complete the 3-2-1 strategy after they finish. They will need to write three things they already knew, two new things they learned, and one question they still have after reading the article.
4. Discuss with students what they wrote using the 3-2-1 strategy.

Part 2 – Interesting Isotopes

Note: The following student activity, Interesting Isotopes, is an adaptation of an activity originally developed by William Robertson in his book, *Chemistry Basics*.

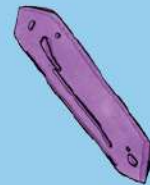
1. Hold up a set of Styrofoam balls. Explain to the class that these Styrofoam balls just happen to be fairly good models of atomic nuclei. Explain that as teams they are going to make some observations about their own set of nuclei from the same element. The information they gather from the models should help them develop the concept of an isotope.
2. Provide handouts for each student. Read through the directions.
3. When students have completed the first 7 steps of their activity, hold a class discussion.
 - What did you find out about your set of Styrofoam atom nuclei?
 - Did others have similar results?
 - Do the differences in mass change the fact that the models are still Styrofoam atom nuclei? No.
 - Do you think that extra neutrons can be added to an atom without changing its physical properties? Yes. *The model shows this concept.*
 - Explain that certain elements have different forms. They may have the same number of protons and neutrons, or they may have more neutrons than protons.



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Classroom Activity continued...

-When there are more neutrons than protons in an atom's nucleus, it is an isotope.

-What happened as more "neutrons" were added to the Styrofoam nucleus? *Mass increased, Styrofoam ball wobbled more and acted strangely.*

-Explain that the nucleus of any element can have an isotope. In most cases, it does not make much of a difference. However, the nucleus can become unstable with too many neutrons. When the nucleus becomes unstable, it will release energy and change into a more stable atom. These unstable atoms are known as **radioactive isotopes**. The process by which it releases energy and changes to a more stable atom is known as radioactive decay.

-Point out that the nucleus of an atom doesn't roll or wobble. Explain that most models have limitations. The real nucleus of an atom also has a strong force called a nuclear force. Protons are held together (even though they have positive charges and should repel each other) in the center of the atom because of this force. It is 100 times stronger than the electromagnetic force that usually causes the like positive charges to repel.

4. Ask students to complete the rest of the worksheet.

5. Collect sets of atomic nuclei.

Extensions

The following two lessons can help further explain the concept of isotopes. They might also be used along with Interesting Isotopes to create three different student stations in your classroom.

1. Tennisium – Students toss tennis balls which represent the protons and neutrons in the nucleus of an atom. More neutrons (tennis balls) are added to the nucleus until it becomes unstable. See handout for students in this curriculum.
2. Isotopes of Pennies – Visit the Science NetLinks Web site at AAAS. The URL is: <http://www.sciencenetlinks.com/matrix.cfm> Scroll down to click on Isotopes of Pennies under Grades 9-12. The lesson and worksheets are available for educational use.

Resources

American Association for the Advancement of Science. (1993). *Benchmarks for Scientific Literacy*. New York: Oxford Press. 79.



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Resources continued...

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Science NetLinks. (2006). *Lessons: Isotopes of Pennies*. <http://www.sciencenetlinks.com/matrix.cfm>

Tocci, S., & Viehland, C. (1996). *Chemistry Visualizing Matter*. New York: Holt, Rinehart, and Winston. 81-96.

Wilbraham, A.C., Staly, D. D., Simpson, C. J., Matta, M. S. (1987). *Chemistry*. Reading, PA: Addison-Wesley Publishing Company. 67-79, 245-249.



Amazing Atoms

Student Reading

Gold is a precious metal that exists on Earth. If you found a piece of gold, you would be holding an element, one of the naturally occurring elements on Earth. (Some elements have been created in laboratories.) If you took this piece of gold and broke it into pieces, and kept breaking it down until you had its smallest possible parts, you would have gold atoms.

The problem with this example is that you wouldn't be able to see the smallest gold parts, atoms. Atoms are incredibly small. You can't see them with a regular microscope. Scientists have recently been able to see some atoms using a very powerful microscope, called a scanning tunneling microscope.

So, an element can be one atom, or an element can be made up of billions and billions of the same kind of atoms.

Let's get back to the individual atoms. All atoms can be broken down into parts. These parts are called subatomic particles. What are these subatomic particles?

There are many subatomic particles in an atom. You need to only learn about three at this time. The three parts of the atom that you need to be concerned with are protons, neutrons, and electrons.

Protons

Protons make up part of the inner core of an atom, known as the nucleus. When looking at subatomic particles, protons are large. A proton's mass is 2,000 times larger than the mass of an electron. Protons also have a positive electrical charge. What's most important to know is that the number of protons determines the element? If the number of protons changes, the atom becomes another element. In other words, the number of protons in an atom determines its identity as an element.

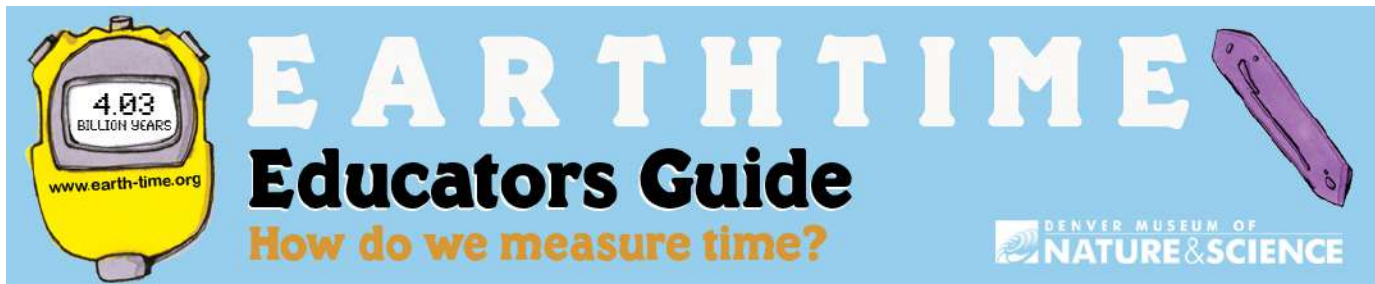
Neutrons

Neutrons are just as large as protons and are also found in the nucleus of the atom. They are neutral in electrical charge, hence the name, neutron. In most atoms, the number of neutrons is the same as protons. But sometimes, there are more or fewer neutrons than protons. This changes the weight of the atom, but not what the element is. So, gold is gold, even if it has an extra neutron and weighs a little more than usual.

Atoms that have more or less than the usual number of neutrons are called isotopes of the particular atom. Remember, protons determine what the atom, or the element, is. Neutrons + protons determine the weight.

Electrons

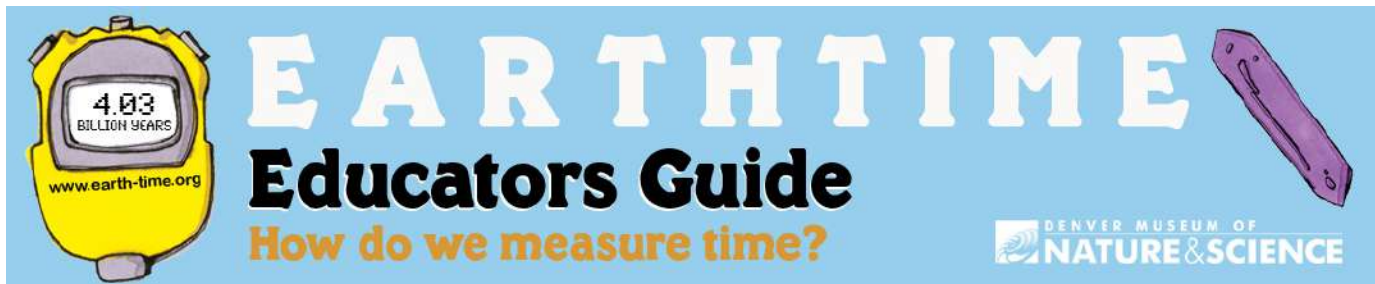
Electrons are the smallest part of the atom. In fact, they are extremely small when compared to protons and neutrons. Electrons have a negative charge and they orbit the nucleus. The number of electrons and protons



is usually the same. If the number of electrons changes, the electric charge changes. Electrons determine how an element will react with another element.

That brings us to an important piece of information. When atoms do combine with other atoms, they form different things known as compounds. A very familiar compound to you is made up of two hydrogen atoms and one oxygen atom – water.

All of the different combinations of protons, neutrons, and electrons, make up the elements on Earth. And all of the combinations of different atoms provide everything we have on Earth. That's amazing!



Name _____ Date _____ Part 2: Interesting Isotopes

Materials:

- 1 tray
- 3 Styrofoam balls representing the nuclei of one atom
- 1 scale

Purpose

To explore the characteristics of isotopes

Your teacher will give you a set of three Styrofoam balls. Each of these represents the nucleus of the same kind of atom.

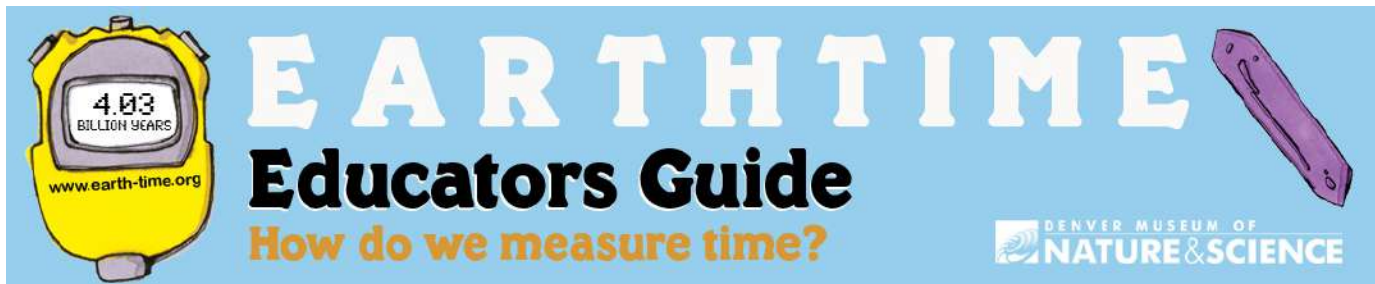
1. Without touching the three Styrofoam balls, observe the three nuclei of the same atom. What do you notice about each of the nuclei?

2. Now moving the nuclei, but not lifting the nuclei, make observations. What do you notice about their movement?

3. Use the scale to mass each of your nuclei. What are their masses?

4. Compare movement to mass. How does the movement change in regards to the nuclei's mass?

Remember:
 Protons have a positive charge.
 Neutrons have no charge.
 Electrons have a negative charge.



5. Atoms usually have the same number of protons and neutrons in the nucleus. Protons provide the identity of the element and never change for that particular element. The number of protons is the same as the number of electrons in an atom. The Styrofoam nuclei are modeling atoms containing protons and neutrons. How do you think the number of protons and neutrons compare in each nucleus? Explain your reasoning.

6. Which Styrofoam nucleus do you think represents a stable element (where the number of protons, neutrons, and electrons are equal?) Why?

7. Which Styrofoam nuclei seem to be less stable?

8. You are now ready for a group discussion about isotopes. Use the following questions to focus your discussion. After your group discussion, complete the following:

9. Explain how the Styrofoam nuclei are similar to the nuclei of real atoms.

10. After your group discussion, write a definition of isotope.

11. After your group discussion, write a definition of radioactive isotope.



Part 2: Interesting Isotopes Teacher Answer Key

Materials:

- 1 tray
- 3 styrofoam balls representing the nuclei of one atom
- 1 scale

Purpose

To explore the characteristics of isotopes

Your teacher will give you a set of three Styrofoam balls. Each of these represents the nucleus of the same kind of atom.

1. Without touching the three Styrofoam balls, observe the three nuclei of the same atom. What do you notice about each of the nuclei?

They should look outwardly the same. Observations should state similarities.

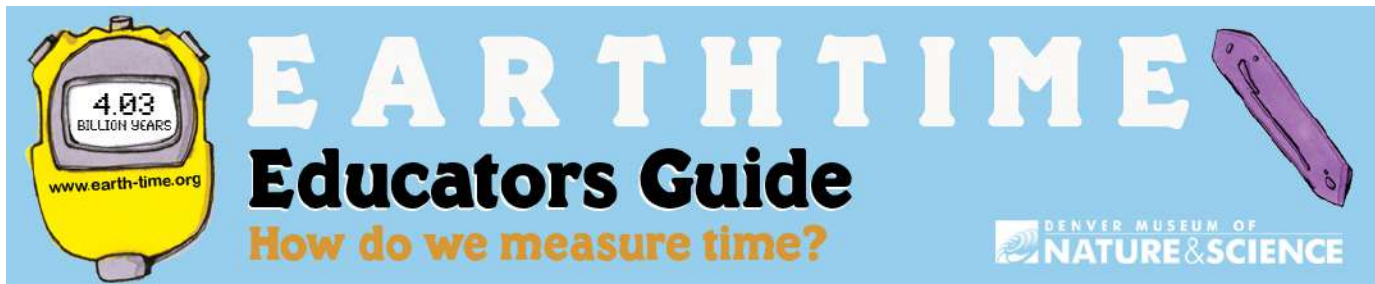
2. Now moving the nuclei, but not lifting the nuclei, make observations. What do you notice about their movement?

The motion of the nuclei should show great differences. They will roll differently: one will roll normally, one will roll with a movement that is slightly off course of a straight roll, the other will move in different directions.

3. Use the scale to mass each of your nuclei. What are their masses?

4. Compare movement to mass. How does the movement change in regards to the nuclei's mass? The greater the mass the more unstable the movement

Remember:
Protons have a positive charge.
Neutrons have no charge.
Electrons have a negative charge.



5. Atoms usually have the same number of protons and neutrons in the nucleus. Protons provide the identity of the element and never change for that particular element. The number of protons is the same as the number of electrons in an atom. The Styrofoam nuclei of atoms contain protons and neutrons. How do you think the number of protons and neutrons compare in each nucleus? Explain your reasoning.

Students should answer that there must be more neutrons in two of the Styrofoam nuclei.

Which Styrofoam nucleus do you think represents a stable element (where the number of protons, neutrons, and electrons are equal?) Why?

The Styrofoam nucleus that had the smallest mass because there was no evidence of instability in its motion.

7. Which Styrofoam nuclei seem to be less stable?

The two nuclei with greater masses appear to be less stable.

8. You are now ready for a class discussion about isotopes.

After your class discussion, complete the following:

9. Explain how the Styrofoam nuclei are similar to the nuclei of actual isotopes of atoms.

The outward appearance of the nuclei and real atoms do not show any differences.

The masses are different even though the nuclei look the same.

The nuclei become unstable if there are too many neutrons in the nucleus.

10. After your class discussion, write a definition of isotope.

Atoms with more neutrons than protons are called isotopes.

11. After your class discussion, write a definition of radioactive isotope.

Unstable atoms that decay spontaneously into a stable form



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5E MODEL

Explore

GRADE LEVEL

High School

PREPARATION

Estimated Preparation: less than 30 minutes

Estimated Activity: 15 minutes

MATERIALS

- Tenniseum student handout
- Tennis balls (The number is determined on how you will use this activity and the number of students in a group. Each student in a group will need two tennis balls and extras are needed to add neutrons to the group).

Extension Activity

Learning Goals/Objectives

To demonstrate that isotopes have different numbers of neutrons

To demonstrate how a nucleus can become unstable

Activity Overview

Student groups form the nucleus of an atom. In each hand they hold a tennis ball representing a proton and neutron. Students toss their tennis balls to each other or devise a system for moving the protons and neutrons around the nucleus. A teacher or student adds neutrons (tennis balls) one at a time to this system of moving protons and neutrons until it becomes unstable. The activity is best done as a demonstration or station activity.

Classroom Activity

1. Provide students with Tenniseum handouts. Students should read the handout.
2. Determine the number of students in a group for this activity. You may want to vary this number to show different atoms (two to four in a group is the recommended number).
3. Have a student group demonstrate how to perform this activity. Add neutrons one at a time.
4. Have students do the activity and answer the questions on their handout.
5. Discuss the results of the activity. Ask the following questions:
 - Were some student groups able to hold more neutrons than others? Yes. Why, or why not? (*Possible answers: larger groups, more coordinated students, easier method for moving protons and neutrons.*)
 - Why was it harder for some groups to “accept” more neutrons? (*See above.*)
 - Did the stability of the nucleus change with the nucleus of different atoms (different teams/groups)? (*It may.*)
6. Talk about the important features of isotopes: the fact that isotopes still have the same chemical properties of the “normal” element and that some isotopes are stable and others are unstable.



Tennisium Activity
Student Page

Purpose

To use a simple model to understand isotopes

Materials

Tennis balls (6-12 per group)
Teams of 2 or groups of 4

There is a new element known as tennisium. It is a very active element, changing states in a variety of situations. In the nucleus of this element are very fuzzy protons and neutrons.

To understand Tennisium, you and your teammates at this station need to create the nuclear force that holds the protons and neutrons together. Each member in your group is part of the nucleus. In your right hand you will hold a proton (a tennis ball). In your left hand, you will hold a neutron (a tennis ball). Remember protons and neutrons are about the same size. The main difference is that the protons have positive charges and the neutrons have no charge.

The nucleus is a very active place. Protons and neutrons are always moving. You and your teammates need to toss the protons and neutrons to each other or move them in some orderly manner. After you have your system down, new neutrons will be pulled into this nucleus one at a time. (A teacher or another student will toss a neutron into the group.) It is your job to try and keep the nucleus stable. There will be a point where the nucleus will not be able to keep the protons or neutrons moving in an orderly manner. In fact, it will begin to decay and lose protons and neutrons.

In your notebook or journal, answer the following questions:

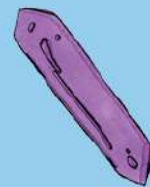
1. What system did you devise to keep the protons and neutrons moving in an orderly manner?
2. As each neutron was added, Tennisium formed a new isotope. How many different isotopes were formed in your nucleus?
3. When did it become hard to “juggle” the protons and neutrons? (When did your atom become unstable?)



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5E MODEL

Explore

GRADE LEVEL

High School

NSES STANDARDS

A, B, D, E, G

PREPARATION

Estimated Preparation Time: 1 hour

Estimated Activity Time: 1 Class Period

MATERIALS

- 2 “zircon crystals” per team
- Graph paper (1 sheet per student)
- Calculators (optional)

Zircon Crystals and Radioactive Decay

Learning Goals/Objectives

To understand that during radioactive decay atoms change into different atoms

To understand that scientists use rates of decay to find the age of rocks

To explore the concept of half-life and its use to determine the age of rocks and minerals

Activity Overview

Students first view Chapters 2 and 4 of the EARTHTIME DVD to learn about zircon and its unique properties. Students count the number of different colored beads in a plastic bag that represent atoms of Uranium-235 (^{235}U) and Lead-207 (^{207}Pb) in a zircon crystal. They then figure out the ratio of uranium to lead atoms. Next, students find the percentage of uranium isotopes left after radioactive decay. Results from teams are shared, and students graph the percentages from class data creating the half-life curve. Students then multiply the number of half-lives times the half-life length of Uranium-235 to find the age of their zircon crystals.

Teacher Background

This is the first in a series of three activities about radioactive decay and radiometric dating. The activities address the same concepts (radioactive decay, half-life, and radiometric dating) in different ways. Multiple exposures to the same concepts will hopefully bring about better student understanding.

What is known about student understanding about half-lives in Grades 9-12 is best described in *Benchmarks for Scientific Literacy* (1993):

“The idea of half-life requires that students understand ratios and the multiplication of fractions, and be somewhat comfortable with probability. Games with manipulative or computer simulations should help them in getting the idea of how a constant proportional rate of decay is consistent with declining measures that only gradually approach zero. The mathematics of inferring backwards from measurements to age is not appropriate for most students. They need only know that such calculations are possible (AAAS, 1993, p. 79).”



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Teacher Background continued...

The activities provided in the Explore stage of learning are more game-like addressing half-life through beads and coins. A Web site providing computer simulations of the decay of various radioactive isotopes is listed in the Extensions section of this lesson.

Students should know that most elements have **isotopes** and that some of these isotopes become unstable with the addition of more neutrons (See the lesson “Amazing Atoms and Interesting Isotopes” if students need more background on this topic.) A strong nuclear force holds the protons and neutrons together. If too many neutrons are in the nucleus, decay can be triggered. This decay is really a change from an unstable isotope (original element) to a stable isotope (new element). The decay process is spontaneous; energy and particles are released as the atom changes into what is known as the daughter isotope. Some radioactive elements undergo many steps in this process to become stable, while other elements may have only one step to change to the new stable element.

A **half-life** is the amount of time it takes for one-half of the original parent isotope to change (decay) to the daughter isotope (new element). Different radioactive isotopes have different **decay rates**. The decay rate is expressed in terms of half-lives. Decay rates of different elements range from seconds to billions of years. Half-lives of elements have been determined through the work of scientists in laboratories studying very large samples of these atoms. The radioactive elements used to date rocks have very long half-lives. Other radioactive elements used to date rocks besides ^{238}U and ^{235}U are ^{40}Ar (Argon), ^{14}C (Carbon), ^{40}K (Potassium), and ^{87}Rb (Rubidium).

Uranium will sometimes be a substitute for zirconium as the ions of both elements have the same charge (+4) and are close to the same size (Mathez, 2004). This is how uranium can get into the zircon crystal structure during crystallization.

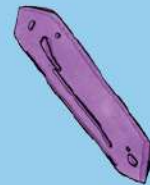
When ^{235}U and ^{238}U are first incorporated into the structure of zircon during crystallization, there is no lead in the crystal. Scientists know that lead atoms will not fit into the crystal lattice. Any lead found in a zircon crystal is a product of uranium decay. The parent isotope ^{235}U decays to ^{207}Pb , and the parent isotope ^{238}U decays to the daughter isotope ^{206}Pb .



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Teacher Background continued...

During each half-life, there is a 50:50 chance that each atom of the parent isotope will decay into the daughter product. If a sample starts with 40 atoms of ^{235}U , there will be 20 atoms of the parent isotope left when it reaches its first half-life. The other 20 atoms will be ^{207}Pb . In another half-life, there will be only 25%, or 10 atoms, of the ^{235}U left and 30 atoms of ^{207}Pb . After three half-lives, only 12.5% of the uranium (5 atoms) will be left in the sample. There will be 35 atoms of Pb-207. This continues ad infinitum.

Geologists look for volcanic rocks that contain zircon. Some volcanic rocks have both zircons that formed in the magma just prior to eruption (the ones we want) as well as older zircons that are incorporated into the eruption. Geologists seek the volcanic rocks that have the fewest of these foreign zircons or xenocrysts.

The bags you will set up will contain different color beads. These beads represent atoms of the different elements in a zircon crystal. A zircon crystal's formula is ZrSiO_4 . Besides, zirconium, silicon, and oxygen, different amounts of ^{235}U and ^{207}Pb will be represented in the bag.

Advance Preparation

Super-sized zircon crystals are created using Ziploc snack baggies and pony beads. You will need to create 30 bags so that each team has two different zircon crystals to investigate.

Note: Another option is to create 16 bags and share among the teams of two.

You will need to purchase:

- 30 snack-size, self-sealing baggies
- Bags of pony beads (500 or 1,000 bead packages) representing different atoms:

Blue = Uranium-235

Yellow = Lead-207

Green = Zircon

White/Clear or another color than those listed = Oxygen

Pink/Red = Silicon

(or, colors of your choice)



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Advance Preparation continued...

You will need different combinations of uranium and lead beads in these numbers to represent stages of radioactive decay:

80 Blue = 0 half-life

40 Blue and 40 Yellow = 1 half-life

20 Blue and 60 Yellow = 2 half-lives

10 Blue and 70 Yellow = 3 half-lives

5 Blue and 75 Yellow = 4 half-lives

To each baggie, add 20 green beads, 20 pink or red beads, and 20 clear (or another color) bead to fill the bag when it is laying flat. The point of having these beads in the bag is so students do not develop a misconception that uranium and lead are the only atoms in a zircon crystal. The beads used for zirconium, silicon, and oxygen only represent the elements in zircon, not the actual amounts of atoms. Do make sure that you have more oxygen beads than zirconium and silicon beads in the bag.

Make six sets of the five bead combinations to provide two “zircon crystals” for each team of students. Tape the opening closed so that beads cannot be removed from the bag.

Challenge Baggies:

For students needing more of a challenge, create baggies where the uranium/lead combinations do not neatly add up to the passage of a single half-life. These baggies fit between the different numbers of half-lives and students determine the approximate age when they graph the decay rates.

Possible combinations:

30 Blue and 50 Yellow

60 Blue and 20 Yellow

50 Yellow and 30 Blue

2 Blue and 78 Yellow (Close to 5 half-lives)



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Vocabulary

Atom – consists of a nucleus (protons and neutrons) and surrounding electrons that make up an element that has all of the element's chemical properties.

Half-life – the time it takes half of the atoms in a radioactive substance to decay.

Isotopes – atoms of the same element, but with different mass numbers; atoms with the same number of protons, but different number of neutrons in nucleus.

Nucleus – center of an atom containing protons and neutrons.

Radioactive decay – spontaneous change of an atom into a different atom or a different state of the same atom.

Radioactive isotope – an element that emits radiation when it decays.

Radiometric dating – using information, such as the half-life of an unstable isotope and the parent to daughter product ratio found in an object, to determine the age of the object.

Classroom Activity

1. Explain to the class that the scientists at EARTHTIME date zircon crystals in the lab using a very complex procedure. Say: "One of zircon's unique characteristics, having two uranium isotopes in its structure, makes it a good crystal to use for dating volcanic ash layers. If zircon has been in a closed system, both uranium isotopes will be exactly the same or close to the same age when dated. Zircon has its own verification system!"
2. Hold up a baggie of beads. With a sense of humor, say to the class: "These are super-magnified, super-sized zircon crystals that were reproduced from samples that came from different layers of volcanic rock. The original size of these zircon crystals was 0.2 mm, which is a little too small for you to look at. However, at this super-size you can determine how many uranium and lead atoms are in a crystal.* The ratio of uranium to lead atoms in these zircon crystals with some



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Classroom Activity continued...

simple math will give you the age of the crystals and some information about half-lives.”

*For those students that are very literal in their thinking, explain that an actual zircon crystal would be made up of trillions of atoms. This is a simple model that is going to help explain the concept of radioactive decay.

- Put the formula for zircon on the board: ZrSiO_4 . Explain that zircon is composed of trillions of repeating building blocks of the following: 1 zirconium atom, 1 silicon atom, and 4 oxygen atoms. Mention that silicon and oxygen are two of the most abundant elements in the earth’s crust.

Pointing at the formula, say: “So, where is the uranium? It isn’t in the chemical formula for zircon.”

Explain to your students that uranium will substitute for zirconium since the ions of both elements have the same charge (+4) and are close to the same size (Mathez, 2004). This is how uranium can get into the zircon crystal structure.

- Say: “You should also know that a crystal is made up of trillions of basic building blocks.”

Tell students that the uranium that locks into the zircon crystal structure has two major isotopes, the isotopes ^{235}U and ^{238}U . ^{235}U decays into ^{207}Pb and ^{238}U decays into the isotope ^{206}Pb . They will be focusing on ^{235}U in this activity.

(The uranium isotope used in this activity is ^{235}U since its half-life is less than the ^{238}U , using dates for students that are easier to understand).

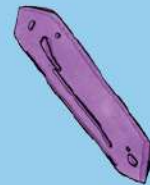
- Provide students with the student handout to read before giving them their baggies.
- Hand out the baggies making sure each team has two different “zircon crystals.”



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Classroom Activity continued...

Explain that the blue beads in the bag represent ^{235}U atoms or the parent isotope. Since ^{235}U is radioactive, it breaks down or decays into a stable element known as ^{207}Pb , the daughter isotope. The yellow beads represent ^{207}Pb atoms. Knowing how many ^{235}U and ^{207}Pb atoms exist in a crystal is key to understanding its half-life and its age.

8. Have students count their uranium and lead atoms and write those numbers down.

9. Ask students to share their results. Record these numbers on the board or overhead projector creating a t-chart:

Uranium atoms (Parent isotopes)	Lead atoms (Daughter Isotopes)
------------------------------------	-----------------------------------

10. Next, students calculate the percentage of the parent isotope atoms in their crystals.

The formula is listed on the student worksheet, but you might want to also write it on the board for the students.

Parent isotopes (^{235}U atoms) / Parent isotopes (^{235}U) and Daughter isotopes (^{207}Pb) X 100 = _____%

Add a third column to add the percentage of parent isotopes found in the crystal.

11. Ask the following questions:

“Who has a zircon crystal with no lead atoms in it? What does this tell you about this crystal?” Possible Answers: *Students should state that it has not yet undergone any radioactive decay. It must have recently formed or crystallized. It has 100% of the uranium it had when it was formed.*

“Who has a zircon crystal that has equal amounts of ^{235}U and ^{207}Pb ?” Remind or explain to students that when half of the uranium has changed to lead, the amount of decay is called a half-life.

“Who has a zircon crystal with very little uranium in it? What does that tell you about the crystal?” Possible answers: *It has undergone a lot of decay. It has to be very old. It has undergone more half-lives.*



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Classroom Activity continued...

“Who has a zircon crystal with only $\frac{1}{4}$ of the uranium left? *Explain that in this crystal that the uranium has decayed through two half-lives. Half of the original amount first decayed, and then half of that amount decayed, so only $\frac{1}{4}$ or 25% of the uranium is left.*

12. Students next graph their results. The Number of parent atoms (U-235 atoms) and Number of half-lives are the labels for the x-axis and the y-axis. Explain to students that they should also label the half-life axis with the percentage of parent atoms left.

Write on the overhead projector or board:

100% = 0 half-lives
50% = 1 half-life
25% = 2 half-lives
12.5% = 3 half-lives
6.25% = 4 half-lives
3.125% = 5 half-lives
1.5625% = 6 half-lives



Half-Lives
Percent of Parent Isotope Left



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Classroom Activity continued...

13. Once the data has been graphed, inform students that **the half-life of ^{235}U is 704 million years**. Ask them how old a volcanic rock would be if two half-lives had occurred or only 25% of the uranium was left in the zircon crystal? *1,408 million years, 1,408,000,000 years, or 1.408 billion years old.*

Ask students to multiply 704 million years by the number of half-lives to find out the age of their zircon crystals. Students with challenge zircon crystals can estimate the age of their crystal using the graph.

14. Ask: “How old is a crystal that has only 12.5% of its parent isotope ^{235}U left? *2,112 million years, 2,112,000,000 years, or 2.112 billion years old.*
15. Ask students what happened to the amount of lead in the crystals. Ask what the graph of the daughter isotope, ^{207}Pb , would look like if they were to graph that data. *The daughter isotope data would show the curve being exactly opposite of the uranium curve.*

Extensions

The following Web site has interactive simulations for a variety of isotopes.

The Physics 2000 Science Trek Web site is one place students can interact with a half-life simulator. Students will need to read through a simple page of information to get to the simulator. There they can choose different isotopes to see their decays.

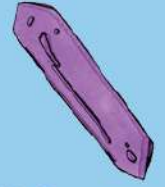
http://www.colorado.edu/physics/2000/isotopes/radioactive_decay3.html



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Resources

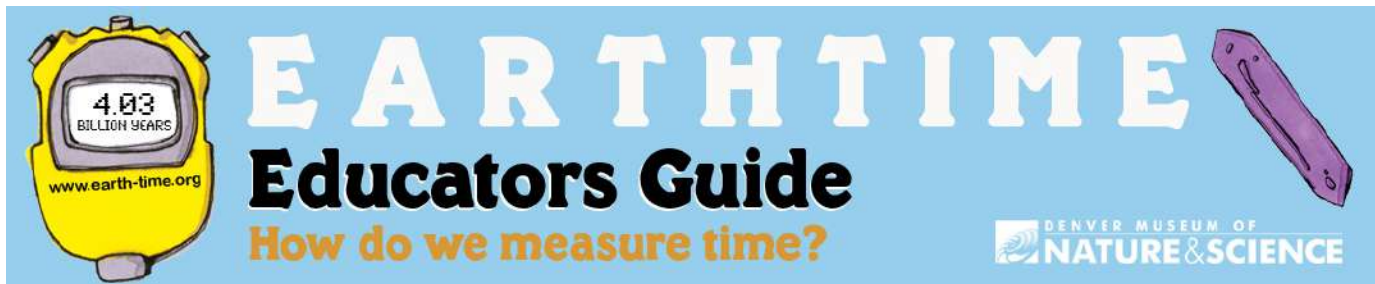
American Association for the Advancement of Science. (1993). *Benchmarks for Scientific Literacy*. New York: Oxford Press. 79.

Lewis, G.B. & McLelland, C.V. (2003). *Explore Deep Time: An Introduction to Geologic Time Teacher Notes*. The Geological Society of America.

Mathez, E. A. (2004, May). A birthstone for earth: the oldest terrestrial material is a crystal of zircon, the sometime substitute that can be a geologist's best friend. *Natural History*.

Sussman, A. (2006). *Dr. Art's Guide to Science: Connecting Atoms, Galaxies, and Everything in Between*. San Francisco: Jossey-Bass. 206-219.

University Of Colorado. (2000). *Physics 2000 Science Trek*. Retrieved September, 2007, from http://www.colorado.edu/physics/2000/isotopes/radioactive_decay3.html



Name _____ Date _____

Zircon Crystals and Radioactive Decay

Explore

Materials

2 “zircon crystals” of different ages

Graph paper

From the DVD, you learned that zircon has its own internal clock or stopwatch that helps scientists date volcanic ash layers. One of the internal clocks or stopwatches in a zircon crystal is the parent isotope, ^{235}U . During crystallization, radioactive ^{235}U is incorporated into the zircon crystal. As U-235 decays or changes, it forms a stable daughter isotope, ^{207}Pb .

You will be provided with two super-sized “zircon crystals.” The ratio of ^{235}U to ^{207}Pb atoms in a “zircon crystal” will help you determine its age.

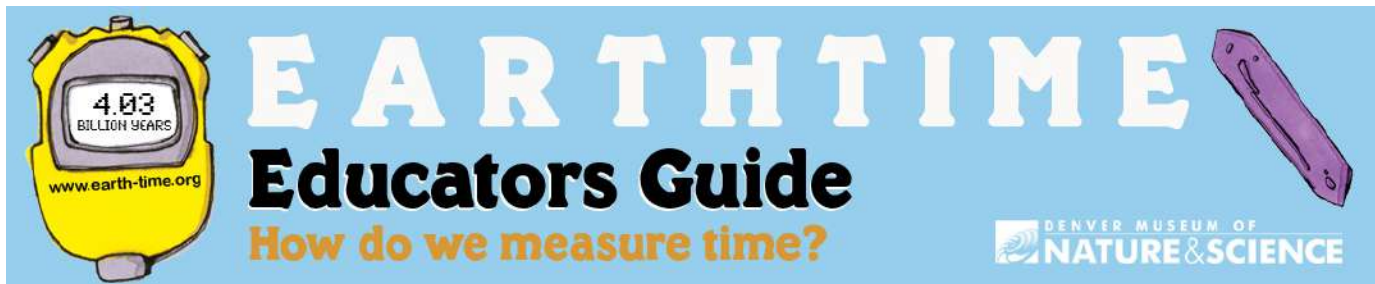
Follow the steps below to determine the age of your crystals and other crystals in the class:

1. Count the number of ^{235}U atoms and ^{207}Pb atoms in each of your “zircon crystals.”
2. Record the counts of the uranium and lead atoms in each crystal.
3. Collect and record counts of ^{235}U and ^{207}Pb atoms of other crystals from teams in your class.
3. Find the percentage of uranium in your crystal. Divide the number of uranium atoms (parent isotopes) by the total number of uranium (parent) atoms + lead atoms (daughter isotopes). Multiply this number by 100 and you will get the percentage of ^{235}U left in the crystal over time.

^{235}U atoms / Uranium-235 + ^{207}Pb atoms X 100 = Percent (%) of ^{235}U left in crystal

4. Collect and record percentages for other uranium and lead atom ratios.
5. The following chart provides information for the half-lives of all radioactive elements:

Percent of Parent Isotope Left	Half-Lives
100%	0
50%	1
25%	2
12.5%	3
6.25%	4
3.125%	5
1.5625%	6
.78125%	7



6. Create a graph where the x-axis is the number of half-lives and the y-axis is the number of ^{235}U (parent) atoms. Plot the points from your data.

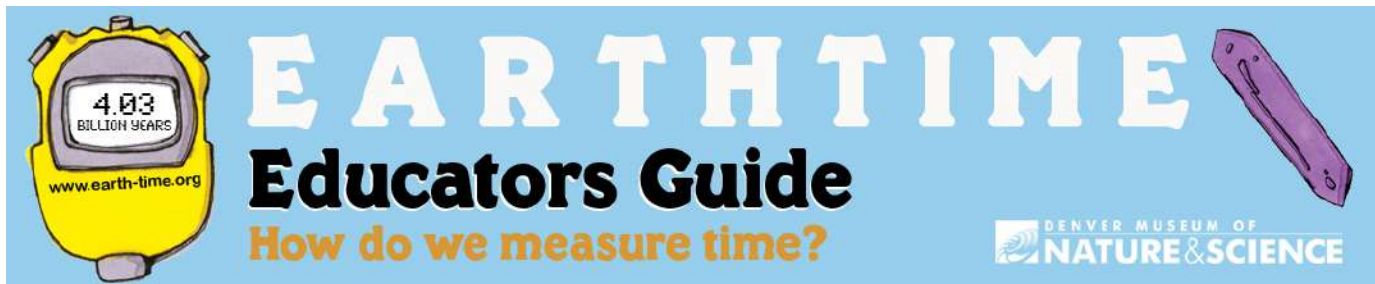
This graph is known as the half-life curve. This curve is the same for all radioactive isotopes. However, the rates of decay (half-lives) are different for different elements. Some radioactive elements have half-lives that are seconds long; others have half-lives that are billions of years long.

7. The half-life of ^{235}U is 704 million years. If you multiply the half-life of ^{235}U by the number of half-lives you will determine the ages of your “zircon crystals.”
How old are your crystals?

8. Look at your graph. Would there ever be a point in time where there were no atoms of ^{235}U in your crystals? Why, or why not?

9. You know that as ^{235}U decays, it changes to ^{207}Pb . What should the graph for ^{207}Pb look like if you were to plot the data for that graph?

10. Why would it be beneficial to geochronologists that a zircon crystal has both ^{235}U and ^{238}U in it?



Name TEACHER KEY Date _____

Zircon Crystals and Radioactive Decay

Explore

Materials

2 “zircon crystals” of different ages

Graph paper

From the DVD, you learned that zircon has its own internal clock or stopwatch that helps scientists date volcanic ash layers. One of the internal clocks or stopwatches in a zircon crystal is the parent isotope, ^{235}U . During crystallization, radioactive ^{235}U is incorporated into the zircon crystal. As ^{235}U decays or changes, it forms a stable daughter isotope, ^{207}Pb .

You will be provided with two super-sized “zircon crystals.” The ratio of ^{235}U to ^{207}Pb atoms in a “zircon crystal” will help you determine its age.

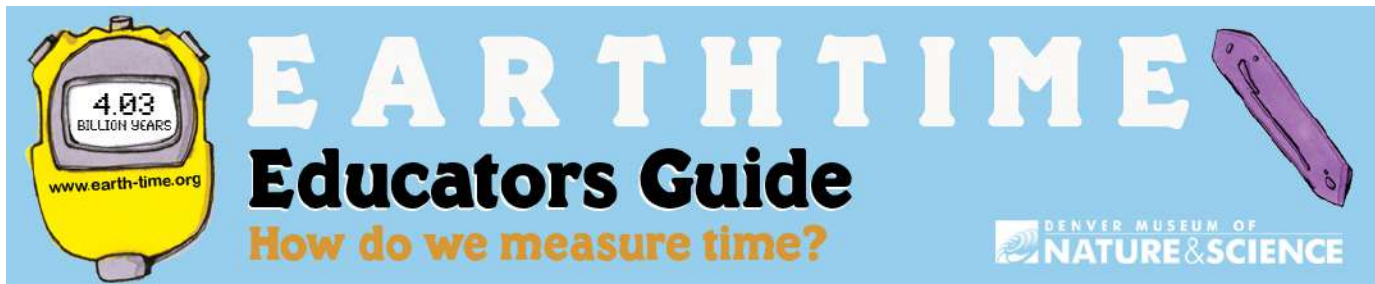
Follow the steps below to determine the age of your crystals and other crystals in the class:

1. Count the number of ^{235}U atoms and ^{207}Pb atoms in each of your “zircon crystals.”
2. Record the counts of the uranium and lead atoms in each crystal.
3. Collect and record counts of ^{235}U and ^{207}Pb atoms of other crystals from teams in your class.
3. Find the percentage of uranium in your crystal. Divide the number of uranium atoms (parent isotopes) by the total number of uranium (parent) atoms + lead atoms (daughter isotopes). Multiply this number by 100 and you will get the percentage of ^{235}U left in the crystal over time.

$$^{235}\text{U atoms} / ^{235}\text{U} + ^{207}\text{Pb atoms} \times 100 = \text{Percent (\%)} \text{ of } ^{235}\text{U} \text{ left in crystal}$$

4. Collect and record percentages for other uranium and lead atom ratios.
5. The following chart provides information for the half-lives of all radioactive elements:

Percent of Parent Isotope Left	Half-Lives
100%	0
50%	1
25%	2
12.5%	3
6.25%	4
3.125%	5
1.5625%	6
.78125%	7



6. Create a graph where the x-axis is the number of half-lives and the y-axis is the number of ^{235}U (parent) atoms. Plot the points from your data.

This graph is known as the half-life curve. This curve is the same for all radioactive isotopes. However, the rates of decay (half-lives) are different for different elements. Some radioactive elements have half-lives that are seconds long; others have half-lives that are billions of years long.

7. The half-life of ^{235}U is 704 million years. If you multiply the half-life of ^{235}U by the number of half-lives you will determine the ages of your “zircon crystals.”
How old are your crystals?

_____ *Will vary* _____

8. Look at your graph. Would there ever be a point in time where there were no atoms of ^{235}U in your crystals? Why, or why not? *No. There should always be some atoms remaining because the amount of decay is always half of the previous half-life. It should never reach zero.*

9. You know that as ^{235}U decays, it changes to ^{207}Pb . What should the graph for ^{207}Pb look like if you were to plot the data for that graph? *The graph should be an exact reversal of the parent decay graph.*

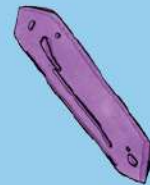
10. Why would it be beneficial to geochronologists that a zircon crystal can have amounts of both ^{235}U and ^{238}U in it? *The dates from both types of uranium should be the same or close if they come from the same crystal since scientists know that uranium locks into zircon during its formation.*



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5E MODEL

Explore

GRADE LEVEL

High School

NSES STANDARDS

A, B, E

PREPARATION

Estimated Preparation Time: 15 minutes

Estimated Activity Time: 30-45 minutes

MATERIALS

Penny for each student and teacher

Volcanic Mineral Activity Handout – 1 per student

Science notebook or graph paper for each student

Volcanic Minerals – A ^{40}K (Potassium-40) Decay Activity

Learning Goals/Objectives

To recognize that geochronologists use more than uranium isotopes to date volcanic minerals

To plot the half-life curve of another isotope

To determine the age of mineral samples

Activity Overview

This is the second of a series of three activities on radiometric dating. Students should have already viewed Chapters 2 and 4 of the EARTH-TIME DVD. Students have learned that unstable radioactive atoms change to stable atoms over time, and each radioactive isotope has its own decay rate. In this second radioactive decay activity, students themselves simulate how another isotope found in volcanic minerals, ^{40}K (Potassium-40), decays. Playing the role of an unstable atom of ^{40}K , and through the probability of coin-tosses, students become stable ^{40}Ar (Argon-40). The data from the coin-tosses is graphed and should show a curve similar to all radioactive isotope decay.

Note: A class of students does not provide a large sample, statistically speaking. Of course, the larger the sample that can be investigated, the more accurate the data you will get. Students should discover this during the investigation. If you have numerous classes of Earth Science, it is recommended that the data from all classes be tallied and graphed together. During the next investigation, students should see the significance of using large numbers of atoms to determine the half-life of elements.

Teacher Background

This is the second in a series of three activities on half-lives of radioactive isotopes and dating rocks. Individual teachers will need to decide on the number of activities to use with their classes to develop student understanding of the concepts of half-life, radioactive decay, and absolute dating. Radioactivity was discovered in 1896. The discovery led to further investigations that, in turn, led to the discovery of several atoms that have unstable radioactive isotopes. Over time, the radioactive isotopes spontaneously decay into stable isotopes and give off radiation in the process.



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Teacher Background continued...

The new, stable isotope is referred to as the daughter product.

The rate at which the nuclei of these unstable isotopes decay is constant. Half-life describes the interval of time during which half of the unstable isotope will decay. After one half-life, half of the original unstable atoms will have decayed to daughter product. After a second half-life, half of the unstable atoms left over from the first half-life will have decayed, leaving one quarter of the original unstable atoms still in their unstable state.

Each radioactive isotope has a different half-life. If we know the half-life of an isotope and if we have the ability to measure the ratio between parent product and daughter product, then we should be able to figure out how long the isotope has been present in a material. This should give a very good idea of how old that material is. This process is known as radiometric dating. Radiometric dating is only possible if we can make accurate measurements of the parent isotope and daughter product.

Vocabulary

Atom – consists of a nucleus (protons and neutrons) and surrounding electrons that make up an element that has all of the element's chemical properties.

Half-life – the time it takes half of the atoms in a radioactive substance to decay.

Isotopes – atoms of the same element, but with different mass numbers; atoms same number of protons, but different number of neutrons in nucleus.

Nucleus – center of an atom containing protons and neutrons.

Radioactive decay – spontaneous change of an atom into a different atom or a different state of the same atom.

Radioactive isotope – an element that emits radiation when it decays.

Radiometric dating – using information, such as the half-life of an unstable isotope and the parent to daughter product ratio found in an object, to determine the age of the object.



EARTH TIME

Educators Guide

How do we measure time?



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Classroom Activity

1. Let students know that there are two characteristics of radioactive decay that they need to know about. One is that there is randomness in the decay of a radioactive atom. Tell them that it is impossible for scientists to know exactly when each of the atoms in a mineral will decay. This can be explained by comparing a decaying isotope (or you can actually demonstrate it) to popping popcorn. There is no way to know which popcorn kernel will pop first in a popper or in a microwave bag. But once the corn kernel pops, it will never be a kernel again. It stays popped corn. Once a radioactive isotope decays into another element, it can never again be the original element. Another characteristic to understand is the half-life of a radioactive element. Both of these characteristics are modeled in the work they have to do during this activity.
2. Explain to your students that today they have a new role in the classroom. They will portray atoms! In fact, each one of them will be a ^{40}K atom. Geologists have determined when ^{40}K is incorporated into a mineral it will decay over time to ^{40}Ar and can act like a time capsule similar to ^{235}U or ^{238}U in a zircon crystal.
3. Provide a handout for each student. Allow time for the students to read the introduction and background information.
4. Explain to your students that their roles are those of individual ^{40}K atoms.
5. Each student should be given a penny that will model the spontaneous decay of ^{40}K atoms.
6. Have students read the directions for the activity. Model how you would like them to flip their coins.
7. Ask students to place the “heads” side of their pennies up and flip them. Students who have the “tails” side showing sit down because they have now become stable ^{40}Ar . Students with pennies that have the “heads” side facing up are still ^{40}K atoms and need to stay standing. Mention, of course, the decayed atoms are much more stable, and this is why students sit in their chairs. The wobbly, moving unstable atoms are less stable because they are standing. Help students record the results from the class during the first half-life or 1.3 billion years section of the chart. Check to see that their totals equal the number of students in the class.
8. Before the second round begins, standing students need their pennies facing “heads” up. Signal the standing students to flip their coins. Once again, ask students who have the tails side of the penny facing up to sit down because they have just turned into stable ^{40}Ar . Record



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How do we measure time?



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Classroom Activity continued...

the data so the number of stable atoms + the number of unstable atoms equal the number of students in class. You want to make sure that your students understand the unstable atoms change into a stable form, but the number of atoms stays the same. Continue the half-life process until no unstable atoms are left. Ask students what a half-life is. *They should answer that it is the time it takes for one- half the radioactive isotopes in a sample to decay to a stable isotope. Remind students that the unstable isotopes are known as parent isotopes and the stable isotopes are known as daughter isotopes.*

9. The half-lives beyond our Earth Time should be explained to avoid confusion and misconceptions. Some students might think that there are crystals older than the Earth on Earth. They need to be focused on the half-life of the element. Explain that even very old minerals will have a lot of ^{40}K or parent atoms in them because ^{40}K has such a long half-life.
 10. Have students graph their results according to the directions given on the handout. Help those students that need help with figuring out the scale for each axis.
 11. Allow students time to answer questions. Then discuss the answers to the questions.
- (Answers follow.) Take the time to discuss the questions to elicit whether or not students understood what happens during radioactive decay.

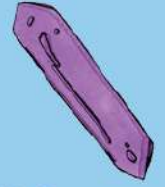
1. The atoms do not disappear, only the nucleus changes. When the protons in the nucleus are no longer the same number, they have “decayed” to a different isotope.
2. This depends on class or classes’ results.
3. It should be 1.3 billion years.
4. This depends on data.
5. This answer will depend on graphed data.
6. Conservation of mass – the total number of ^{40}K and ^{40}Ar atoms will always equal the original parent isotopes in the rock sample.
7. If you know how many half-lives have passed, you know how much time has passed in Earth’s history, so it is like a clock or stop-watch; it helps tell time.
8. Two half-lives or 2.6 billion years of age. If this rock came from a layer above or below a fossil layer, it can help date the rocks near it.
9. The results from a small sample might not produce a true half-life. Results might be close, but not exactly 50-50. The larger the sample the closer students should get to an exact half-life.



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Classroom Activity continued...

10. With radioactive decay, half of the parent atoms will decay during each half-life. There should never be a point in time where all of the parent atoms have changed to daughter isotopes.

“Mystery Sanidine” answers:

- A. 2.6 billion years
- B. 1.3 billion years
- C. 2.6 billion years

Extensions

The Geological Society of America has a curriculum on Deep Time that is free to teachers. It contains information and activities on relative and radiometric dating. Information on this curriculum can be found at <http://www.geosociety.org/educate/CDs.htm>

Resources

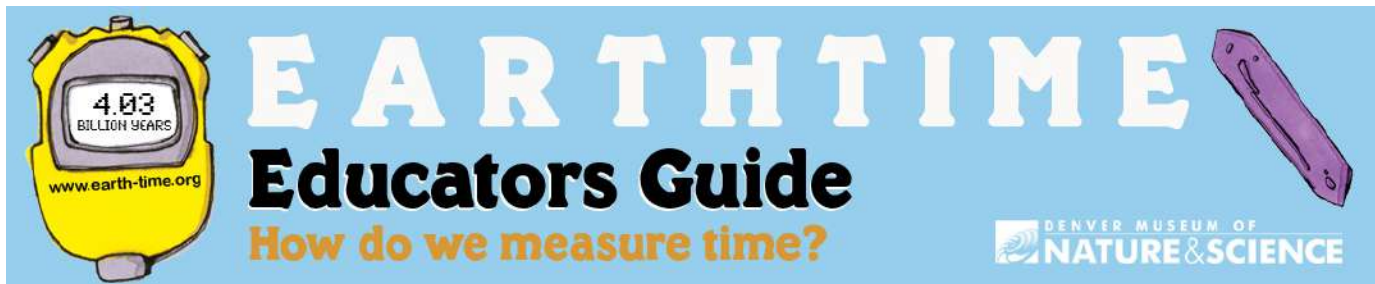
Carelton College. (2006). *Hands-On Activities for Teachers: “Class as an artifact: A radiometric dating activity.”* Retrieved from www.acad.carleton.edu/curricular/BIOL/classes/bio302/Pages/ClassFossil.html

Firestone, R. B. (2000, May 22). *The Berkeley Laboratory Isotopes Project*. Retrieved from <http://ie.lbl.gov/education/isotopes.htm>

Swertka, A. (2002). *A guide to the elements*. New York: Oxford University Press.

Tarback, E. J., & Lutgens, F. K. (2003). *Earth science*. Upper Saddle River, NJ: Prentice Hall.

Adapted from lessons by Dr. Sharon Johnson and Carleton College Hands-On Activities for Teachers: “Class as an Artifact: A Radioisotope Dating Activity.”



Name _____ Date _____

Volcanic Mineral Activity

Drs. Kirk Johnson and Sam Bowring prefer the use of ^{238}U for radiometric dating because they can cross-check the date of the zircon sample by also dating the sample using ^{235}U , another radioactive isotope. If the dates are the same, they know that the results are extremely accurate. However, ^{235}U and ^{238}U are not the only radioactive isotopes used to date volcanic rocks and layers.

We will investigate a model of another element's half-life. It, too, is found in some volcanic minerals. ^{40}K (Potassium-40) is an isotope that decays to ^{40}Ar (Argon-40) in essentially one-step, a simple decay process to investigate.

“Finding the Age of A Volcanic Mineral Using Potassium-Argon Dating”

Background and Review: We know that everything is made of atoms. Some atoms, like uranium or potassium, have **unstable** forms. The **unstable** forms “**radioactively decay**,” or break down, over time. Scientists have found that the time it takes for an **unstable** atom to decay is unique to each atom. Scientists have also found out that each radioactive element breaks down at a constant rate.

Potassium (K) is a well-known, common element. It is found in soil and even in us. One type or isotope of potassium called ^{40}K is **unstable**. It represents about .012% of all potassium on Earth. Over time **unstable** ^{40}K breaks down, or decays, forming **stable** ^{40}Ar . Argon is a different element on the Periodic Table and it is a gas.

It takes 1.3 billion years for one-half of the ^{40}K in a mineral sample to decay into ^{40}Ar . The time it takes for one-half of the radioactive atoms in a rock or crystal to break down is known as its half-life.

Geologists need to find samples of volcanic minerals that incorporated ^{40}K just before eruption. Why is this important? ^{40}Ar will not be trapped in a mineral until it cools way below the temperature of the magma (from $>800^\circ\text{C}$ to less than 500°C). At higher temperatures, the ^{40}Ar leaks out. However, once it cools, the ^{40}Ar is trapped in the crystal.

What would the decay look like?

If a volcanic mineral sample started with 100 atoms of ^{40}K , it would take 1.3 billion years for it to decay to 50 atoms of ^{40}K and 50 atoms of ^{40}Ar ! Wait another 1.3 billion years and you would have 25 atoms of ^{40}K and 75 atoms of ^{40}Ar . Remember, the ^{40}K doesn't just disappear, it decays to ^{40}Ar .

For your information: Not all unstable atoms have half-lives of billions, or even thousands of years. For example, the half-life of ^{210}Pb is 22 years, ^{222}Rn (Radon) is 4 days, and ^{231}Th (Thorium) is one day!

Let's do another activity that further demonstrates the concept of a half-life and how knowing the half-life of an element can be used to determine the age of a volcanic ash layer.



Sanidine Mystery

Scenario: A team of Denver Basin geologists found crystals of sanidine in volcanic ash layers east of Denver. (^{40}K is always found in sanidine.) The sanidine crystals were suitable for dating. After finishing your activity, you will determine the age of some of these mineral samples.

In this activity you, and your classmates, are each an unstable ^{40}K atom!

Materials:

A penny for each student and teacher
Science Notebook or Graph Paper
Class of Students

Procedure:

1. Each student creates a chart like the one below in his/her science notebook.

Toss Number	Heads	Tails	Total Number of Students
<i>Years Elapsed for Each Toss: 1.3 billion years</i>	<i>Number of ^{40}K Unstable Atoms</i>	<i>Number of ^{40}Ar Stable Atoms</i>	<i>Total Number of Atoms</i>
0 0 years			
1 1.3 billion			
2 2.6 billion			
3 3.9 billion			
4 5.2 billion			
5 6.5 billion			
6 7.8 billion			

- The class now stands. Each person has a penny. The penny represents an “unstable” ^{40}K atom. Since each person is starting out as ^{40}K the “heads” side of the penny should be showing before the first flip.
- The teacher directs everyone to flip their penny and determine whether it is heads or tails. This flip represents the passing of one half-life. The students that flip tails get to sit down. Tails means that they have now become a stable ^{40}Ar atom.
- The number of students sitting down is recorded in the chart followed by the number of students standing (flipping heads on the penny). The total of heads and tails is recorded in the last column. This total will always equal the total number of students in the class.
- The second round begins. Only the standing unstable ^{40}K atoms flip their pennies. Those that flip tails sit down. They are now stable ^{40}Ar atoms.



6. Once again, everyone in the class records the number of stable atoms (everyone seated) and the number of unstable atoms (everyone standing), and then totals the numbers to make sure that the total equals all the students in the class.
7. Repeat for the remaining time intervals or until everyone is seated.

Graph: Make a line graph of the data collected by following the steps below.

1. The y-axis will represent the number of unstable atoms (^{40}K) left after each toss. Starting with 0, scale the y-axis.
2. The x-axis will represent the toss number or years elapsed. Since each toss represents 1.3 billion years, you will need to be able to represent 7.8 billion years on your x-axis scale. Start your scale with 0.
3. Plot the number of ^{40}K atoms vs. time.
4. Draw your line.

Check For Understanding: Answer the following questions in your notebook before you continue.

1. Why did we count both heads and tails?
2. How many tosses did it take for half of the class to sit down?
3. How many years did it take for half of the ^{40}K atoms to decay to ^{40}Ar ?
4. How many half-lives are represented by your graph?
5. Using the class data, determine the age of a mineral that has 10 Argon-40 atoms?
6. Why did we have to count everyone seated after each toss and not just the people who threw heads for the toss?
7. Why are radioactive elements like ^{40}K referred to as atomic clocks?
8. Would the graph look different if we were able to repeat the investigation?
9. What would probably happen to the graph if we could collect data from multiple classes?
10. At the end of this activity, no atoms of ^{40}K were left. Is this possible with radioactive decay?

Sanidine Mystery: Using what you have learned from the background reading and the activity, work the following problems in your notebook. Show your work.

- A. One sample of sanidine contained 5 atoms of ^{40}K (Potassium-40). When the mineral sample was formed, it contained no ^{40}Ar . It did contain 20 atoms of ^{40}K at its formation. What is the age of the sanidine sample?
- B. Another sample of sanidine contained 10 grams of ^{40}K . There are also 10 atoms of ^{40}Ar . What is the age of the sample?
- C. The last sample contained 15 atoms of ^{40}K and 45 atoms of ^{40}Ar . What is the age of the sample?



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5E MODEL

Explore

GRADE LEVEL

High School

NSES STANDARDS

A, B, D, G

PREPARATION

Estimated Preparation: 1 hour

Estimated Activity: 1 period

MATERIALS

- 1 shoebox with lid
- 100 pennies
- 100 paper clips
- Student Handout, Penny Isotope, 1 per student
- Student Handout, Radioactivity Factoids, 1 per student

Penny Isotope Activity

Learning Goals/Objectives

To determine the half-life of an isotope from data collected

To become aware of some of the limitations or challenges of radiometric dating

Activity Overview

Students have learned that radiometric dating uses the ratio of the present parent atoms/present parent atoms + the daughter atoms to find the age of a mineral or rock. In this activity, pennies are used to simulate the decay of the penny isotope in a rock. The data from the coin-tosses is collected by each group and then aggregated into class data. The half-life of the penny isotope is then determined from graphed class data. The results of this data are compared to the smaller group data.

Many of the ideas in this activity were gathered from multiple sources – workshops, teachers, Web sites, etc. Many of these previous versions had no known author. We would like to acknowledge all of the teachers who have written an isotope activity, ultimately contributing to this lesson.

Teacher Background

This is the third in a series of three activities about radioactive decay and radiometric dating. The activities address the same concepts (radioactive decay, half-life, and radiometric dating) in different ways. Multiple exposures to the same concepts will hopefully bring about better student understanding.

What is known about student understanding about half-lives in Grades 9-12 is best described in *Benchmarks for Scientific Literacy* (1993):

“The idea of half-life requires that students understand ratios and the multiplication of fractions, and be somewhat comfortable with probability. Games with manipulative or computer simulations should help them in getting the idea of how a constant proportional rate of decay is consistent with declining measures that only gradually approach zero. The mathematics of inferring backwards from measurements to age is not appropriate for most students. They need only know that such calculations are possible (AAAS, 1993, p. 79).”



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Teacher Background continued...

The activities provided in the Explore stage of learning are more game-like, addressing half-life through beads and coins. A Web site providing computer simulations of the decay of various radioactive isotopes is listed in the Extensions section of this lesson.

Students should know that most elements have **isotopes** and that some of these isotopes become unstable with the addition of more neutrons (See the lesson “Amazing Atoms and Interesting Isotopes” if students need more background on this topic.). A strong nuclear force holds the protons and neutrons together. If too many neutrons are in the nucleus, decay can be triggered. This decay is really a change from an unstable isotope (original element) to a stable isotope (new element). The decay process is spontaneous; energy and particles are released as the atom changes into what is known as the daughter isotope. Some radioactive elements undergo many steps in this process to become stable, while other elements may have only one step to change to the new stable element.

A **half-life** is the amount of time it takes for one-half of the original parent isotope to change (decay) to the daughter isotope (new element). Different radioactive isotopes have different decay rates. The decay rate is expressed in terms of half-lives. **Decay rates** of different elements range from seconds to billions of years. Half-lives of elements have been determined through the work of scientists in laboratories studying very large samples of these atoms. The radioactive elements used to date rocks have very long half-lives. Other radioactive elements used to date rocks besides ^{238}U and ^{235}U are ^{40}Ar (Argon), ^{14}C (Carbon), ^{40}K (Potassium), and ^{87}Rb (Rubidium).

Uranium will sometimes be a substitute for zirconium as the ions of both elements have the same charge (+4) and are close to the same size (Mathez, 2004). This is how uranium can get into the zircon crystal structure during crystallization.

When ^{235}U and ^{238}U are first incorporated into the structure of zircon during crystallization, there is no lead in the crystal. Scientists know that lead atoms will not fit into the crystal lattice. Any lead found in a zircon crystal is a product of uranium decay. The parent isotope ^{235}U decays to ^{207}Pb , and the parent isotope ^{238}U decays to the daughter isotope ^{206}Pb .



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Teacher Background continued...

During each half-life, there is a 50:50 chance that each atom of the parent isotope will decay into the daughter product. If a sample starts with 40 atoms of ^{235}U , there will be 20 atoms of the parent isotope left when it reaches its first half-life. The other 20 atoms will be ^{207}Pb . In another half-life, there will be only 25%, or, 10 atoms, of the ^{235}U left and 30 atoms of ^{207}Pb . After three half-lives, only 12.5% of the uranium (5 atoms) will be left in the sample. There will be 35 atoms of Pb-207. This continues ad infinitum.

Geologists look for volcanic rocks that contain zircon. Some volcanic rocks have both zircons that formed in the magma just prior to eruption (the ones we want) as well as older zircons that are incorporated into the eruption. Geologists seek the volcanic rocks that have the fewest of these foreign zircons or xenocrysts.

Advance Preparation

- Copies of student handout, *Penny Isotope Activity*, one per student
- Copies of student handout, *Radioactive Factoids*
- Gather 15 boxes with lids
- Gather 1500 pennies, or purchase two-sided math counters (red/yellow), 100 per team
- 1500 paper clips, to be divided 100 per team
- Depending on the level of the students, the math skills (graphing) may need to be reviewed before or during the activity.

Vocabulary

Atom – the smallest particle of an element that has all the element's chemical properties. Consists of protons and neutrons in a nucleus surrounded by electrons.

Daughter product – the resulting atom after undergoing radioactive decay. This may be a final, stable atom or may be an intermediate, unstable atom that will, in turn, have its own daughter product.

Half-life – the interval of time during which half of the unstable atoms undergo radioactive decay.

Isotopes – atoms that have the same number of protons but different numbers of neutrons. One element can have several isotopes, and some isotopes are more stable than others.



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Vocabulary continued...

Nucleus – central part of an atom that contains protons and neutrons.

Parent atom – the original unstable isotope that undergoes radioactive decay.

Radioactivity – process of a nucleus emitting energetic particles.

Radiometric dating – using information, such as the half-life of an unstable isotope and the parent to daughter product ratio found in an object, to determine the age of the object.

Classroom Activity

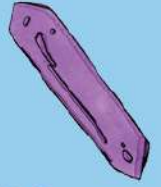
1. Introduce students to their new isotope, the penny isotope. Explain that it is part of the structure of the volcanic shoebox rock. The penny isotope is a radioactive, unstable isotope.
2. Explain that inside each shoebox rock, these penny isotopes are radioactively decaying to a stable isotope. They, as geoscientists, will be able to determine the half-life of the penny isotope.
3. Explain that each shoebox rock always has 100 penny isotopes in it at its formation. They will need to follow the procedure on their penny isotope activity to follow the penny's decay. Read over instructions with students.
4. When all teams have completed six time intervals, ask teams to share their data. Call on every group so that others can record their results.
5. Allow time for teams to graph their collective data and answer questions.
6. Then ask students the following questions during a class discussion:
 - Why is this method of dating important?
 - What are some possible problems you can see with this method of dating? How do scientists deal with these obstacles?
7. Share Radioactivity Factoids with the class.
8. Explain the Concept Rating guide. Before reading the Factoid sheets, students rate their understanding of the concepts listed on the left-hand side of the chart. After reading the statements and discussing student experiences based on the activity and sections viewed on the DVD, students revisit their understanding. Some concepts will continue to be hard to understand because of little student background in chemistry. Awareness is an appropriate stage for these students and they need to be told that this level of knowledge is fine



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Classroom Activity continued...

at this point in time. Encourage them to continue to learn more about elements and isotopes.

9. Discuss the answers to the problems/questions in the student hand-out.
10. Determine individual student understanding of material in this activity through completion of the handouts.



Name _____ Date _____

Class _____

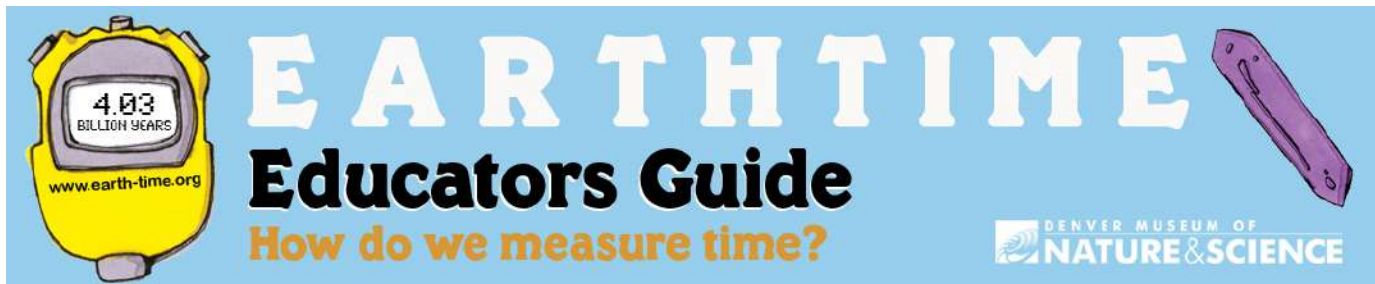
Penny Isotopes/Some Radioactive Factoids

Rate your knowledge of these concepts. Mark an X in the appropriate box.

Concepts	Heard/Aware of	Know	Can Describe
isotope			
radioactive decay			
half-life			
radiometric dating			

Some Radioactive Factoids

- Radioactivity was discovered in 1896.
- This discovery lead to further investigations which, in turn, lead to the discovery of several atoms that have unstable radioactive isotopes that, over time, will spontaneously decay into stable isotopes and give off radiation.
- The new, stable isotope is referred to as the daughter product.
- The rate at which the nuclei of these unstable isotopes decay is constant.
- While decay is constant, the actual amount that decays is not.
- Half-life describes the interval of time during which half of the unstable isotope will decay.
- After one half-life, half of the original unstable atoms will have decayed to daughter product.
- After a second half-life, half of the unstable atoms left over after the first half-life will have decayed, leaving one quarter of the original unstable atoms still in their unstable state.
- Each radioactive isotope has a different half-life.
- If we know the half-life of an isotope and if we have the ability to measure the ratio between parent product and daughter product, then we should be able to figure out how long the isotope has been present in a material. This should give us a very good idea of how old that material is. This process is known as radiometric dating.
- Radiometric dating is only possible if we can make accurate measurements of the parent isotope and the daughter product. Very small amounts of either can make measurement difficult.



Name _____ Date _____

Class _____

Penny Isotope Investigation

Purpose:

The purpose of this lab is to determine the half-life of an isotope from data collected, and to become aware of some of the limitations or challenges of radiometric dating.

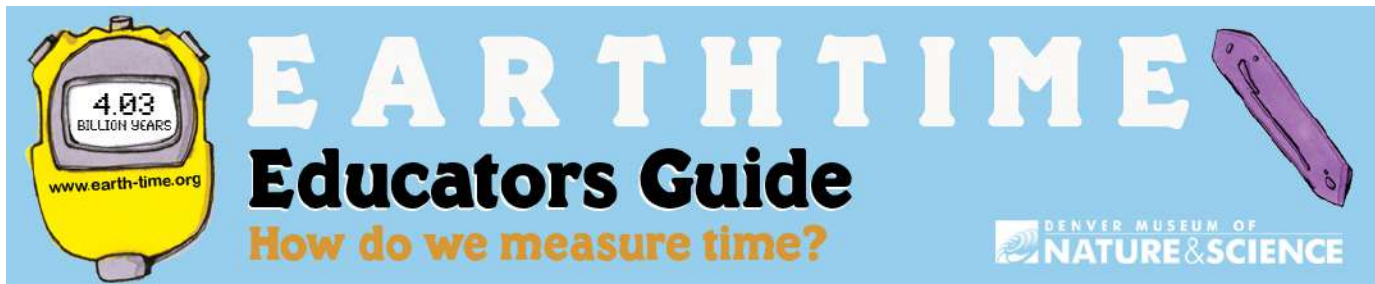
Materials:

- 1 shoe box with lid per group
- 100 pennies per group
- 100 paperclips per group
- marker

Question: What is the half-life of the penny isotope?

Procedure:

1. Place all of the pennies in the box with heads up. The box represents a rock with a given isotope. The pennies are the radioactive isotope. Heads up represents the parent isotope. Tails up represents the daughter product. At time "0" all of the isotopes are in their unstable form.
2. Cover the box and turn it over twice.
3. Uncover the box and remove all atoms that have decayed into the daughter product. In this case, all pennies that are tails up should be removed.
4. Record the number of pennies that remain in the Results section.
5. Replace the removed pennies with paperclips to represent the stable daughter products.
6. Repeat steps 2 through 5 until most or all of the isotopes have decayed to daughter product.
7. Using the chart from the Results section, make a graph of the decay rate for your penny isotope. Time will be represented by number of trials and should be on the x-axis. The number of parent atoms should be on the y-axis.
8. Record and add the results of all of the groups on the class data chart in the Results section.
9. Graph the class data on a new graph using the totals from each .
9. Use your class data to determine the half-life of the isotope. Look at the graph and find the time interval where half of the original parent atoms decayed.



Name _____
Class _____

Date _____

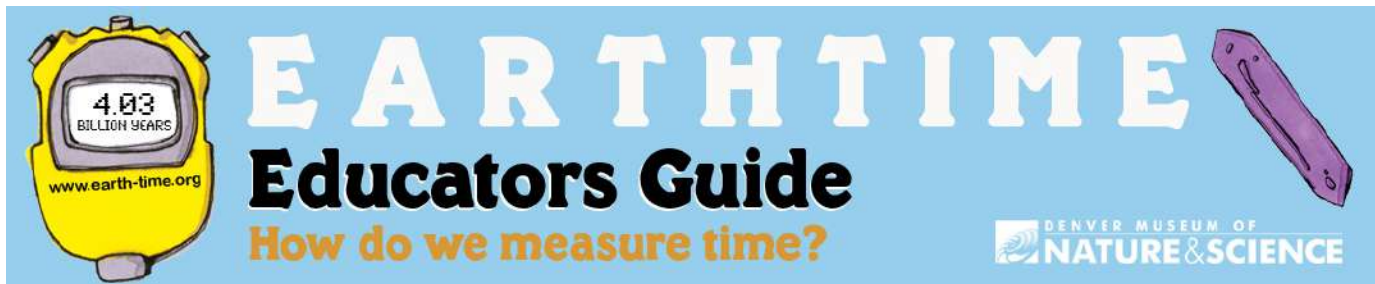
Observations/Results:

Group Data From Penny Isotope Half-Life Experiment

Time Interval	Number of Unstable Parent Atoms Remaining
Time = 0	
Time = 1	
Time = 2	
Time = 3	
Time = 4	
Time = 5	
Time = 6	

Class Data of Unstable Parent Atoms Remaining (Pennies)

Time Interval	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Time = 0																
Time = 1																
Time = 2																
Time = 3																
Time = 4																
Time = 5																
Time = 6																



EARTHTIME

Educators Guide

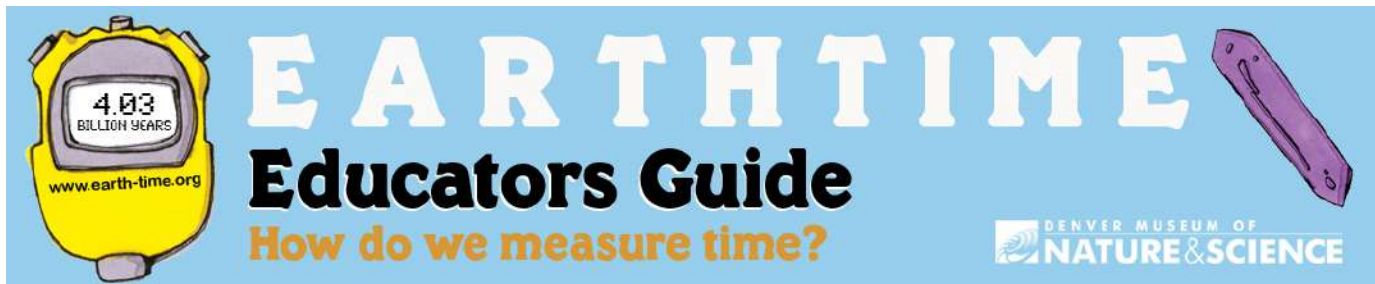
How do we measure time?

Penny Isotope Group Graph

[illegible]

Number of Shakes (Time)





Name _____
Class _____

Date _____

Penny Half-Life

One half of atoms of the isotope have decayed after _____ shakes of the box.

Three quarters of the atoms of the isotope have decayed after _____ shakes of the box.

Seven eighths of the atoms of the isotope have decayed after _____ shakes of the box.

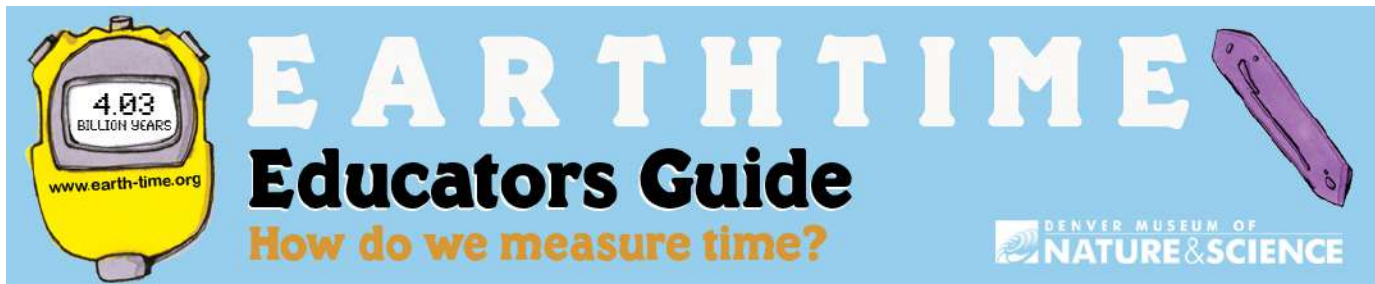
The half-life of the the isotope is _____ shakes of the box.

Penny Isotope

Directions: All questions should be answered in complete sentences unless otherwise noted.

Compare the half-lives of both your group data and class data.

1. Are they different?
2. Which set of data do you think is more reliable and why?
3. What do you think would happen to the graph you repeated your experiment?
4. Why do you think scientists have to make very careful measurements on extremely large amounts of atoms to determine the radioactive decay rate of a particular atom?



Name _____ TEACHER KEY _____ Date _____
Class _____

Penny Isotope

Directions: All questions should be answered in complete sentences unless otherwise noted.

Compare the half-lives of both your group data and class data.

1. Are they different? *There should be a difference.*
2. Which set of data do you think is more reliable and why? *A larger sample provides more reliable data. The larger the sample, the more reliable the data.*
3. What do you think would happen to the graph you repeated your experiment? *More data would make the graph more reliable.*
4. Why do you think scientists have to make very careful measurements on extremely large amounts of atoms to determine the radioactive decay rate of a particular atom?
Possible answers: The more data that is collected the more likely the decay rate will be accurate. Without careful measurements, more sources of error could occur and it would be less likely that the half-life determined for that particular isotope would be a reliable measure.



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5E MODEL

Explain

GRADE LEVEL

High School

NSES STANDARDS

A, B, D, E, F G

PREPARATION

Estimated Preparation: Less than 30 minutes

Estimated Activity: 45 minutes

MATERIALS

- Earth-Time DVD: Chapter 3
- Scientific Process: Observation, Hypothesis, and Prediction, 45
- Scientific Process: In the Field
- Data Collection and Collaboration, and 6 – Scientific Process: In the Lab - Testing and Data Analysis
- Handout - 1 per student, copies of student version: How Do Scientists Date Fossils? - Or, reproduce the backside of the How Do We Measure Time? Poster. There are 6 pages from the poster to copy. The choice of the article will depend on your student population or time you have to read.
- Handout - Comprehension Monitoring (Choose the handout appropriate for your students. One handout refers to paragraphs; the other refers to sections in the article.)
- Television and DVD player, or, LCD Projector with computer

How Do Scientists Date Fossils?

Learning Goals/Objectives

To explain how scientists date rocks

To provide an example of how teams of scientists work together to find a solution to a problem

Activity Overview

In the video, Drs. Kirk Johnson and Sam Bowring explain the teamwork required to date a volcanic ash layer that is sandwiched between layers of rock that contain fossils. The different steps of the process are covered from collection of rock material in the field through the procedures for radiometric dating at the EARTHTIME laboratory at M.I.T. A reading follows the video viewing to further develop an understanding of the dating process. Pages from the back of the Denver Museum of Nature & Science/EARTHTIME How Do We Measure Time? Poster or the How Do Scientists Date Fossils? article included in this curriculum. The poster pages can also be downloaded at www.earth-time.org. Click on Education.

Teacher Background

During the “explain” stage of the 5E model, exposure to expository text is one type of experience that teachers can use with students to facilitate their learning the underlying concepts. However, it is important to have different experiences with concepts/ideas before reading difficult text. Once students have experiences/prior knowledge about a concept/idea, they are more motivated to read to understand. Classroom and life experiences help students make meaning of the text. The DVD chapters and prior activities provide the experiences students should have before reading the selections. It is imperative that the reading comes after the experience.

Classroom Activity

1. Briefly review the isotope and radioactive decay activities with your students. Inform them that they will be viewing video segments showing the absolute dating process.
2. Show DVD Chapter Segments. Stop the video between chapters to ask the following questions:



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Classroom Activity continued...

Chapter 3 – What are two things that paleontologists and geologists are good at doing? What does a geochronologist do? Dr. Kirk Johnson compares regional ancient rainforest plants to other ancient rainforest plants around the world. Why does he want to know the exact age of his rocks?

Chapter 5 – How are zircon crystals collected? Why is it necessary to collect large quantities of rock for the lab?

Chapter 6 – What are the steps in the process of dating the age of a zircon crystal in the laboratory?

- *Please do not hesitate to use your own questions. The types of questions asked should depend on the age and background of your students.*

3. The purpose of the reading selection is to provide further explanation or clarification of the radiometric dating process explained in the video. Provide copies of the reading selection and directions to students. Assign the reading after first explaining the reading strategy.

Students should mark each paragraph* in the selection with one of the following codes:

I = Interesting Information
I* = Important Information
Q = I have a question about this.
C = Confusing
D = Difficult
M = Main point

The marks are placed in the margin of the paragraph. After marking the code in the margins of the article, students write their questions and comments regarding the coding.

The responses can be written in the margins or in student notebooks. If you do not want students to mark copies of the article, have students use sticky notes to code and write responses.

Examples:

Q – Why is zircon considered durable?

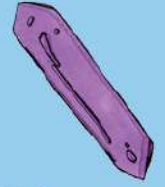
I – No lead can be incorporated into a zircon crystal when it forms.



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Classroom Activity continued...

This coding system, based on the Comprehension Monitoring System (Smith and Dauer, 1981) provides a way for students to discuss the article. First, the students work together in pairs or small groups to compare their responses.

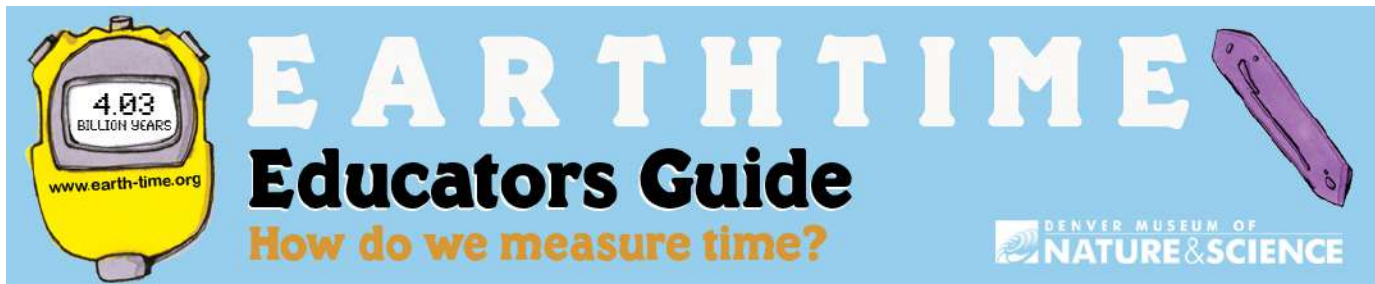
** If your students have a good understanding of the material, you might want to have them mark the sections of reading instead of each paragraph.*

4. Next, allow time for the class to discuss what they've learned, what they still do not understand, and what they found interesting in the reading. This metacognitive process will help further understanding of the concepts presented. The discussion can provide clarity, especially for those who have reading problems or process information orally.
5. Optional: After discussing the article, you might want to ask students to write two things they learned from the article and one question they still have about radiometric dating. (There will probably be plenty of questions. Do not feel obligated to answer all of these questions. You might ask students to research some of their questions. Some of your students will not have enough background to understand the concepts addressed. However, the information presented should at the very least provide an awareness of the complexity of the work and perhaps spark an interest in the work of all scientists involved.)

Resources

Johnson, K. & Bowring, S. (2008). *Introduction to the Scientists and the Science behind EARTHTIME*. Denver Museum of Nature and Science.

Smith, R. J., and V. L. Dauer. "A Comprehension-Monitoring Strategy for Reading Content Area Materials." *Journal of Reading* 28 (1984): 144-147.



Denver Museum of Nature and Science
How Do You Measure Time?
Student

Comprehension Monitoring

The purpose of reading this article is to further your understanding about radiometric dating. The comprehension monitoring strategy is intended to help you do this.

Directions:

1. Become familiar with the following codes. Refer to them as you read each paragraph in the article.

I = Interesting Information
I* = Important Information
Q = I have a question about this.
C = Confusing
D = Difficult
M = Main point

2. Your teacher will tell you how to mark your text. If you are allowed to keep the article, you might be asked to make comments in the margin. If you are returning the article to your teacher, you might be asked to use sticky notes for coding and responses.

3. As you read each paragraph, do the following:

- You need to decide on an appropriate code and write it in the margin or on a sticky note. If you are using sticky notes, place them next to the paragraphs as you read.
- Write a response related to the code in the margin or on the sticky notes.

Examples:

Q – Why is zircon so important for dating rocks?

C – I'm not so sure I understand how a mass spectrometer works.

4. After reading and responding to the article, compare your responses with teammate(s). Discuss understandings and questions that you have about information in the article.

5. Participate in the class discussion.



Student Worksheet

Denver Museum of Nature and Science How Do Scientists Date Fossils?

Comprehension Monitoring

The purpose of reading this article is to further your understanding about radiometric dating. The comprehension monitoring strategy is intended to help you do this.

Directions:

1. Become familiar with the following codes. Refer to them as you read each section in the article.

- I** = Interesting Information
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Examples:

- Q – Why is zircon so important for dating rocks?
- C – I'm not so sure I understand how a mass spectrometer works.

4. After reading and responding to the article, compare your responses with a teammate/teammates. Discuss understandings and questions that you have about information in the article.

5. Participate in the class discussion.

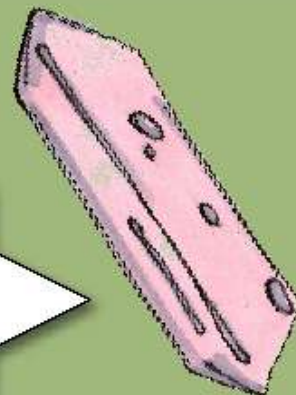
1 STABILITY vs. INSTABILITY

How can studying zircon help us understand time? Its combination of stability and instability makes it the perfect big time problem solver.



STABILITY

From the moment a zircon forms, it is one tough crystal. Zircon is dense, inert, and non-magnetic. It also resists weathering, withstands temperature extremes, and strongly rejects lead when it forms. In these ways, Zircon is incredibly stable.

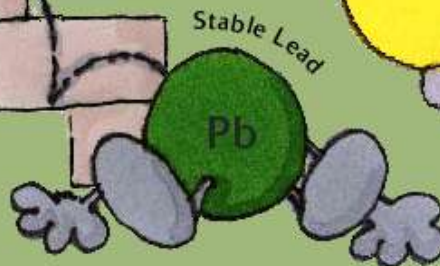


INSTABILITY

Within this tough crystal, however, there is a useful instability. Zircon contains unstable, or radioactive, uranium. From the moment a zircon crystal forms, unstable uranium begins to decay into stable lead. Over time, the amount of uranium decreases and the amount of lead increases.

When scientists study a zircon crystal and measure the ratio of uranium to lead, it is like a very precise stopwatch, one that can date events from a few hundred thousand years ago to several billion years ago.

It takes 4.468 billion years for the half of the Uranium-238 to change to Lead-206.



2 FORMATION



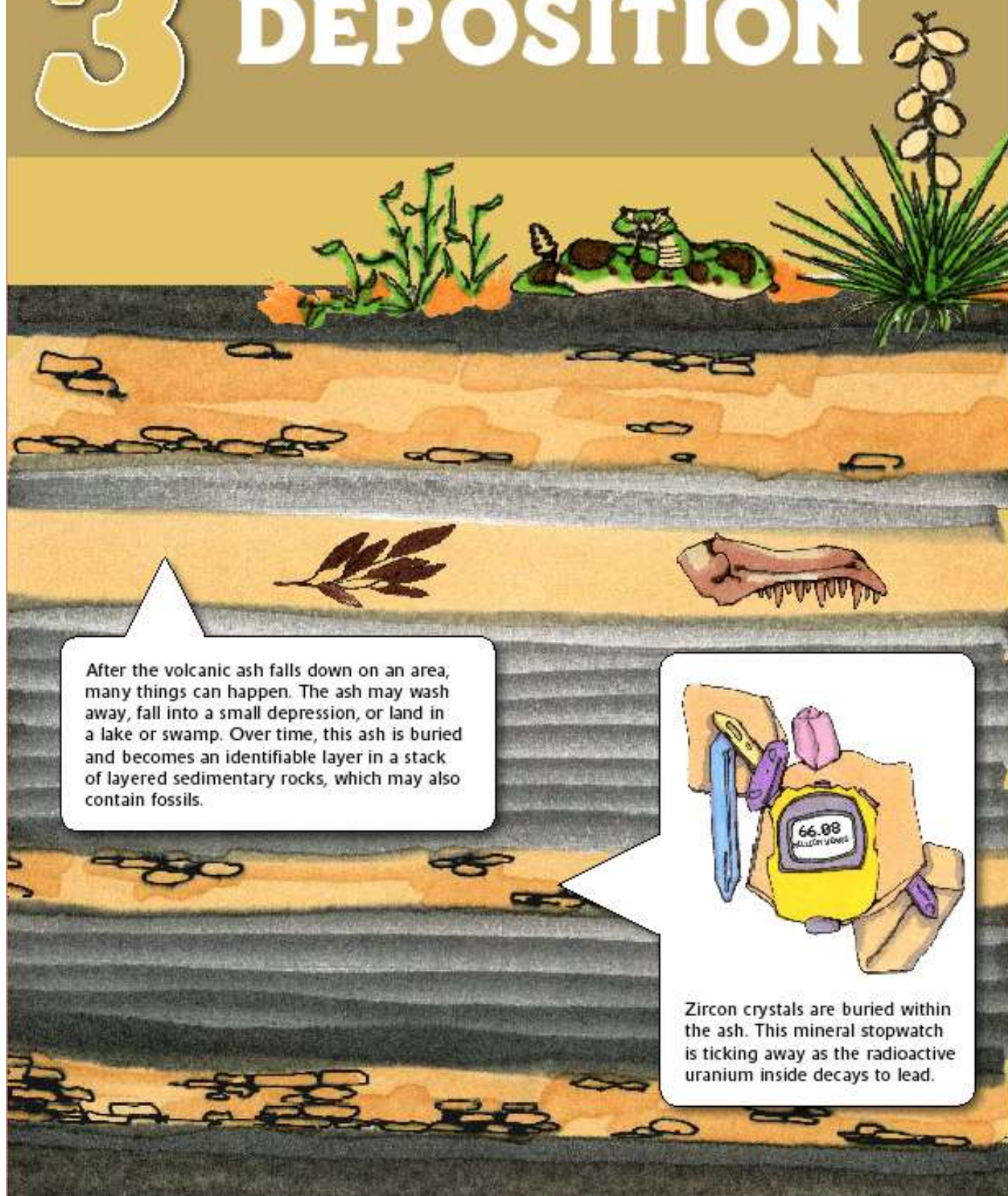
When a volcano erupts, gases originally dissolved in the magma form bubbles so quickly that they explosively shred magma into microscopic glass shards and mineral crystals. This is volcanic ash. Common minerals found in volcanic ash are feldspar, quartz, mica, and zircon. While zircon is formed in the same way as the rest of the minerals, it is unique because it is extremely durable and contains radioactive uranium, but no lead.



Crystals in close-up of volcanic ash

3

DEPOSITION

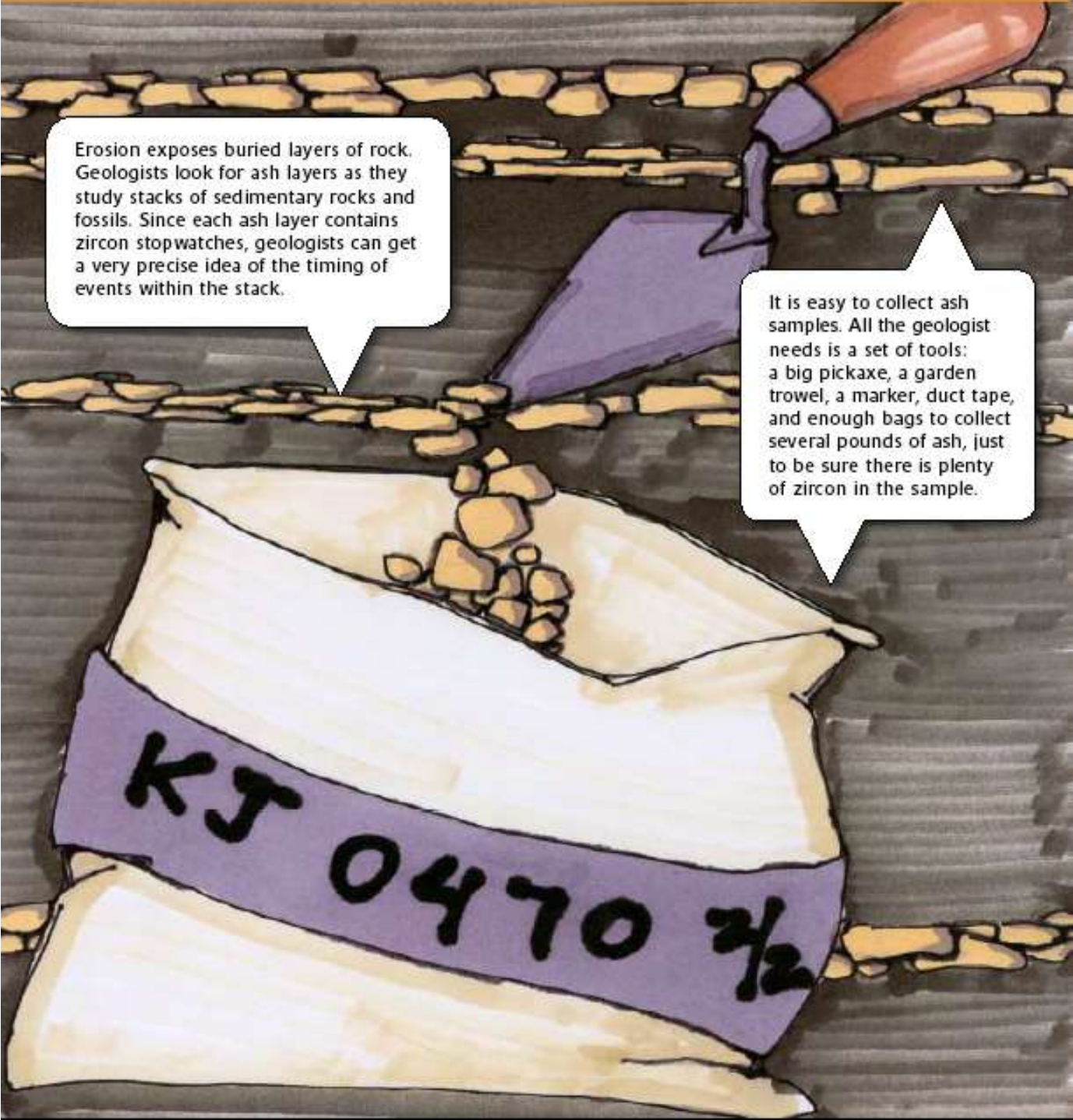


After the volcanic ash falls down on an area, many things can happen. The ash may wash away, fall into a small depression, or land in a lake or swamp. Over time, this ash is buried and becomes an identifiable layer in a stack of layered sedimentary rocks, which may also contain fossils.



Zircon crystals are buried within the ash. This mineral stopwatch is ticking away as the radioactive uranium inside decays to lead.

4 EROSION & DISCOVERY



Erosion exposes buried layers of rock. Geologists look for ash layers as they study stacks of sedimentary rocks and fossils. Since each ash layer contains zircon stopwatches, geologists can get a very precise idea of the timing of events within the stack.

It is easy to collect ash samples. All the geologist needs is a set of tools: a big pickaxe, a garden trowel, a marker, duct tape, and enough bags to collect several pounds of ash, just to be sure there is plenty of zircon in the sample.

5 CONCENTRATION



In the lab, geologists crush the ash sample and wash away all the fine dust and clay.

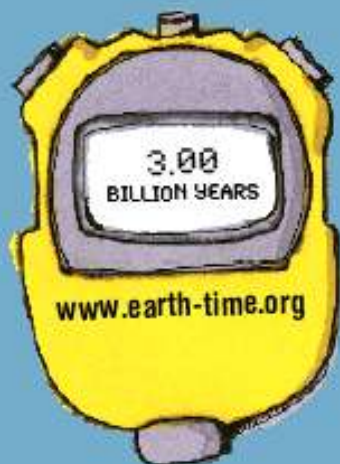
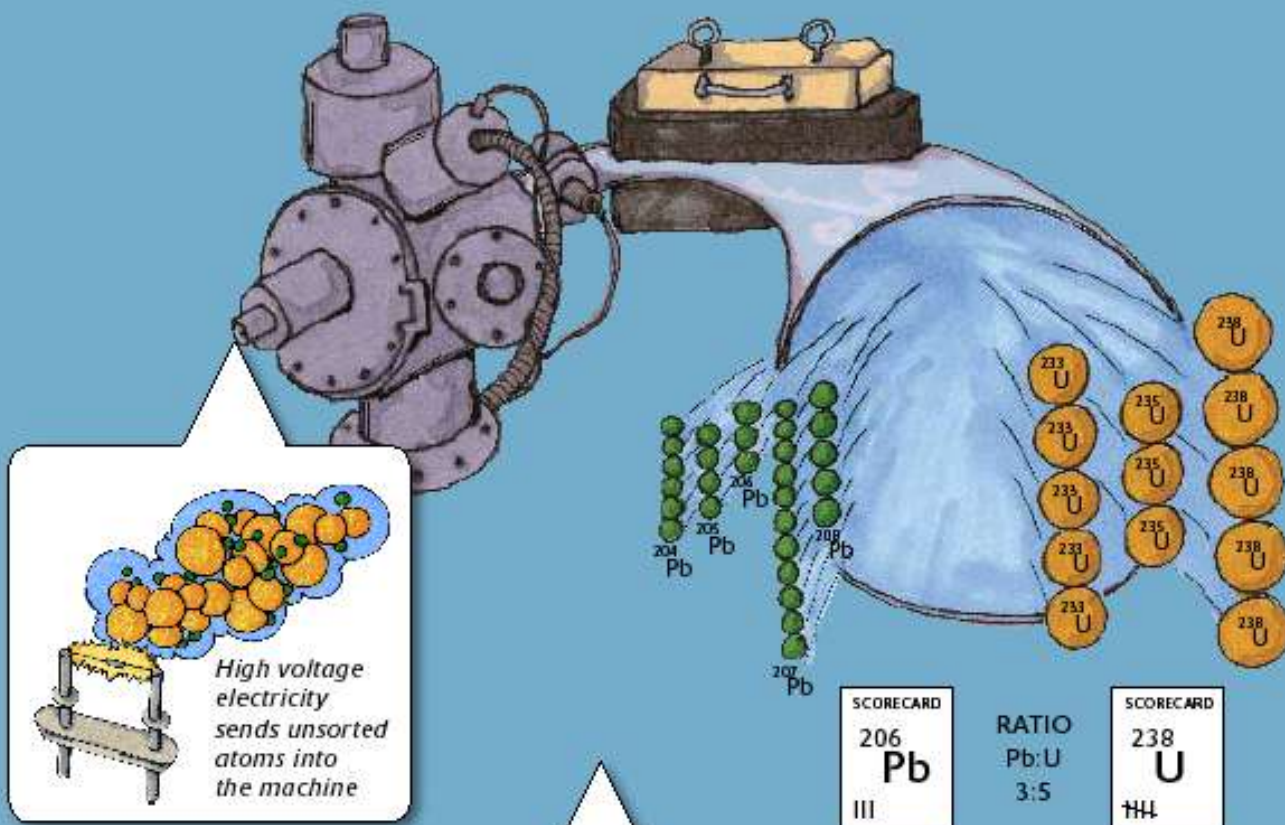


Zircon's unique properties make it possible to separate it from all other ingredients in the ash sample. Zircon is dense but not magnetic, so geologists first use a large magnet to get rid of the magnetic minerals.



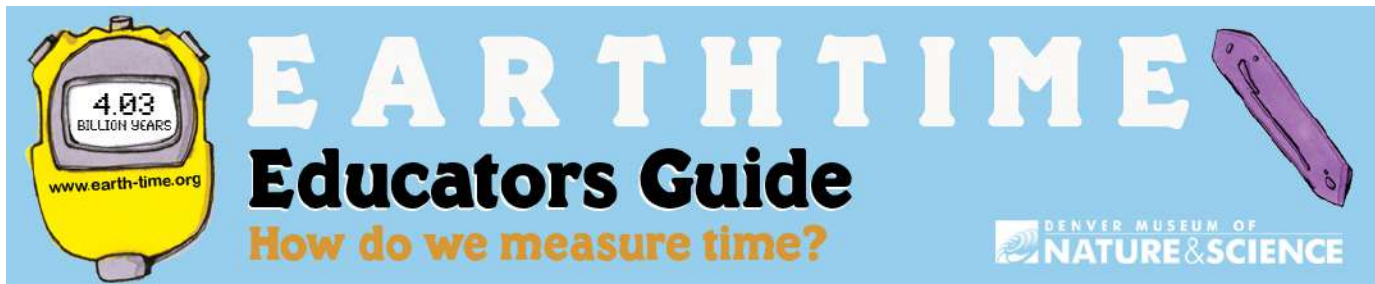
Next, they separate the zircon crystals from the remaining minerals using heavy (high density) liquids. The zircon crystals are so dense that they sink to the bottom while the lower density crystals float in the heavy liquid.

6 READING THE STOPWATCH



After removing the zircon from the heavy liquid, scientists dissolve the individual tiny zircon crystals and separate the uranium and lead from all the other elements in the zircon. To read the stopwatch, the uranium and lead are put in a mass spectrometer, a machine that separates and counts individual atoms. The ratio of uranium to lead atoms allows scientists to calculate how many years have passed since the volcano erupted and the lead atoms started to accumulate in the zircon crystals.

So, if a scientist wants to solve a big time problem, like the age of a mountain range, the answer just might be inside a zircon crystal.



Introduction to the Scientists and the Science behind EARTHTIME.

Two scientists, Sam Bowring and Kirk Johnson, worked with Denver Museum of Nature & Science educators Sharon Unkart and Linda Block-Gandy to create this curriculum. The following section is a reading for students and teachers who want to learn more details about radiometric dating and the geologic time scale.

EARTHTIME: The Beginning

Sam Bowring, a geologist and geochronologist, is Professor of Geology at the Massachusetts Institute of Technology in Cambridge, Massachusetts. Sam uses the radioactive decay of uranium to lead to determine the age of zircon crystals in ancient rocks and volcanic ash. Sam's laboratory can measure extremely small amounts of lead and determine some of the most precise dates in the world. Many scientists are using these dates to construct time lines for earth history including mountain-building and animal evolution.

Sam has discovered and dated the oldest known rocks on the Earth – the 4.03 billion year old Acasta Gneiss from the Northwest Territories of Canada. He has also provided the most precise dates for the base of the Cambrian, the Permian-Triassic boundary, and the Cretaceous-Tertiary boundary. In addition to dating volcanic ash layers in rock, Sam's lab is also involved in a variety of projects to measure lead contamination in food and soils.

Kirk Johnson, a paleobotanist and stratigrapher, is Vice President and Chief Curator of the Denver Museum of Nature & Science. He studies fossil plants, focusing his efforts on the greenhouse Earth of 50 to 100 million years ago. In 1994, the discovery of a 64 million year old tropical rainforest in Castle Rock, Colorado surprised Kirk. He responded by launching the Denver Basin Project, an ongoing effort to interpret the fossils of the bed-rock beneath Denver. Kirk's basic approach is to find and excavate rock outcrops that contain fossil leaves. These fossils allow him to reconstruct ancient vegetation and climate. First, he measures the thickness of rock layers that contain the fossils. Then, he places the fossil leaf sites in their vertical order in the rock layers so that he can measure change through time. Using this method, he was able to show that plants suffered a major mass extinction at the same time



© Kirk Johnson

Layered rocks from the Meeteetse Formation in Wyoming. This is a great place to search for ancient volcanic ash layers.



that the dinosaurs went extinct. The precision with which he measured the layers allowed him to support the argument that an asteroid impact caused this extinction event. In the badlands, where Kirk does his fieldwork, the layered rocks often contain layers of volcanic ash. Dating these layers allows Kirk to know how much time is represented in a given thickness of layered rock.

In 2001, Kirk and Sam realized they could help each other. Kirk had interesting fossil sites with many volcanic ash layers and Sam was able to date these layers precisely. Their collaboration became part of a larger effort now called EARTHTIME, which strives to bring geochronologists, paleontologists, and stratigraphers together to better understand, measure, and use geologic time.

Zircon: The Basics

Zircon is an ideal mineral for geochronology. It is a common but not abundant mineral in igneous rocks. Once formed, it is resistant to change and can survive many episodes of weathering, erosion, transport, and redeposition. It is no surprise that the oldest mineral on Earth is a 4.4 billion year old zircon from 3 billion year old sandstone in Australia. Zircon is what we refer to as an “accessory mineral.” In other words, it is not a major rock forming mineral. Zircon varies in abundance, but it is usually less than 0.1% of a rock sample. Here is a basic overview of how zircon crystals:



Zircon crystals

© Sam Bowring

a) form in magma chambers, b) erupt from volcanoes in volcanic ash, c) are deposited then buried, and d) are finally sampled, processed, and analyzed to yield radiometric dates.

How Zircon Forms

Zircon is a silicate mineral with a chemical formula of ZrSiO_4 . Like all mineral formulae, this is a simplification of what is really contained in a mineral. When zircon crystallizes from magma, it incorporates a lot of minor or trace elements not listed in its chemical formula. These elements include the Rare Earth Elements (REE's) Hafnium (Hf), Uranium (U) and Thorium (Th); there are many others as well. The REE's are a group in the periodic table from Lanthium through Lutecium and are also referred to as the Lanthanides.

Elements substitute for each other when they have the same charge and nearly the same ionic radius or size. Uranium is important because it can freely substitute for Zirconium (Zr) in the crystal structure. In the case of U and Zr, both have a +4 charge and nearly the same radius. Uranium occurs in much lower concentration than Zr in the crystal because it is much less common in the magma. However, zircon crystals typically contain anywhere from less than 1 part per million (ppm) Uranium to more than 1 part per hundred (1%).



Zircon crystals vary in size but are typically elongate and 100-250 microns long and 20-50 microns wide (one of the hairs on your head is about 100 microns in diameter).

It is important to understand that zircon excludes lead (Pb) when it forms. This means that, over time as the U decays to Pb, we can be sure that all of the Pb in a zircon comes from the decay of U. Scientists use this Pb to calculate the age of the grain. On the other hand, if Pb was included in the crystal when it formed, we would have to find some way to tell that Pb apart from the Pb produced in the zircon by the decay of the U; this would make the process much more difficult.

The amount of uranium in a zircon crystal is important for geochronology for two reasons. The first reason is simple: the more uranium there is, the more lead (Pb) there will be from radioactive decay. In general, if there is a lot of Pb and U in a zircon, scientists can use a smaller grain of zircon and their analyses will be more precise. The second reason U in a zircon crystal is important is a little more complicated.

When the two main isotopes of uranium, ^{235}U and ^{238}U , decay to ^{207}Pb and ^{206}Pb respectively, the process releases energy. This energy, over time, can lead to damage or distortion of the crystal structure. In a perfect world, the Pb ions produced from the decay of both isotopes of uranium would be in approximately the same location in the crystal even though they do not have the same charge or size as the uranium. However if the radiation damage is severe enough, the Pb can begin to leak out of the crystal, moving along the damaged zones. If this occurs, we no longer have a “closed system” and the date we calculate from measuring the amounts of U and Pb in a crystal will be too young. Fortunately, geochronologists can choose the best zircons and, in some cases, actually remove the damaged parts of the crystals so that they analyze Pb from a true closed system.

How zircons are erupted from volcanoes and deposited in sediments

Scientists, who want to know the rates of geological or biological processes, such as climate change or evolutionary rates of change, must have a way of dating rocks with high precision. In general, fossils can be found in sedimentary rocks that were deposited in the oceans, on the banks of rivers, in lakes, and in swampy areas. To form and preserve sedimentary rocks, the sediments must be buried before they can be eroded. The thicknesses of layers, and the time it takes to deposit those layers, can vary a great deal. For example, in the deep ocean it may take more than 1 million years to deposit 1 meter of sediment. However, in a coastal area, that much could be deposited in a single storm event lasting less than a day.

The best way to date a sequence of sedimentary rock layers is to find a volcanic ash bed from a single volcanic eruption, within the rock layers. Accumulations of sedimentary rocks that contain layers of volcanic ash are pretty common. Those ash layers can be as thin as 1 mm or up to many meters thick. These layers represent ash that was blown high into the atmosphere during a violent volcanic eruption and then transported by the wind. In some cases, ash can be transported thousands of kilometers. When it finally settles out of the air, if it falls in a body of water, it may form only a very thin layer.



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Imagine a landscape of hills and valleys blanketed in ash from a volcanic eruption. On average, the hills are areas that erode and the valleys and lakes are the areas where sediments pile up. Immediately after the ash blankets the landscape, rain and wind begin to remove the ash from the high places and transport it to low areas, like riverbeds and lakes. Geologists can often distinguish between volcanic ash that falls directly out of the air from ash transported by wind and water before re-deposition. The former is better for dating because it was directly deposited by the eruption. Because the process of erosion and deposition can take place very quickly, the re-deposited ash can also be used. However, these samples are sometimes mixtures because older rocks and zircons can be eroded at the same time.



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Volcanic ash beds in a sequence of coal seams in Colorado. The ash beds are the very light-colored layers.

To a geologist, a layer of volcanic ash represents a geological instant in time. The thickness of the layer is related to the size of the eruption. The thickness is also related to how close the site of deposition is to the volcano. Right next to the volcano, you may find a layer from a single eruption that is more than 1 meter thick. Two thousand kilometers away, a layer only 1 mm thick may represent the same eruption. Both represent the same eruption event and thus the same instant in time.

If we were to examine a layer of ash under a microscope, we would see a mixture of very small fragments of glassy volcanic rock and small crystals. In order to understand these fragments and crystals, it is useful to go back in time and imagine what is going on beneath the volcano a few seconds before it erupts. Under the volcano, we would find an almost-round chamber that contains melted rock or magma. Minerals, such as quartz, feldspar, and zircon are crystallizing from the magma. This mixture of crystals and magma also contains a lot of dissolved gas such as water vapor, carbon dioxide, and sulfur dioxide. As the magma chamber cools, the gas rapidly forms bubbles in the magma and leads to an explosive eruption, not unlike shaking a can of soda and opening it. The erupted material, which we call ash, contains cooled bits of liquid magma (now solid) and minerals that formed before the eruption. Some of these minerals are zircon crystals.

Deposition and Burial

It turns out that zircon crystals are very resistant and, once formed, are very hard to destroy. Many rocks, especially sandstones, contain zircon crystals that came from the erosion of older rocks. As a result, these zircons are usually much older than the sand in which they are found. If an ash layer is deposited on top of that sand, then buried by more sand, the zircons in the ash will be much younger than the

zircons in the sand above and below the ash layer. Even though the zircons in the sandstone come from an older rock somewhere else, scientists often analyze these zircons to date the source area of the sand. The age of these transported crystals can be very different from the age provided by the ash, but it can still be of great use to geologists.

Sampling, Processing, and Analyzing Zircon Crystals

Geologists must examine sequences of rock layers to find volcanic ash beds. Our present day landscape is the result of tectonic uplift and erosion. This has resulted in sequences of rocks that are exposed along the walls of canyons and the sides of mountains. The same rocks that are exposed at the surface also occur beneath our feet, but we cannot easily access them. Geologists study layers of rocks exposed by erosion and carefully describe the rocks, layer by layer. During this close examination, it is often possible to find layers that are different from the surrounding ones. Some of these layers are volcanic ash. In some cases, within the volcanic ash, we find fossils of plants and animals. The volcanic ash buried, and perhaps killed, these organisms.



Samuel Bowring collecting a volcanic ash sample in Wyoming. (Arrows point to ash layers.)

© Kirk Johnson

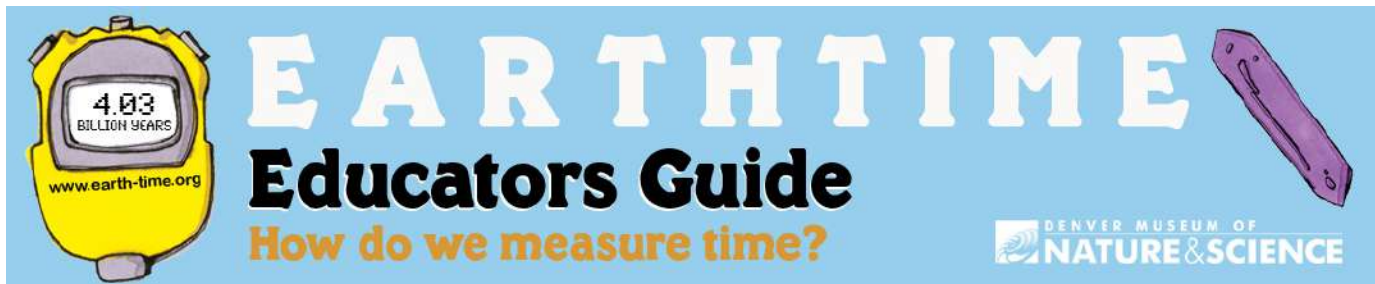
Sometimes there will be as many as a dozen layers of ash in a sequence of rocks that is only a meter thick. Rather than collect every single layer, we use our experience to choose layers that are most likely to yield

high quality zircon crystals. In general, ash beds can look very different from each other in the field. Some are almost pure clay and can be cut into cubes using a knife or rolled into a ball. Clay minerals form when the glassy shards that formed the original volcanic ash break down through the process of weathering. Fortunately, zircons are very resistant to this type of weathering and survive intact as other minerals change in the process. Other ash beds are very hard and must be broken with a hammer. These have often had silica or SiO₂ from groundwater added to them, which make them much harder. This is essentially the same process that produces petrified wood. Once geologists have identified an exposed volcanic ash layer, they must spend a great deal of time in the field cleaning off the layer above the ash. They use a range of tools – from paintbrushes, to knives, to small chisels and picks – to clean all of the surrounding rock from the volcanic ash. This is very important because the rocks



© Greg Wilson

Kirk Johnson inspecting a coal seam that contains thin ash beds in Montana. (Arrows point to ash layers.)



above and below may also contain zircons. However, these are not from the eruption, but instead are from the erosion of older rocks. Next, the samples are carefully removed and placed in plastic bags. The bags are then labeled before being sent back to the geochronology lab.

The other way geologists can find ash beds is to examine drill cores. In many areas where no rock layers are exposed, drill cores are available, usually because of exploring for oil, gas, or water. Scientists examine these cores to learn more about the rock layers under the surface. Most cores are only about 2-3 inches in diameter, but in some cases enough ash can be collected to separate zircons and obtain a date. Once the samples get to the lab, they must be broken down so that we can separate the few crystals of zircon from the rest of the volcanic rock. The first step in the process is to wash the samples in soapy water. Because zircons are very dense and larger than the clay minerals, the clay floats away and the crystals settle to the bottom of the large beaker. Next, we use a strong magnet to remove all magnetic minerals; zircon is not magnetic and is not affected by a magnetic field like iron-rich minerals. Then, the minerals are put in a liquid that has a density three times higher than that of water. In this liquid, quartz and feldspar float because they are less dense than the liquid. Zircon sinks because it has a density that is greater than the liquid. The result is a concentrate composed mostly of zircon crystals, which we can then examine under a microscope. The zircon crystals that are best for geochronology are clear, free of cracks, and big enough to handle with tweezers. Geochronologists can manipulate zircons that are as small as 35-50 microns long. Remember, there are 1000 microns in a millimeter! Once selected, the zircons are then ready for analysis.



© Kirk Johnson

Disaggregating an ash bed sample in water and detergent at the lab in Cambridge, MA.

Reading the Stopwatch: Processing the Zircon Crystals and Getting a Date

In order to determine a date from a zircon crystal, it is necessary to know the number of atoms of U and Pb in a single zircon crystal. To measure these numbers, the zircon is dissolved in very hot hydrofluoric acid (HF). The resulting solution is then processed through an ion-exchange column. Simply put, this allows us to chemically separate the U and Pb from all of the other elements in the zircon (Si, O, Zr, REE's, etc).

The pure Pb and U are then loaded onto a thin filament of metal and put in a mass spectrometer. The inside of the mass spectrometer is a

Using a powerful magnet to separate nonmagnetic zircon crystals from magnetic grains at the lab in Cambridge, MA



© Kirk Johnson



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Using heavy liquids to separate heavy zircon crystals from less dense grains at the lab in Cambridge, MA.

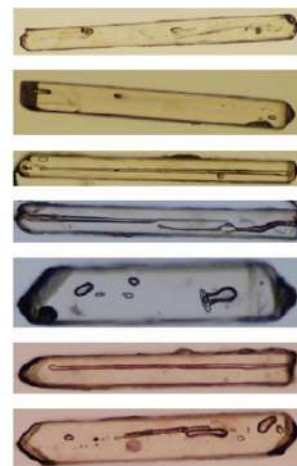


© Kirk Johnson

The mass spectrometer at the lab in Cambridge, MA.

vacuum chamber. An electrical current is passed through the filament and, like a light bulb, the filament is heated until it glows. This causes the Pb to be made into positive ions and 8000 volts accelerate the ions into a magnetic field. The magnetic field can be adjusted so that individual masses (206Pb and 207Pb, for example) are each deflected, forcing them into unique paths that reach a detector at the other end of the machine. In this way, by switching the magnetic field back and forth, scientists can measure the ratio of 206Pb to 207Pb.

This will not give us the exact number of atoms of each in the crystal, however, because all of the chemical processing and analysis results in the loss of many of the atoms – as much as 90%! To compensate for this loss, scientists add a known number of atoms of isotopes of Pb and U that do not occur in nature at the beginning of the process. Then, they measure the ratio of that added isotope (205Pb and 233U, for example) to 206Pb, 207Pb, 235U and 238U and calculate how many atoms they started with. They often only measure a small fraction of what they started with. This is called isotope dilution. Once the mass spectrometer has measured the ration of U ions to Pb ions, those numbers are used in the decay equation and a date for the sample is calculated. The resulting radiometric date is assigned a statistical error based on a number of factors. For the last few decades, these errors have not been much better than 1 %. For example, a 100 million year old sample with 1% error would be 100 million years plus or minus 1 million years. Recent advances in the techniques of U-Pb dating are now allowing labs like Sam's to estimate ages with errors as small as 0.1% or even less – that is only 100,000 years!



Zircon crystals ready to be dated.

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What This Means for the Geologic Time Scale

For more than 200 years, scientists have used the relative sequence of fossils in rock layers to create a relative time scale. Since the discovery of radioactivity in the early 1900s, geochronology has been used to make numerical time estimates on the first occurrence and duration of distinctive fossils and for the age of the relative time periods. Geochronological techniques are being improved all the time and more and more rocks are being dated. Thus, the geologic time scale is constantly being updated and improved as better quality dates are processed. Periodically, a new timescale is published that serves as the standard until it is updated. The most recent timescale was published in 2004 (Gradstein, F., Ogg, J. and A. Smith, 2004, A Geologic Time Scale 2004. Cambridge Univ. Press, Cambridge, 589 p. also available at <http://www.stratigraphy.org/gts.htm>). This is the timescale that we use for this curriculum.

In the following list the beginning of each time interval is listed:

Holocene Epoch 10,000 years ago
Pleistocene Epoch 1.81 million years ago
Pliocene Epoch 5.33 million years ago
Miocene Epoch 23.03 million years ago
Oligocene Epoch 33.9 million years ago
Eocene Epoch 55.8 million years ago
Paleocene Epoch 65.5 million years ago
Cretaceous Period 145.5 million years ago
Jurassic Period 199.6 million years ago
Triassic Period 251 million years ago
Permian Period 299 million years ago
Carboniferous Period 359.2 million years ago
Devonian Period 416 million years ago
Silurian Period 443.7 million years ago
Ordovician Period 488.3 million years ago
Cambrian Period 542 million years ago
Proterozoic Eon 2500 million years ago
Archaean Eon not defined but likely 4,567 million years ago



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5E MODEL

Elaborate/Evaluate

GRADE LEVEL

High School

NSES STANDARDS

A, C, D, E, G

PREPARATION

Estimated Preparation: 1-2 hours

Estimated Activity: 2 class periods

MATERIALS

- Copies of Data Cards for each team of two students
- Copies of Denver Basin rock formation sheets for each team
- Envelopes for data cards and formation fact sheets
- Copy of the Denver Basin Handout for each student
- Overview of the Denver Basin and stratigraphic column
- Denver Basin Map Key
- Copies of blank Denver Basin quadrant maps with geologic sites
- Colored pencils for each team
- Student Science Notebooks or paper
- Computers with Internet Access
- GoogleEarth application installed on the computers
- KML software downloaded from EarthTime website (www.earth-time.org)

Denver Basin Activity - Putting It All Together

Learning Goals/Objectives

To use evidence from multiple sources to determine the age of rocks

To use evidence from multiple sources to determine ancient environments

To use maps to help understand the geology of an area

To use radiometric data to create a better understanding of an area

To use basic principles of geology to understand the relative age of rock layers

To use technology to integrate multi-disciplinary information

Activity Overview

In this activity, students work like geologists analyzing different kinds of data from a variety of sources to better understand the geologic history of an area. Fossil evidence, radiometric dates, and rock types are provided from various sites in the Denver Basin. Students first read about the makeup and history of the various rock formations in the Denver Basin. Students analyze and use information from geologic sites on a map to determine the specific formations of the Denver Basin Stratigraphic Column. Once students have determined the layers of the Denver Basin and created their own geologic map, they use KML overlay files with Google Earth to “tour” the Denver Basin 3-dimensionally.

Teacher Background

Students should have already been introduced to the Principles of Superposition, Horizontality, and Lateral Continuity. In this activity, relative positions of rock formations, the composition of rocks, fossils, and radiometric dates from various formations provide information about the Denver Basin’s past.

The Denver Basin

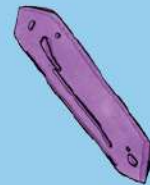
Denver is part of what is known as the Front Range. The Front Range is where the eastern edge of the Rocky Mountains meets the High Plains in Colorado from its northern borders to the south central part of the state. It includes Denver and its metropolitan area.



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OPTIONAL MATERIALS / INFORMATION FOR CLASS

- Reference materials from school library
- Johnson, Kirk R., and Robert G. Raynolds. Ancient Denvers. Denver: Denver Museum of Nature and Science. 2003.
- Websites:
Denver Museum of Nature and Science: Ancient Denvers
<http://www.dmnh.org/main/minisites/ancientDenvers/index.html>

Earth-Time: Geologic timescales
<http://www.earth-time.org/timescale.html>

Teacher Background continued...

With mountains, buttes, cliffs, foothills, mesas, and layered rock outcrops, scientists have long known that the area has undergone many changes over millions of years in Earth's history. Three hundred million years of Earth time is represented in the Denver Basin and a wealth of fossil evidence continues to grow with each new discovery providing a richer picture of the past.

Many of the different layers (rock formations) of the Denver Basin are exposed in areas around the Denver Metro Area. Scientists know that mountains were built through uplifting and leveled through erosion. As the mountains were built they also eroded depositing some of their sediment in the Denver Basin causing it to sink. As the basin itself eroded, the layers were exposed. Although you see evidence of these layers on the surface, they also extend thousands of feet in the earth. A sliced red onion has been used as an analogy for the structure of the layers of the Denver Basin. Or, you might think of a bowl where layers of dough were added until the bowl is full. The last layer to be filled is in the center of the bowl.



© Kirk Johnson

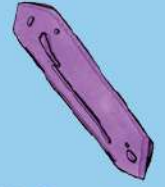
In the early 1990s, there were some very interesting geologic discoveries in the Denver area. While building a new airport (Denver International Airport) on the plains east of Denver, fossils of ancient palm trees were



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Teacher Background continued...

found. South of Denver in a town called Castle Rock, fossil evidence of an ancient rainforest was discovered. And under the Colorado Rockies' baseball field, dinosaur bones were found.

Scientists wanted to know just how old rocks *were* underneath the Denver Basin. Dr. Kirk Johnson and other scientists from the museum drilled a 2,256-foot core of continuous rock near Kiowa, Colorado. Using the findings (evidence) from this core and evidence from other locations around the area, the museum staff and other scientists created a map of the Denver Basin. They learned and continue to learn more about Earth time on the Front Range.

Dr. Johnson was also able to find the Cretaceous-Tertiary boundary at multiple locations in the Denver Basin region. The Cretaceous-Tertiary boundary, also known as the K-T boundary, is a thin ash rock layer that separates the Cretaceous time period from the Tertiary time period. It also separates the Mesozoic Era from the Cenozoic Era. What does this mean? It means that major environmental changes occurred at the time of the formation of this rock band. A major asteroid impact occurred in the ocean off the Yucatan Peninsula in Mexico. Dinosaur fossils are found before this rock band, but not after it. This impact has led many scientists to believe it is the cause of the extinction of the dinosaurs, as well as other organisms and ecosystems.

As a paleobotanist, Dr. Johnson researches the plant fossils he has uncovered at many sites in the Denver Basin. The clues provided in the fossils he finds help him reconstruct the environments of the Earth's past. He hopes to further understand past environments with each new discovery that is made.

The growing understanding of the Denver Basin has been enhanced by the work of the geochronologists at EARTHTIME. Their work has provided museum scientists with accurate dates that not only pinpoint when a geologic event occurred, but how long an event might have lasted.

These dates, ancient plants, animals, rock composition, and rock formations in this lesson will help your students construct a picture of different environments and how the Denver Basin has changed over *millions* of years.



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Vocabulary

Principle of Faunal/Floral Succession – fossils change in a definite order and time periods can be identified by the fossil content.

Advance Preparation

Note: It is optimal for the sets of these materials to be reproduced in color. However, the expense of color copies may be beyond your classroom budget. The pictures were selected to provide good black and white copies. It is best to check the black and white copies from your school copy machine before running off multiple copies. You may need to adjust the light/dark setting to get the best possible copies.

The geologic map has been divided into quadrants with up to twelve data points each. **Not all formations in the Denver Basin are shown in each quadrant.** Data cards should be divided into sets according to the site numbers in the quadrants.

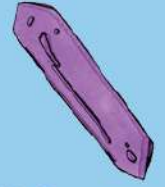
1. Prepare a set of data cards on heavyweight paper for each team. (You may want to laminate these cards so they can be used for a longer period of time.)
 - a. Cut the data cards in half.
 - b. Fold the cards to reveal the site number, but hide the data.
 - c. Place cards in a large envelope.
2. Prepare a set of Formation Fact Sheets for each team.
3. Prepare blank Denver Basin outline/site maps for each team.
4. Prepare Denver Basin Information and Denver Basin block-diagram handouts for students.
5. Download Google Earth if not already on school computers. (You can download the free version at www.earth.google.com.) If you are not familiar with the application, there is a quick online tutorial in the menu under Product Tour. Dial-up connections cannot be used with the program.
4. Download the KML overlay at the EARTHTIME Web site (www.EARTHTIME.org) under the Education menu.
4. Arrange to have computers available for students during the second day of this activity.



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Classroom Activity

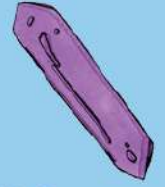
1. Introduce students to the activity. Explain that in this lesson they will be doing the actual work of geologists. They will use data that was gathered through radiometric dating, fossil evidence, and rocks at actual sites to understand the location of formations and the history of the Denver Basin. They should also be able to locate the K-T boundary on the map.
2. First provide students with the information sheet about the Denver Basin. Read and discuss the information section of the student hand-out with your class.
3. Next discuss the Denver Basin block-diagram and the stratigraphic column.
4. Hand out the formation fact sheets.
5. Have students read about each of the formations. Ask students what they thought was most important about each formation. What did they learn? Were there any animals, plants, or environmental information that seemed unique to the formation?
6. Hand out a quadrant packet with the associated data to the student teams. Explain to the students that they will determine where the different formations are exposed (or are at the surface) by analyzing actual data collected by the teams of scientists at the various numbered sites. **Explain that not every group will have all of the layers found in the Denver Basin.** The large dot near the center of the basin (located on map three) locates the position of the Kiowa core. The stratigraphic column to the right of the map shows the relative thicknesses of the layer excavated from the core.
7. Explain that the lines on the map are the boundary lines of the formations. They are not contour lines.
8. Hand out the data cards. Explain that each card gives information about fossils, rocks, or radiometric dating from the site. The numbers on the cards correlate to the site numbers on the map.
9. Guide students to group data cards according to how they fit between formation boundary lines. Students use the data collected and information from the fact sheets to determine the formations on their maps.
10. After formations have been identified on their maps, students need to color each of the formations using the stratigraphic column as a legend.
11. Students should also identify the K-T boundary on their maps.
12. After the quadrant maps have been colored according the geologic specifications, students need to compare and match-up their quadrant maps:



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Classroom Activity continued...

- When put together, do the formations match up? If not, why?
 - Teams that are in disagreement about the formations on their maps should discuss how the data informed their decisions. Teams then need to discuss how to solve the problem(s).
13. Questions to ask:
- The stratigraphic column shows the progression of time, from oldest rock formations at the bottom of the column to youngest formations at the top of the column. Is there any pattern or progression of the age of rock formations as they are exposed on the surface of your map? If so, where are the oldest rock formations located and where are the youngest formations located?
 - Look at your data. Who thinks they know where the K-T boundary is on the map? What evidence do you have from your data that supports your conclusion?"
 - Does it look like rocks are deposited uniformly in time? Do all formations span the same amount of time?
 - How do the actual dates, provided through radiometric dating, further your understanding of the Denver Basin?
 - How does radiometric dating further the understanding of Denver Basin's history?
 - If you were going to dig a cored well, where would you put it to gather the most possible information about the Denver Basin? How deep would it need to go to get to the basement rock (hint: the Cash register building is 700')?
13. Optional: Explain that once they have identified each formation, where each fossil belongs and have also determined the age of a layer where possible, they need to stack or "deposit" their fossil and rock formation cards, from oldest to youngest, using the numbers on the Formation Fact Sheets. This is another way to represent the stratigraphic column.

Day 2

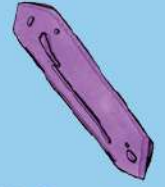
Once students have created their final Denver Basin maps, arrange a time for them in your school's computer lab to see the exposed formations in 3-dimensions. Students can fly over the terrain using KML overlays of the actual Denver Basin Maps.



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Classroom Activity continued...

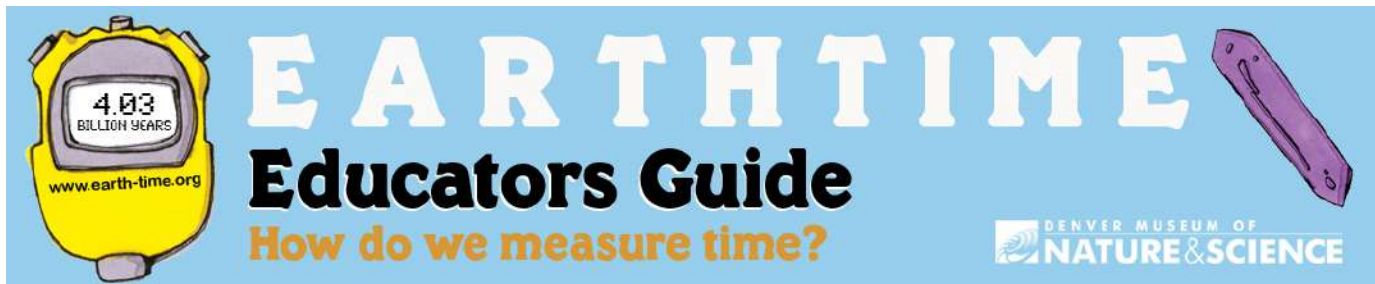
1. If students do not have experience with Google Earth, demonstrate how to use each of the navigation tools.
2. Clicking on the KML files should open Google Earth. The files should open at the correct geographic location. You can drag the other two files onto Google Earth to combine all of the data.
3. Allow time for students to explore the site using all of the navigation tools.
4. Ask students to find 39° 42.125' N latitude, 105° 12.121' W longitude, using the pointer (arrow) on the screen. The latitude and longitude are listed at the bottom of the screen. As they move the pointer, the location is shown. Once at this location, ask them to double click on the blue circle. It will bring up pictures of the location showing a road cut near Interstate-70. The layers of rock here are from the Morrison, Dakota Sandstone, and Pierre Shale Formations.
5. Students should then explore each of the formations in the Denver Basin following the map overlay to determine the types of terrain in which the formations were exposed. Students can also use the tool bar in the upper right-hand corner to tip the image. This will highlight the changes in topography.
6. Discuss the types of terrain that are found in the Denver Basin. Discuss the range of time that is exposed in the Denver Basin.

Extensions

Challenge: Students who finish the assignment early can do this activity. Most of the Denver Basin formation ancient environments were interpreted in paintings. Have students use their data clues and fact sheets to figure out which painting represents a particular rock formation. Download copies of the paintings at www.EARTHTIME.org.

Resources

Johnson, Kirk R., and Raynolds. Robert G. (2006). *Ancient Denvers*. Denver Museum of Nature and Science. Denver.



Name _____ Date _____

Denver Basin: Putting It All Together

Part One

In this activity, you will use fossil evidence, rocks, and absolute dates to determine formations that have been exposed at the surface in the Denver Basin. Geologic maps will be produced based on your analysis of the data.

Materials

Denver Basin Block Diagram

Denver Basin Data Cards

Denver Basin Formation Fact Sheets

Denver Basin Formation Outline/Site Map

Denver Basin Information Sheet

Colored pencils or markers (red, purple, green, yellow, orange, blue, brown)

1. Read the information sheet on the Denver Basin.
2. Your teacher will provide information about the block-diagram and stratigraphic column to the class.
3. You and your teammate will be given a quadrant map of the Denver Basin. The outlines show where formations of the Denver Basin are exposed at the surface. The lines represent boundaries of the formations on the map. **Not all formations may be located on your quadrant map.**
4. The map numbers and dots show the location of geologic sites. At these locations, data was gathered about the formation.
5. The numbered data cards correlate to the numbered geologic sites. Your job is to analyze information from sites within the geologic boundaries outlined on your map. Group the data cards according to the site numbers you find between the lines. This will give you more clues about each formation on your map.
6. Use the information from your data cards and formation fact sheets to determine the different formations on your map.
7. Once you have determined the formations on your map, use the stratigraphic column as a legend to color the formations on your map.
8. Teams will be coordinated so that all four quadrant maps can be put together. Once this has been done, answer the following questions in your science notebooks/journals:
 - a. Did all of the formations on your maps match-up? If not, how will the differences be resolved?
 - b. Looking at your combined Denver Basin maps, where are the oldest formations located? Where are the youngest formations located?
 - c. Look at your data. Where do you think the K-T boundary is located? Why do you think this is the K-T boundary?
 - d. How do the actual dates, provided through radiometric dating, help you better understand the Denver Basin?



Part 2

Computer Lab: Google Earth

Note: If you have not used Google Earth, your teacher will provide you with a tutorial or instructions to learn how to use the navigation tools.

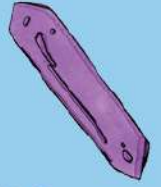
1. You will need to open the Denver Basin KML file by clicking on it. Once the application has opened on your screen, follow your teacher's directions.
2. Take some time to maneuver around the area.
3. At the bottom of the screen there is information as to where your pointer is located. The latitude and longitude are given. Move your pointer to find Latitude 39°42.125' N, Longitude 105°12.121'. This is the location of a road cut that shows layers of the Morrison, Dakota Sandstone, and Pierre Shale formations. Double click on the location until you are zoomed in. Tilt your map so that you can see the layers of rock. There is also a blue dot to click on that will show you a photograph of the layers.
4. Fly along the western edge of the Denver Basin. What is the terrain like?
5. Describe the type of terrain you found when you flew over the following formations:
 - Fountain
 - Morrison
 - Dakota Sandstone
 - Denver
 - Fox Hills
 - Laramie



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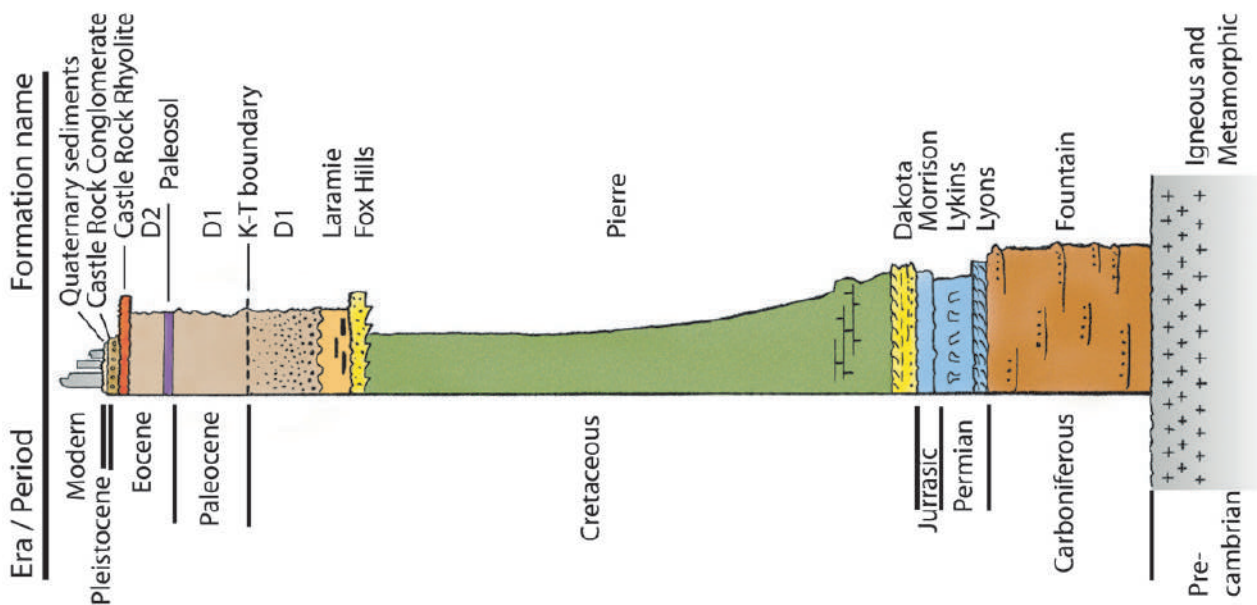
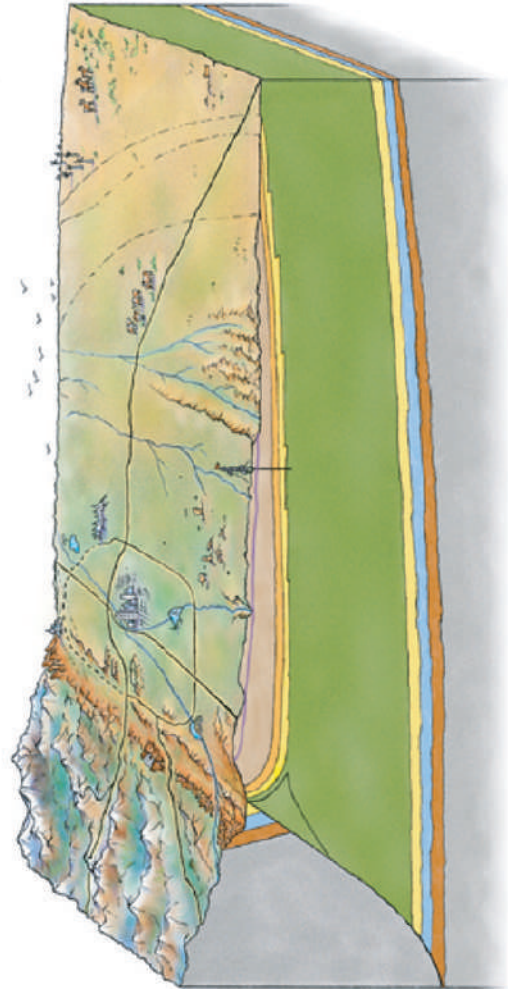


The Denver Basin Stratigraphic Column

The image below shows a block diagram of the Denver Basin. It shows what you would see if you took a giant knife and cut a giant east-west slice 14,000 feet into the earth. The different colors represent different rock formations. By looking at the composition of the rock and the types of fossils found within the rock, scientists can interpret what past environments may have looked like.

The diagram to the left is called a stratigraphic column. It shows the same rock formations but this time, they represent the rocks that would be encountered by digging a well in the center of the basin. Denver's 700' tall Wells Fargo Center (the "cash register building") is drawn to scale, showing how thick the layers are. Since these layers come to the surface around the edge of the Denver Basin, this stratigraphic column will be used to create a geologic map of the surface of the Denver Basin.

The colors of your map will match the colors of the stratigraphic column. By "digging holes" in the basin and looking at the data that comes from each site, you will be able to piece together the geologic map in the same way that scientists piece together data to inform our understanding of the rock record and ancient history of the planet.

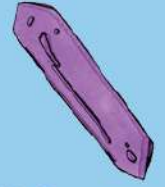




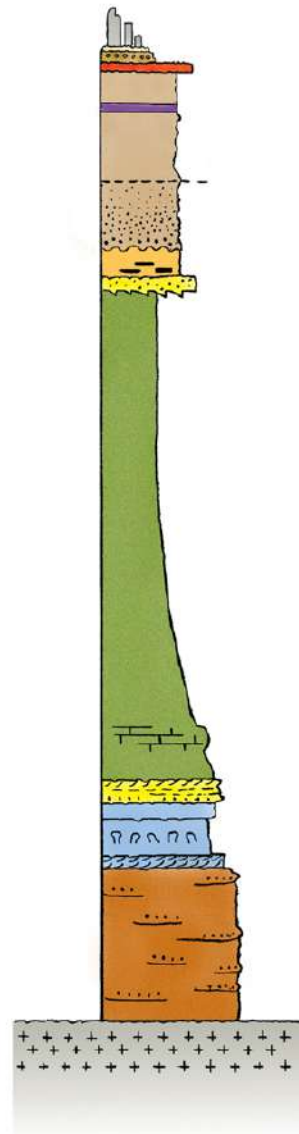
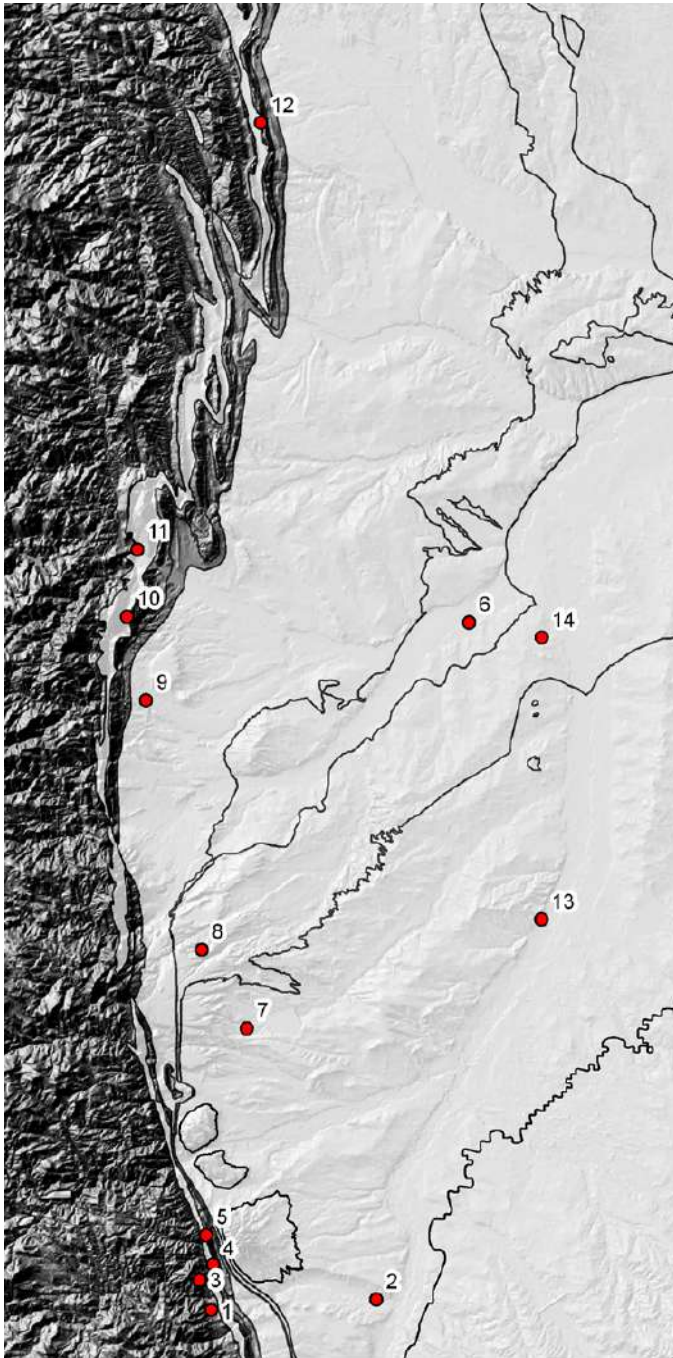
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0 2.5 5 10 15 20
Kilometers

Denver Basin Map 1

HS L6 ~ Page 11

STUDENT PAGE



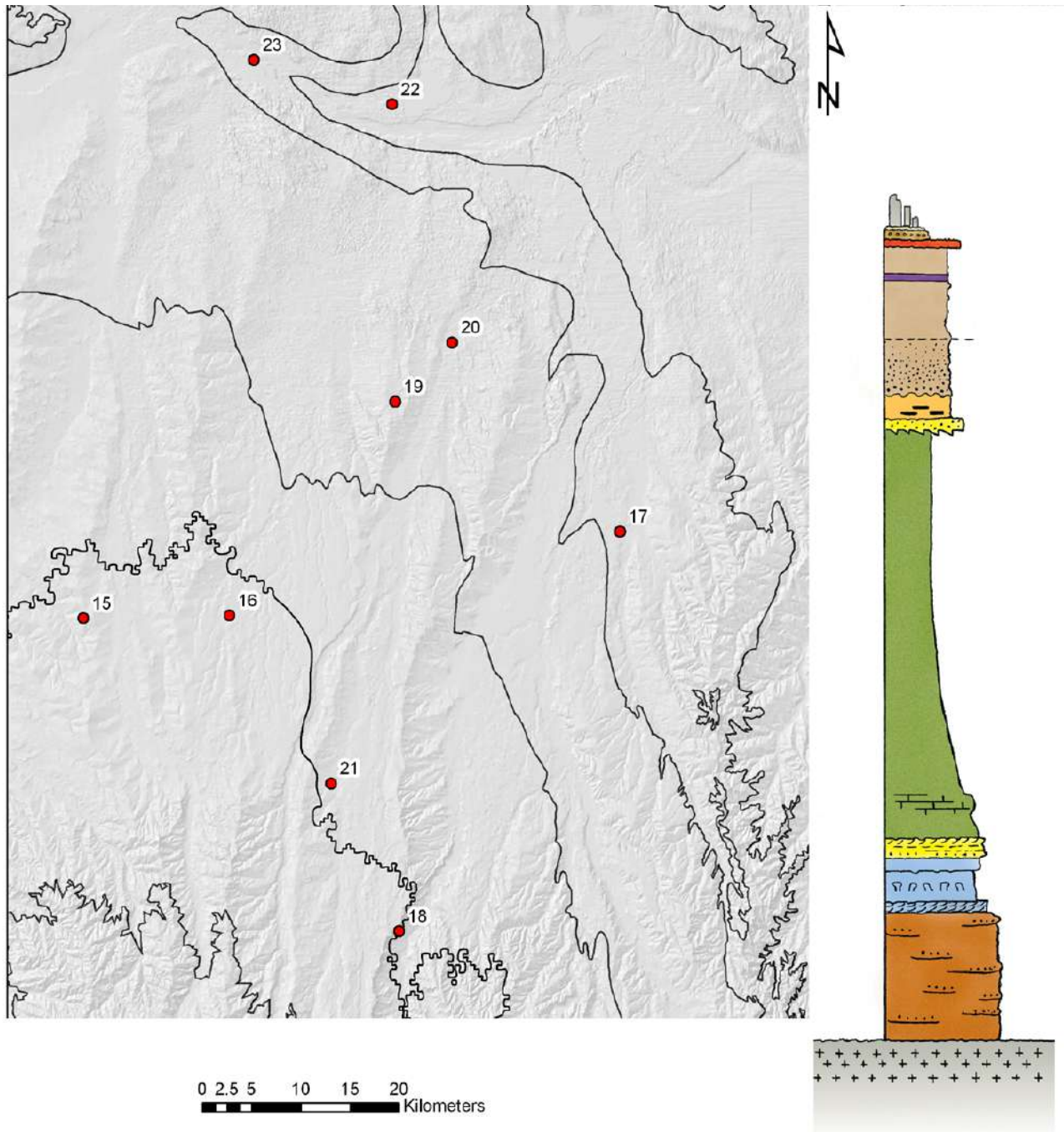
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Denver Basin Map 2



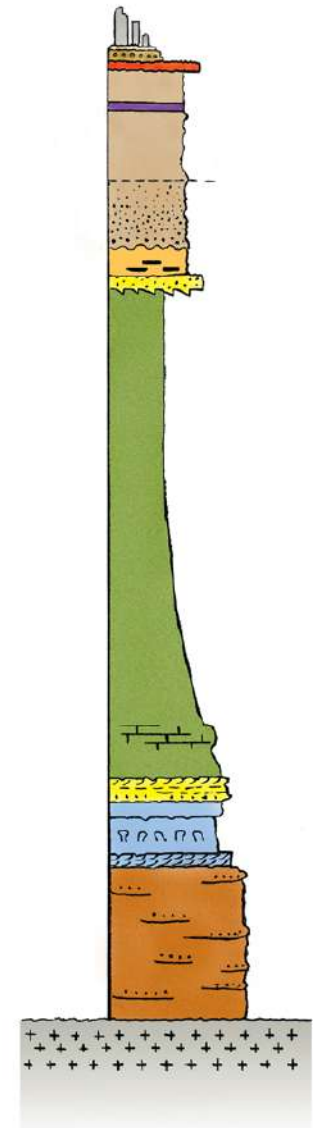
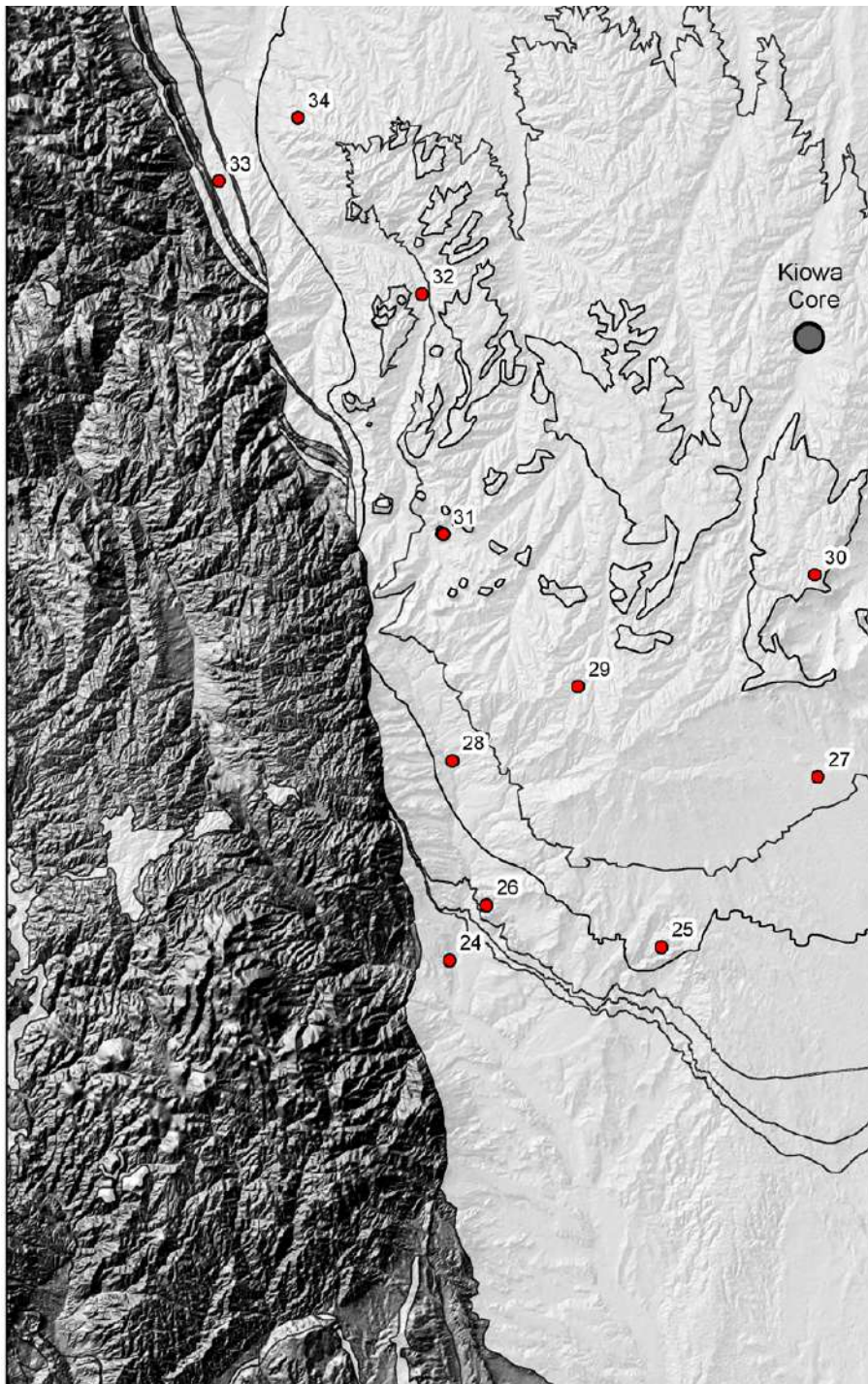
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Kilometers

Denver Basin Map 3



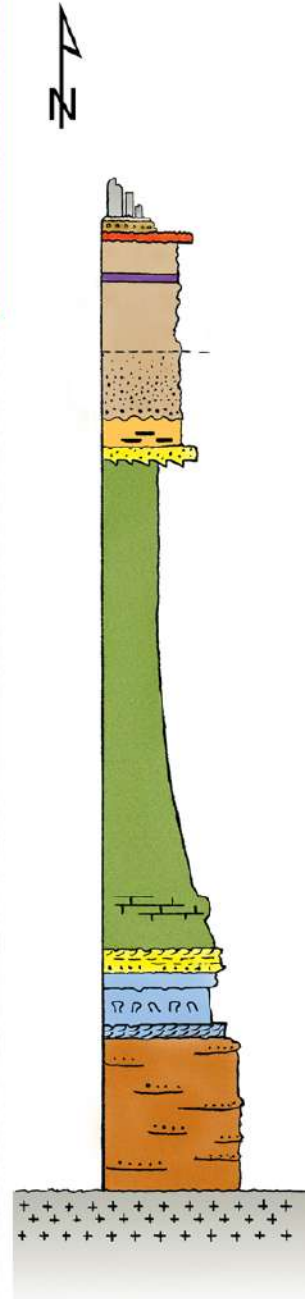
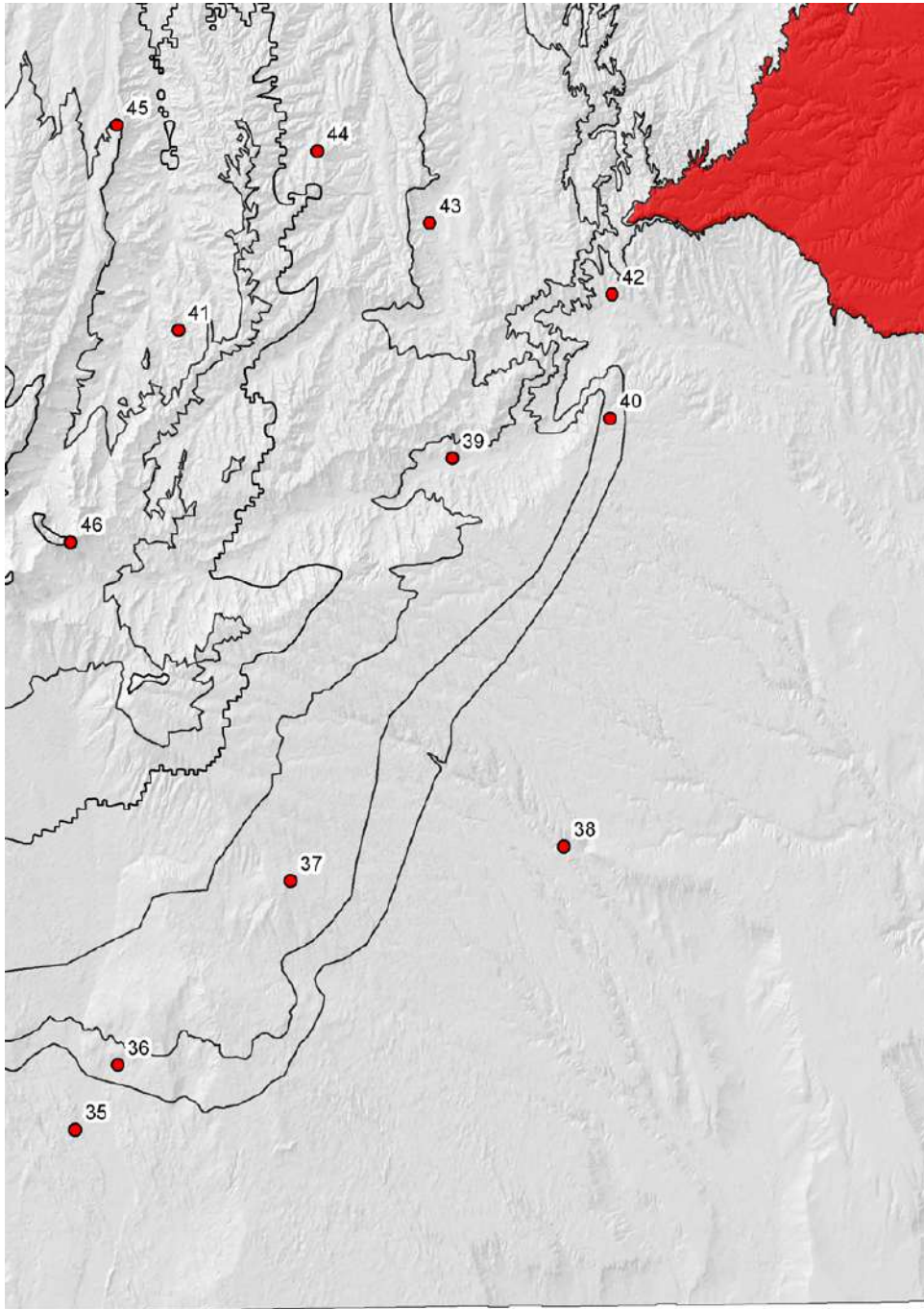
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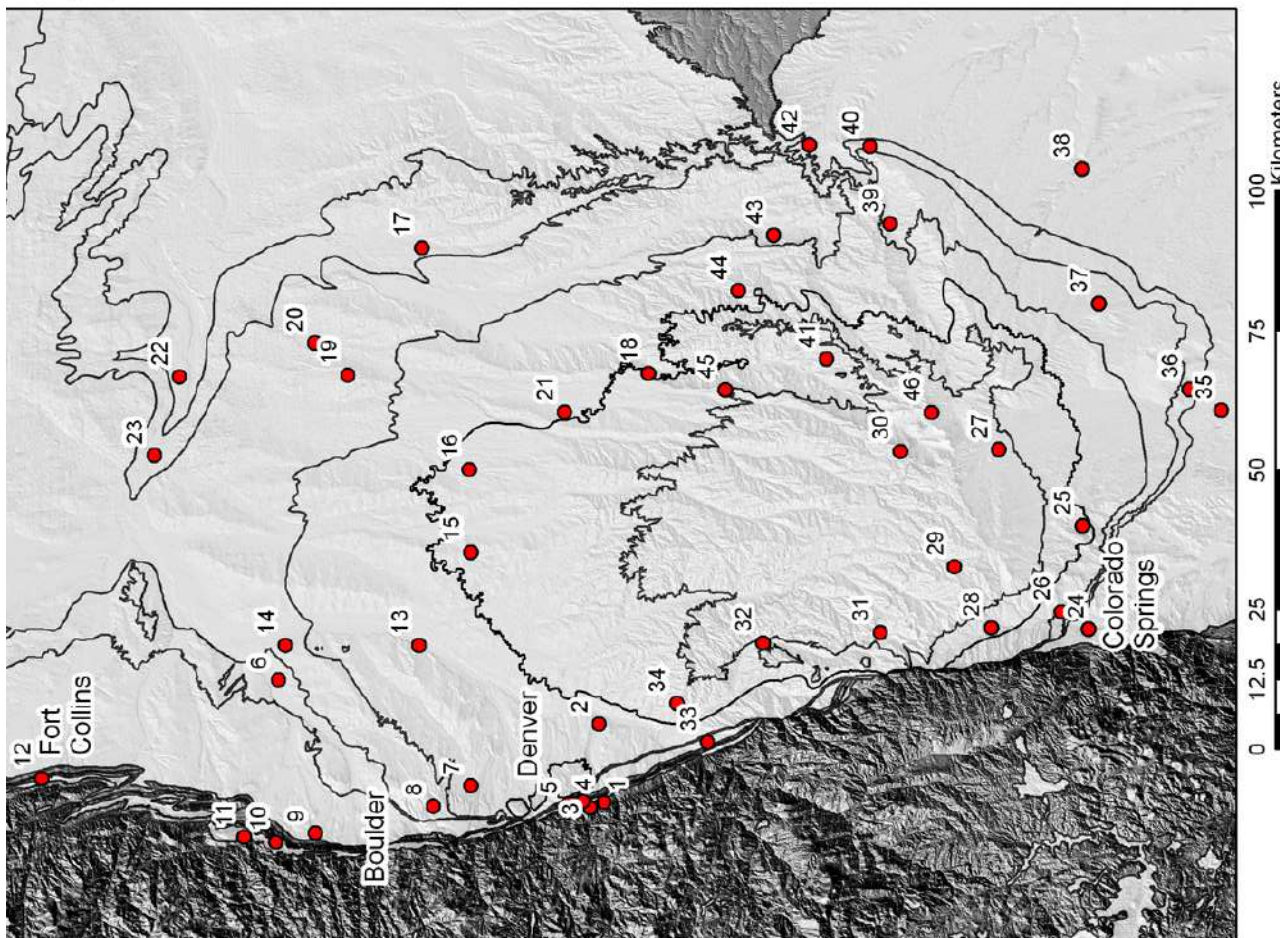
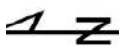
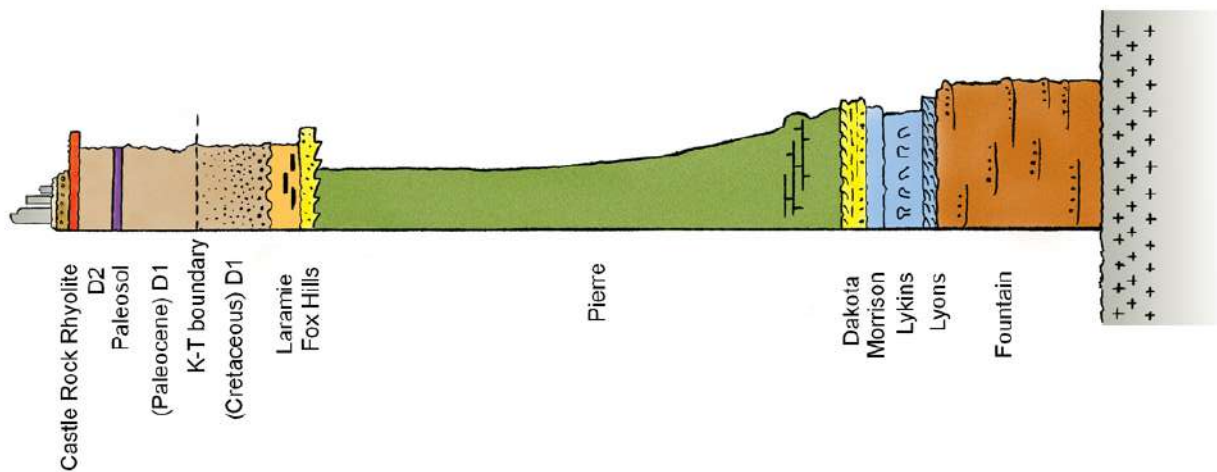
Denver Basin Map 4



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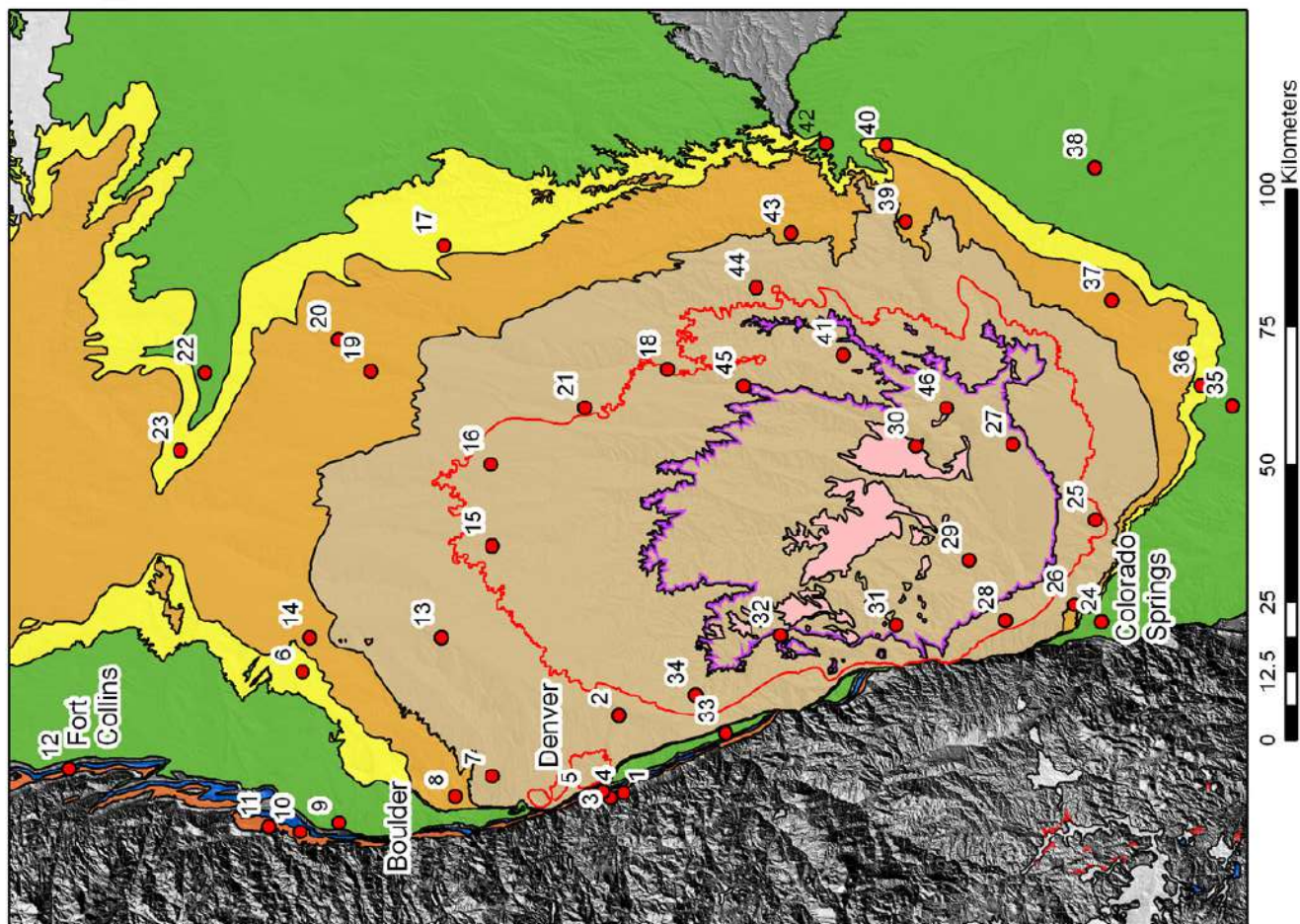
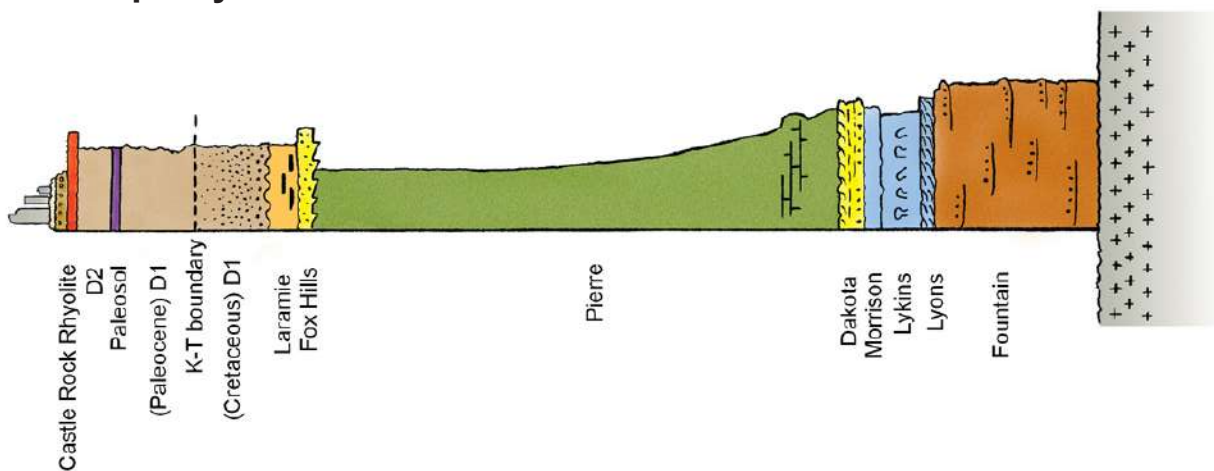
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Teacher Map Key





Precambrian igneous and metamorphic rocks

Description of the rocks:

These rocks, formed in high-temperature, high-pressure environments deep in the Earth, are very hard, making them more difficult to erode. Much of the Front Range that we see today is exposed Precambrian rock, including the sparkling Pikes Peak granite. Formed about 1.0 billion years ago, this granite and the other rocks in the unit are all that is left after the younger softer upper portions of the Rocky Mountains eroded away. In the center of the Denver Basin, the Precambrian rocks are about 2 miles below us.

Ancient Environment:

Landscape: none (sub-surface)

Plants: none

Animals: none

What it looks like today:



© Kirk Johnson



Fountain Formation

Description of the rocks:

This formation contains over a thousand feet of reddish sandstone, mudstone, and conglomerate, originally laid down by rivers draining off the Ancestral Rockies during the Pennsylvanian and Permian periods. Coarse pieces of quartz and granite within the sandstone are a good clue that a mountain range was eroding somewhere upstream. The name for this formation comes from Fountain Creek in Colorado Springs.

Ancient Environment:

Landscape: Mountainous with early forests.

Plants: *Lycopod* and *Sphenopsid* trees (100' tall, relative of horsetail rush, all parts of the tree were photosynthetic, including the trunk!)

Animals: Small amphibians, fish, protomammals, giant cockroaches, and dragonflies

What it looks like today:



© Kirk Johnson



Lyons Sandstone

Description of the rocks:

This reddish-orange colored sandstone is the remnant of giant sand dunes and rivers which formed along the edge of the ancestral Rocky Mountains. The sand grains are blown up one side of the dune and slip down the other. Stacks of sand were eventually buried and cemented to form fossilized sand dunes. The structure of the dunes, called cross-beds, is still visible in some places. Today, this rock is quarried in sheets which are broken into smaller pieces to make flagstone. Occasionally, footprints and impressions of ancient raindrops are preserved in the stone!

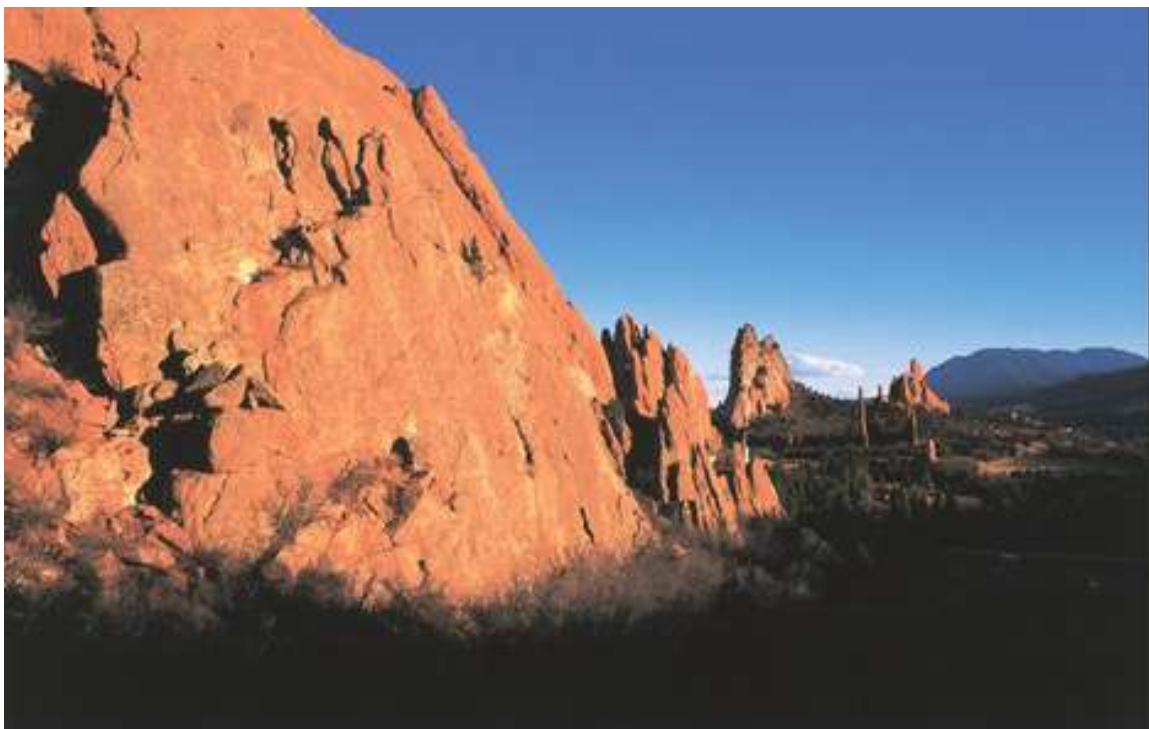
Ancient Environment:

Landscape: Dry and seasonal climate, immense sand dunes.

Plants: Early conifers and cycads.

Animals: somewhat larger protomammals (the size of dogs with squat-bodies) that ate plants.

What it looks like today:



© Kirk Johnson



Lykins Formation

Description of the rocks:

The Lykins formation is a series of cream-colored layers of wavy limestone amid thick piles of brick red mudstone. The mudstone is extremely soft and weathers so quickly that it is rarely exposed at the surface. The limestone was created by stromatolites, which are formed by cyanobacteria (algae and bacteria that live together). These odiferous, slimy mounds live in shallow salty pools.

Ancient Environment:

Landscape: Subtropical with humid, stinky, swampy tidal flats.

Plants: algae

Animals: not preserved as fossils

What it looks like today:



© Kirk Johnson



Morrison Formation

Description of the rocks:

The famous Morrison Formation is named after the small town of Morrison, just west of Denver. It is composed primarily of mudstone layers, with some fluvial sandstones and limestone pond deposits in between. This formation stretches into Wyoming and Utah, its characteristic purple and red colors make it instantly recognizable. About 400 feet thick, the Jurassic Morrison is loaded with dinosaur fossils. They've been quarried in well-known spots such as Wyoming's Como Bluff, Garden Park in Cañon City, and Dinosaur National Monument in Utah. At Dinosaur Ridge, along Alameda Parkway, visitors can see fossilized dinosaur bones and cross-sections of dinosaur footprints still in the rock. The very first *Apatosaurus* was described from this layer in 1877 by O. C. Marsh.

Ancient Environment:

Landscape: Monotonous flat landscape with lazy rivers

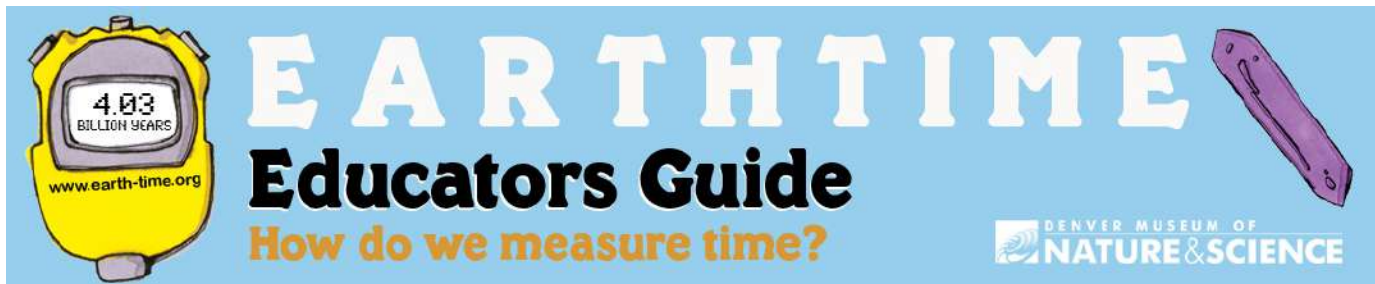
Plants: Ferns, conifers and cycads dominate the landscape

Animals: Large plant-eating dinosaurs such as sauropods, and meat-eating dinosaurs such as *Stegosaurus* and *Allosaurus*

What it looks like today:



© Kirk Johnson



Dakota Sandstone

Description of the rocks:

The best exposures of this sandstone formation are found along the Dakota Hogback, a ridge that runs for miles along the eastern front of the Rocky Mountains. The sandstone of this now-uplifted layer comes from the flat shore that was here 100 million years ago, during the Cretaceous, deposited just before the Western Interior Seaway covered the area. Ripple marks in this sandstone are evidence of the water's edge.

Ancient Environment:

Landscape: Beach

Plants: herbaceous ferns, broadleaf flowering trees, conifers

Animals: Dinosaurs such as *Iguanodon*, shrimp (known from burrows)

What it looks like today:



© Kirk Johnson



Pierre Shale

Description of the rocks:

This soft, dark grey rock was created by layers of marine mud that fell to the bottom of a shallow seaway, which split North America in half from North to South near the end of the Cretaceous period.

Ancient Environment:

Landscape: Saltwater sea, 600' deep.

Plants: (none fossilized)

Animals: Pterosaurs, mosasaurs, ammonites, Baculites, fish, giant clams

What it looks like today:



© Kirk Johnson



Fox Hills Sandstone

Description of the rocks:

These light colored, sandstone rocks mark the retreat (regression) of the interior seaway by preserving the beach. Few fossils are preserved in this sandy environment.

Ancient Environment:

Landscape: Beach along the retreating interior seaway

Plants: Ferns, conifers, broadleaf trees

Animals: *Ankylosaur*, turtles, crocodiles, shrimp (known from burrows)

What it looks like today:



© Kirk Johnson



Laramie Formation

Description of the rocks:

As the Western Interior Seaway continued to retreat, its western edge was characterized by vegetated coastal swamps of estuaries, which deposited in this yellowish to brown rock layer. Coal beds are frequently found in the lower part of this Cretaceous formation. About 200-400 feet thick in the middle of the Denver Basin, the Laramie is around 2100 feet below the surface. There is an unconformity between this formation and the one above it, the Arapahoe Conglomerate. This means that there is a period of time unaccounted for in the rock record.

Ancient Environment:

Landscape: Warm, swampy and fairly flat with closed-canopy forests

Plants: Palms, broadleaf trees, ferns

Animals: Dinosaurs such as *Triceratops* and *Tyrannosaurus rex*, crocodiles, early mammals

What it looks like today:



© Kirk Johnson



D1 (Arapahoe Conglomerate, Denver Formations, and Dawson Arkose)

Description of the rocks:

The Front Range, our local Rocky Mountains, arose at two times during the Laramide Orogeny. As the tops of these new mountains eventually began to erode, their sediments added more layers to the Denver Basin. These sediments never completely solidified, leaving layers that are much more like soil than they are like rock. From oldest to youngest, they are the Arapahoe Conglomerate, the Denver Formation, and part of the Dawson Arkose. About 2000 feet thick in the center of the Basin, these rocks include most of the aquifers supplying groundwater to the Denver metro area.

Ancient Environment:

Landscape: Very warm and wet (tropical), large forests grew along the base of the newly rising Rocky Mountains.

Plants: Broadleaf trees, ferns, cycads, palm, conifers and gingers.

Animals: Dinosaurs such as *Triceratops* and *Tyrannosaurus rex*, crocodiles, early mammals

What it looks like today:



© Kirk Johnson



K-T boundary

Description of the rocks:

The K-T boundary marks the global mass-extinction when the dinosaurs became extinct. It occurred when an asteroid crashed into the ocean near Mexico. Although this was not the largest mass-extinction that our Earth has experienced, it was the most recent. The K-T boundary occurred in the middle of the D1 formation and often appears as ~3 cm thick whitish clay between layers of coal or mudstone. This layer is hard to spot with your eye but can be measured in the lab because it contains a much higher concentration of iridium (a very rare element), shocked quartz (crystals that were blown into the air during the asteroid impact) and an increase in fern spores just above it.

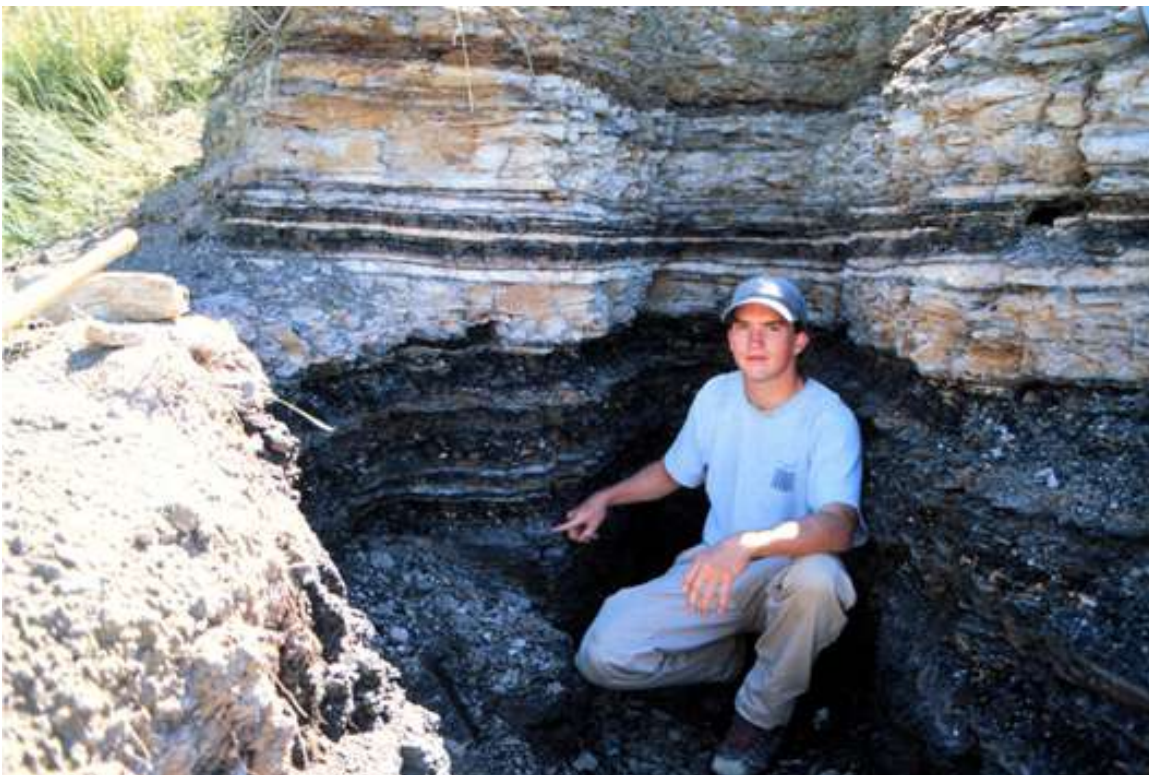
Ancient Environment:

Landscape: Fires burn much of the landscape, ferns are the first plants to come back

Plants: At least 30% of plants go extinct

Animals: All of the dinosaurs and ammonites go extinct at this point in time; turtles, crocodiles and small mammals survive

What it looks like today:



© Kirk Johnson



Denver Basin Paleosol

Description of the rocks:

Paleosol is the remains of a soil that formed beneath a tropical forest. This particular soil in the Denver Basin is a brilliant red, orange, and/or purplish clay layer at the base of the D2 sequence. On your map, it will look like a thin line. The original soil, similar to the rich red soils of modern Georgia and the Amazon Basin, was exposed and weathered for several million years. Averaging 20 feet thick, today the paleosol clay is mined for brick making.

Ancient Environment:

Landscape: Hot, dry, forested

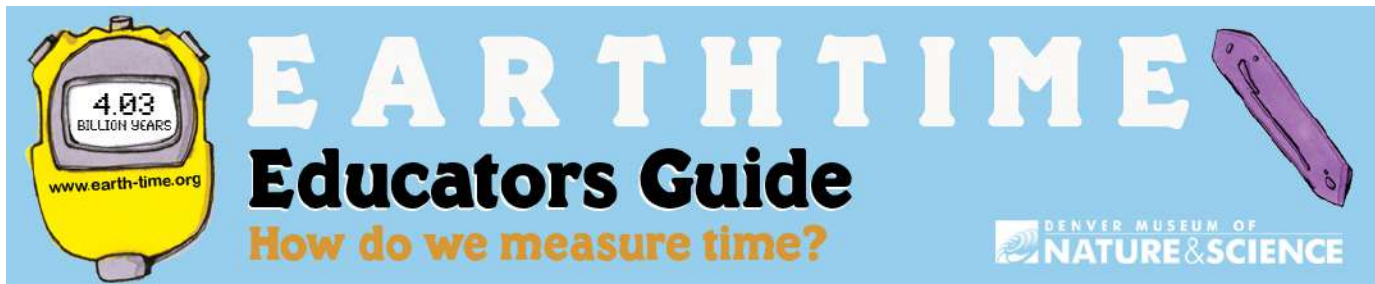
Plants: Forests of broadleaf trees

Animals: Mammals like *Coryphodon*, turtles, crocodiles

What it looks like today:



© Kirk Johnson



D2 (Dawson Arkose)

Description of the rocks:

The layer represented by the second phase of the Laramide uplift is called the D2 sequence and contains the upper part of the Dawson Arkose. This white sandstone is composed of pieces of Pikes Peak granite, deposited across the basin by rivers during the Eocene. Fossil leaves and petrified wood have been found in this layer. Mammal bones and teeth, better known from Eocene rocks in Wyoming and other places, are rare during this time in the Denver Basin. The D2 sequence can be several hundred feet thick and contains shallow groundwater aquifers. Ponderosa pines frequently grow on this material today, a good clue when you're looking for this layer.

Ancient Environment:

Landscape: Hot, dry, forested

Plants: Forests of broadleaf trees

Animals: Mammals like *Coryphodon*, turtles, crocodiles

What it looks like today:



© Kirk Johnson



Castle Rock Rhyolite

Description of the rocks:

This rock was formed when a volcano, located in the Rocky Mountains, erupted and spewed a cloud of superheated airborne rock into the air. This superheated ash cloud welded together as it blanketed the ground and killed everything that it covered. In some places, this rock is 20 feet thick and it is now used as building stone.

Ancient Environment:

Landscape: Hot, dry

Plants: (not fossilized)

Animals: Large mammals like *Brontotheres* and rhinoceroses

What it looks like today:



© Kirk Johnson



Castle Rock Conglomerate

Description of the rocks:

This rock is the remnant of a catastrophic flood that rushed down the canyons of Castle Rock Rhyolite. It contains angular, refrigerator-sized pieces of Castle Rock Rhyolite as well as the bones of large animals that were swept into its wake. Although this rock was once at the bottom of a river, it is now a high cap rock topping buttes in the town of Castle Rock.

Ancient Environment:

Landscape: Warm, dryer, still recovering from the volcanic event

Plants: Palm trees, broadleaf trees, giant Sequoias

Animals: Large mammals like *Titanotheres* and rhinoceroses

What it looks like today:



© Kirk Johnson



Quaternary Sediments

Description of the rocks:

Quaternary sediments are bits of dirt and rock that eroded from the Rocky Mountains over the past few hundred thousand years, but have not yet formed rocks. These bits of sediment often contain bones of animals that lived during the Ice Age and record the arrival of people to this part of the planet.

Ancient Environment:

Landscape: Seasonal, cool, mix of open prairies and woodlands

Plants: Grasses, conifers

Animals: Mammoths, mastodon, camels, lions, bison, cheetahs, giant ground sloths

What it looks like today:



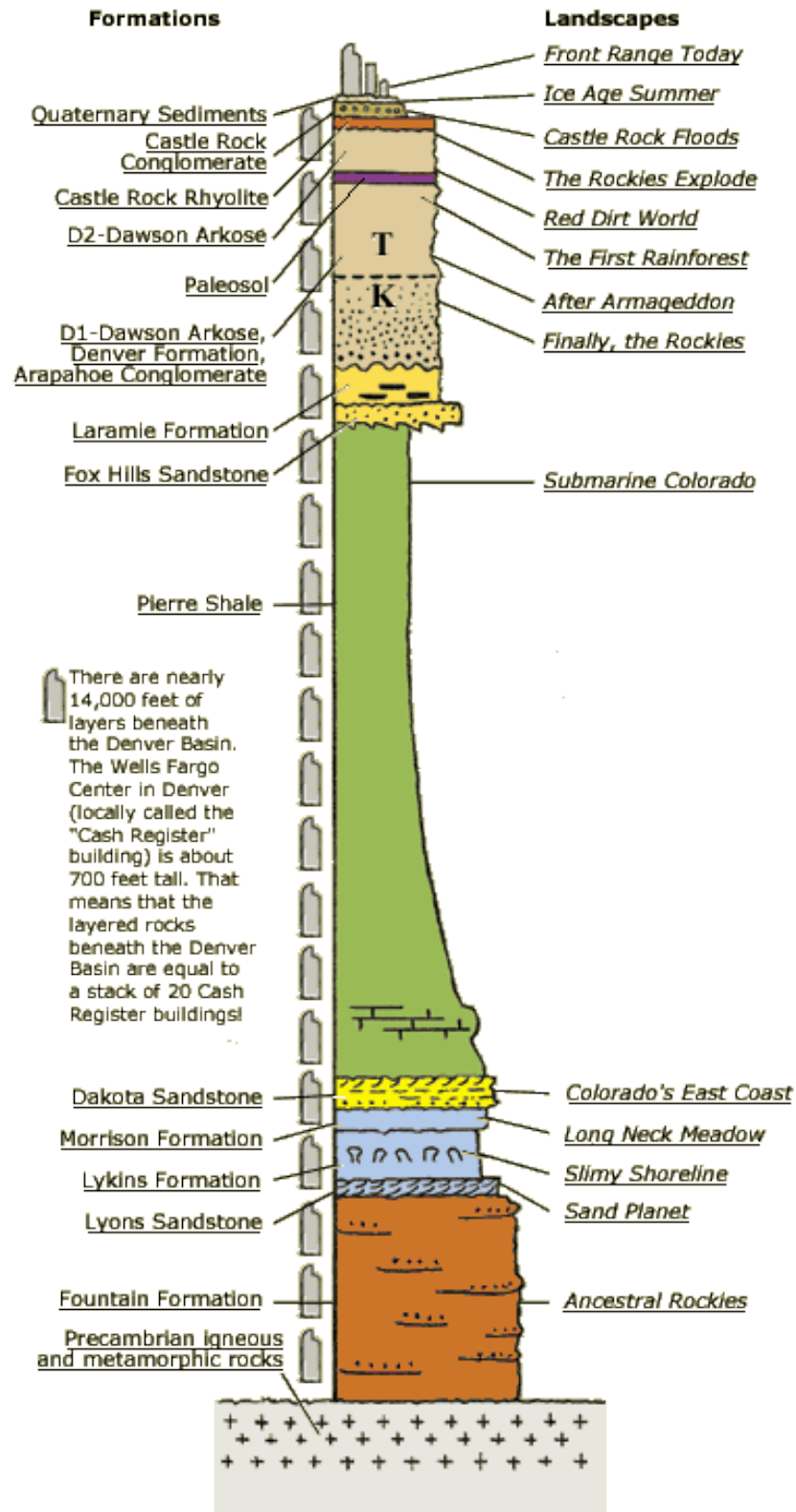
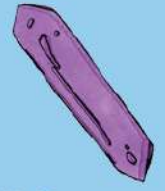
© Kirk Johnson



EARTH TIME

Educators Guide

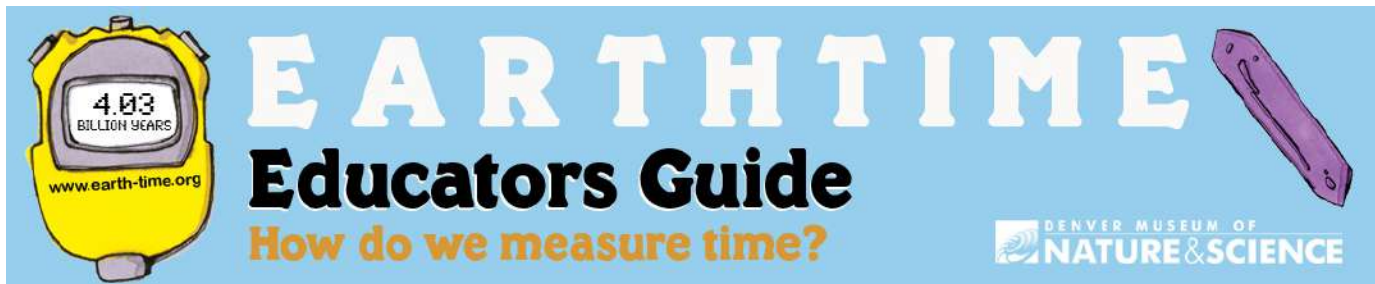
How do we measure time?





Data Card Answer Key

Field no	Data	Formation
1	Apatosaurus	Morrison
2	Ash layer	KD1
3	Lycopod tree trunk	Fountain
4	Ripple marks	Dakota
5	Roadcut	I 70 roadcut
6	Animal burrows	Fox Hills
7	<i>Triceratops</i>	KD1
8	<i>Triceratops</i>	Laramie
9	Ammonite	Pierre
10	Stromatolite	Lykins
11	Protomammal trackway	Lyons
12	Sauropod footprint	Jurassic
13	<i>T-rex</i> leg bone	KD1
14	Ash layer	Laramie
15	Giant palm leaf	TD1
16	Lion jaw bone	Quaternary sediments
17	<i>Ankylosaur</i> scute	Fox Hills
18	Shocked quartz and iridium	K-T boundary
19	Fossil leaves	Laramie
20	Fossil leaves	Laramie
21	<i>Hadrosaur</i> pelvis	KD1
22	<i>Mosasaur</i> tooth	Pierre
23	No data found	Fox Hills
24	Pterosaur bones	Pierre
25	Fossil leaves	TD1
26	Fossil leaves	KD1
27	Coryphodon tooth	D2
28	Ash layer	TD1
29	Mammoth tusk	Quaternary sediments
30	Ash layer	CR Rhyolite
31	<i>Titanotheres</i> bones	CR Conglomerate
32	Large variety of fossil leaves	TD1



Data Card Answer Key (cont.)

Field no	Data	Formation
33	Ammonite	Pierre
34	Fossil leaves	TD1
35	No data found	Pierre
36	No data found	Fox Hills
37	<i>Triceratops</i> skull	Laramie
38	<i>Inoceramus</i> clams	Pierre
39	Coal	Laramie
40	<i>Iguanodon</i> footprints	Fox Hills
41	Mammal jaw	TD1
42	Ash layer	Pierre
43	Fossil leaves	Laramie
44	Bison jaw	Quaternary sediments
45	Paleosol (fossil soil)	TD1
46	No data found	CR Rhyolite



Rock description: Mudstone, ranging in color from light green to purplish red

Data found: Large dinosaur bones from a sauropod



Rock description: Layers of dark coal with light colored stripes that contain volcanic ash.

Data found: The lab dates this ash to be 68.15 +/- 0.03 million years old using the Uranium-Lead technique.



Rock description: Coarse reddish rock with chunks of quartz and granite.

Data found: Trunk of a large *Sphenopsid* tree.



Rock description: Light brown sandstone

Data found: Ripple marks in the rock



Rock description: Bands of yellow, red and gray rocks tilt up out of the ground and are exposed in a roadcut.

Data found: Superposition of rock layers exposed at the surface



Rock description: White sandstone

Data found: Burrows of marine animals living in shallow water.



Rock description: Orange-brown sand and mudstone, poorly consolidated

Data found: *Triceratops* skull



Rock description: Orange-brown sand and mudstone, poorly consolidated

Data found: *Triceratops* skull



Rock description: Dark grey, brittle rock that looks like dirt on the surface. Thin layers peel off.

Data found: Ammonite



Rock description: Laminated pink and white sandstone.

Data found: Stromatolite (a mound of photosynthetic bacteria and algae)



Rock description: Reddish-orange colored sandstone.

Data found: Footprints of a protomammal.



Rock description: Mudstone with green, red and purplish colored stripes.

Data found: Footprint of a large sauropod.



Rock description: Mustard yellow to brown colored mudstone.

Data found: *T-rex* leg bone.



Rock description: Mudstone with some coal and ash.

Data found: The lab dated the ash and got an age of 68.10 +/- 0.04 million years.



Rock description: Thick coal seam with ashes running through it in layers.

Data found: Giant palm leaves. The lab dated the ash and found it to be 65.49 +/- 0.6 million years old.



Rock description: Unconsolidated soil

Data found: Lion jaw bone



Rock description: White sandstone

Data found: *Ankylosaur* scutes



Rock description: Coal seam with a layer of white ash running through the middle.

Data found: The ash contained shocked quartz and an increased amount of iridium.



Rock description: Brown mudstone

Data found: Fossil leaves



Rock description: Brown mudstone

Data found: Fossil leaves from a broadleaf tree



Rock description: Brown sandstone

Data found: Hadrosaur pelvis



Rock description: Dark grey, shale

Data found: *Mosasaur* tooth



Rock description: White sandstone

Data found: No data found



Rock description: Dark grey, crumbly rock

Data found: Pterosaur bones



Rock description: Light brown mudstone

Data found: Fossil leaf



Rock description: Light brown mudstone

Data found: Fossil leaf



Rock description: White sandstone

Data found: Coryphodon tooth



Rock description: Mustard brown rock with a sand channel running through it and some possible volcanic ash.

Data found: The lab dated the rock to be 64.8 +/- 0.1 million years old.



Rock description: Unconsolidated sand

Data found: Mammoth tusk



Rock description: Pink, welded volcanic tuff

Data found: The lab dated this to be 36.7 +/- .1 million years old.



Rock description: Conglomerate of cobbles containing some large chunks of welded tuff.

Data found: Titanotherium bones



Rock description: Brown mudstone and siltstone

Data found: Large variety of well preserved fossil leaves



Rock description: Dark shale

Data found: Ammonite



Rock description: Brown mudstone

Data found: Fossil leaves



Rock description: Dark grey shale like rock

Data found: No data found



Rock description: Light cream colored sandstone

Data found: No data found



Rock description: Brown mudstone

Data found: *Triceratops* skull



Rock description: Dark grey siltstone that breaks into thin pieces

Data found: Fossil *Inoceramus* clams



Rock description: Layers of mudstone and black rock

Data found: Coal



Rock description: White sandstone

Data found: Iguanodon footprints



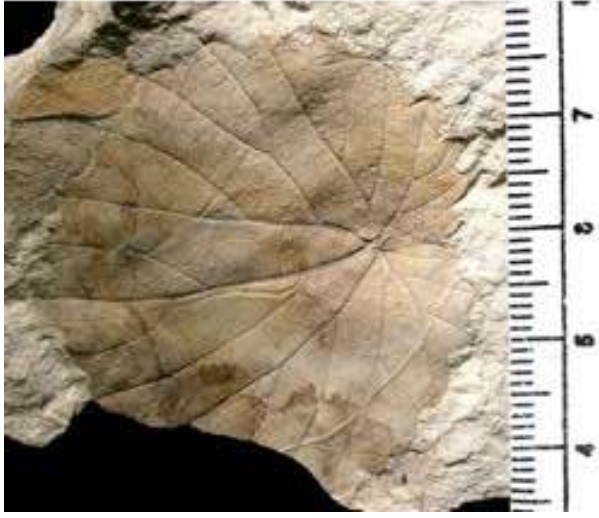
Rock description: Brown mudstone and siltstone

Data found: Mammal jaw



Rock description: Dark grey shale, crumbly to the touch, some volcanic ash evident

Data found: The lab dated the ash and found it to be 72.5 +/- .1 million years old.



Rock description: Brown mudstone

Data found: Fossil leaf



Rock description: Unconsolidated dirt

Data found: Bison jaw



Rock description: Stripe of bright red rock, about ten feet thick

Data found: Fossil soil



Rock description: Rock description: whitish, welded volcanic rock

Data found: No data found



Optional Activity

Teacher Key to Ancient Environments

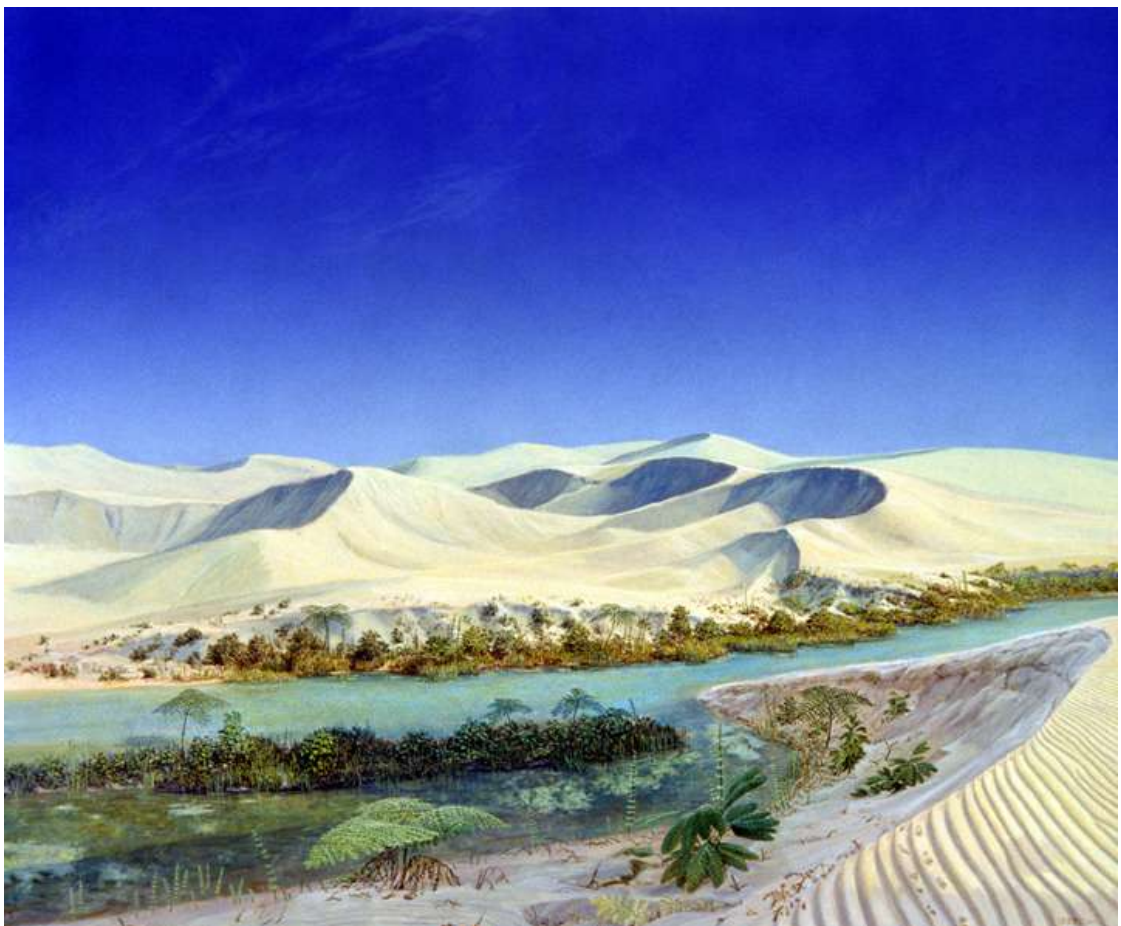
Picture #	Picture Title	Formation Cards	Age
1	Ancestral Rockies	Fountain	300 mya
2	Sand Planet	Lyons	280 mya
3	Slimy Shoreline	Lykins	250 mya
4	Stegosaurus Snacks	Morrison	170 mya
5	Long Neck Meadow	Morrison	150 mya
6	Colorado's East Coast	Dakota Sandstone	100 mya
7	Submarine Colorado	Pierre Shale	70 mya
8	<i>Triceratops</i> Swamp	Pierre Shale	68 mya
9	Finally the Rockies	D1	66 mya
10	After Armegeddon 1	D1	65.4 mya
11	After Armegeddon 2	D1	65 mya
12	The First Rainforest	D1	64 mya
13	Red Dirt World	D2	55 mya
14	The Rockies Explode	Castle Rock Rhyolite	37 mya
15	Castle Rock Floods	Castle Rock Conglomerate	34 mya
16	Ghost Predator	Quaternary Sediments	16 kya
17	Ice Age Summer	Quaternary Sediments	12 kya
18	Front Range Today	Quaternary Sediments	Present Day

mya = Million Years Ago

kya = Thousand Years Ago



1



2



3



4



5



6



7



8



9



10



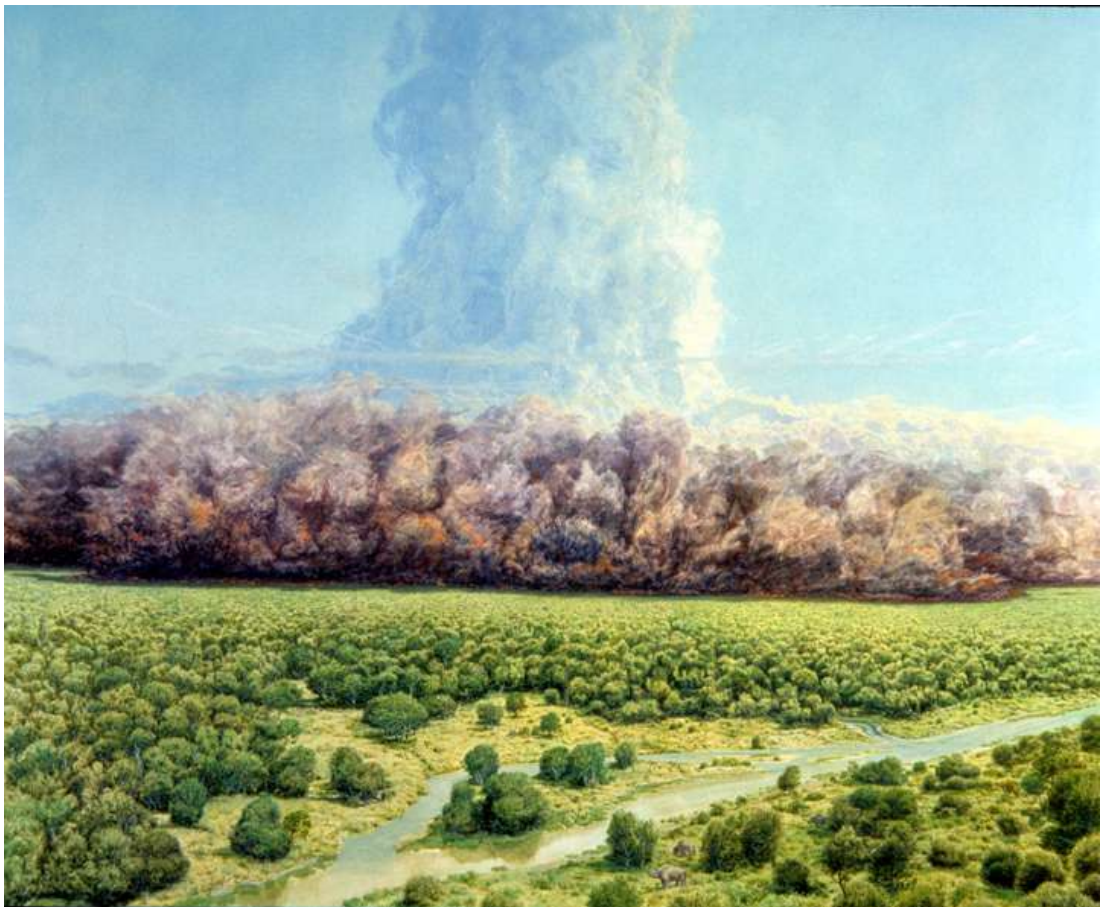
11



12



13



14



15



16



17



18



EARTHTIME

Educators Guide

How do we measure time?



DENVER MUSEUM OF
NATURE & SCIENCE

5E MODEL

Evaluate

GRADE LEVEL

High School

NSES STANDARDS

A, D

PREPARATION

Estimated Preparation: 15 minutes

Estimated Activity: 15 minutes

EarthTime Assessment

Learning Goals/Objectives

To assess student understanding of radioactive decay dating and absolute time

To assess student understanding of how scientists measure the age of the Earth

Activity Overview

A short quiz is provided to further assess student understanding of Earth time. The quiz consists of constructed response and selected response items. It can be used as a pre- and post-quiz.

Teacher Background

This short quiz can be used as a summative assessment. Items have been developed similar to the types of items used on many of the standardized state science assessments.

Advance Preparation

EarthTime Quiz – 1 copy per student

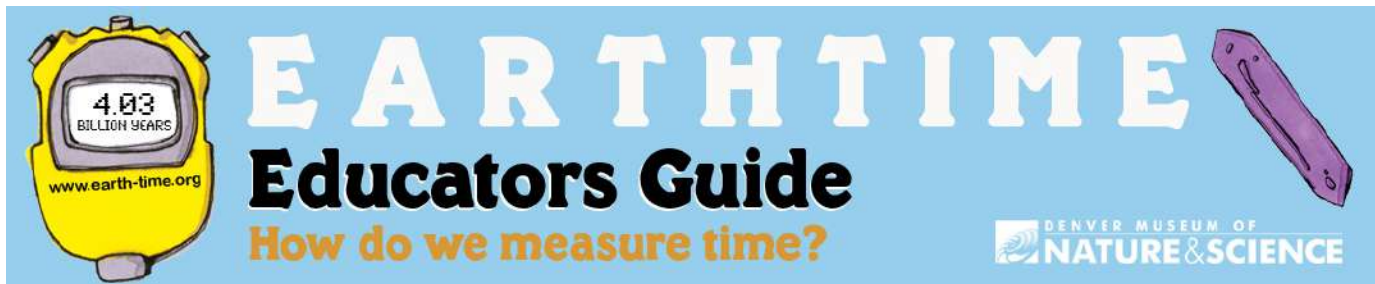
Classroom Activity

1. Students complete the quiz applying knowledge from previous activities.
2. Discuss answers to the quiz after collecting papers.
3. See Teacher Key

Resources

Lewis, G. B. & McLelland, C.V. (2003). *Explore Deep Time: An Introduction to Deep Time*. Boulder: The Geological Society of America.

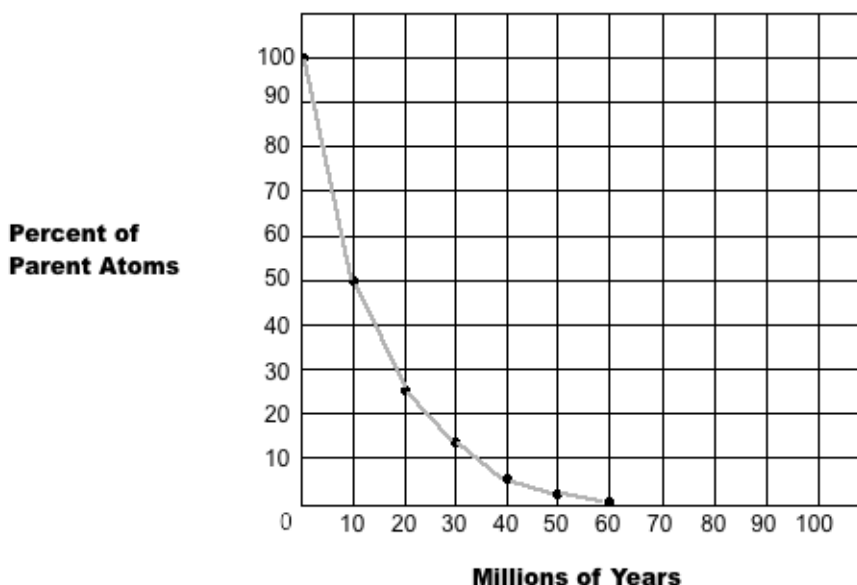
University Of Colorado. (2000). Physics 2000 Science Trek. Retrieved September, 2007, from http://www.colorado.edu/physics/2000/isotopes/radioactive_decay3.html



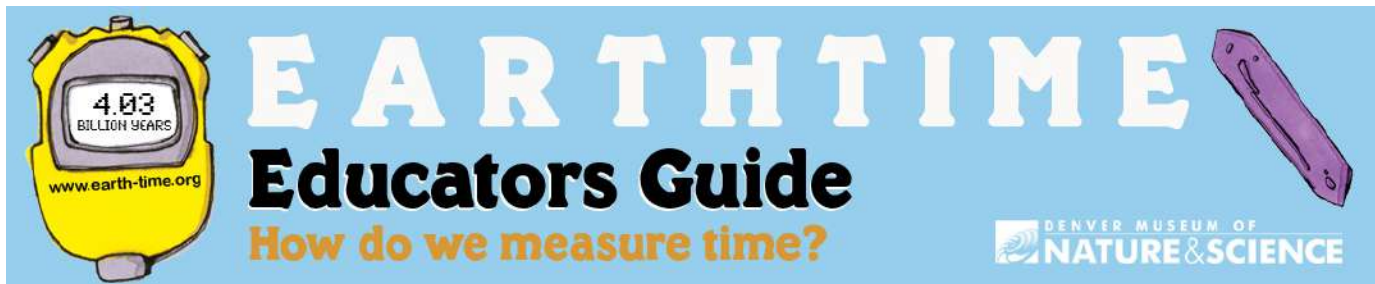
Name _____ Date _____
 High School Earth-Time Assessment

Use the radioactive decay curve and chart to answer questions 1-8.

Radioactive Decay Rate

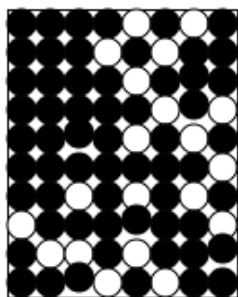


Percent of Parent Atoms Remaining	Half-Lives
100%	0
50%	1
25%	2
12.5%	3
6.25%	4
3.125%	5
1.5625%	6



Diagrams A, B, and C are volcanic mineral samples representing 80 atoms. The light circles are unstable parent atoms. The dark circles are stable daughter atoms.

Sample A *Remember: Number of parent atoms/Parent + daughter atoms
X 100 = Percent of atoms remaining*

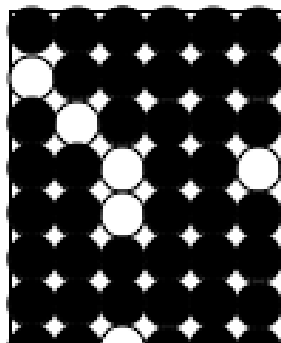


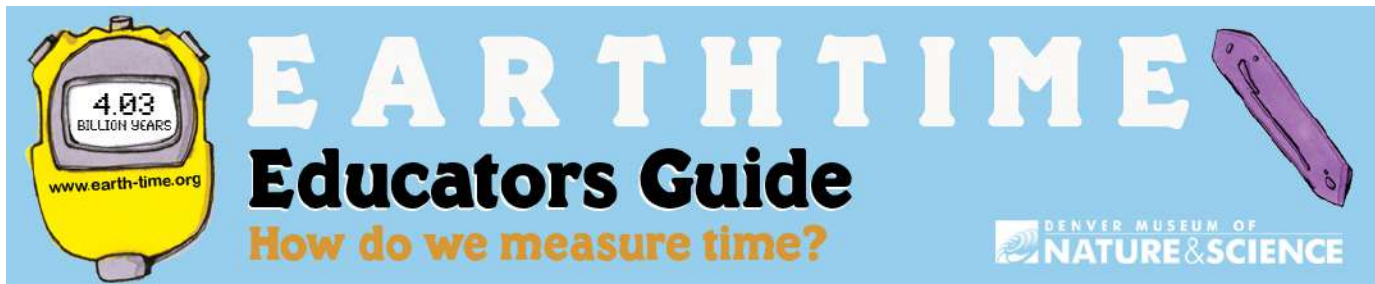
1. Using the decay curve, how many half-lives have occurred?
 - a. 1
 - b. 2
 - c. 3
 - d. 4

2. Use the decay curve to determine the age of the sample. How old is the sample?
 - a. 10 million years
 - b. 20 million years
 - c. 30 million years
 - d. 40 million years

Use the diagram below to answer questions 3-5.

Sample B





3. What is the percentage of parent atoms that has not yet changed?

- a. 6.25%
- b. 12.5%
- c. 25%
- d. 50%

4. How many half-lives has Sample B undergone?

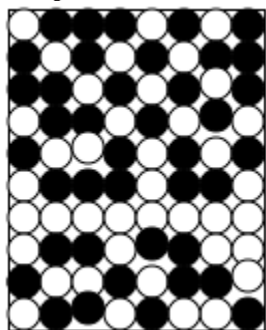
- a. 1
- b. 2
- c. 3
- d. 4

5. How old is Sample B?

- a. 20 million years old
- b. 30 million years old
- c. 40 million years old
- d. 50 million years old

Use the diagram below to answer questions 6-8.

Sample C

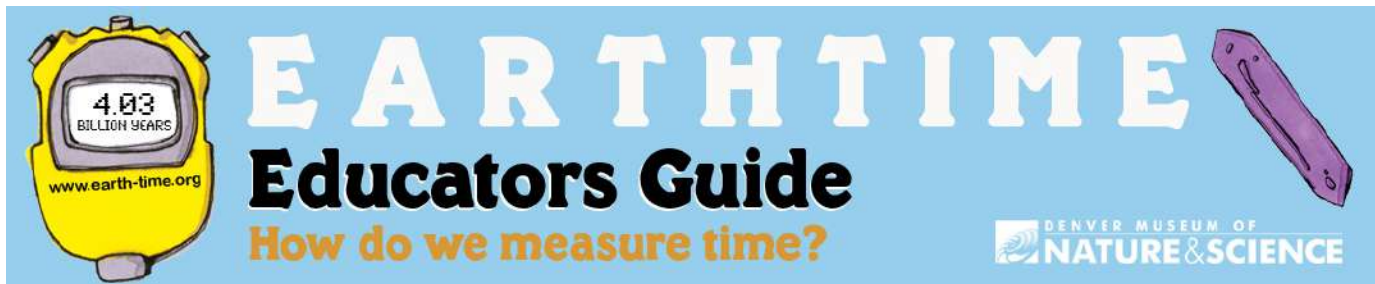


6. How many half-lives has Sample C undergone?

- a. 1
- b. 2
- c. 3
- d. 4

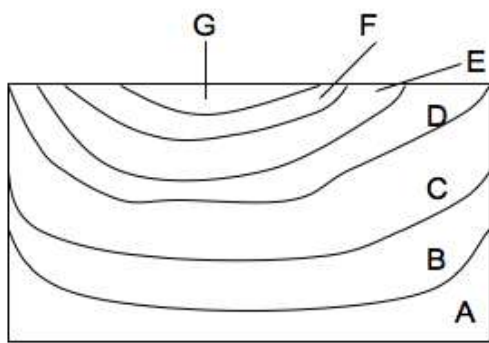
7. What is the percentage of daughter atoms in the sample?

- a. 6.25%
- b. 12.5%
- c. 25%
- d. 50%

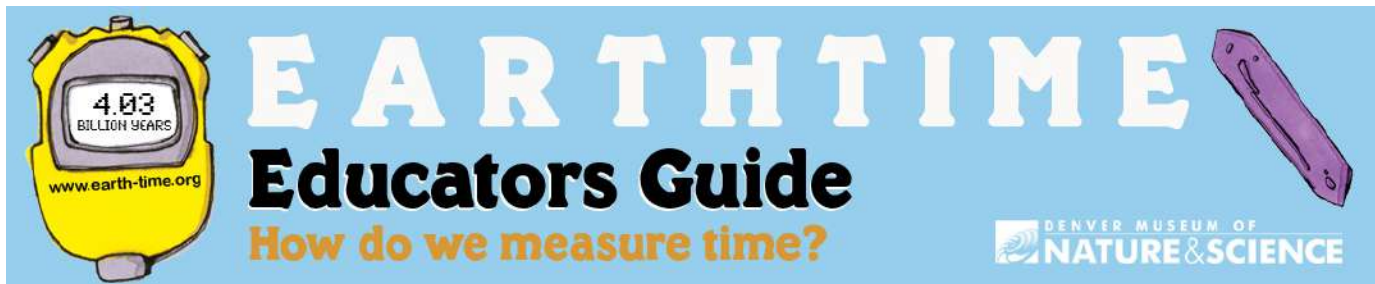


8. How old is Sample C?
- 10 million years old
 - 20 million years old
 - 30 million years old
 - 40 million years old

Below is a diagram of a geologic basin.



9. According to the diagram, which formation is the oldest?
- A
 - C
 - E
 - G
10. According to the diagram, which formation is the youngest?
- A
 - C
 - E
 - G
11. If a volcanic ash layer at the top of Formation C is 55 million years old and ash from a layer at the bottom of Formation E is 35 million years old, what would be the age range of Formation D?
- 45 to 65 million years old
 - 44 to 54 million years old
 - 36 to 54 million years old
 - 35 to 65 million years old

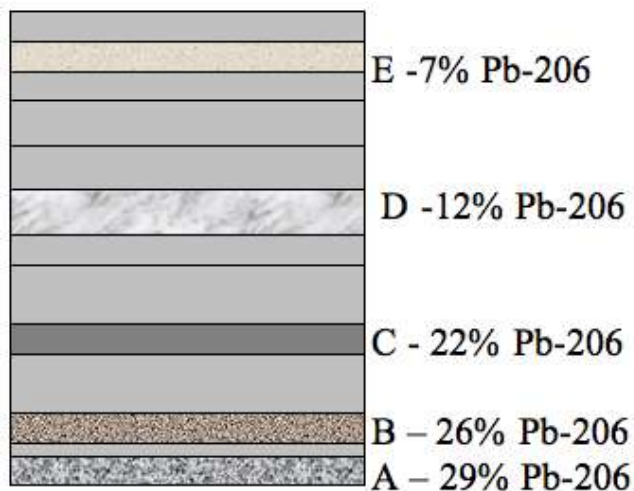


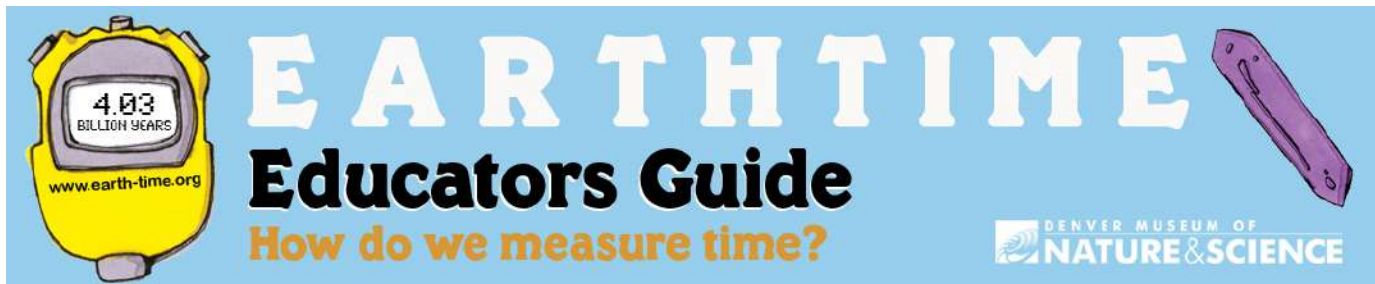
12. The absolute age of Formation F has not been determined. From the diagram, what can you determine about its age?

13. How do the radiometric dates of rock layers help you understand this geologic basin diagram?

14. At a site in the Denver, there were 5 different volcanic layers of rock that were able to be dated in the EarthTime lab. The percentages of Lead-206 found in the samples are listed below.

15. What do these percentages of daughter atoms in the volcanic layers tell us about this outcrop at this site?

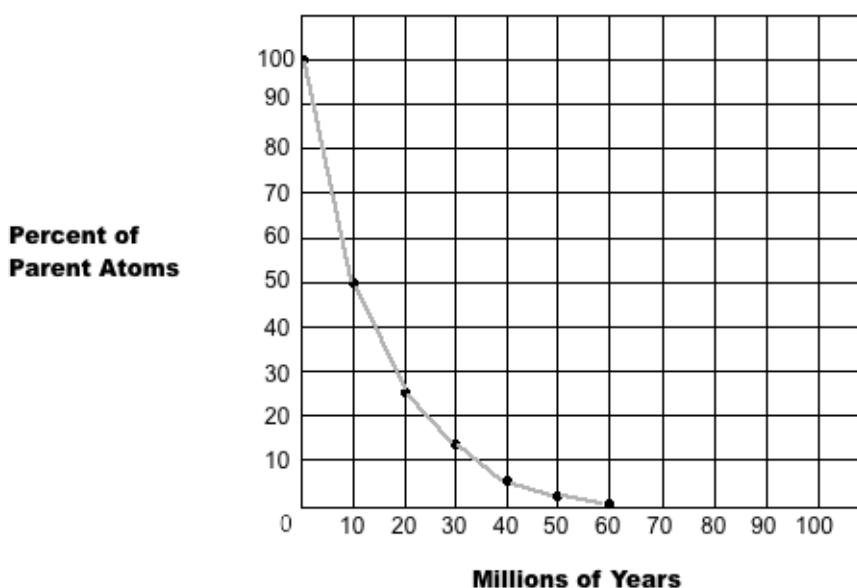




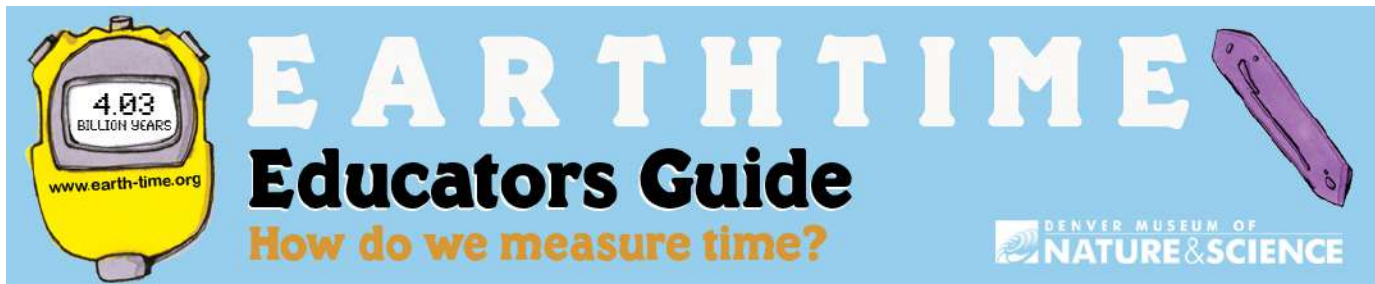
Name _____ **TEACHER KEY** _____ Date _____
High School Earth-Time Assessment

Use the radioactive decay curve and chart to answer questions 1-8.

Radioactive Decay Rate

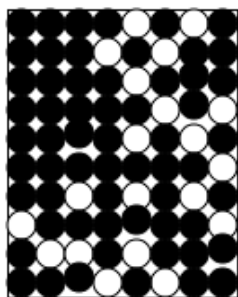


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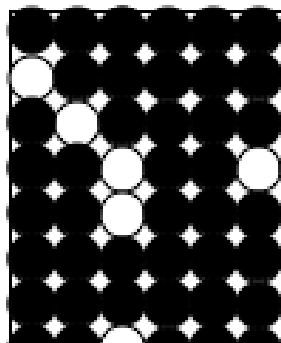


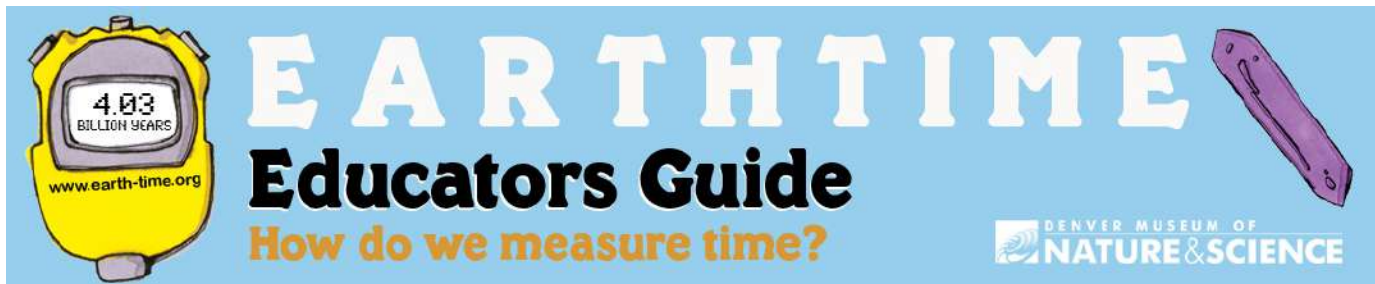
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 - a. 1
 - b. 2***
 - c. 3
 - d. 4

2. Use the decay curve to determine the age of the sample. How old is the sample?
 - a. 10 million years
 - b. 20 million years***
 - c. 30 million years
 - d. 40 million years

Use the diagram below to answer questions 3-5.

Sample B





3. What is the percentage of parent atoms that has not yet changed?

- a. 6.25%
- b. 12.5%***
- c. 25%
- d. 50%

4. How many half-lives has Sample B undergone?

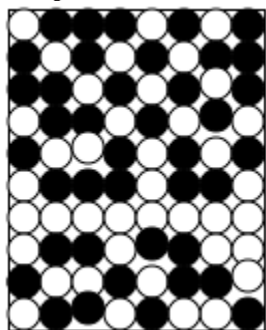
- a. 1
- b. 2
- c. 3***
- d. 4

5. How old is Sample B?

- a. 20 million years old
- b. 30 million years old***
- c. 40 million years old
- d. 50 million years old

Use the diagram below to answer questions 6-8.

Sample C



6. How many half-lives has Sample C undergone?

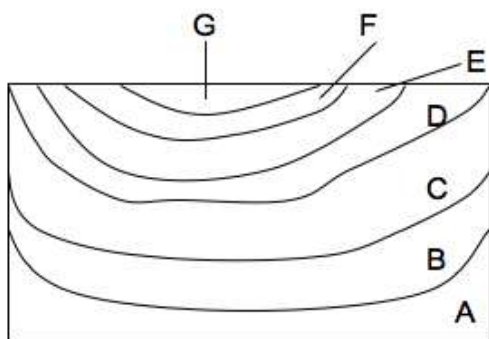
- a. 1***
- b. 2
- c. 3
- d. 4

7. What is the percentage of daughter atoms in the sample?

- a. 6.25%
- b. 12.5%
- c. 25%
- d. 50%***

8. How old is Sample C?
- 10 million years old***
 - 20 million years old
 - 30 million years old
 - 40 million years old

Below is a diagram of a geologic basin.



9. According to the diagram, which formation is the oldest?
- A***
 - C
 - E
 - G
10. According to the diagram, which formation is the youngest?
- A
 - C
 - E
 - G***
11. If a volcanic ash layer at the top of Formation C is 55 million years old and ash from a layer at the bottom of Formation E is 35 million years old, what would be the age range of Formation D?
- 45 to 65 million years old
 - 44 to 54 million years old
 - 36 to 54 million years old***
 - 35 to 65 million years old



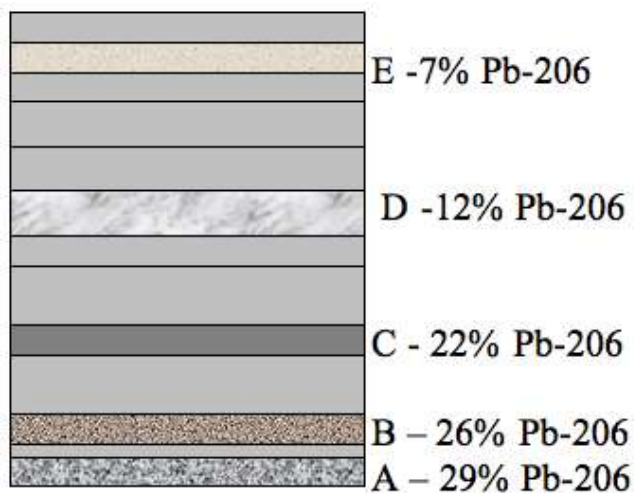
12. The absolute age of Formation F has not been determined. From the diagram, what can you determine about its age?

It should be younger than 35 million years because the sediment is on top of Formation E.

13. How do the radiometric dates of rock layers help you understand this geologic basin diagram?

It adds more than the order of deposition, it provides a numerical times to when the layers were deposited.

14. At a site in the Denver, there were 5 different volcanic layers of rock that were able to be dated in the EarthTime lab. The percentages of Lead-206 found in the samples are listed below.



What do these percentages of daughter atoms in the volcanic layers of tell us about this outcrop at this site?

The oldest layers are at the bottom and the youngest layers are at the top of the outcrop.