ScienceNews

EDUCATOR GUIDE

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January 16, 2021

Shaking Up Earth

SOCIETY FOR SCIENCE

SN EDUCATOR GUIDE

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About this Guide

In this Guide, based on the online *Science News* article "How the Earth-shaking theory of plate tectonics was born," students will learn about the development of the theory of plate tectonics and discuss how scientific theories are formed.

This Guide includes:

Article-based Comprehension Q&A — Students will answer questions about the online *Science News* article "How the Earth-shaking theory of plate tectonics was born," which explores how scientists formed the theory of plate tectonics. A version of the story, "Shaking up Earth," can be found in the January 16, 2021 issue of *Science News*. Related standards include NGSS-DCI: HS-ESS2; HS-ETS1.

> **Student Comprehension Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

Cross-curricular Discussion Q&A — Students will discuss the development of the theory of plate tectonics to determine how scientific theories are created. Related standards include NGSS-DCI: HS-ESS2; HS-ETS1.

> **Student Discussion Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

Activity: Get to know your local geology

> **Summary:** Students will work in groups to research the geology of their region or state and will analyze geologic maps to determine how the data displayed in the map reveal the area's geologic and tectonic history. Related standards include NGSS-DCI: HS-ESS1, HS-ESS2.
>
> **Approximate class time:** 2 class periods

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Article-based Comprehension, Q&A

Directions for teachers: Ask your students to read the online *Science News* article "How the Earth-shaking theory of plate tectonics was born," which recounts how plate tectonics became a unifying theory in earth science, and answer the following questions. This story is the first installment of a series that celebrates *Science News*' upcoming 100th anniversary by highlighting some of the biggest advances in science over the last century. A version of the story, "Shaking up Earth," can be found in the January 16, 2021 issue of *Science News*. Please note that the questions do not cover the "Crucible of life" sidebar. For more on plate tectonics, and to see the rest of the series as it appears, visit *Science News*' Century of Science site at www.sciencenews.org/century.

1. What is the theory of plate tectonics? Explain it.

Plate tectonics describes how Earth's outermost layer, called the lithosphere, is broken into rock slabs (or plates) that float on an inner layer of hot churning fluid. Over eons, the plates collide, diverge and grind past one another to create features such as volcanoes, earthquakes, ocean basins and mountains.

2. Why does the article compare the theory of plate tectonics to Albert Einstein's general theory of relativity?

Just as Einstein's general theory of relativity upended our understanding of the universe, plate tectonics revolutionized our understanding of the Earth.

3. What early idea set the stage for plate tectonics? When was this idea proposed and what did it attempt to explain?

In 1912, a German meteorologist proposed that Earth's continents were on the move — an idea that is now known as continental drift. This idea holds that colliding continents are responsible for geologic formations such as mountains and that at one time, the continents were joined together as one supercontinent dubbed Pangaea. Continental drift would explain why fossils of the same organisms and rocks of the same type and age are found on either side of the Atlantic Ocean.

4. How did continental drift challenge accepted views of Earth? How was the idea initially viewed by other scientists?

Scientists at the time thought the Earth's crust was rigid and locked in place — a principle called uniformitarianism — and that mountains sprung up as the crust slowly cooled and contracted after its formation. While some scientists found continental drift intriguing, many geologists were skeptical of the idea.

5. What were critics' main arguments against continental drift?

Critics argued that continental drift contradicted uniformitarianism (which held that Earth's continents must be immovable), that the idea couldn't explain how the continents move and that it was a collection of unrelated observations not supported by data.

6. What explanation did English geologist Arthur Holmes come up with for how the continents might move? How did the geology community react to this explanation?

Holmes suggested that the continents might float like rafts atop a layer of thick, partially molten rocks deep inside Earth. Holmes admitted that he lacked data to back up his suggestion, and continental drift was largely shelved by the geology community for decades.

7. What scientific advances helped revive the idea of continental drift beginning in the 1950s? What historical event contributed to these advances?

Sonar mapping developed during World War II revealed the extent of a rift in the ocean floor. Magnetometers revealed alternating stripes of magnetic polarity in seafloor rocks, suggesting each of the stripes formed at different times. A global network of seismograph stations led scientists to discover and measure earthquakes along mid-ocean ridges and beneath trenches. And steel probes inserted into cores drilled into the seafloor revealed that the ridges were much hotter than the surrounding seafloor.

8. What is "seafloor spreading" and how does it connect to continental drift?

Circulating hot rock within the Earth pushes to the surface and forces apart areas of lithosphere. As the lava burbles up between, new seafloor is made. Mid-ocean ridges are where new seafloor is born and deep ocean trenches are where old lithosphere is reabsorbed into Earth's interior. This cycle is responsible for the growing and shrinking of the seafloor that brings continents together and splits them apart.

9. What sets the unified theory of plate tectonics apart from the idea of continental drift?

Plate tectonics says not only that continents drift, but also explains how and why they drift and connects the details of what is known to be happening within the Earth to the details of lithospheric movement and the features visible on Earth's surface.

10. How have people benefited from the understanding of plate tectonics?

Understanding how Earth recycles its crust has allowed people to better prepare for earthquakes, tsunamis and volcanoes. It has also shaped scientific research that has led to insights about Earth's climate and the evolution of life on the planet.

11. What questions do scientists still have about plate tectonics?

Why is Earth the only place in the solar system that seems to have plate tectonics, when and how did plate tectonics begin and when might it end?

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Student Comprehension Worksheet

Directions: Read the online *Science News* article "How the Earth-shaking theory of plate tectonics was born," which recounts how plate tectonics became a unifying theory in earth science, and answer the following questions. A version of the story, "Shaking up Earth," can be found in the January 16, 2021 issue of *Science News*. Please note that the questions do not cover the "Crucible of life" sidebar. For more on the story of plate tectonics, and to explore other big science advances over the last 100 years, visit *Science News*' Century of Science site at www.sciencenews.org/century.

1. What is the theory of plate tectonics? Explain it.

2. Why does the article compare the theory of plate tectonics to Albert Einstein's general theory of relativity?

3. What early idea set the stage for plate tectonics? When was this idea proposed and what did it attempt to explain?

4. How did continental drift challenge accepted views of Earth? How was the idea initially viewed by other scientists?

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Cross-curricular Discussion, Q&A

Directions for teachers:

Use the online *Science News* article "How the Earth-shaking theory of plate tectonics was born," and the prompts below to have students explore scientific theories and determine the process behind creating theories. A version of the story, "Shaking up Earth," appears in the January 16, 2021 issue of *Science News*. As a final exercise, have students discuss the definition of a scientific theory and compare it with hypotheses and scientific laws.

This story is the first installment in a series that celebrates *Science News*' upcoming 100th anniversary by highlighting some of the biggest advancements in science over the last century. For more on the story of plate tectonics, and to see the rest of series as it appears, visit *Science News*' Century of Science site at www.sciencenews.org/century.

Want to make it a virtual lesson? Post the online *Science News* article "How the Earth-shaking theory of plate tectonics was born," to your learning management system. Pair up students and allow them to connect via virtual breakout rooms in a video conference, over the phone, in a shared document or using another chat system. Have each pair submit its answers to the second set of questions to you.

Thinking about theories

Discuss the following questions with a partner before reading the *Science News* article.

1. What does it mean to say that you have a theory about something? Think of a theory you've had about something outside of science.

Typically, when people say that they have theory, it means that they have an idea or philosophy. Student examples of theories will vary.

2. What is one scientific theory you have learned about this year in science? Explain what you remember about it.

Student answers will vary, but may include the general theory of relativity, evolution, etc.

3. How does the general use of the term theory differ from its use in a scientific context?

Theories in science are explanations rooted in data. Having a theory outside of the scientific context may be based on observations or data, or the term may be used to state a logical idea.

The theory of plate tectonics

Read the online *Science News* article "How plate tectonics upended our understanding of Earth," and answer the following questions individually before discussing them as a class.

1. What is the theory of plate tectonics? Over how many years was it developed?

The theory of plate tectonics states that the Earth's surface is broken up into various pieces (plates) and describes how and why they are constantly in motion and how that motion is linked to features seen on Earth. The theory was developed over about 50 years.

2. Who helped develop the theory and what did they contribute to it? What types of scientists were they and where were they from?

Meteorologist Alfred Wegner proposed the idea of continental drift in 1912, and geologist Arthur Holmes added to that proposal years later with an explanation for how the continents might drift. These ideas were the precursors to the development of the theory of plate tectonics. From there, seismologists, geophysicists, mathematicians and physicists established the ideas, such as seafloor spreading, and found the data necessary to develop the theory. Notable scientists include Lynn Sykes, Harry Hess, Robert S. Dietz, Robert Parker, W. Jason Morgan and Dan McKenzie. The researchers were from England and the United States.

3. Before the theory's development, what were the conflicting lines of thought?

Wegner's proposal sparked debates between mobilists, who supported the idea that the Earth's surface was in motion, and fixists, who thought the Earth's surface was static.

4. What did scientists need to resolve the conflict? Why did the conflict take so long to resolve?

In order to resolve the debate, scientists needed evidence. Wegner made his proposal in the early 1900s, but scientific evidence for why the continents move and how didn't become available until after World War II, when technological advancements allowed scientists to study Earth's surface and interior, and particularly the bottom of the oceans, in unprecedented detail.

5. How was evidence communicated to other members of the scientific community? Why was the communication important?

Evidence was communicated at conferences attended by scientists including geologists and geophysicists. By building on each other's ideas and using each other's data, the scientists were able to go beyond the idea of continental drift and come up with the unified theory of plate tectonics.

Defining a scientific theory

Discuss the following questions with a classmate.

1. Based on your answers to the questions above, how would you define a scientific theory?

A scientific theory is an explanation for how and why a natural phenomenon occurs based on evidence.

2. Think about a scientific hypothesis that you have written or look up an example of a hypothesis. How would you define a hypothesis? How is it different than a theory?

A hypothesis is a proposed explanation for a scientific question that hasn't been validated with evidence. A theory relies on evidence to explain phenomena, whereas a hypothesis is proposed before the gathering of evidence. A hypothesis can become a theory once it is proven or disproven with supporting evidence.

Possible Extension

What is a scientific law that you have learned about in school? Explain how a scientific law is different than a scientific theory. For more information, watch this Ted-Ed video called "What's the difference between a scientific law and a theory?" by educator Matt Anticole.

Student answers will vary, but could include Newton's three laws of motion, Bernoulli's principle, etc. A scientific law is different than a scientific theory in that it describes and predicts the relationships among variables, whereas a scientific theory describes how or why something happens.

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Student Discussion Worksheet

Directions: Discuss and answer the following questions about the online *Science News* article "How the Earth-shaking theory of plate tectonics was born." A version of the story, "Shaking up Earth," appears in the January 16, 2021 issue of *Science News*. For more on the story of plate tectonics and other big advancements in science over the last 100 years, visit *Science News*' Century of Science site at www.sciencenews.org/century.

Thinking about theories

Discuss the following questions with a partner before reading the *Science News* article.

1. What does it mean to say that you have a theory about something? Think of a theory you've had about something outside of science.

2. What is one scientific theory you have learned about this year in science? Explain what you remember about it.

3. How does the general use of the term theory differ from its use in a scientific context?

The theory of plate tectonics

Read the online *Science News* article "How plate tectonics upended our understanding of Earth," and answer the following questions individually before discussing them as a class.

1. What is the theory of plate tectonics? Over how many years was it developed?

2. Who helped develop the theory and what did they contribute to it? What types of scientists were they and where were they from?

3. Before the theory's development, what were the conflicting lines of thought?

4. What did scientists need to resolve the conflict? Why did the conflict take so long to resolve?

5. How was evidence communicated to other members of the scientific community? Why was the communication important?

Defining a scientific theory

Discuss the following questions with a classmate.

1. Based on your answers to the questions above, how would you define a scientific theory?

2. Think about a scientific hypothesis that you have written or look up an example of a hypothesis. How would you define a hypothesis? How is it different than a theory?

Possible Extension

What is a scientific law that you have learned about in school? Explain how a scientific law is different than a scientific theory. For more information, watch this Ted-Ed video called "What's the difference between a scientific law and a theory?" by educator Matt Anticole.

Shaking Up Earth

Activity Guide for Teachers: Get to Know Your Local Geology

Purpose: Students will work in groups to research the geology of their region or state and will analyze geologic maps to determine how the data displayed in the map reveal the area's geologic and tectonic history. Then, students will discuss how the data were gathered and how the maps were constructed from that data. The groups will plan an investigation to gather data and integrate it into their state's geologic map to answer questions they have after their initial study of the map.

Procedural overview: After reading the online *Science News* article "How the Earth-shaking theory of plate tectonics was born," students will discuss how new technologies and scientific understandings contributed to the development of the theory of plate tectonics. A version of the article, "Shaking up Earth," appears in the January 16, 2021 issue of *Science News*.

Students will then work in groups to locate and analyze geologic maps that describe their state or region's geologic and tectonic history. The class will discuss how geologic data are gathered and used to construct geologic maps. and then the groups will plan an investigation to gather additional geologic data to integrate into their state's geologic map. This activity can be delivered virtually; details are provided in the activity.

Approximate class time: 2 class periods

Supplies:
Paper
Pencils
Teacher background sheet
Student worksheet
Computer with internet access
Interactive meeting and screen-sharing applications for virtual learning (optional)
Audio or video capture and editing hardware and software (optional)

Directions for teachers:
For this to be a successful activity, students will need to understand how to read geologic and topographic maps. If you need to review the subject before teaching, read the How to Read a Geologic Map background sheet.

The setup
Review the teacher background sheet "How to Read a Geologic Map" and study any geologic maps that you plan to assign to your students. You can choose maps from your region or state, or you can choose maps from a part of the United States you consider geologically interesting or that has been significantly shaped by plate tectonics.

Assign students the online *Science News* article "How the Earth-shaking theory of plate tectonics was born" to read as homework before the class period in which the first part of this activity will be conducted. As part of their homework assignment, instruct students to answer the following questions.

1. Summarize Alfred Wegener's original concept of continental drift.

Wegener proposed that Earth's landmasses might be moving and that mountains form when continents collide as they drift across the planet's surface. He suggested that all of today's continents were once joined as a single landmass that he called Pangaea and that continents slowly drift across Earth's surface.

2. Identify three reasons why geologists objected to Wegener's continental drift hypothesis.

Many scientists thought Wegener's hypothesis was speculative and not grounded in prevailing principles such as uniformitarianism. Uniformitarianism states that the slow geologic processes that can be observed operating on Earth today are responsible for shaping Earth in the past. Some scientists were concerned that Wegener did not propose a mechanism that explained how continents moved. Other scientists dismissed Wegener's idea because he was a meteorologist and climatologist and not a geologist or geophysicist.

3. Summarize the theory of plate tectonics.

Plate tectonics describes how Earth's outermost layer is broken into rock slabs (or plates) that float on an inner layer of hot churning fluid. The plates collide, diverge and grind past one another over eons to create features such as volcanoes, earthquakes, ocean basins and mountains.

4. Name some technological advancements since the early 20th century that made it possible to gather evidence to support the theory of plate tectonics.

Student answers will vary. Students may mention that World War II brought about rapid advances in submarines and sonar technologies, which enabled scientists to explore and map the ocean floors. These explorations revealed the presence of deep-ocean trenches and a continuous underwater mountain chain with a long crack down its center.

The development of magnetometers for measuring magnetic fields enabled scientists to study the magnetic orientation of seafloor rocks, which showed patterns of alternating magnetic orientation.

Submersible technology and photographic and videographic technologies enabled scientists to directly observe seafloor rocks, trenches, ridges and geologic processes that occur on the seafloor.

The proliferation of nuclear weapons led governments and scientists to develop a global, standardized network of seismograph stations in the 1960s to locate underground weapons tests. This network of seismograph stations also helped scientists locate the sources of earthquakes, which tend to occur in places of tectonic activity.

New drilling and probe equipment enabled scientists to record the temperatures of rocks at and below the seafloor from ships on the ocean surface. The data gathered from these temperature surveys helped scientists determine the presence of magma or other heat sources near Earth's surface.

First day work
Quickly review students' homework responses with the class before moving on to classroom work. During the first day, the class will discuss the evolution of the theory of plate tectonics and investigate of how plate tectonics shapes geology. Then, you will deliver your tutorial on how to read a geologic map.

Class discussion
During the discussion on the evolution of the theory of plate tectonics, have students use the classroom whiteboard to construct a timeline starting with Alfred Wegener in 1912 and ending with the Annual Meeting of the American Geophysical Union in the spring of 1967. Make sure the students include when scientific evidence became available to support the theory. Remind them that an idea can take a very long time to become a theory and that theories are supported by evidence. Give students the option to quickly go online to fill any gaps in the timeline or to address the discussion questions.

Cover the following questions in the class discussion.

1. How were Harry Hess and Robert S. Dietz influenced by the earlier ideas of Wegener and Arthur Holmes?

Wegener and Holmes both proposed incomplete hypotheses. Wegener proposed an alternative explanation for the formation of mountains. Instead of resulting from the contraction of cooling rock, he proposed mountains resulted from the collision of landmasses. This was a reinterpretation of existing evidence. Wegener's concept of continental drift also explained why the outlines of continents fit together like puzzle pieces and why some rock layers and landforms appeared on continents separated today by thousands of kilometers of ocean.

To explore whether the continental drift hypothesis had merit, Holmes had to think through the problem from a different angle. He proposed a possible mechanism for continental drift — that the continents floated on layers of molten rock. But there was no supporting evidence for this mechanism. By evaluating whether old explanations fit all of the new evidence or if the existing evidence could be interpreted in a new way, Hess and Dietz were able to construct a model for circulation of material within Earth, including moving plates of rock at Earth's surface, that explained all of the observations and patterns in the data and that supported Wegener and Holmes's hypotheses.

2. What types of evidence changed scientists' minds about the mechanisms governing tectonic plates?

As scientists and engineers studied other geologic processes and phenomena, data they collected suggested that the oceans had formed slowly over time and that seafloor rocks were still forming at mid-ocean ridges and being destroyed at deep-ocean trenches. Measurements of heat flow at different places on Earth's surface provided evidence that heat distribution within Earth's interior is not constant. The distribution of earthquakes and volcanoes on Earth's surface also pointed to a pattern that could be explained by previously unrecognized processes that formed, destroyed and moved rocks at Earth's surface.

3. How do you think plate tectonics research has advanced since 1967?

Many technologies have been developed or have advanced since the 1960s that have helped scientists gather evidence and evaluate that evidence in new ways. For example, scientists use satellites and imaging technologies as well as computer modeling and mapping technologies to study tectonic plate movements. Scientists can measure and model the temperature, density and motion of rock deep within Earth's interior. This has led scientists to understand the forces caused by the upwelling of hot rock from Earth's center and the slow sinking of cold, dense rock where plates collide.

Scientists also have been able to reconstruct the past movements of tectonic plates, and they have learned how tectonic plate movements influence the atmosphere, the distribution of natural resources, and Earth's magnetic field.

Online investigation

This component of the activity is meant to stretch student thinking about the ways in which plate tectonics influence geologic features. Have students work either individually or in groups for a set amount of time doing plate tectonic searches online.

Have the students combine the term "plate tectonics" with a state name, a land feature or a natural resource to see what they might discover. For instance, if they search "plate tectonics" and "Alaska," they might learn about the meeting of the North American and Pacific plates and the role of tectonics in earthquakes and volcanoes. A search for "plate tectonics" and "natural gas" would introduce students to the idea that tectonic forces affect the formation and distribution of natural resources. When students finish their research, list their discoveries on the classroom whiteboard. Make sure some of their answers address the following question.

1. What geologic features are caused by tectonic processes?

The student answers will vary. The table below outlines major regional landforms caused by tectonic forces — it is included only for teacher reference; students are not expected to create a similar table.

The separation and collision of tectonic plates cause a variety of observable geologic features or landforms on local, regional and global scales. Tectonic forces cause faulting, or fracturing of rock, that can be observed at local or regional scales. Faulting offsets rock layers and can cause small ridges or cracks to form.

Separation, or divergence, of tectonic plates causes features related to stretching or tension. Collisions, or convergence, of tectonic plates cause features related to compression or squeezing together. Transform boundaries, where plates slide past each other horizontally, cause features formed by shear stress. The locations of volcanoes are also related to tectonic settings. In general, large-scale patterns of rock type, as well as regional landforms and local features can all be caused by tectonic processes that affect the stresses placed on rock.

Tectonic Plate Boundaries and Landforms

Landform	Description	Type of plate boundary	Dominant forces	Example
Deep-ocean trench	*A deep depression in the ocean where one tectonic plate sinks beneath another*			*Mariana Trench, Aleutian Trench*
Volcanic mountain chain	*A line of volcanic mountains on land or in the ocean, commonly parallel to an ocean trench*	*Convergent*	*Compression , collision or subduction*	*Aleutian Islands, Cascade Mountains*
Folded mountains	*A chain of mountains composed of folded and deformed rock layers*	*Convergent*	*Compression or collision*	*Appalachian Mountains, Swiss Alps, Himalaya Mountains*
Plateau	*A large, flat region that rises above surrounding regions on at least one side*	*Convergent*	*Compression or collision*	*Colorado Plateau, Tibetan Plateau*
Fault-block mountains	*A chain of mountains composed of blocks of rock offset by faults that are lifted up or dropped down relative to each other*	*Divergent (or convergent in back-arc areas)*	*Tension or stretching*	*Sierra Nevada Mountains, Grand Teton Mountains*
Rift valley	*A long valley with steep walls formed when a block of rock drops downward along parallel faults*	*Divergent*	*Tension or stretching*	*Mid-Atlantic Ridge, East African Rift Valley, Thingvellir (Iceland)*
Basin-and-range province	*A large region composed of alternating narrow faulted mountain ranges and flat basins or valleys*	*Currently debated; divergence, transform shear or back-arc extension in subduction zones*	*Tension or stretching*	*the Great Basin (North America), Junggar Basin (China)*
Linear valleys or ridges	*Long, thin valleys or ridges of rock bordered by fractured or folded rock and may contain small ponds or wetlands*	*Transform*	*Shear*	*San Andreas Fault, North Anatolian Fault (Turkey)*

Off-set streams or rivers	*Stream or rivers that take a strong and sudden turn to the left or right before resuming their original direction of flow*	*Transform*	*Shear*	*Wallace Creek (California)*
Sag pond	*A small body of fresh water that forms in a depression within a fault zone*	*Transform*	*Shear*	*San Andreas Lake, Carrizo Plain of California*

How to read a geologic map
During this portion of class, show students examples of geologic maps and explain what the maps show and how they can be interpreted. You may want to refer to the teacher background sheet to prepare your lecture.

At the end of class, assign a map to the class for homework. Ideally, the example maps will not be the ones you assign to students. The map assigned for homework will be used in the second day of this activity. It can be from your region or state or any area you find geologically interesting. You will need to prepare a features list based on the map you have chosen.

For homework, ask the students to answer two questions.

1. List the important geologic features shown on the map.

The students' answers should include the features you want them to know.

2. List any features or symbols that you do not understand.

You will need to anticipate what the students are unlikely to understand on the geologic map that you assign them.

Day 2 work
Begin the class with a quick review of the homework. Review anything the students do not understand about the assigned geologic map. The remainder of class will be spent on group work. Students will conduct additional research on the assigned geologic region, looking for more maps and supporting materials. They will analyze their findings and plan an investigation to address any unanswered geologic questions they have about their assigned study area.

Conduct research
Assign students to groups and direct them to use the internet and other resources to research the region shown in the map that you assigned for homework. If performing this activity remotely, sort students into breakout groups for a set period of time, about 10 minutes, and then rotate through each group to observe and guide student participation as needed.

Students may be able to find useful materials at the local library, local agricultural extensions or state geologic surveys. If you want students to focus on a specific type of tectonic feature, assign groups to research states that are rich in geologic data and maps or that have obvious tectonic structures, such as Alabama, California, Colorado, Nevada, Pennsylvania, Virginia or Wyoming.

1. For what state or region did you find a geologic map?

Student answers will vary. Example answers are given for the state of Nevada.

2. What source did you use to find a geologic map of your state?

I searched several sites, but I chose to use the interactive 1:500,000 scale Geologic Map of Nevada from the Nevada Bureau of Mines and Geology, University of Nevada, Reno, which I found at http://www.nbmg.unr.edu/Maps&Data/ and https://gisweb.unr.edu/NevadaGeology/.

3. What information does the map show?

The map shows the locations of different rock units, including the age and type of rock in the unit. The map also shows the locations of faults, the type of fault or the relative motion of the rocks on either side of the fault. The interactive map could be toggled to turn on and off the different layers and labels. The map also indicates the location of young, unconsolidated sediments and uses text labels and shaded relief to indicate the locations of mountains and valleys.

4. What information does the map not show?

The map I used does not include topographic contour lines to indicate the shape of the land surface. The map I used also did not show the strike and dip of the different rock layers. It also did not show the direction of motion of the tectonic plate on which the state is currently located or the direction or magnitude of stresses acting on the rocks in the state.

5. How can you use the data presented in the map to identify geologic features and landforms caused by plate tectonics?

Geologic maps show the rock units, sediments that cover rocks and geologic structures, such as faults. Faults and other contacts between rock units are indicated by specific symbols. I can trace rock units, faults and contacts by following the colors or symbols across the map. The shapes formed by the rock units and contacts and their distribution across a region can be interpreted to identify structures such as folds, valleys, mountains, rifts, ridges and plateaus.

Analyze data

Bring groups back together as a class to answer the following questions about your region or state's specific geologic history. If conducting the activity remotely, share your screen with the geologic map open, so that all students can observe the same material. Students may want to keep the map open in a window on their screens so that they can refer to details more easily. As students analyze your state or regional geologic map, they may need support in reading the geologic map. Review background information with them as needed.

You may need to help students identify geologic features such as folds and faults. As an example, have students look at the image of China's Piqiang Fault shown in the "Crucible of life" section of the online *Science News* article "How the Earth-shaking theory of plate tectonics was born." Ask students how a large fault like that might appear on a geologic map of rock layers. More images of this fault and region are available on NASA's Earth Observatory. To explore how folds appear on geologic maps, you may want to refer students to the American Geological Union's blog post "Valleys and Ridges: Understanding the Geologic Structures in Central Virginia Pt.1" and Section 5 of the U.S. Geological Survey report "Digital Cartographic Standards for Geologic Map Symbolization."

Online, interactive maps can be an engaging tool for students exploring state geology, but students may struggle with identifying rock types and ages depending on how thorough the legend and other tools are. Encourage students using interactive maps to explore the tools and options before attempting to answer the questions. For example, some digital maps offer attribute tables that supplement the labels provided in the keys. Some digital maps also offer the option for click-on or hover-over pop-up boxes that provide additional information about specific rock units or structures on the map.

For their analyses, the students should answer these questions.

1. How would you describe the average age or the range in ages of rocks exposed at Earth's surface in your state?

The rocks shown on the geologic map of Nevada range from young, Quaternary sediments (geologic units with the prefix of Q *in their labels) to Proterozoic basement rocks (geologic units labeled as* Xm*) that are up to about 2 billion years old.*

2. What types of rocks (sedimentary, metamorphic or igneous) are most common in your state?

Nevada contains all three types of rock in different areas. Approximately half of the state, primarily in the valleys or lowland areas, is covered in young, unconsolidated sediments and dunes, which could become sedimentary rock over millions of years in the future. Most of the hills, mountains and highlands of the state are composed of igneous and some metamorphic rocks.

3. What structures on the geologic map can be directly related to the tectonic history of the state?

Nevada is characterized by a series of alternating small highlands or mountain ranges composed of older igneous and metamorphic rocks interspersed with valleys or basins filled with unconsolidated sediments, most likely eroded from the highlands. These basins and ranges are bounded by faults, most of which are normal faults, although some are strike-slip or thrust faults. The pattern of uplifted and down-dropped blocks bounded by normal faults suggests that the continent was stretched or pulled apart over a large area. This large-scale tension was likely caused by the motions of tectonic plates.

4. In what type of geologic or tectonic setting do the types of rocks located in your state generally form?

The Quaternary sediments form in dry, desert conditions, where there are uplifted rocks that can be broken down and the sediments transported and deposited in surrounding basins. Some of the older sedimentary *rocks are limestones, which form in lakes and oceans. Many of the igneous rocks in the highland areas are older and are volcanic. The wide range of rock types in Nevada indicates that the area has had a long and active history. Nevada has been covered by ocean and has had active volcanoes; it has also experienced significant erosion and deposition.*

5. How does the geologic or tectonic setting in which the rocks in your state formed relate to the current geologic and tectonic setting of your state?

Today, Nevada is located in the high desert between the western coastal ranges and volcanoes of California, Oregon and Washington and the Rocky Mountains in the states to the east. The young sediments in the basins and the alternating patterns of basins and ranges suggest that, in the past, all of the older igneous and metamorphic rocks formed a single unit or province that was stretched and pulled apart over time to form the new pattern of ranges and valleys. The presence of the igneous and metamorphic rocks also indicates that these rocks were once part of the edge of the continent that was colliding with North America to form the Rocky Mountains.

6. How does the theory of plate tectonics explain the types of rocks and landforms in your state?

Nevada is located near the edge of the North American continent. The Rocky Mountains to the east likely formed from the collision of continents. The volcanically active coastal ranges to the west are active because an oceanic plate is subducting beneath the west coast of the continent. The stresses caused by the formation of these two mountain ranges and the movement of tectonic plates along the San Andreas Fault cause tension, or stress, on the rocks in Nevada. This stress leads to earthquakes and the uplift and down-dropping of rocks along Nevada's many faults. Nevada most likely had a lot of highland areas that have been pulled apart to form the basins where the sediments are currently being deposited.

Plan an investigation

After the class has identified some of the geologic and tectonic processes that shaped the geology of your state, divide students back into groups. Groups should discuss the following topics and answer the questions to plan an investigation.

Student groups should identify a question they have about your state or region's geologic history that is not answered by the map. At the end of the class period, the groups should submit their final proposal for your review. You may choose to share these proposals in a group folder or document so that groups can review the questions and proposals of the other groups.

1. How do scientists gather the data used to construct a geologic map?

Early geologic maps were constructed based on the observations of amateur and professional scientists who observed and mapped the rock layers exposed at Earth's surface in local road cuts, outcrops, quarries and canyons. Today, gathering data about Earth's surface is conducted with the assistance of technology, including satellite imagery, aerial photography, aeromagnetic and gravity surveys, rock cores, seismologic surveys and ground-penetrating radar.

2. What questions do you have about the rock units, geologic structures and landforms of your state or area that are not answered by the map you analyzed?

I want to know more about how the ranges and basins in Nevada formed.

3. List at least three questions you could answer by conducting an investigation to improve the map. Then, choose one of the questions to answer in your investigation.

If you removed the basins, would the rocks in the mountains fit together in an observable pattern? How much have the blocks that now make up the basins dropped relative to the adjacent blocks that form ranges? What type of bedrock is under the Quaternary sediments in the basins?

4. What type of data is required to answer your question, and how could you gather that information?

I would need evidence about the rock units that are under the sediment deposits. I could use satellite or seismological technology to penetrate through the Quaternary sediments to "see" the rocks under the sediments. Or I could excavate areas in different basins or drill through the sediment and into the rocks beneath to get cores that could be analyzed to determine the type and age of the rock.

5. How could you incorporate the new information into the existing geologic map?

A new map could be made for each basin or for the state that illustrates the rock types under the sediments. This information could be added to the map by using the same colors, symbols and labels. Perhaps the addition of a texture over the basin rocks could be used to indicate that the rocks are overlain by Quaternary sediments.

6. As a group, create a proposal for an investigation to answer your question. Include the question to be answered, a summary of the data to be gathered and a procedure for gathering that information. Then, describe how the data and the answer to the question will be presented. This proposal will be submitted to your teacher.

We propose to conduct a geologic survey in Cave Valley, Nevada. The question we want to answer is "What type of bedrock is under the Quaternary sediments in Cave Valley?" Our hypothesis is that the bedrock underneath the sediments in Cave Valley will match the types of rocks in the Schell Creek Range to the east and the Egan Range to the west.

We propose to do a combination of excavating near the edges of the valley where the sediments are likely thinner, collecting rock core samples closer to the center of the valley where the sediments are likely thicker and gathering satellite gravity data for the entire valley to determine if the rocks in the center of the valley are similar to the ones in the adjacent ranges. We will map the type and age of all bedrock we can identify and add that information to the existing map by using the same colors, symbols and labels. We also will add a texture over the basin rocks to indicate that they are overlain by Quaternary sediments.

Additional resources

Science News:
C. Gramling. Shaking up Earth. Published January 13, 2021
B. Mason. Marie Tharp's groundbreaking maps brought the seafloor to the world. Published January 13, 2021
M. Temming. An upwelling of rock beneath the Atlantic may drive continents apart. Published February 4,

2021
B. Geiger. An enormous supervolcano may be hiding under Alaskan islands. Published December 7, 2020
C. Gramling. Plate tectonics may have started 400 million years earlier than we thought. Published April 22, 2020
C. Gramling. 3 questions seismologists are asking after the California earthquakes. Published July 12, 2019
A. Witze. Evidence falls into place for once and future supercontinents. Published January 11, 2017

Geologic maps:
Wisconsin Geological and Natural History Survey. How to read a geologic map
U.S. Geological Survey. Introduction to geologic mapping
U.S. Geological Survey. Geologic maps of U.S. states
U.S. Geological Survey. National geologic map database

U.S. Geological Survey. The state geologic map compilation (SGMC) geodatabase of the conterminous United States
U.S. Geological Survey. GeMS (Geologic Map Schema)
National Park Service. State geologic maps
National Park Service. Tectonic landforms and mountain building
Association of American State Geologists. State geological survey database
American Geosciences Institute. Interactive database for geologic maps of the United States
Geological Society of America. Geologic time scale.

SN EDUCATOR GUIDE

January 16, 2021

Shaking Up Earth

Activity Guide for Students: Get to Know Your Local Geology

Directions:
In this activity, you will learn about plate tectonics and research the geology of your state or region. You will work in groups to analyze geologic maps to determine how the data displayed in the map reveal the geologic and tectonic history of the state. Then, you will discuss how the data displayed in the map were gathered and how maps are constructed from those data. For the last step, your group will plan an investigation to gather data and integrate the data into your state's geologic map.

The setup
After you have read the *Science News* article "How the Earth-shaking theory of plate tectonics was born," answer the following questions as part of your homework.

1. Summarize Alfred Wegener's original concept of continental drift.

2. Identify three reasons why geologists objected to Wegener's continental drift hypothesis.

3. Summarize the theory of plate tectonics.

4. Name some technological advancements since the early 20th century that made it possible to gather evidence to support the theory of plate tectonics.

Class discussion
After your class has reviewed the answers to the homework questions, you will discuss the evolution of the theory of plate tectonics and do a timeline to show how the data grew to support the theory. Be prepared to answer the following questions.

1. How were Harry Hess and Robert S. Dietz influenced by the earlier ideas of Wegener and Arthur Holmes?

2. What types of evidence changed scientists' minds about the mechanisms governing tectonic plates?

3. How do you think plate tectonics research has advanced since 1967?

Online investigation

With your group, you will use library and internet resources to investigate how the movement of tectonic plates influences the formation of geologic features. Pay special attention to which plate motions cause each type of geologic feature and how that structure forms.

Answer the following question.

1. What geologic features, or landforms, are caused by tectonic processes?

How to read a geologic map

Your teacher will explain how to read a geologic map and provide you with references or resources to support you as you complete the homework assignment. You will be asked to review a geologic map provided by your teacher and answer the following questions.

1. List the important geologic features shown on the map.

2. List any features or symbols that you do not understand.

Day 2 work

Conduct research

After the class has reviewed the answers to the homework assignment, rejoin your group. With your group, research your state's geology. Use internet resources, your local library, local agricultural extensions or your state's geological survey to find different geologic maps and resources for your state or the state or region assigned by your teacher. Analyze the key, scale and symbols of the map. Answer the following questions in your group:

1. For what state or region did you find a geologic map?

2. What source did you use to find a geologic map of your state?

3. What information does the map show?

4. What information does the map NOT show?

5. How can you use the data presented in the map to identify geologic features and landforms caused by plate tectonics?

Analyze data
Carefully analyze your state or regional geologic maps. Then, use the maps to answer the following questions with the class.

1. How would you describe the average age or the range in ages of rocks exposed at Earth's surface in your state?

2. What types of rocks (sedimentary, metamorphic or igneous) are most common at Earth's surface in your state?

3. What structures on the geologic map can be directly related to the tectonic history of the state?

4. In what type of geologic or tectonic setting do the types of rocks located in your state generally form?

5. How does the geologic or tectonic setting in which the rocks in your state formed relate to the current geologic and tectonic setting of your state?

6. How does the theory of plate tectonics explain the types of rocks and landforms in your state?

Plan an investigation
After your class has identified landforms and types of rocks located within your state, discuss the following topics with your group and answer the questions. Plan an investigation to answer questions about your state or region's geologic history and make a proposal for the investigation.

1. How do scientists gather the data used to construct a geologic map?

2. What questions do you have about the rock units, geologic structures and landforms of your state or area that are not answered by the map you analyzed?

3. List at least three questions you could answer by conducting an investigation to improve the map. Then, choose one of the questions to answer in your investigation.

4. What type of data is required to answer your question, and how could you gather that information?

5. How could you incorporate the new information into the existing geologic map?

6. As a group, create a proposal for an investigation to answer your question. Include the question to be answered, a summary of the data to be gathered and a procedure for gathering that information. Then, describe how the data and the answer to the question will be presented.

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