Strand: 8.4.1

**Emphasis:** Uneven distribution of Earth’s natural resources (Cu)

**Anticipated Time Required** *(assuming 50 minute class periods):*

**Episode 1:** The Copper Conundrum  The Value and Distribution of Copper **50 minutes**

**Episode 2:** The Big Hole: Why and How? **20 minutes** *(Ep. 2 & 3 can be taught together over 2 days)*

**Episode 3:** Utah: Location and Surface- Changes Over Time and Space  
  Part 1: **25 minutes**; Part 2: **20 minutes**

**Episode 4:** What’s On Your Edge? **50 minutes**

**Episode 5:** Pushy Magma!: **50-90 minutes** *(Can be taught over 2 days if needed)*

**Episode 6:** In Hot water! **50 minutes**

**Episode 7:** The Copper Conundrum- SOLVED! **50-90 minutes** *(depending on writing ability of students and need to respond to formative feedback)*

**Dominant CCC:** Patterns, Energy and Matter, Cause and Effect

**Dominant SEP:** Construct a scientific explanation, Develop and use a Model

**Management Strategies to support equitable access to content:**

1. Use exit tickets for quick formative feedback to see where students are having problems. Ask questions that will reveal depth of understanding and misconceptions.
2. Students should be doing most of the work throughout this storyline. That means that the teacher must move around and listen to what students are thinking. Adjust instruction, pacing and grouping of students based on what you are hearing and observing. All students can work in groups, but it may take a few tries to find the right combination of learners.
3. Assess student models as they are developing them. You do not need to "grade" every task your students record, but walk around with a stamp or pen and acknowledge progress, thinking and effort. This will keep students on task, as they will know that their work and thinking is important. You will be able to give immediate feedback and see errors early on.

**Shopping list:**

Rock samples: quartzite, sandstone, limestone, shale, quartz monzonite (similar to granite), some type of ore *(group sets- 8 sets is usually a good number for middle school)*

Glue Sticks

Chart Paper and Markers *(group sets)*

Water, cups or beakers, salt, hot pot/ tea kettle with hot plate ice, timer, electronic scales

*Samples of copper (wire, pipes, pennies, etc.) would be good to have on hand to use as samples throughout*
### Anchor Phenomenon:
Earth’s copper resources are distributed unevenly around the world.

### Student Performance Expectation:
Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geological processes. (Evidence includes: 1. Hospitable host rock (sedimentary processes); 2. Layers are fractured by tectonics (tectonic processes); 3. Regional igneous activity (igneous processes/volcanism); 4. Hydrothermal fluids (igneous processes/volcanism); 5. Uplifting to expose stock (tectonic processes))

<table>
<thead>
<tr>
<th>Dominant Disciplinary Core Idea (DCI)</th>
<th>Dominant Crosscutting Concept (CCC)</th>
<th>Dominant Science and Engineering Practice (SEP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resources (minerals, water, energy) are distributed unevenly around the planet as a result of past geological processes. All Earth’s processes are the result of energy flowing and matter cycling within and among Earth’s systems.</td>
<td>Cause and Effect Energy and Matter Systems and Systems Models</td>
<td>Develop and use a model Construct an Explanation</td>
</tr>
</tbody>
</table>

### Science Experiences

<table>
<thead>
<tr>
<th>CCC/SEP</th>
<th>What are students doing?</th>
<th>What specific understandings should students get from this experience? (What pieces of the performance expectation does the experience provide?)</th>
<th>New questions students have to propel us to the next science experience</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Patterns Asking questions Analyze/ Interpret Data</td>
<td>Ask questions about the cause of copper’s value. Analyze and interpret data (maps) and ask questions about the patterns on World Distribution of Copper Map, Plate Tectonics Map, and Earth’s Volcanism Map.</td>
<td>Copper is a valuable, limited, natural resource that is used in many ways. We depend on copper for our lifestyle (wires, pipes, electronics). Copper is distributed near plate boundaries and volcanoes. Copper is a natural resource.</td>
<td>How is copper formed? What causes copper to be distributed near plate boundaries? Why is there a pattern of volcanism and occurrence of copper porphyry? What is porphyry?</td>
</tr>
<tr>
<td>2</td>
<td>Matter and Energy</td>
<td>Cause and Effect</td>
<td>Patterns</td>
<td>Ask questions</td>
</tr>
<tr>
<td>---</td>
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<td>----------------</td>
<td>---------</td>
<td>--------------</td>
</tr>
<tr>
<td>3</td>
<td>Stability and Change</td>
<td>Scale and Change</td>
<td>Develop and a Model</td>
<td>Develop and use a conceptual model for how Utah’s location, surface and subsurface have changed over time as recorded in the rock record (rock samples)</td>
</tr>
<tr>
<td>4</td>
<td>Matter and Energy</td>
<td>Ask questions</td>
<td>Obtain, Evaluate, &amp; communicate information</td>
<td>Asking questions about causes for changes in rocks over large scales Revisiting 3 maps and obtaining, evaluating and communicating information.</td>
</tr>
</tbody>
</table>
| 5 | **Matter and Energy**  
**Systems and Models**  
**Develop and use a model** | Develop a conceptual model for how energy drives plate movement resulting in subduction zones and volcanic features through the cycling of matter.  
Develop and use a model for how a magmatic body intrudes an existing (host) rock and solidifies. Be sure to define the system and the interactions between the components in the systems.  
During oceanic-continental subduction, oceanic crust and water is pushed down under the over-riding continental plate. The oceanic plate will melt due to heat, changes in pressure and the presence of water. Magma will push its way into zones of weakness resulting in a huge magmatic body intruding into host rock (Paleozoic sedimentary rocks). Intrusive and extrusive igneous rock results from subduction. Bingham monzonite stock is an intrusive igneous rock that cooled inside of very old sedimentary rock (Eocene).  
Matter= oceanic and continental crust, water  
Energy= TE | What are hydrothermal fluids?  
What causes hydrothermal fluids?  
What are the parts in the plate tectonics system? | Student models that identify the cause of plate motions as convection and slab drag |
|---|---|---|---|
| 6 | **Matter and Energy**  
**Systems models**  
**Plan and carry out an investigation** | Plan and carry out an investigation to determine how the temperature of a fluid effects the solubility of a solute in that fluid.  
Develop a model to understand how fluids transport and deposit minerals within rock layers  
Fluids that are in the host rock from subduction and volcanism are extremely hot and are known as hydrothermal fluids. Hydrothermal fluids carry minerals. Hydrothermal fluids can move through pore spaces and fissures in rocks. Hydrothermal fluids form veins or deposits when they cool and harden. Minerals are deposited in rocks by hydrothermal fluids. Copper was deposited into existing rock in Bingham Monzonite Stock | How does all the evidence fit together?  
How do the patterns we’ve studied relate to energy and matter at Kennecott and in the distribution of copper? | Clearest Point, Muddiest Point |
| 7 | **Cause and Effect** | Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is due to several geologic processes that | What are some other natural resources? | Final Scientific Explanation |
| Construct a scientific explanation | caused by geological processes. | must act on existing matter containing the right ingredients. The geologic processes include: sedimentary processes (layering of sediments and compaction and lithification over time); Igneous processes (volcanism, melting of crust, heating of fluids); tectonic processes (subduction of oceanic crust under continental crust; large-scale compressional forces; large-scale extensional forces | What cause formation of other natural resources? What are some other patterns of resource distribution? |
## 8.4.1 Learning Episode 1

### Student Science Performance

<table>
<thead>
<tr>
<th>Topic: Natural Resources- Copper</th>
<th>Title: The Copper Conundrum: The Value and Distribution of Copper</th>
</tr>
</thead>
</table>

**Overarching Performance Expectations (Standard) from State Standards or NGSS:**

**8.4.1** Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geologic processes.

### Lesson Performance Expectations:

Ask questions about the value, use and source for copper. Analyzing the data (maps) and ask questions about the patterns on World Distribution of Copper Map, Plate Tectonics Map, and Earth’s Volcanism Map.

**CCC:**

**SEP:**

### Students Will. . . To Construct Meaning

#### Part 1: Copper is Valuable

1. Read an article about the value of copper (why do people steal copper?) Write down ideas on why copper is valuable.
2. Article: *Thieves Somehow steal 6 Miles of Copper from Utah Highway.*
3. Watch a short video clips about the value of copper.
   - *NOVA: The Value of Copper*  
     - [https://www.pbslearningmedia.org/asset/nvhe_vid_copper](https://www.pbslearningmedia.org/asset/nvhe_vid_copper)

#### Part 2: Copper is Unevenly Distributed

Analyze the data (maps) about the patterns on World Distribution of Copper Map, Earth’s Tectonic Plates, and Earth’s Volcanism Map.

1. Students make observations about World Distribution of Copper in small groups. Students record observations in lab notebook.
2. Students share out observations with class. (This is an assessment for teacher to ensure that students have interpreted the map correctly.)
3. Students record questions they have about data (map).
4. Students make observations about Crustal Plates Map. Use same format as above.
5. Students record patterns found both the maps.

### Teacher Will. . . To Support Students

#### Part 1: Copper is Valuable

1. Make copies of article for each student.
2. Lead a discussion on why people would want to steal copper. Have students write down ideas in lab notebook.
   - (The point here is to get students engaged in natural resources, their value and how their lives are connected to the use of natural resources) You could also bring in pennies, copper wire, pipes, etc. for the student to observe and interact with.
3. Show video clip. Direct students to watch for properties of copper, uses and copper and reasons why copper is so valuable. Tell students to record answers in lab notebook. Lead a class discussion after video and review properties, uses and reasons.
4. Identify copper as a natural resource. Review what this means and have students take notes in notebook.

#### Part 2: Copper is Unevenly Distributed

1. Introduce phenomenon: Copper is unevenly distributed.
2. Hand out World Distribution of Copper Map. Have students work in small groups to analyze and interpret the data and note any patterns. Instruct students to record observations in lab notebook.
3. Listen to groups and circulate as students are analyzing data. Ensure that each student is recording something in lab notebook. Lead class discussion and clarify ideas as needed.
4. Hand out Plate Tectonics Map to groups. Have...
7. Students find patterns on all the maps.
8. Students generate and record questions in lab notebook about patterns and distribution of copper.

Management Strategy: Plan for map activity by arranging students in group formation at beginning of class. Make groups of 2-4 students. Be sure to have color copies of maps for each group. Do not pass out all maps at once. Give one at a time and require students to record observations in notebook before moving on to next map. Use a timer to keep time urgent and moving. Give groups 2-3 minutes to make and record observations.

students work in small groups to analyze and interpret the data and note any patterns. Instruct students to record observations in lab notebook.

Assessment of Student Learning

Proficient: Exit ticket should reflect 3 of these BIG ideas: Copper is a valuable, limited, natural resource that is used in many ways. We depend on copper for our lifestyle (wires, pipes, electronics). Copper is distributed near plate boundaries. Copper is distributed near volcanoes. Copper is a natural resource. Teacher should be monitoring and checking for understanding throughout lesson.

Not proficient: Student give one or none of the BIG ideas.
# 8.4.1 Learning Episode 2

## Student Science Performance

<table>
<thead>
<tr>
<th>Topic: Utah’s Bingham Canyon Mine</th>
<th>Title: The Big Hole-Why and How?</th>
</tr>
</thead>
</table>

### Overarching Performance Expectations (Standard) from State Standards or NGSS:

**8.4.1** Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geologic processes.

### Lesson Performance Expectations: Ask questions about the cause of the distribution of copper in Utah (Oquirrh and Rio Tinto/Kennecott Copper Mine)

**Note:** The mine is known as the Bingham Canyon Mine, Kennecott Copper Mine and Rio Tinto Copper Mine. Rio Tinto purchased the mine, but allowed the Kennecott name to remain.

**CCC: Matter and Energy/ Cause and Effect**

**SEP: Ask questions**

### Students Will . . . To Construct Meaning

#### Images of Mine

1. Analyze images of Bingham Canyon Mine. Record observations in lab notebook.

2. Write a preliminary explanation/model for how copper ended up in this location, i.e. the cause. Include any geoscience processes in your model/explanation and include any evidence you may have. You may use drawing, diagrams, words. Include energy and matter in your explanation.

3. Ask questions about the cause of the distribution of copper in Utah, particularly at this location.

### Management Strategy: It is very important that each student construct a preliminary explanation for the formation and distribution of copper at this location. This will guide you in deciding what evidence you will need to provide to help students make sense of the phenomenon. This should be completed in the lab notebook. You can circulate while students are constructing models and take notes on a clipboard, or you can have students leave notebooks with you opened to the correct page and then you can scan them.

### Teacher Will . . . To Support Students


2. Show pictures of Bingham Canyon Mine (Rio Tinto/ Kennecott Mine. You can print copies or shown on screen using PowerPoint.

### Images:

- [https://thewere42.files.wordpress.com/2013/05/e72909b96b9df9dda7811d426c1ff43.jpeg](https://thewere42.files.wordpress.com/2013/05/e72909b96b9df9dda7811d426c1ff43.jpeg)

### Virtual Tour:


3. Prompt students to write a preliminary explanation/model for how copper ended up in this location. Students need to include any geoscience processes they think are the causes for the distribution of copper in the Oquirrh Mountains.

4. Ask probing questions as you circulate around the room to help students clarify their current understanding and explanation of formation of mine at this particular location in Utah. Focus thinking on matter cycles and energy flows in explanation.
Assessment of Student Learning

Pre-assessment

This lesson establishes where your students are in their understanding of the geoscience processes that lead to the distribution of copper in the Oquirrhs. You will need to take time to review student models and explanations so that you can decide which of the subsequent lessons are necessary to provide enough evidence and conceptual understanding for students to construct a correct explanation at end of instruction. This assessment also becomes a reference point for the student in her own learning.
## Student Science Performance

### Overarching Performance Expectations (Standard) from State Standards or NGSS:

**8.4.1** Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geological processes.

### Lesson Performance Expectations:

Construct a conceptual model for how Utah’s location, surface and subsurface have changed over time as recorded in the rock record.

**CCC:** Stability and Change/Scale, Proportion and Quantity  
**SEP:** Develop and use a model

### Students Will... To Construct Meaning

#### Part 1: Utah’s Paleogeography Puzzle

1. Take notes on rules for reading rock layers (Stratigraphic Laws).
2. In a group of 2-4, investigate the data presented on the maps. Record the type of data presented.
3. Arrange maps of Utah over time (paleogeography) in a sequential order based on surface topography and cross section. Cite one piece of evidence for why you chose each map in that order. Use color name of paper that map is on when you cite your evidence.
4. Check order with key and fix order as needed.
5. Record the correct order of maps in notebook and write a one sentence description of each map that describes what Utah looked like during this time. Add the heading and geologic time from the card your teacher gives you.
6. Record information in lab notebook on how Utah has changed location compared present day North America throughout geologic time.
7. Record ideas for what has caused these changes over time.

#### Part 2: Reading the Rocks!

1. Use Bingham-Central Oquirrh Mountains Rock Column for this episode present in The Bingham-Central Qquirrh Mountains.
2. Study rock column. Note types of rocks.
3. Look at hand samples that match rock types in Rock Column. Record observations about types of rock in lab notebook.

### Teacher Will... To Support Students

#### Part 1: Utah’s Paleogeography Puzzle

2. Arrange students into groups of 2-4.
3. Review rules for reading rock layers (Stratigraphic Laws):
   1. Original Horizontalty- all sedimentary rocks are originally deposited in horizontal layers.
   2. Superposition- In an undisturbed sequence, the oldest layer is on the bottom, youngest layer on the top.
   3. Cross-cutting Relations-Any intrusion, crack, fault in rock layer happens after the rock was laid down.
4. Instruct students to use evidence on maps to arrange in order. Reveal first map if necessary to get students started.
5. Guide students to consider the rock layers underneath the map to assist in putting the maps in order.
6. Facilitate group discussion of how Utah’s surface as changed overtime, emphasizing the big ideas: Utah’s location and surface has changed dramatically over time (not “stable” over large scales). Utah was once located at the western edge of the North American continent. Utah’s rock layers have been cracked and folded over time.

#### Part 2: Reading the Rocks!
4. Record connections and patterns between Utah: A Geologic History and Bingham-Central Mountains Rock Column.
5. Glue Rock Column in lab notebook. Match maps to rock column. Record the map name where it matches on the Rock Column.
6. Draw a model that shows 4-6 significant stages in Utah’s geologic past (scale) that includes the changes to the location, surface and subsurface and the cause for each change. If you do not know the cause, make a note of this in your model. Use the maps and rock column to guide your model.

1. Prepare one copy of the Rock Column handout for each student ahead of time.
2. Hand out rock samples on a numbered tray. Rock samples: quartzite, sandstone, limestone, shale, quartz monzonite (similar to granite), some type of ore.
3. Instruct students to record observations about rocks in lab notebook.
4. Circulate among students and groups to give support where needed.
5. Instruct students to glue Rock Column in lab notebook.
6. Prompt students to draw a model that shows 4-6 significant stages in Utah’s geologic past (scale) that includes the changes to the location, surface and subsurface and the cause for each change. If you do not know the cause, make a note of this in your model. Use the maps and rock column to guide your model.

Bonus:
7. Using the maps and Rock Column, tell what each rock sample reveals to you about past environments in Utah.
8. Tie today’s lesson to phenomenon for distribution of copper and unique conditions in Utah throughout geologic time.
9. Management Strategies: It is okay to remove several maps from this sequence if needed. You do not want to overwhelm your students with information. Maps 3 and 5 have been removed from this activity. Be sure to pre-arrange groups of 2-4. Consider giving roles in the group that rotate, so everyone has a chance to speak.
10. Use a tray or container for distributing rock samples. Draw a grid on a piece of paper and label each square #1-6. Put a rock in each square. Keep a key for yourself. When students return rocks, it is easy to see that all rocks are present or what is missing.

Assessment of Student Learning

Proficient Model: Student will include at least 4 distinct time periods in Utah that would include:
Utah at edge of continent and sedimentary rocks deposited.
Utah was covered in sand for a long time.
Utah’s crust has been folded and cracked.
Magma has intruded into some of the cracks in rocks.
Precious metals have been placed into cracks in rocks.
Various lakes have covered Utah.
Lake Bonneville covered much of northern Utah.
There is no current volcanic activity in Utah.

C. Penrod
Utah’s location, surface (sea-level) and subsurface have changed over time.
Utah’s geologic history is recorded in the rock layers.
Utah’s Sedimentary rocks were laid down in Utah hundreds of millions of years ago

<table>
<thead>
<tr>
<th>Event</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-The Early Years: Paleozoic</td>
<td>330 + MYA</td>
</tr>
<tr>
<td>B-Wind Deposited Sands: Early Jurassic</td>
<td>208 MYA</td>
</tr>
<tr>
<td>C- Coal Formation: Late Cretaceous</td>
<td>145 MYA</td>
</tr>
<tr>
<td>D-Oil Shale and Fossil Fish: Eocene</td>
<td>45 MYA</td>
</tr>
<tr>
<td>E-Uplift and Volcanics: Oligocene</td>
<td>33 MYA</td>
</tr>
<tr>
<td>F-Precious Metals Emplaced: Miocene</td>
<td>17 MYA</td>
</tr>
<tr>
<td>G-Water and Ice: Pleistocene</td>
<td>1.8 MYA</td>
</tr>
<tr>
<td>H-These are the Places:</td>
<td></td>
</tr>
<tr>
<td>Holocene (Present)</td>
<td></td>
</tr>
</tbody>
</table>

C. Penrod
## Bingham-Central Oquirrh Mountains Rock Column

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>Formation</th>
<th>Lithology / Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Alluvium &amp; Lake Bonneville deposits</td>
<td>Lake Bonneville sediment SEDIMENTARY</td>
</tr>
<tr>
<td>Pliocene</td>
<td>Salt Lake valley-filling deposits</td>
<td>Pre-Lake Bonneville Sediment SEDIMENTARY</td>
</tr>
<tr>
<td>Miocene</td>
<td>Shaggy Peak rhyolite plug</td>
<td>Volcanic Rock IGNEOUS</td>
</tr>
<tr>
<td>Oligocene</td>
<td>Laticic volcanic rocks of the West Traverse Mountains</td>
<td>Volcanic ash flows IGNEOUS</td>
</tr>
<tr>
<td>Eocene</td>
<td>Laticic volcanic rocks of Bingham Canyon</td>
<td>Intrusive rock Large stratovolcano IGNEOUS</td>
</tr>
<tr>
<td></td>
<td>Bingham quartz monzonite porphyry</td>
<td>Thermally-altered intrusive rock IGNEOUS</td>
</tr>
<tr>
<td></td>
<td>Bingham monzonite stock</td>
<td>Fine-grained intrusive rock IGNEOUS</td>
</tr>
</tbody>
</table>

### Cretaceous

251–145 Cenozoic Era 39

20% During the Late Cretaceous Sevier orogeny, Bingham’s Oquirrh Group rocks, along with older and younger strata, were moved southeastward some tens of miles on the Cluffton–Neha thrust. At depth, beneath Bingham, they may rest on intrusive strata.

### Permain

250–286 Eour Carboniferous 290

### Paleozoic Era

Pennsylvania

250–330 MYA

<table>
<thead>
<tr>
<th>Quirihr Group</th>
<th>Formation</th>
<th>Lithology / Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freeman Peak Formation</td>
<td>Quartzite, sandstone, shale SEDIMENTARY</td>
</tr>
<tr>
<td></td>
<td>Curry Peak Formation</td>
<td>Siltstone, sandstone SEDIMENTARY</td>
</tr>
<tr>
<td></td>
<td>Bingham Mine Formation</td>
<td>Quartzite, limestone SEDIMENTARY</td>
</tr>
<tr>
<td></td>
<td>Commercial La M</td>
<td>Limestone SEDIMENTARY</td>
</tr>
<tr>
<td></td>
<td>Jordan La M</td>
<td>Limestone SEDIMENTARY</td>
</tr>
<tr>
<td></td>
<td>Butterfield Peaks Formation</td>
<td>Quartzite Sandstone Limestone SEDIMENTARY</td>
</tr>
<tr>
<td></td>
<td>West Canyon Limestone</td>
<td>Limestone SEDIMENTARY</td>
</tr>
</tbody>
</table>

Adapted from Utah’s Spectacular Geology by Lehi Hintze © 2005
Converging Plate Boundaries and Subduction Zones

There are 2 main types of converging (moving together) plate boundaries that create subduction zones. At these boundaries (where two plates collide), the heavier of the two - usually an oceanic one - sinks (or is pulled) under the other plate in a process called **subduction**. Subduction zones are an important tectonic setting, as many volcanoes occur along or near these converging plate boundaries.

The two plate boundaries that create subduction zones are:

1. **Oceanic-oceanic plate boundaries:**
   If the subducting plate subducts beneath an adjacent oceanic plate, an **island arc** is formed from rising volcanoes in the ocean. Examples include the volcanoes that form the Aleutians, the Kuriles, Japan, and the Philippines, all located at the northern and western borders of the Pacific plate (an oceanic plate) up against other oceanic plates.

2. **Oceanic-continental plate boundaries:** if the subducting oceanic plate subducts beneath continental lithosphere, then a similar belt of volcanoes will be generated on the continent. These are called **volcanic arcs**. Examples include the Cascade volcanic arc of the U.S. Pacific northwest, and the Andes volcanic arc of South America.
Magma Generation at Subduction Zones

When the (typically very old) oceanic crust sinks back into the mantle in a subduction zone (see Figure 1), it comes progressively under greater pressure and temperature. Its rocks contain significant amounts of water, carbon dioxide and other fluids which are released into the overlaying mantle wedge.

**Melting the mantle by adding fluids**
This addition of fluids lowers the melting point of the mantle (in a similar way as adding salt lowers the melting point of ice). As a result, the mantle rocks in the wedge overlying the subducting slab produce partial melts-magmas.

As the magmas are lighter than the mantle and start to rise above the subduction zones to produce a linear belt of volcanoes (see figure 2) parallel to the oceanic trench. The best example are the subduction zones around the Pacific Ocean, often called the "**Ring of Fire**" (see figure 3).

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**Figure 1: Subduction Zone**

**Figure 2: Volcano in the Pacific Ocean**

**Figure 3: Pacific Ring of Fire**
### 8.4.1 Learning Episode 4

<table>
<thead>
<tr>
<th>Student Science Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topic:</strong> Plate Boundaries and Subduction</td>
</tr>
</tbody>
</table>

**Overarching Performance Expectations (Standard) from State Standards or NGSS:**
8.4.1 Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geologic processes.

**Lesson Performance Expectations:**
Ask questions about causes for changes in rocks over large scales and Obtain, evaluate and communicate information about the cause of changes to Earth’s crust

**CCC:** Matter and Energy

**SEP:** Ask questions ; obtain information

<table>
<thead>
<tr>
<th>Students Will . . . To Construct Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part 1: Setting the Stage</strong></td>
</tr>
<tr>
<td>1. As a group, revisit three maps from Lesson 8.4.1 and questions about patterns. Discuss with partner what you have learned so far.</td>
</tr>
<tr>
<td>2. Add maps from 8.4.3 to discussion and generate questions about what can cause changes to Earth over such large temporal and spatial scales. Also, record ideas on how matter and energy relates to these changes. Reflect on Utah’s Geologic History Maps and Rock Column as needed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Teacher Will . . . To Support Students</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part 1: Setting the Stage</strong></td>
</tr>
<tr>
<td>1. Prepare copies of maps</td>
</tr>
<tr>
<td>2. Listen as students discuss maps and generate questions.</td>
</tr>
<tr>
<td>3. Guide thinking to focus on matter and energy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Part 2: Read to Obtain Information</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Jigsaw articles in small group to obtain and communicate information that will help explain the cause of these changes to Earth’s surface.</td>
</tr>
<tr>
<td><strong>Titles:</strong> Converging Plate Boundaries and subduction Zones and Magma Generation at Subduction Zones.</td>
</tr>
<tr>
<td>2. Record information about the causes for changes to Earth’s surface and how matter and energy are a part of this geoscience process.</td>
</tr>
<tr>
<td>3. Share/communicate information gathered from your reading to other students in group.</td>
</tr>
<tr>
<td>4. Take notes and record information form classmates.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Part 3: Predictions and Reasoning</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Predict what type of plate boundary is found on the western edge of North America and provide reasoning for prediction.</td>
</tr>
<tr>
<td>2. Examine crustal plates map and record type of plate boundary at western edge of North America to test your prediction.</td>
</tr>
<tr>
<td>3. Answer these questions: What are two important pieces of information you gathered today that can be used to help you explain the phenomenon (uneven distribution of copper). What is one question you still have?</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Materials:</strong></th>
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</thead>
<tbody>
<tr>
<td>Maps (Copper Distribution, Plates, Volcanism) from Episode 1</td>
</tr>
<tr>
<td>Copies of Converging Plate Boundaries and subduction Zones and Magma Generation at Subduction Zones</td>
</tr>
<tr>
<td>Exit tickets</td>
</tr>
</tbody>
</table>
(uneven distribution of copper). What is one question you still have?

**Management Strategy:**
Always be thoughtful when assigning a reading in the science classroom. Some students have reading difficulties and need scaffolding such as reading with a partner and following along with a highlighter or summarizing at the end of the article. Be sure to check for understanding. You may also read as a class, but only ask volunteers to read.

**Assessment of Student Learning**
Exit Ticket should include two of the following:

- Subduction occurs at an ocean to continent plate boundary.
- There is a subduction zone on the western coast of North America.
- Many volcanoes occur along subduction zones.
- Matter is recycled and used as magma when a plate subducts and melts.
- When a plate sinks, it is subjected to heat and pressure and can alter the rate of melting.
- Magma is produced from melting plates.

**Converging Plate Boundaries and Subduction Zones**

There are 2 main types of converging (moving together) plate boundaries that create subduction zones. At these boundaries (where two plates collide), the heavier of the two - usually an oceanic one - sinks (or is pulled) under the other plate in a process called **subduction**. Subduction zones are an important tectonic setting, as many volcanoes occur along or near these converging plate boundaries.

The two plate boundaries that create subduction zones are:

1. **Oceanic-oceanic plate boundaries:**
   If the subducting plate subducts beneath an adjacent oceanic plate, an **island arc** is formed from rising volcanoes in the ocean. Examples include the volcanoes that form the Aleutians, the Kuriles, Japan, and the Philippines, all located at the northern and western borders of the Pacific plate (an oceanic plate) up against other oceanic plates.
2. **Oceanic-continental plate boundaries:** if the subducting oceanic plate subducts beneath continental lithosphere, then a similar belt of volcanoes will be generated on the continent. These are called *volcanic arcs*. Examples include the Cascade volcanic arc of the U.S. Pacific northwest, and the Andes volcanic arc of South America.

---

**Magma Generation at Subduction Zones**

When the (typically very old) oceanic crust sinks back into the mantle in a subduction zone (see Figure 1), it comes progressively under greater pressure and temperature. Its rocks contain significant amounts of water, carbon dioxide and other fluids which are released into the overlaying mantle wedge.

**Melting the mantle by adding fluids**

This addition of fluids lowers the melting point of the mantle (in a similar way as adding salt lowers the melting point of ice). As a result, the mantle rocks in the wedge overlying the subducting slab produce partial melts—magmas.

As the magmas are lighter than the mantle and start to rise above the subduction zones to produce a linear belt of volcanoes (see figure 2) parallel to the oceanic trench. The best example are the subduction zones around the Pacific Ocean, often called the "**Ring of Fire**" (see figure 3).
8.4.1 Learning Episode 5

Student Science Performance

<table>
<thead>
<tr>
<th>Topic:</th>
<th>Title:</th>
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</thead>
<tbody>
<tr>
<td>Magma Bodies and Plate Tectonics</td>
<td>Pushy Magma!</td>
</tr>
</tbody>
</table>

**Overarching Performance Expectations (Standard) from State Standards or NGSS:**

8.4.1 Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geological processes.

**Lesson Performance Expectations:** Develop a conceptual model for how energy drives plate movement resulting in subduction zones and volcanic features through the cycling of matter

Develop and use a model for how a magmatic body intrudes an existing (host) rock and solidifies

**CCC: Energy and Matter**

**SEP: Develop and use a model**

### Students Will . . . To Construct Meaning

#### Part 1: What Happen Here?

1. Record observations about rocks in picture.
2. Write two questions you have about the rocks
3. Construct an explanation for what caused the visible difference in the rocks.
4. Use pictures #1 and 2.

#### Part 2: Magma Bodies

5. Develop and use a model for how a magmatic body intrudes an existing (host) rock and solidifies.
6. Include matter and energy in the model and what is causing the changes.
7. Use the resources teacher provides.

#### Part 3: What is making the plates move?

8. In a small group (2-4) use resources provided to develop a conceptual model for how energy drives plate movement resulting in subduction zones and how this relates to volcanic activity on large chart paper. Parts of system/model should include:
   - Structure of Earth
   - Convection Currents
   - Core as source of heat
   - Crustal plates on top of mantle
   - Subduction zone
   - Magma body below surface
   - Magma intrusion into existing rock layers.
9. Include a written explanation of geoscience processes involved.
10. Include matter and energy in the model and what is causing the changes.
11. Share models with class.

### Teacher Will . . . To Support Students

#### Part 1: What Happen Here?

1. Show picture(s) of igneous intrusion.
2. Prompt students to write down two questions they have about what they see and to give a preliminary explanation.

#### Part 2: Magma Bodies

3. Prepare resources for students about magma bodies and how they intrude host rock.
4. Monitor progress by moving around classroom while students are developing models.
5. Ask guiding questions to keep students on track with CCC- energy and matter and cause and effect.
6. Resources:
   - [https://www.nationalgeographic.org/encyclopedia/magma/](https://www.nationalgeographic.org/encyclopedia/magma/)
   - Slides 1-3 and 11 are particularly helpful.

#### Part 3: What is making the plates move?

7. Instruct students develop a conceptual model for how energy drives plate movement resulting in subduction zones and how this relates to volcanic activity large chart paper.
8. Have student groups share their models. The purpose of this activity is to uncover what students are thinking, to clear up any misconceptions they may have and to assess what other information they still need.
9. Lead a class discussion and refer to disciplinary core ideas to be sure all the needed components of the model are present.
12. Individually develop a conceptual model and record in lab notebook for how energy drives plate movement resulting in subduction zones and volcanic features through the cycling of matter.

**Management Strategy:**
One way to stay on top of your students’ models is to have them discuss what they are thinking and to share their thoughts with the class. Students will put incorrect or incomplete information on posters at times. Be thoughtful and carefully as you clear up these errors in class. Consider saying something such as, “Interesting. Does anyone have another idea?” Use student responses to help clarify and give needed information. Model how to think through a problem and change your thinking as you learn from others. By the end of the discussion, all correct information should have been presented so that students will be successful on individual models. The benefit of group to individual models is that there is less correction needed on an individual level after students have processed and reflected on a group level.

10. Refer back to rules for reading rock layers (Stratigraphic Laws) and discuss how they apply here:

1. **Original Horizontality** - all sedimentary rocks are originally deposited in horizontal layers.
2. **Superposition** - In an undisturbed sequence, the oldest layer is on the bottom, youngest layer on the top.
3. **Cross-cutting Relations** - Any intrusion, crack, fault in rock layer happens after the rock was laid down.

13. Instruct students to develop a conceptual model and record in lab notebook for how energy drives plate movement resulting in subduction zones and volcanic features through the cycling of matter.

14. Be sure to tie this lesson back to the phenomenon.

**Materials:**
- Copies of resources as desired for students (pictures and diagrams included in lesson)
- Chart Paper
- Markers
- Access to showing resources from internet

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**Assessment of Student Learning**

**Proficient:** Student models should identify the cause of plate motions as convection (Thermal energy) and slab drag (gravity) as source of plate movement. Model should include:

- Structure of Earth
- Convection Currents
- Core as source of heat
- Crustal plates on top of mantle
- Subduction zone
- Magma body below surface
- Magma intrusion into existing rock layers

Student models should refer to plate tectonics and volcanics (melting of plates; cooling of magma) as geoscience processes.
Pictures to use:
### 8.4.1 Learning Episode 6

#### Student Science Performance

<table>
<thead>
<tr>
<th>Topic: Solubility: Heat Energy and Matter</th>
<th>Title: In Hot Water!</th>
</tr>
</thead>
</table>

**Overarching Performance Expectations (Standard) from State Standards or NGSS:**

8.4.1 Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geologic processes.

**Lesson Performance Expectations:** Plan and carry out an investigation to determine how the temperature of a fluid affects the solubility of a solute in that fluid.

- **CCC:** Systems and systems models
- **SEP:** Plan and carry out an investigation

#### Students Will. . . To Construct Meaning

**Part 1: Investigation**

Plan and carry out an investigation to determine how the temperature of a fluid affects the solubility of a solute in that fluid.

1. Discuss objective with lab group (3-4 students) and design a simple experiment to generate data.
2. Report as a lab group to teacher with lab notebooks completed to get approval.
3. Gather needed supplies.
4. Carry out investigation and record data.
5. Share findings with class.
6. Analyze data and write 2-3 statements with evidence that represent findings.
7. Draw a model of your system and label the components and interactions.

**Part 2: Connecting to Hydrothermal Fluids**

1. Read *Hydrothermal Mineral Deposits*.
2. Discuss in group what hydrothermal means and how it is connected to plate tectonics.
3. Record ideas in lab notebook.
4. Clean up area and return supplies.
5. Discuss how your investigation relates to hydrothermal fluids and natural systems. Record the connections in your lab notebook.
6. Return to the system model you drew in step 6 above (Part 1). Write down what each part of your system represents in the hydrothermal system you read about.
7. Create a model in your lab notebook on how hydrothermal fluids transport and deposit minerals within rock layers and cracks.
8. Exit ticket 2 post-it notes: What is your clearest point from today’s lesson? What is your muddiest point?

#### Teacher Will. . . To Support Students

**Part 1: Investigation**

1. Gather and provide supplies: Water, cups or beakers, salt, hot pot/ tea kettle with hot plate ice, timer, electronic scales.
2. Check each lab groups’ notebooks as they finish. Give a timeframe and set timer.
3. Prompt students to fix parts of their idea that need to be changed. Don’t tell them- prompt them through questions.
4. Be sure each student has a way to collect data.
5. Give supplies they request when lab group has satisfactory “procedure.”
6. Work with slow groups once others have supplies.
7. Monitor progress.

**Part 2: Connecting to Hydrothermal Fluids**

1. Prepare a copy of *Hydrothermal Mineral Deposits for each student.*
2. Lead discuss as necessary.
3. Instruct students to discuss how investigation relates to hydrothermal fluids and natural systems. Record the connections in lab notebooks.
4. Guide students as they complete the systems part of the lab.
5. Check models with students before the end to class. Can be done whole class, small group, etc.
6. Pass out 2 post-it notes per student. Make and post 2 large poster-size papers on your wall or write on your whiteboard: Clearest Point (1 poster) and Muddiest Point (1 poster).

**DO NOT tell students what to do!** Let them figure it out. The goal is to determine the effect of temperature on the solubility of a solute in a fluid. Students will be using water- the universal solvent- and salt (the solute) in this investigation. The idea is that they will figure out that they
**Management Strategy:** Give out materials only to groups who have **planned** an investigation. Stamp or initial lab notebooks when students are ready for materials. This means they have recorded what they will do and how they will collect data in their lab notebook (ie procedure and a data table). Be flexible on how students go about this. It is okay and expected that each group will have a slightly different iteration on how to investigate and how to record data.

**Materials**
- Water, cups or beakers, salt, hot pot/ tea kettle with hot plate ice, timer, electronic scales
- Copies of *Hydrothermal Mineral Deposits* for each student

**Assessment of Student Learning**
This lesson utilizes a formative assessment strategy called “Clearest Point” and “Muddiest Point.” This formative assessment will help the teacher determine if there are any problems in understanding of making sense of the evidence presented in class to explain the phenomenon.

**Proficiency** for hydrothermal models include 3 or more of the following:
- Hydrothermal fluids carry minerals.
- Hydrothermal fluids can move through pore spaces and fissures in rocks.
- Hydrothermal fluids cool over time and deposit minerals in rocks.
- Extremely hot fluids that originate from subduction and volcanism that are found within rock pore spaces are known as hydrothermal fluids.

**Hydrothermal Mineral Deposits Edited from Encyclopedia Britannica**

Hydrothermal mineral deposits are those in which hot water concentrates, moves, and deposits minerals in existing rock (Figure 1). Pure water, however, cannot form hydrothermal deposits. Other substances, such as salts, must be present in the water to allow minerals to dissolve in the water that then becomes a **hydrothermal solution**.

Figure 1: Mineral deposit in rock

The water in a hydrothermal solution can come from several **sources**. It may come from crystallizing magma, from a rock undergoing metamorphism, or it may be rainwater or seawater that trickles down into deep fractures in rocks where it will be heated, react with existing rocks, and then become a hydrothermal solution (See figure 2). The solutions are heated by magma, also causing a rising motion of the solution. Other sources of heating may include energy released by radioactive decay or by faulting of the Earth’s crust. While hydrothermal solutions not uncommon within Earth’s crust, hydrothermal mineral deposits, are quite rare.

Figure 2: Sources of hydrothermal water- magma and rain.
Porphyry Deposits
One type of hydrothermal deposit is a **porphyry copper deposit**. Porphyry means that the rock’s texture is a mixture of coarse and fine mineral-grains (See figure 3). Igneous rocks, produced by volcanism, are porphyritic. Intrusive igneous rock that hardens deep within Earth can be subjected to tectonic forces that, over millions of years, shatter the rock, leaving many fissures and spaces for fluids to move. Hydrothermal solutions, containing copper and other metals, move through the fine fractures in the rock, leaving behind tiny particles of copper throughout the igneous rock body. Porphyry coppers are often associated with stratovolcanoes.

Figure 3: Porphyritic Rock
Hydrothermal mineral deposits are those in which hot water concentrates, moves, and deposits minerals in existing rock (Figure 1). Pure water, however, cannot form hydrothermal deposits. Other substances, such as salts, must be present in the water to allow minerals to dissolve in the water that then becomes a **hydrothermal solution**.

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## Student Science Performance

<table>
<thead>
<tr>
<th>Topic: Copper</th>
<th>Title: The Copper Conundrum: SOLVED!</th>
</tr>
</thead>
</table>

### Overarching Performance Expectations (Standard) from State Standards or NGSS:
**8.4.1** Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geological processes.

### Lesson Performance Expectations:
Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geological processes.

**CCC: Cause and Effect**

**SEP: Construct a scientific explanation**

### Students Will... To Construct Meaning

#### Part 1: Respond to Muddiest/Clearest
1. Read to obtain information on cause of copper porphyry. See *Hydrothermal Deposits* reading part 2.
2. Record information from video about uses of copper, cause of copper porphyry and the deposition of copper by hydrothermal fluids (Video from Rio Tinto Kennecott Copper 14 mins). [https://vimeo.com/kennecott/review/107297079/32f89a536e](https://vimeo.com/kennecott/review/107297079/32f89a536e)

#### Part 2: Prepare Evidence for Claim
3. Use the graphic organizer *Writing a Scientific Argument* to organize thoughts and evidence to support your claim on why copper is unevenly distributed.

#### Part 3: Construct an Explanation
1. Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geological processes. Use patterns, cause and effect, and/or matter and energy to support your thinking when presenting evidence.

### Teacher Will... To Support Students

#### Part 1: Respond to Muddiest/Clearest
1. Prepare copies of reading *Hydrothermal Deposits*.
2. Preview video to identify parts that have information that students may still need. Minutes 1:00-3:40 are especially helpful and appropriate.

#### Part 2: Prepare Evidence for Claim
3. Prepare a graphic organizer for each student.
4. Model how to complete with the first piece of evidence.

#### Part 3: Construct an Explanation
5. Present the final piece of this storyline: Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth’s mineral resources is caused by geological processes. Use patterns, cause and effect, and/or matter and energy to support your thinking when presenting evidence.
6. Model how to organize a scientific explanation.
7. Collect and assess final explanations of the phenomenon.

### Management Strategy:
Check graphic organizer before students construct explanation. If all needed information is included on graphic organizer, writing is much easier for students and much easier for you to grade. Another alternative to writing is to have students create a model of the major steps/processes that led to the uneven distribution of copper in the Oquirrhs. Evidence must also be presented in the model.

### Materials
- Copies of graphic organizer
- Video Clip Link (embedded in lesson)
- Copies of *Hydrothermal Deposits*
Assessment of Student Learning

Proficient evidence includes:
Uneven distribution of copper is due to:
Location near a subduction zone (must occur at correct plate tectonic setting)
Available matter (from subduction and melting of plate)
Fracturing of host rock to allow intrusions (result of plate tectonics- forces)
Igneous process of melting, movement and hardening of magma
Presence of hydrothermal fluids and metals in the fluids
Cooling of fluids over time as they move into existing rock (copper porphyry)
Metals are deposited in rock
Tied to geologic processes (tectonics and igneous processes) and the cycling of matter due to the flow of (thermal) energy and gravitational forces.
Writing a Scientific Argument

Name ______________________________________

Phenomenon: ______________________________________

Claim: ______________________________________

Support claim with evidence

<table>
<thead>
<tr>
<th>Evidence # 1</th>
<th></th>
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<tbody>
<tr>
<td>Evidence # 2</td>
<td></td>
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<tr>
<td>Evidence # 3</td>
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Reasoning

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