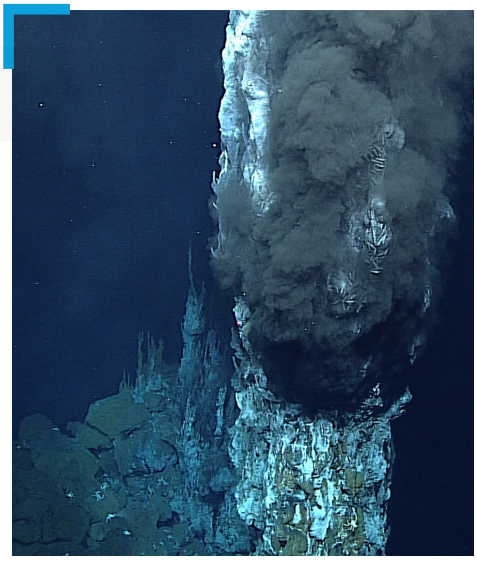
Investigation: How Black Smoker Vent Chimneys Form



A "black smoker" where the super-hot vent fluid meets very cold ambient sea water (2°C) of the deep sea. Minerals that are carried in the fluid precipitate out of solution forming spectacular vent chimneys. *Image courtesy of NOAA Ocean Exploration.*

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: 6-8 Chemistry, Geology

TIME NEEDED: Two 50-minute class periods

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

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.

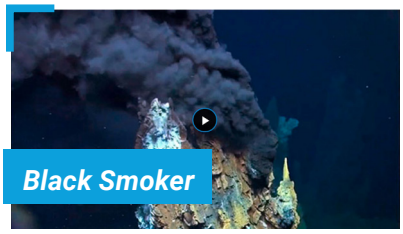
MATERIALS:

Student Handout

Student Worksheet: How Black Smoker Vent Chimneys Form (1 per student)

Videos and Images

- Black Smoker (1:09) *NOAA Ocean Exploration*
- 40 Years of Hydrothermal Vent Exploration (5:40) *Ocean Exploration Trust*
- Hydrothermal Vents Around the World
- Deep-sea Dialogues: Hydrothermal Vents (9:30) *NOAA Ocean Exploration*
- Vent Formation Demonstration (1:08) *NOAA Ocean Exploration*
- *Optional:* Vent Chimney Cross Section Samples



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

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Performance Expectations (PEs)
MS-PS1-2

Disciplinary Core Ideas (DCIs)
PS1.A Structure and Properties of Matter
PS1.B Chemical Reactions

Crosscutting Concepts (CCs)
Patterns

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

COMMON CORE CONNECTIONS
RST.6-8.1, RST.6-8.7
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.

Investigation Materials (Set-up for each group of 3-5 students)

- 1 tray for materials
- 1 locker stand (or something similar for the base)
- 1 clear plastic cup with a small hole made at the bottom of the cup to fit tightly around the point of the syringe.
- One 10 mL plastic syringe
- Two 140 or 250 mL beakers (or 2 small, plastic cups can be used)
- 400 mL water, distilled if available
- Enough of each of the following chemicals to create a saturated solution (Approximately one spoonful of each):
  - Magnesium sulfate (Epsom salt)
  - Sodium carbonate (washing soda, not baking soda)
- Plastic spoons or laboratory spatulas and stirring rods
- Container for liquid waste

EQUIPMENT:

- Computer and projector for class viewing of videos

SET-UP INSTRUCTIONS:

- Cue up images and videos to show the class.
- Prepare a blank "I Notice, I Wonder" chart on the board or computer to project for students.
- Prepare trays with all lab materials listed for each group.
  Do not pre-mix the saturated solutions for students. Saturated solutions should be prepared by students so they can make some initial observations.

Educator Guide

Background

Hydrothermal vents are the result of seawater 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.

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 composed 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. Hydrothermal Vents Basics provides more information about all types of hydrothermal vents.

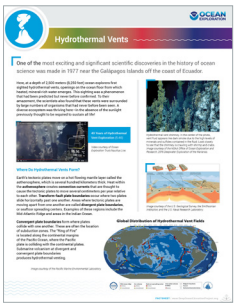
Educator Guide cont.

Educator Note

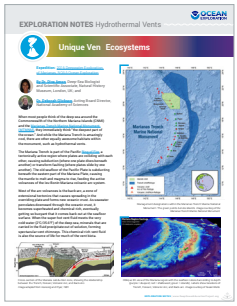
- Students should have prior knowledge of chemicals reactions, solutions, and precipitates.
- A variety of student interaction techniques and examples of student questions are provided throughout this activity to engage students in the process of sensemaking.

FOR MORE INFORMATION:

- *Hydrothermal Vents* Fact Sheet



- *Unique Vent Ecosystems* Exploration Note



Experience the Phenomenon

Tell students you are sharing an interesting phenomenon about hydrothermal vents today.

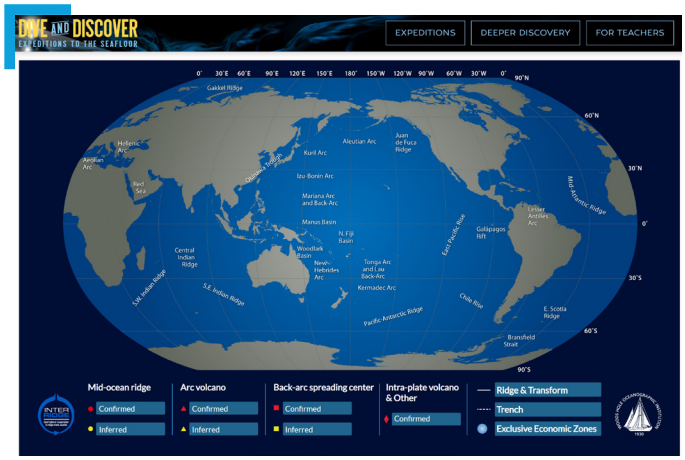
Distribute the Student Worksheet: How Black Smoker Chimneys to each student. They will be able to work together but must write down their own answers and draw their own model/diagram.

Play both of the following videos and ask students to record their observations (I Notice) and questions (I Wonder) on their student worksheets as they watch. Pause after each video to give students time to record all of their observations and questions.

- Black Smoker (0 - 1:09) *NOAA Ocean Exploration*
- 40 Years of Hydrothermal Vent Exploration (2:17 - 5:40) *Ocean Exploration Trust*

Video courtesy of the Ocean Exploration Trust.

Provide some more context and background for students by sharing Hydrothermal Vents Around the World and asking them what sort of pattern they see regarding where these vents are located.



Map courtesy of Woods Hole Oceanographic Institution.

Ask students to share and discuss their observations and questions with their group and then with the whole class.

Record observations and questions 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"? Is it hot?
- Why is it flowing out of the chimney?
- Where is it coming from?
- What are these structures made of?

Educator Guide cont.

Guide students toward the observations and questions relating to how vent chimneys form.

Have students answer questions 1-4 on their student worksheet. They should have time to brainstorm and write down one way they think vent chimneys could form.

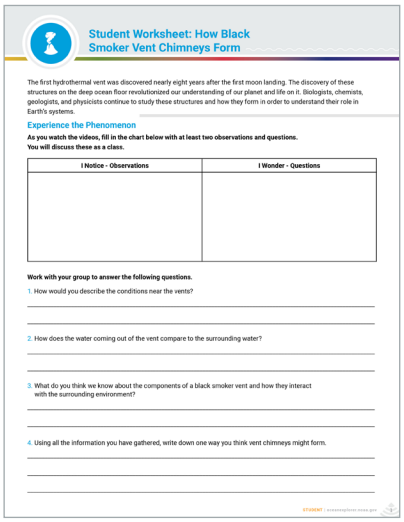
Circulate around the room to get a sense of what ideas students are using to explain how the chimneys form.

Guiding Questions

- 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? Do we need more evidence?

Investigate

Have students work in small groups and follow the procedures on their Student Worksheet to set up the investigation.


Student Worksheet: How Black Smoker Vent Chimneys Form

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 and how they form in order to understand their role in Earth's systems.

Experience the Phenomenon

As you watch the videos, fill in the chart below with at least two observations and questions. You will discuss these as a class.

I Notice - Observations	I Wonder - Questions

Work with your group to answer the following questions.

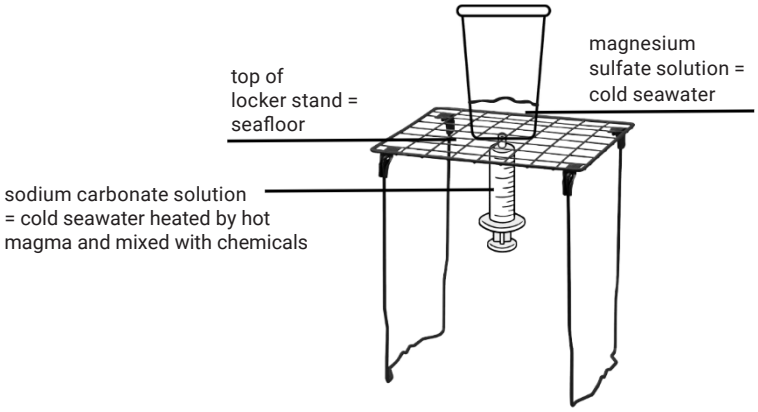
1. How would you describe the conditions near the vents?
2. How does the water coming out of the vent compare to the surrounding water?
3. What do you think we know about the components of a black smoker vent and how they interact with the surrounding environment?
4. Using all the information you have gathered, write down one way you think vent chimneys might form.

Vent Formation Demonstration: *Preparing the Saturated Solutions*

- In one beaker, have students make a saturated solution of magnesium sulfate (Epsom salt) by mixing ~1 tsp of Epsom salt with ~140 mL of distilled water.
- In the second beaker, have students make a saturated solution of sodium carbonate (washing soda) by mixing ~1 tsp of washing soda with ~140 mL of distilled water.
- **Ask** students to record their observations on their data table.

Student Group Procedure: *Combining the Two Saturated Solutions*

- Use a plastic syringe to collect 10mL of the sodium carbonate solution from the beaker.
- Gently place the full syringe into the hole on the bottom of the empty, plastic cup. DO NOT push the contents of the syringe into the cup yet.
- Then, fill the empty plastic cup with all of the magnesium sulfate solution.
- Finally, gently press the syringe to expel the sodium carbonate solution into the cup with the magnesium sulfate solution.
- Observe closely as the liquid in the syringe combines with the liquid in the plastic cup.
- Answer questions 5-10 on their student worksheets.



Example of lab-setup with labels indicating what each part of the set-up represents in the ocean.

Educator Guide cont.

Lead a discussion to build understanding once they have completed their investigation. 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 solutions. Therefore, we know that a new substance was formed through a chemical reaction.

Share the equation for the reaction (below) and have them write it down on their student worksheet. 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 to share their observations and questions and use the following prompts to facilitate a discussion.

- What happened in this reaction?
- How did the white substance in the beaker form? What is this?
- How can this help us explain what we observed?

Give students time to record their explanation on their student worksheets.

Put the Pieces Together

Help students draw a parallel between the reaction they observed when the Epsom salt and washing soda solutions were combined and the reactions that occur as hydrothermal fluid mixes with seawater at a hydrothermal vent. **Show** students the Vent Formation Demonstration video (1:08).

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 **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.

Guiding questions:

- What have we figured out so far?
- What evidence supports our claims?

Show students the clip of Deep-Sea Dialogues: Hydrothermal Vents video from 3:04-4:00 min, which provides an explanation of how black smoker chimneys form.

Have students answer the discussion questions, revise their explanations, and draw their final diagrams to answer the driving question.

Video courtesy of NOAA Ocean Exploration.

Educator Guide cont.

Extensions

- **Have** students make additional observations to add to their notice and wonder charts. Project the Vent Chimney Cross Section Samples and inform students that the image shows three samples collected from vent chimneys. Have them focus on patterns they can observe across the three samples. Students should 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.
- **Have** students use filter paper to collect and dry the white material formed by mixing the two solutions to answer 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?*
- This lesson can be used as a starting point to figuring out several big science ideas using the resources and investigation questions below.

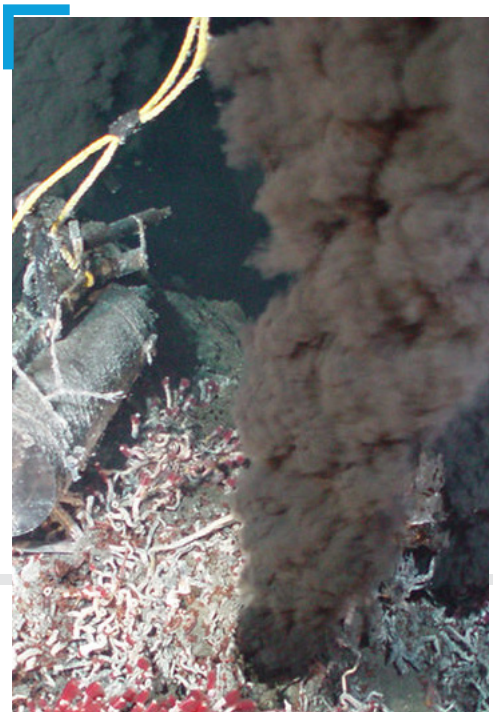
Resources

- Hydrothermal Vents Around the World
- NASA Study Reproduces Origins of Life on Ocean Floor
- Let's Talk with Susan Humphris about the Chemistry of Deep Sea Vents | AMNH
- The Discovery of Hydrothermal Vents

Investigation 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.
  - Student Investigation: Life on a Hydrothermal Vent *(NOAA Ocean Exploration)*
  - Living on a Chimney Activity *(Ocean Exploration Trust)*



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

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.

Educator Guide cont.

Assessment

Opportunities for formative assessment are embedded throughout the lesson and through class discussions. The student explanations and answers on the student worksheet and drawings that are developed at the end of the lesson 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.

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
- Student Worksheet: How Black Smoker Vent Chimneys Form (pdf): https://oceanexplorer.noaa.gov/edu/materials/vent-chimney-formation-student-worksheet.pdf
- 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/
- 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
- Deep Sea Dialogues: Hydrothermal Vents (video): https://oceanexplorer.noaa.gov/edu/multimedia-resources/dsd/dsd.html#hydrothermal-vents
- Vent Formation Demonstration (video): https://oceanexplorer.noaa.gov/edu/materials/vent-formation-demo.mp4

Page 2:
- Hydrothermal Vents Basics (black and white smoker comparison): https://divediscover.whoi.edu/hydrothermal-vents/ventbasics/

Page 3:
- Making Sense of Deep-Sea Phenomena (pdf): https://oceanexplorer.noaa.gov/edu/materials/NOAA-NSTA-sensemaking-phenomenon.pdf
- Hydrothermal Vents (fact sheet): https://oceanexplorer.noaa.gov/edu/materials/hydrothermal-vents-fact-sheet.pdf
- Unique Vent Ecosystems (pdf): https://oceanexplorer.noaa.gov/edu/materials/vent-ecosystems-exploration-notes.pdf
- Student Worksheet: How Black Smoker Vent Chimneys Form (pdf): https://oceanexplorer.noaa.gov/edu/materials/vent-chimney-formation-student-worksheet.pdf
- Black Smoker (video): https://oceanexplorer.noaa.gov/explorations/12fire/logs/photolog/photolog.html#cbpi=/explorations/12fire/logs/sept18/media/video/black-smoker.html
- 40 Years of Hydrothermal Vent Exploration (video): https://www.youtube.com/watch?v=UVzBjY8oLkk
- Hydrothermal Vents Around the World (map): https://divediscover.whoi.edu/hydrothermal-vents/vents-around-the-world/

Page 4:
- Student Worksheet: How Black Smoker Vent Chimneys Form (pdf): https://oceanexplorer.noaa.gov/edu/materials/vent-chimney-formation-student-worksheet.pdf

Page 5:
- Vent Formation Demonstration (video): https://oceanexplorer.noaa.gov/edu/materials/vent-formation-demo.mp4
- Deep Sea Dialogues: Hydrothermal Vents (video): https://oceanexplorer.noaa.gov/edu/multimedia-resources/dsd/dsd.html#hydrothermal-vents

Page 6:
- Chimney Cross section comparison (images): https://oceanexplorer.noaa.gov/edu/materials/vent-chimney-cross-section-images.pdf
- Hydrothermal Vents Around the World (map): https://divediscover.whoi.edu/hydrothermal-vents/vents-around-the-world
- 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
- Discovery of Hydrothermal Vents (web page): https://www.whoi.edu/oceanus/feature/the-discovery-of-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

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