Investigation: How Black Smoker Vent Chimneys Form

Overview

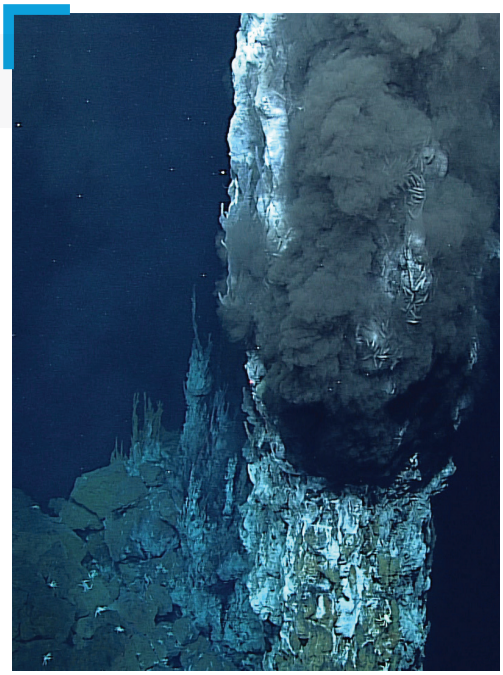
TOPIC: Hydrothermal Vents

FOCUS: Students investigate how a solid forms from the mixing of two liquids and use the science ideas they develop to help explain how chimneys form at hydrothermal vents (phenomenon).

GRADE LEVEL: 6th-8th (chemistry/geology)

TIME NEEDED: Two 45- or 50-minute class periods

PHENOMENON (DRIVING QUESTION): How do chimneys form at black smoker hydrothermal vents?



Black smoker chimney. *Image courtesy of NOAA Ocean Exploration.*

OBJECTIVES/ LEARNING OUTCOMES: Students will:

- **Analyze and interpret data on the properties of substances before and after two substances interact to determine if a chemical reaction has occurred.**
- **Use patterns in evidence from investigations and scientific sources to develop and revise an explanation of how changes in matter lead to the formation of black smoker chimneys.**

MATERIALS:

Individual Student Materials

- *Vent Chimney Student Activity Sheet* (page 11)

NEXT GENERATION SCIENCE STANDARDS (NGSS)

It is important to note that although these are the elements that are identified in the performance expectation (PE), other elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) are incorporated when appropriate. PEs are examples of how the three dimensions could be assessed at the end of instruction and are not meant to be used as curriculum but instead as a guide to build coherent learning progressions.

MS-PS1: Matter and Its Interactions

Performance Expectations
MS-PS1-2

Disciplinary Core Ideas (DCI)
PS1.A
PS1.B

Crosscutting Concepts
Patterns

Science & Engineering Practices (SEP)
Analyzing and Interpreting Data
Constructing Explanations
Obtaining, Evaluating, and Communicating Information

COMMON CORE CONNECTIONS
ELA/Literacy - RST.6-8.1, RST.6-8.7
Mathematics - 6.RP.A.3, 6.SP.B.4, 6.SP.B.5, MP.2

OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS
Principle 1, FC b

Overview cont.

MATERIALS (cont.):

Group Materials for Hands-On Investigation

- (2) 250-mL beakers
- Plastic 1-mL transfer pipette
- 400 mL water, distilled if available
- Enough of each of the following chemicals to create a saturated solution of each:
  - Magnesium sulfate (Epsom salt)
  - Sodium carbonate (washing soda)
- Plastic spoons or laboratory spatulas and stirring rods
- *Filter paper (optional)*
- *Funnel (optional)*

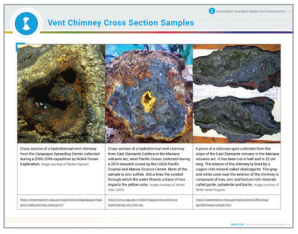
EQUIPMENT

- Video projection or online sharing capability

SET-UP INSTRUCTIONS:

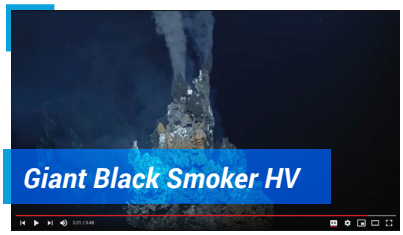
For in-person instruction:

- Cue up images and videos for student viewing
  - Black Smoker (video)
  - Hydrothermal Vents Around the World (map)
  - Giant Black Smoker Hydrothermal Vent (video)
  - Chimney Cross section comparison (images)
  - 40 Years of Hydrothermal Vent Exploration (video)
  - Timelapse of Hydrothermal Vent Formation (video)
  - Hydrothermal Vent Basics (black and white smoker comparison)
  - Deep Sea Dialogues: Hydrothermal Vents (video)
- Print the *Vent Chimney Student Activity Sheet* (page 11) as a handout (one per student).
- Print the article: NASA Study Reproduces Origin of Life on Ocean Floor and the Interview with Susan Humphris (one per student or pair)



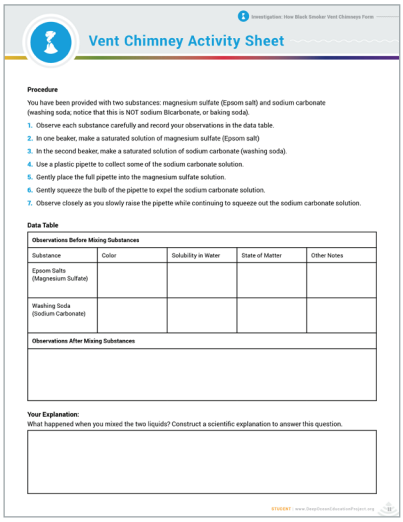
For online learning:

- Share links or digital copies of all materials listed above with students using a preferred online platform.



Video courtesy of Ocean Exploration Trust/ Nautilus Live..

A time-lapse video of a miniature hydrothermal chimney forming in the lab, as it would in early Earth's ocean.
Credits: NASA/JPL-Caltech/Flores



Educator Guide

Background

Hydrothermal vents are the result of sea water percolating down through fissures in the ocean crust near spreading centers or subduction zones. The cold seawater is heated by hot magma, and reemerges to form the vents.

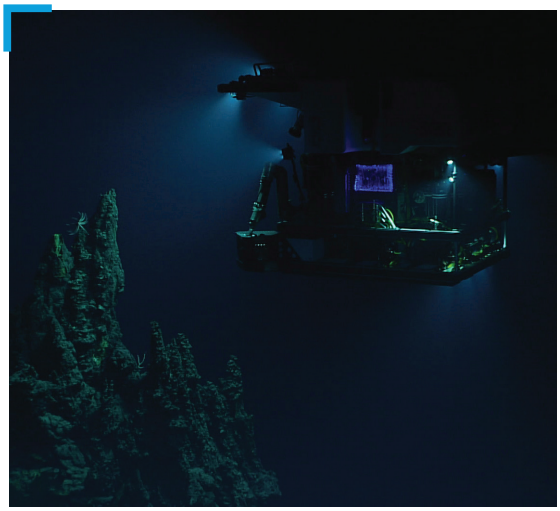
Different types of vents can form based on water temperature and other conditions. At some hydrothermal vents known as black smokers, rocky chimneys can rise more than 50 meters from the sea floor. These chimneys can grow as fast as 30 centimeters per day. These vents get their name from the color of the minerals found in the scalding fluid that billows from these chimneys.

Educator Note

For this activity:

- A variety of student interaction techniques are recommended to support equitable participation and access to science learning.
- Examples of student questions are provided throughout this activity. Use these questions to engage students in the process of sense-making to move their learning forward.

FOR MORE INFORMATION: *Hydrothermal Vents Fact Sheet*



The remotely operated vehicle *Deep Discoverer* surveying a 14-meter hydrothermal chimney. *Image courtesy of NOAA Ocean Exploration.*

Introducing the Phenomenon

Engaging in Observation

Tell students that you are sharing an interesting phenomenon with them, and ask them to make a t-chart on a sheet of paper with one column labeled "I notice..." and a second column labeled "I wonder...."

Show students the NOAA Ocean Exploration Black Smoker video recorded in the Northeast Lau Basin during the 2012 Submarine Ring of Fire expedition. Ask students to record observations ("I notice…") and questions ("I wonder…") to their t-charts charts as they watch the video.

Video courtesy of MARUM, University of Bremen and NOAA-Pacific Marine Environmental Laboratory.

Ask students to share their observations and questions with a partner and then with the whole class. As students share their ideas with the class, record them on a full class Notice and Wonder chart. Students will likely focus on the black, "smoky" fluid flowing from the chimney.

Students might ask questions like the following.

- How do these structures form?
- What is that black "smoke"?
- Why is it flowing out of the chimney? Where is it coming from?

Compile student questions without evaluating them or attempting to answer them and encourage students to focus on observations, rather than inferences. For example, ask students, "Which observations make you say that?"

Educator Guide cont.

Engaging in Observation cont.

Explain to students that the first video was recorded near the Fiji Islands and introduce another black smoker near the Galapagos Islands. Show students the locations marked on this map of Hydrothermal Vents Around the World (Woods Hole Oceanographic Institution). Play the Ocean Exploration Trust Giant Black Smoker Hydrothermal Vent video and ask students to add to their Notice and Wonder charts as they watch. Again, have students share their observations and questions with a partner and then with the whole class. Record these on the class chart.

Map courtesy of Woods Hole Oceanographic Institution.

Guiding Questions

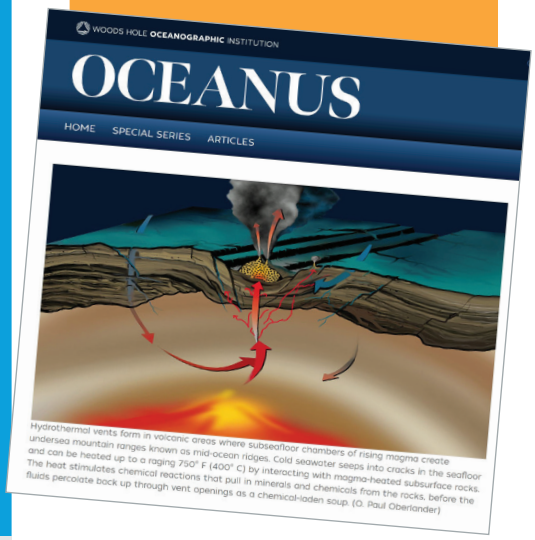
What did we learn from watching the video about how black smoker chimneys can change over time?

- How might the scientist know the age of the chimney?
- How can chimney age help us understand how they form?
- If chimneys can grow and become extinct, then how do they form in the first place?

Tell students that hydrothermal vents were first seen by humans less than 50 years ago. To emphasize how recent and challenging this discovery was, point out to students that the **first hydrothermal vent was discovered** nearly eight years *after* the first moon landing. The discovery of these structures on the deep ocean floor revolutionized our understanding of our planet and life on it. Biologists, chemists, geologists, and physicists continue to study these structures to understand their role in Earth's systems, and these scientists continue to make new discoveries.

LEARN MORE

Learn more about the discovery of hydrothermal vents: https://www.whoi.edu/oceanus/feature/the-discovery-of-hydrothermal-vents/



EDUCATOR GUIDANCE

Students might notice that both videos included the phrase black smoker, and they might ask whether there are other types of hydrothermal vents. Black smokers are one of two main types of hydrothermal vents. The other main type is white smokers. As the name suggests, these vents emit fluid that has a cloudy white appearance. The fluid emitted from these vents is cooler than black smoker fluid, and white smoker chimneys are generally smaller than black smoker chimneys and are comprised of different substances. There are also areas of the seafloor where colorless hot fluid is emitted. There are important connections and differences among these three forms of hydrothermal activity. This lesson will focus on black smokers, which produce the largest and fastest-growing chimneys. You can read more about all types of hydrothermal vents here (Hydrothermal Vents Basics).

Educator Guide cont.

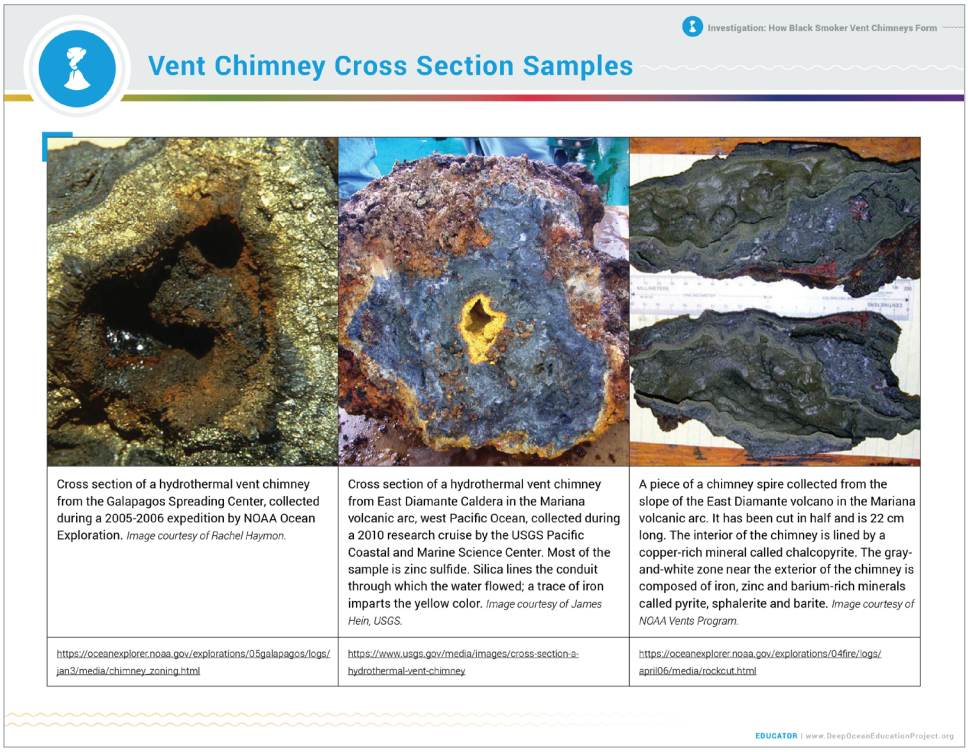
Obtaining Information and Gathering Evidence

At some point in the discussion of the first two videos, students are likely to ask questions about the composition, temperature, or other properties of the chimneys, the black fluid the chimneys eject, or the surrounding seawater. Or, students may ask how scientists study black smokers. Refer back to these student questions, and tell students that they will be watching one final video that shows them some of the ways scientists study black smokers and other hydrothermal vents. Show the Ocean Exploration Trust video 40 Years of Hydrothermal Vent Exploration (5:40). Ask students to add to their notice and wonder charts as they watch. Again, have students share their observations and questions with a partner and then with the whole class and update the class chart. This video includes clips from multiple expeditions and is very dense with information. You may want to pause for discussion after each segment or use the following questions to help students process the information presented.

- What are the different ways we saw scientists studying hydrothermal vents?
- What new information could we gather from the video?
- What questions or topics of study did scientists talk about?
- Are all hydrothermal vents the same?
- What do they all have in common?
- How would you describe the conditions near the vents?
- How does the water coming out of the vent compare to the surrounding water?

Video courtesy of the Ocean Exploration Trust.

In the 40 Years of Hydrothermal Vent Exploration video, students saw a robotic arm collecting a rock sample from a vent structure. Tell students that they will now have an opportunity to observe three samples collected in this way from vent chimneys. Project the *Vent Chimney Cross Section Samples* and ask students to add to their notice and wonder charts. Ask students to focus on patterns that they can observe across the three samples.



Students are likely to notice that while the three chimneys have different appearances and might be made of different materials, they all appear to have a concentric layered structure. Again, have students share their observations and questions with a partner and then with the whole class and update the class chart.

Educator Guide cont.

Introducing the Phenomenon cont.

Developing Initial Explanations

At this point, students have gathered a good deal of information, and they should be ready to start synthesizing that information into initial explanations of how chimneys form. Say to students, "Let's try to use what we know so far to explain how these chimneys form. What initial ideas do you have? The goal is to construct a written explanation, but you can use pictures, drawings, or models to support your explanation. Think about the following questions to help you develop your ideas."

- What do we think we know about the components of a black smoker vent?
- What do we think we know about how these components interact?
- What do we think we know about changes in energy and matter in a black smoker vent?

Have students spend a few minutes quietly writing out their ideas on paper. As students write, circulate around the room to get a sense of what ideas students are using to explain how the chimneys form. After students have had a chance to write their initial explanation, facilitate a whole-class discussion to build understanding of the evidence students have gathered, so far, and to highlight gaps in the initial explanations. Based on your observations of student explanations, call on select students to highlight useful or contrasting ideas or questions. Encourage students to elaborate on their evidence and reasoning and to build on and critique others' claims, evidence, and explanations.

Prompts might include:

- What have we figured out, so far?
- What evidence supports that claim?
- How does this explanation fit the evidence we have so far about this phenomenon?

NOTE

Over time, the height, width and thickness of a chimney structure builds around the vent flow while the temperature and chemical composition of the hydrothermal fluid varies. Concentric circles of various mineral zones form like tree rings in the chimney wall and evolve with changes in thermal and chemical gradients, as well as changes in chimney wall permeability. The different colors that can be seen in this sliced piece of hydrothermal vent structure reveal some of the different minerals that composed the vent wall.

A venting black smoker emits jets of particle-laden fluids. *Image courtesy of NOAA.*

Educator Guide cont.

Making Sense of the Phenomenon

Investigating a Related Phenomenon

Say to students, "So, one of the things we noticed is that the chimneys are forming where two liquids are mixing, but how can that work? How can something solid form by mixing two liquids? We're going to investigate a similar phenomenon that we can observe up close."

Have students work in small groups to follow the procedures on the *Vent Chimney Student Activity Sheet* (page 11).

Building Understanding

Ask students to record and share what they noticed when they mixed the two solutions, along with initial ideas about why this happened. Have students discuss their explanations within their small groups and then share with the class. Lead a discussion to build understanding from the investigation.

Use the following questions to prompt student thinking.

- Did a chemical reaction occur when you mixed the two liquids? How do you know?
- Was a new substance created? How do you know?

The goal of this discussion is for students to make sense of the idea that the white substance that appeared in the beaker when the two liquids mixed had different properties than the original Epsom salt and washing soda. Therefore, we know that a new substance was formed through a chemical reaction.

Now, share the equation for the reaction (below), and have students add to their Notice and Wonder charts. This equation includes the name and formula for each chemical involved in the reaction, and it labels each as dissolved or solid. Students should notice that the white solid they observed after mixing the two liquids was magnesium carbonate, which is poorly soluble in water.

REACTION EQUATION →

$$Na_2CO_3 + MgSO_4 \rightarrow Na_2SO_4 + MgCO_3$$

Sodium carbonate (dissolved) + Magnesium sulfate (dissolved) → Sodium sulfate (dissolved) + Magnesium carbonate (solid)

Ask students how the equation can help explain what they observed. Ask students to share their observations and questions and use the following prompts, as needed, to facilitate a discussion to build understanding.

- What's happening in this reaction?
- Where is the white substance in the beaker coming from?
- What is it? How do we know?
- How can this help us explain what we observed?

Educator Guide cont.

Making Sense of the Phenomenon cont.

Why Does It Matter?

Students might be wondering why this all matters or why scientists care so much about these "smoking" chimneys at the bottom of the ocean. The following two profiles of scientists working on questions related to hydrothermal vents provide some general context, as well as some information that can support students' sensemaking. Remind students that one reason scientists are fascinated with hydrothermal vents is the possibility that life on Earth originated near these vents. Have students read this article: NASA Study Reproduces Origins of Life on Ocean Floor.

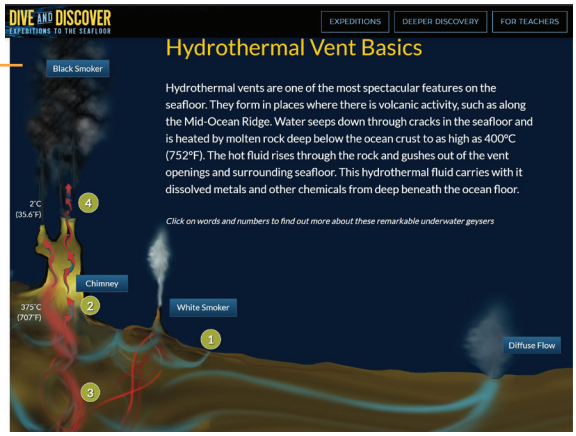
Ask students to look closely at the time-lapse video embedded in the article and to think about how that experiment is similar to and different from the reaction they observed. You can also have students read this scientist profile from the American Museum of Natural History: Let's Talk with Susan Humphris about the Chemistry of Deep Sea Vents.

After reading, ask students if there is anything from the interview that they can add to their models. You can use Humphries' discussion of her research interests to fuel students' efforts to figure out how chimneys form. She discusses the idea that chemical reactions are occurring between the seawater and rock at hydrothermal vents. If time is limited, have half of the class read each article and then share the main ideas in student pairs. Be sure that all students view the time-lapse video from the NASA article.

Obtaining Information

Tell students they will now be returning to the black smoker chimney phenomenon and obtaining information from a model that scientists have developed to explain how black smoker chimneys form. Have students follow these steps and add to their Notice and Wonder charts as they explore the model.

1. Go to the Hydrothermal Vent Basics webpage from Woods Hole Oceanographic Institution.
2. Read the overview information.
3. Click the "Black Smoker" button and read through the general description.
4. Click through the numbered buttons and read the information provided.



Black smoker
This is not smoke pouring out of the chimney. Rather it is hydrothermal fluid that is so hot (350° to 400°), it can melt lead (Pb). The fluid carries dissolved metals from deep beneath the ocean floor. When the fluid mixes with sea water, these metals combine with sulfur to form tiny black particles. These particles make the fluid look like smoke.

Revising Our Explanations

Guide students to now revise their explanations, drawing on all the evidence they have recorded on their Notice and Wonder charts from the videos, discussions, and articles, as well as evidence from the investigation. Have students spend a few minutes quietly writing out their ideas on paper. Remind students that they can use a drawing or model to support their explanation. As students work, again circulate around the room to get a sense of what ideas students are using to explain how the chimneys form.

Educator Guide cont.

Putting the Pieces Together

Building Consensus

After students have had a chance to write/draw their revised explanations, facilitate a discussion to build consensus around a common explanation of how black smoker chimneys form. Based on your observations of student explanations, call on select students to highlight useful or contrasting ideas or questions. The goal of this discussion is to help students draw a parallel between the reaction they observed between epsom salt and washing soda and the reactions that occur as hydrothermal fluid mixes with seawater at a hydrothermal vent. There are multiple complex reactions occurring at vents, but students should be able to use the idea that substances dissolved in two solutions can react to form new substances that might be solids that precipitate out of the solution. At black smoker hydrothermal vents, some of these solids form the growing chimneys and others are responsible for the smokey appearance of the fluid exiting the chimneys.

A few prompts to focus the discussion include:

- What have we figured out, so far? What evidence supports our claims?
- How are these explanations similar? How are they different?
- How could we modify what we have, so that we account for the evidence we agree is important to consider?

What Did We Figure Out?

Show students the clip of Deep-Sea Dialogues: Hydrothermal Vents video from 3:04-4:00, which provides an explanation of how black smoker chimneys form. Ask students to compare it to their own explanations and to the consensus explanation. Ask students, "How are our classroom explanations similar to and different from the explanation in the video?"

Extensions

- If time allows, have students use filter paper to collect and dry the white material formed by mixing the two solutions. Prompt students with the question: How could you collect evidence to support the claim that this material is a new substance with different properties than sodium carbonate or magnesium sulfate?

  Also prompt students to think about how they could collect evidence that there is really sodium sulfate dissolved in the water after mixing the two liquids. Students might suggest various tests for the substance, or they might suggest that you allow a sample of the solution to evaporate to see whether any substance is left behind.

- This lesson can also be used as a starting point to figuring out several big science ideas. In future lessons students could investigate the following questions.
  - Where around the world do vents form?
  - What causes them to form in these locations?
  - Why are there different types of vents?
  - Are vents similar to geysers on land?
  - Why do scientists think life might have started near hydrothermal vents?

- These additional activities connect the physical creation of vents to the biological communities that colonize them.
  - Life on a Hydrothermal Vent Investigation
  - Living on a Chimney Activity (Ocean Exploration Trust)

Educator Guide cont.

Scientific Terms

- **Hydrothermal vent:** Opening on the ocean floor from which heated, mineral-rich water emerges.
- **Hydrothermal fluid:** Super-heated, chemical rich water that rises out of the hydrothermal vent chimney. The water is heated by magma below the Earth's crust.
- **Black smoker:** Hydrothermal vent chimneys formed from deposits of iron sulfide, which is black.
- **Chimney:** The physical structure above a hydrothermal vent opening that is formed by the minerals precipitating out of the hydrothermal fluid as it mixes with the surrounding seawater.
- **Precipitate:** Precipitation is the process of conversion of a chemical substance into a solid from a solution by converting the substance into an insoluble form or a super-saturated solution. When the reaction occurs in a liquid solution, the solid formed is called the precipitate.

Assessment

Opportunities for formative assessment are embedded throughout the lesson. The student explanations that are developed at the end of the lesson (whether written or drawn) could be used as an opportunity for summative assessment of learning.

LOOK FORS:

The following components should be included in students' final explanations. These may be represented through a combination of words, pictures, and symbols.

- Seawater has substances dissolved in it, but it is generally a clear liquid.
- Seawater that seeps into rock near hydrothermal vents picks up new substances that dissolve from the rock and is then known as hydrothermal fluid.
- Hydrothermal fluid is a liquid solution containing many dissolved substances.
- When hydrothermal fluid mixes with seawater, chemical reactions occur that produce solid particles.
- We know that chemical reactions are occurring because substances with new properties are being formed.
- Some of these small solid particles make the fluid look smokey as it comes out of the vent.
- Some of these solid particles build up around the vent to form chimneys. These chimneys can grow as more solids are deposited.

Adaptations

ONLINE LEARNING

- Image and video links can be provided through a preferred online platform with students divided into small online breakout groups to work through elements of the activity.

DIFFERENT GRADE/ LEARNING LEVELS

- Guidance based on student background as well as possible extensions are provided within the Educator Guide.
- Some students may benefit from having transcripts (or closed captions) of the videos to both reference and highlight.

Vent Chimney Student Activity Sheet

Procedure

You have been provided with three substances: magnesium sulfate (Epsom salt) and sodium carbonate (washing soda; notice that this is NOT sodium BIcarbonate, or baking soda) and water.

1. Observe each substance carefully and record your observations in the data table.
2. In one beaker, make a saturated solution of magnesium sulfate (Epsom salt).
3. In the second beaker, make a saturated solution of sodium carbonate (washing soda).
4. Use a plastic pipette to collect some of the sodium carbonate solution.
5. Gently place the full pipette into the magnesium sulfate solution.
6. Gently squeeze the bulb of the pipette to expel the sodium carbonate solution.
7. Observe closely as you slowly raise the pipette while continuing to squeeze out the sodium carbonate solution.

Data Table

Observations Before Mixing Substances				
Substance	Color	Solubility in Water	State of Matter	Other Notes
Epsom Salts (Magnesium Sulfate)				
Washing Soda (Sodium Carbonate)				
Observations After Mixing Substances				

Your Explanation:

What happened when you mixed the two liquids? Construct a scientific explanation to answer this question.

Investigation: How Black Smoker Vent Chimneys Form Links and Resources

Page 1:
- Black smoker (image): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/may11/media/1605vent-hires.jpg

Page 2:
- Black Smoker (video): https://oceanexplorer.noaa.gov/explorations/12fire/logs/photolog/photolog.html#cbpi=/explorations/12fire/logs/sept18/media/video/black-smoker.html
- Hydrothermal Vents Around the World (map): https://divediscover.whoi.edu/hydrothermal-vents/vents-around-the-world/
- Giant Back Smoker Hydrothermal Vent (video): https://www.youtube.com/watch?v=KtFFmDGIsa4&list=PLRk9nnqFxr29uuSUM7NlxLR1wIbnMUxU8
- 40 Years of Hydrothermal Vent Exploration (video): https://www.youtube.com/watch?v=UVzBjY8oLkk
- Chimney Cross section comparison (images): https://oceanexplorer.noaa.gov/edu/materials/vent-chimney-cross-section-images.pdf
- Timelapse of Hydrothermal Vent Formation (video): https://solarsystem.nasa.gov/news/863/nasa-study-reproduces-origins-of-life-on-ocean-floor/
- Hydrothermal Vents Basics (black and white smoker comparison): https://divediscover.whoi.edu/hydrothermal-vents/ventbasics/
- Deep Sea Dialogues: Hydrothermal Vents (video): https://oceanexplorer.noaa.gov/edu/multimedia-resources/dsd/dsd.html#hydrothermal-vents
- NASA Study Reproduces Origin of Life on Ocean Floor (article): https://solarsystem.nasa.gov/news/863/nasa-study-reproduces-origins-of-life-on-ocean-floor/
- Scientist profile on Susan Humphris: https://www.amnh.org/learn-teach/curriculum-collections/deep-sea-vents/the-chemistry-of-deep-sea-vents

Page 3:
- Hydrothermal Chimney (image): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/dailyupdates/media/apr28-hires.jpg
- Black Smoker (video): https://oceanexplorer.noaa.gov/explorations/12fire/logs/photolog/photolog.html#cbpi=/explorations/12fire/logs/sept18/media/video/black-smoker.html

Page 4:
- Hydrothermal Vents Around the World (map): https://divediscover.whoi.edu/hydrothermal-vents/vents-around-the-world/
- Giant Back Smoker Hydrothermal Vent (video): https://www.youtube.com/watch?v=KtFFmDGIsa4&list=PLRk9nnqFxr29uuSUM7NlxLR1wIbnMUxU8
- Discovery of Hydrothermal Vents (web page): https://www.whoi.edu/oceanus/feature/the-discovery-of-hydrothermal-vents/
- Hydrothermal Vents Basics: https://divediscover.whoi.edu/hydrothermal-vents/ventbasics/

Page 5:
- 40 Years of Hydrothermal Vent Exploration (video): https://www.youtube.com/watch?v=UVzBjY8oLkk
- Chimney Cross section comparison (images): https://oceanexplorer.noaa.gov/edu/materials/vent-chimney-cross-section-images.pdf

Page 6:
- Vents (image): https://oceanservice.noaa.gov/facts/vents.html

Page 8:
- NASA Study Reproduces Origin of Life on Ocean Floor (article): https://solarsystem.nasa.gov/news/863/nasa-study-reproduces-origins-of-life-on-ocean-floor/
- Scientist profile on Susan Humphris: https://www.amnh.org/learn-teach/curriculum-collections/deep-sea-vents/the-chemistry-of-deep-sea-vents
- Hydrothermal Vent Basics (webpage): https://divediscover.whoi.edu/hydrothermal-vents/ventbasics/

Page 9:
- Deep Sea Dialogues: Hydrothermal Vents (video): https://oceanexplorer.noaa.gov/edu/multimedia-resources/dsd/dsd.html#hydrothermal-vents
- Life on a Hydrothermal Vent (activity): https://oceanexplorer.noaa.gov/edu/materials/life-on-hydrothermal-vent-investigation.pdf
- Living on a Chimney (activity): https://nautiluslive.org/resource/living-chimney

Partners

OCEAN EXPLORATION

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Created in cooperation with the National Marine Sanctuary Foundation under federal award NA19OAR0110405 for the Deep Ocean Education Project.

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