HOW TO USE THIS RESOURCE

The images for this resource, showing the chalk cliffs of Dover, England, and the microscopic skeletons of coccolithophore algae, can serve as an anchoring phenomenon to explore the key concepts described below. The pedagogical practice of using phenomena to provide a context for understanding science concepts and topics is an implementation practice supported by the Next Generation Science Standards (NGSS). Phenomena are observable occurrences that students can use to generate science questions for further investigation or to design solutions to problems that drive learning. In this way, phenomena connect learning with what is happening in the world while providing students with the opportunity to apply knowledge while they are building it.

The "Implementation Suggestions" and "Teaching Tips" sections provide options for incorporating the images into a curriculum or unit of study and can be modified to use as a standalone activity or to supplement an existing lesson. The student handout includes reproductions of the images and the "Background Information" section.

KEY CONCEPTS

A. Environmental factors such as topography, temperature, and ocean pH can determine the ability of microscopic algae to survive and reproduce over the geologic timescale.
B. Specific biological processes, geologic internal processes (tectonic uplift), and surface processes (weathering and erosion) are causal agents in building up and wearing down the Cliffs of Dover over time.
C. The geologic record found in the chalk cliffs of Dover can help predict the future effects of climate change on the chemical composition (e.g., ocean pH) and biodiversity of the oceans.

NGSS PERFORMANCE EXPECTATIONS

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

BACKGROUND INFORMATION

The White Cliffs of Dover (Figure 1) are a striking geological, ecological, historical, and cultural feature of the English coastline. Rising up to 350 ft (110 m) along 8 miles (13 km) of the English Channel, the cliffs are composed of chalk, which gives them their unique white color. Chalk is a sedimentary rock made of a substance called calcium carbonate ($CaCO_3$). This substance forms from the microscopic skeletons of phytoplankton, such as coccolithophores.

Coccolithophores, such as *Emiliania huxleyi* (Figure 2), are a type of microscopic algae often found at the base of marine food chains. Coccolithophores secrete calcium carbonate, which forms plates called coccoliths. These coccoliths cover the coccolithophores' surfaces in hard shells. When coccolithophores die, their shells sink to the seafloor and form chalky sediments. This process has been going on for millions of years and is responsible for the vast deposits of chalk around the world.

Emiliania huxleyi is named after Cesare Emiliani and Thomas Henry Huxley, who were among the first to discover the coccolithophores within seafloor sediment. In 1868, Huxley, a scientist and educator, gave a public lecture in Norwich, England, titled "On a Piece of Chalk." Huxley explained that the chalk he was using to write on the blackboard was made of the same material as Norwich's white bedrock: fossilized skeletons of coccolithophores.

Because coccolithophores live in shallow oceans, Huxley concluded that a shallow sea had once covered Norwich and left behind chalky bedrock. Even today, coccolithophores continue to provide evidence of environmental change over time. For example, coccolithophore species that are sensitive to seawater acidity are being used to track global trends in ocean acidification resulting from climate change.

Technical Details: The sample of *Emiliania huxleyi* shown in Figure 2 was collected in the English Channel. The coccolithophores were filtered from the seawater and then imaged with a scanning electron microscope at the Natural History Museum in London. The image was subsequently colorized using a computer. Each coccolithophore is approximately 4 micrometers in diameter, around half the size of a red blood cell.

IMPLEMENTATION SUGGESTIONS

The following suggestions outline several options for incorporating the images into a unit of study as the anchoring phenomenon:

Engagement, establishing prior knowledge, and providing context:

- Begin the lesson by showing the image of the Cliffs of Dover (Figure 1) and asking students to make observations using the sentence stems "I notice …", "It reminds me of …", and "I wonder …" Use a think-pair-share protocol to have them make observations about what's happening in the image. Record class observations, noting when students make similar observations and drawing attention to the range of student-generated questions from this brief observation.
  - Observations may include that a flat field drops off in a cliff down to water, the rocks of the cliff are a much lighter color than the rocks below, some sections of the cliff have grasses or plants growing on them, there are no trees or visible animals, and the water is a light gray color with some waves.
- Split students into groups of two to four. Give each group the Cliffs of Dover image (Figure 1), a new microscopic image of coccolithophores (Figure 2), and a piece of chalk. Let students know that these three objects are all closely related to each other. Lead groups through the Question Formulation Technique described below to explore the relationship between these items.
  - Prompt students to ask as many questions as they can about the images and chalk. Set a time limit, such as 5 minutes, giving a 1-minute warning.
  - As students ask questions, they should follow these rules: Write down every question, don't get sidetracked by answers, write the entire time, and each group member must ask two questions before anyone can share a third.
  - Each group should number and record their questions. Depending on the time limit, groups may need prompting to continue writing. Remind them that in science there are always more questions to ask!
  - When time is up, students should identify each question as open- or close-ended. They can do this with a highlighter or symbols. You may want to highlight the difference between open- versus close-ended questions for students with an example.
    - Open-ended: "How do temperature and rainfall impact the cliff's appearance?" (does not have one short, limited "correct" answer)
    - Close-ended: "Where was the picture taken?" (has one short, limited "correct" answer)
  - Each group member should pick a different close-ended question and revise it to be more open-ended or investigable.
  - To share out, each group should then pick the open-ended question they are most curious about. Have each group record their question on the board, making sure to include the question's number out of the total number of questions the group originally asked. For example:
    - 18/20: Why are the cliffs and chalk white, while the sphere is green? (where 18 is the number of the question and 20 is the total number of questions that the group asked)

- Discuss patterns in the questions or possible investigations students could carry out to answer their questions. Draw attention to revised questions, which may come from lower down in lists (e.g., 18/20 vs. 2/20), and emphasize that asking questions leads to even better questions.

- At this point, have students read the "Background Information" for the images. Explain that the Cliffs of Dover (Figure 1), and much of England, are made of chalk very similar to the chalk the students have on their table. The other image (Figure 2) shows the calcium carbonate skeletons of microscopic algae called coccolithophores, which live in shallow oceans. Over time, these skeletons can collect on the seafloor and lithify to form chalk.
  - It may be helpful to show the location of the Cliffs of Dover on a map of England and to compare the calcium carbonate coccolithophore skeleton to an oyster shell or coral skeleton.
- Give each group of students a blank piece of paper (11" × 17" paper works well if available) and ask them to fold it into thirds. Students should label the sections as "A) Past," "B) Present," and "C) Future." In each section, ask students to create a visual model explaining respectively A) how the chalk in the Cliffs of Dover formed, B) why the cliffs look the way they do in Figure 1 now, and C) a prediction of what the cliffs will look like in 100+ years.
  - Each section should include a representation of the macroscopic and microscopic scale. It may be helpful to give students an example of what an inset looks like, such as a designated circle where they can zoom in on a detail of the cliffs.
  - Have students initial their contributions to the model. As they work, ask them to make sure all group members' initials are in each section.
  - It may be helpful to remind students that their models do not need to be artistically accurate sketches. Scientific models can include diagrams, physical replicas, mathematical representations, and analogies that are used to predict or explain phenomena. Models that are diagrams often rely on labels, arrows, symbols, and color-coding.
  - When all the models are finished, students can conduct a "gallery walk" to view other models and generate questions, feedback, and new ideas.
  - These initial models may represent the formation of the cliffs incorrectly. Although the cliffs formed through accumulation of dead coccolithophores on the seafloor, lithification into chalk, geologic uplift, and weathering into cliffs, student representations will vary. These processes are further explored in the sections below, which allow students to revise their models.

Exploration, investigation, and assessment:

- Exploration:
  - In the activity "Weighing the Evidence for a Mass Extinction — In the Ocean," students learn about the importance of microfossils to our understanding of the geologic record and mass extinctions. It may be helpful to modify or shorten the activity based on students' math background and previous knowledge of the K-T boundary extinction event.
    - Make sure students understand that forams are microscopic zooplankton with skeletons similar to those of the coccolithophores that make up chalk.
    - Clips of the short film *The Day the Mesozoic Died* may be used to introduce this activity and give context for the K-T extinction event. For a general introduction, use 0:00–5:05. For more information on the K-T boundary and foraminifera (to be shown after or during the activity), use 5:05–15:30.
    - The poster *Foraminifera — Earth's Microscopic Recordkeepers* can serve as an additional resource for students.
  - Students should now have a basic understanding of how marine sediments accumulate and may become part of the geologic record. Ask students to consider the following question: "If chalk is made of the

skeletons of marine algae, why do we now find chalk in cliffs and on dry land?" After sharing answers, show the *Plate Tectonics* animation to introduce the underlying principles of geologic uplift.
  - After completing these two activities, groups should return to their initial models and revise the "A) Past" section. It is suggested that students use a new color to make their revisions. This revision will serve as a brief formative assessment to ensure that students have a solid understanding of how chalk forms before moving on to the next activities.
- Investigation:
  - Students then investigate the impact of rising CO_2 levels on marine systems, and its implications for calcium carbonate structures, in the hands-on activity "Ocean Acidification." It may be helpful to modify this activity based on students' math and chemistry backgrounds.
    - In addition to this activity, students can place their piece of chalk in the "seawater" from the activity and observe changes over a 24-hour period. This can be set up during the previous class period.
  - Alternatively, the "Trends in Atmospheric Carbon Dioxide" Data Point provides an opportunity for students to explore quantitative evidence for global climate change.
- Assessment:
  - Groups should once again return to their initial models and revise the "B) Present" and "C) Future" sections. It is suggested that students use a new color to make revisions. Any misconceptions or student questions about "C) Future" models can be used to transition to discussion of global and regional climate change, human impacts, and designing solutions.

Extension:
- The *Understanding Global Change* Click & Learn provides students with a platform to further explore and model the underlying processes of ocean acidification, mass extinctions, and landscape changes. Alternatively, this interactive can be used as part of the "Assessment" section.
- Students can further research and model a local geologic/landscape formation or impact of climate change. This can be done on the reverse side of the Cliffs of Dover model using the same format of "A) Past," "B) Present," and "C) Future."
- As time and materials allow, students can create a 3D model of the uplift, weathering, and erosion processes that create cliff faces. This open-ended exploration can be done with a stream table or paint tray; other resources may include sand, gravel, modeling clay, water, and cups with holes of different sizes in the bottom.

TEACHING TIPS

- Present students with the images first, before they read the background information.
- Background information may be edited to support student proficiency, course sequence, etc.
- The image(s) may be projected in lieu of handouts.
- Printed images can be laminated for use in multiple classes.
- Pair or group students to work through one or more of the implementation suggestions.

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