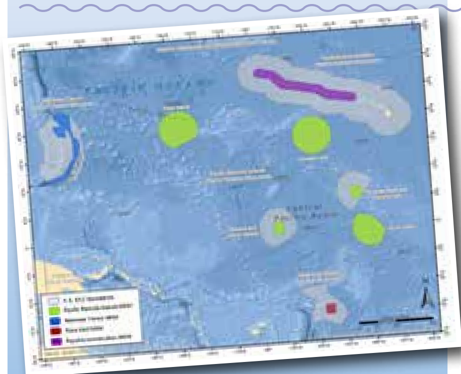
Hohonu Moana:
Exploring Deep Waters Off Hawaii Expedition 2015

Cobalt-rich Ferromanganese Crust Ecosystems



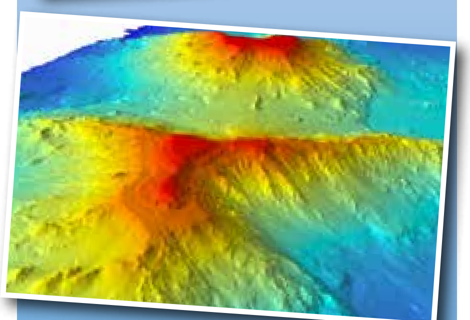


Image captions/credits on Page 2.

lesson plan

Grade Level

9-12 (Earth Science)

Focus

Ecosystems associated with cobalt-rich ferromanganese crusts

Focus Question

What types of ecosystems are associated with cobalt-rich ferromanganese crusts, and how can these ecosystems be protected from the impacts of mining these kinds of mineral resources?

Learning Objectives

- Students will define cobalt-rich ferromanganese crusts, explain how they are formed, discuss their associated ecosystems, and discuss the positive and negative impacts of mining these mineral resources from the deep ocean.

- Students will evaluate competing design solutions for protecting ecosystems associated with cobalt-rich ferromanganese crusts from potential human impacts.

Materials

- ❑ Computers with Internet access
- ❑ Copies of *Deep-sea Minerals Investigation*, one copy for each student or student group

Audio-Visual Materials

- ❑ (Optional) Interactive white board

Teaching Time

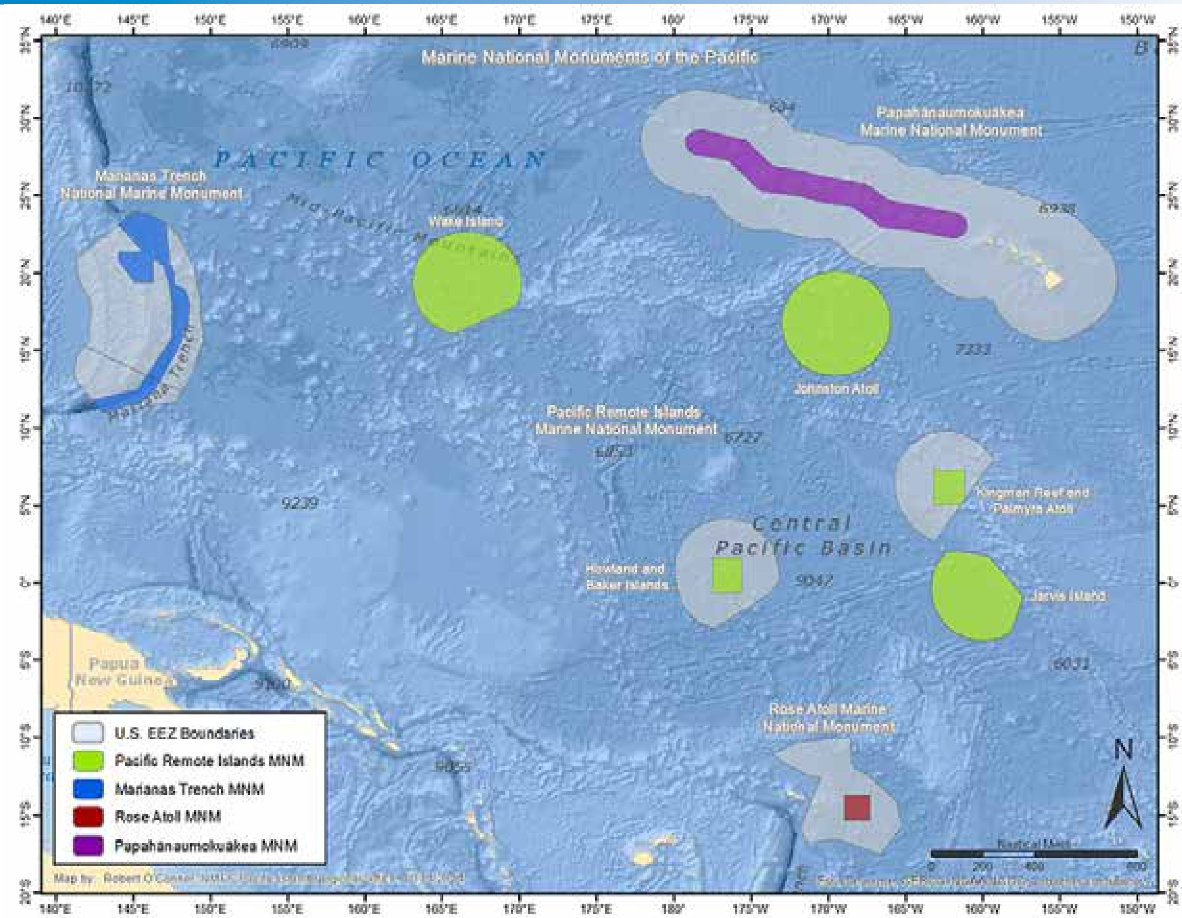
Two to three class periods, plus time for student research

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30



Marine National Monuments of the Pacific. Image credit: Robert O'Conner, NMFS, Pacific Island Regional Office (PIRO)
http://www.fpir.noaa.gov/Graphics/MNM/Pacific_MNM_DRAFT_10_14_2014.jpg

Key Words

archipelago
atoll
Marine National Monument
cobalt
ferromanganese crust
seamount

Background

Marine protected areas (MPAs) are areas of the marine environment where there is legal protection for natural and cultural resources. In the United States, marine national monuments are marine protected areas that are created by Presidential Proclamation (this is a different creation process than for national marine sanctuaries, which are designated by NOAA or Congress and require extensive public process, local community engagement, stakeholder involvement, and citizen participation for designation and management).

The two largest U.S. Marine National Monuments of the United States are Papahänaumokuäkea Marine National Monument (PMNM) northwest of the inhabited main Hawaiian Islands, and Pacific Remote Islands Marine National Monument (PRIMNM) which consists of Wake,

Images from Page 1 top to bottom:
Marine National Monuments of the Pacific. Image credit: Robert O'Conner, NMFS, Pacific Island Regional Office (PIRO)
http://www.fpir.noaa.gov/Graphics/MNM/Pacific_MNM_DRAFT_10_14_2014.jpg

3D image of Academician Berg seamount in the Papahanaumokuakea Marine National Monument. Image credit: C. Kelley (created from data obtained by the Schmidt Ocean Institute).

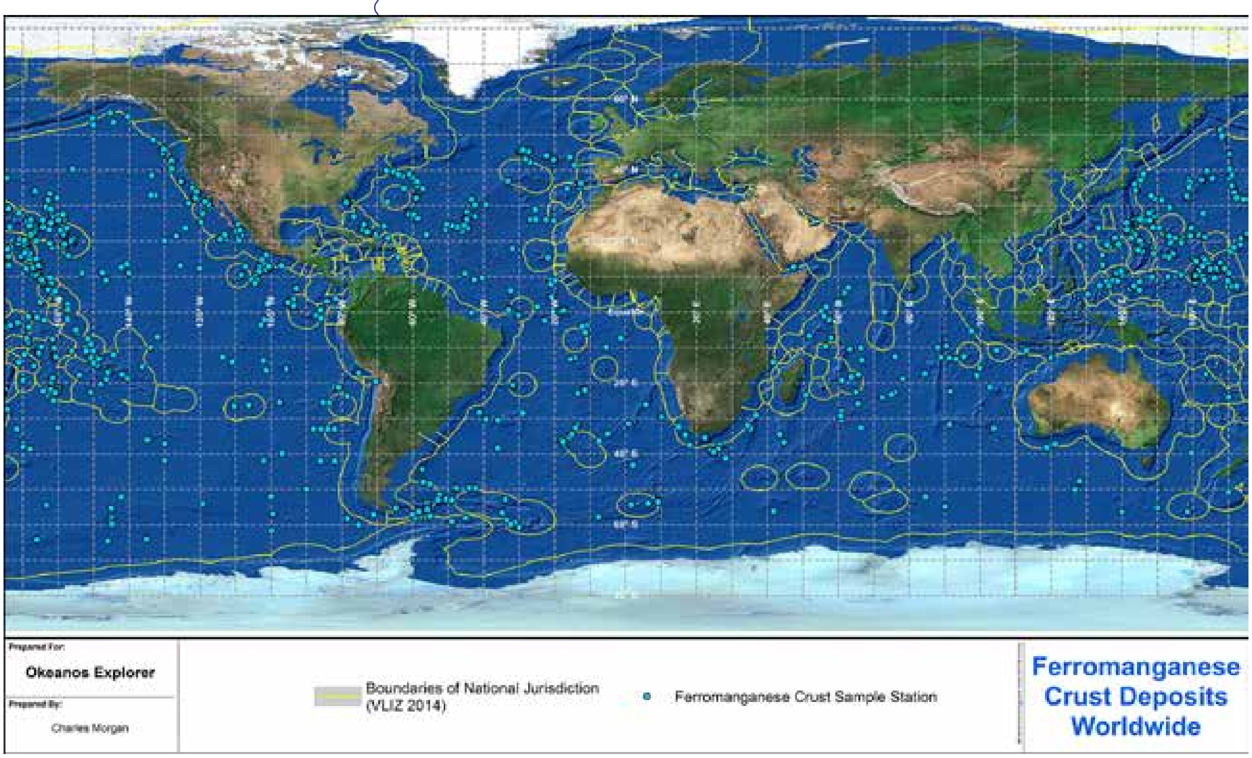
A Hawaiian species of gorgonian called *Rhodaniridogorgia* bending in the current. Image credit: NOAA-HURL archives.

Hawaiian bubblegum coral at 350 m depth with anemones, brittlestars, and other animals living in their colonies. Image credit: NOAA-HURL archives.

Howland, Baker and Jarvis Islands, Johnston Atoll, Kingman Reef and Palmyra Atoll. Besides being the two largest Marine National Monuments, they are also among the world's most remote MPAs. Many of the species found in these MPAs are found nowhere else on Earth (species that are found in only one specific location are said to be "endemic" to that location). The marine habitats of PMNM, for example, are home to over 7,000 species, 25% of which are endemic. For additional information about PMNM and PRIMNM, please see the essay, "Exploration of the two largest marine protected areas of the United States," by Daniel Wagner and Samantha Brooke. [http://oceanexplorer.noaa.gov/okeanos/explorations/ex1504/background/mpas/welcome.html]

In addition to containing unique biological, geological, and cultural resources, PMNM and PRIMNM also contain significant mineral resources including cobalt-rich ferromanganese crusts. (Other mineral resources discussed in this lesson include manganese nodules and massive sulfide deposits.) These minerals are presently the focus of seafloor mining interests. Although these monument areas are rich in deep seabed minerals, mining cannot occur due to the protected status of the areas. The study of these protected areas will provide data and information that can be used as an environmental baseline for understanding the marine environment and ecology where these types of mineral resources are found.

Cobalt-rich ferromanganese crusts have unusually high concentrations of certain metals, particularly cobalt, manganese, and nickel, that



The *Okeanos Explorer* Exploration Strategy

The overall *Okeanos Explorer* strategy is based on finding anomalies; conditions or features that are different from the surrounding environment. This is because anomalies may point the way to new discoveries, which are part of the ship's mission. Changes in chemical properties of seawater, for example, can indicate the presence of underwater volcanic activity, hydrothermal vents, and chemosynthetic communities. Once an anomaly is detected, the exploration strategy shifts to obtaining more detailed information about the anomaly and the surrounding area. An important concept underlying this strategy is a distinction between exploration and research. As a ship of discovery, the role of *Okeanos Explorer* is to locate new features in the deep ocean, and conduct preliminary characterizations of the site that provide enough data to justify potential follow-up by future expeditions.

This strategy involves three major activities:
- Underway reconnaissance;
- Water column exploration; and
- Site characterization.

Underway reconnaissance involves mapping the ocean floor and water column while the ship is underway, and using other sensors to measure chemical and physical properties of seawater. Water column exploration involves making measurements of chemical and physical properties "from top to bottom" while the ship is stopped. In some cases these measurements may be made routinely at pre-selected locations, while in other cases they may be made to decide whether an area with suspected anomalies should be more thoroughly investigated. Site characterization involves more detailed exploration of a specific region, including obtaining high quality imagery, making measurements of chemical and physical seawater properties, and obtaining other appropriate types of data.

In addition to state-of-the-art navigation and ship operation equipment, this strategy depends upon four key technologies:
- Telepresence;
- Multibeam sonar mapping system;
- CTD (an instrument that measures conductivity, temperature, and depth) and other electronic sensors to measure chemical and physical seawater properties; and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery in depths as great as 6,000 meters).

are used to add properties such as hardness, strength and corrosion resistance to steel and super alloys used in the aerospace industry. These metals are also used in products such as photovoltaic and solar cells, superconductors, advanced laser systems, catalysts, fuel cells, powerful magnets, and cutting tools.

Deep-sea ferromanganese crusts form on submerged rock surfaces in sites around the world. They are most common on the flanks of seamounts, which are underwater mountains (often remnants of extinct volcanoes) that rise 1,000 meters or more above the surrounding seafloor. The thickest and most cobalt-rich crusts are found on the flanks and summits of seamounts at depths of 800-2,500 meters. The thickest crusts found to date are within the boundary of the PMNM. For more information about cobalt-rich ferromanganese crusts, please see the essay, "Cobalt-Rich Ferromanganese Deep-Sea Crust Deposits in the Hawaiian and Johnston Island Exclusive Economic Zone," by Charles Morgan. [http://oceanexplorer.noaa.gov/okeanos/explorations/ex1504/background/crusts/welcome.html] For more information about seamounts, please see the essay, "Seamounts: underwater islands of the Pacific," by Les Watling. [http://oceanexplorer.noaa.gov/okeanos/explorations/ex1504/background/seamounts/welcome.html]

Whether mining becomes reality in various locations in the Pacific depends upon decisions that must consider how the process of extracting these resources will affect all of the other resources in the same area. Answering this question depends upon knowing what resources presently exist in an area of potential mineral extraction, and how these resources interact with other marine ecosystems. Providing habitat information on seamounts with cobalt-rich crusts is a key focus of the Hohonu Moana: Exploring Deep Waters Off Hawaii Expedition 2015, aboard the NOAA Ship *Okeanos Explorer*. This is the first expedition of a planned three year effort called the Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE).

CAPSTONE will focus on systematically collecting baseline information to support science and management needs within and around the U.S. Marine National Monuments and other protected places in the Pacific Ocean. Science priorities include:
- surveying habitats in areas that have recently been added or may soon be added to marine monuments and sanctuaries;
- identifying and characterizing vulnerable marine habitats, particularly deep-sea coral & sponge communities;
- characterizing seamounts within the Pacific Crust Zone (an area about 3,000 kilometers southwest of Japan that contains the world's oldest seamounts where many metallic compounds have been deposited over about 150 million years to form relatively thick crusts);

- collecting information on the geologic history of Central Pacific Seamounts, including those that may be relevant to our understanding of plate tectonics and subduction zone biology and geology; and
- providing a foundation of publicly accessible data and information products to spur further exploration, research, and management activities.

This expedition will use deepwater mapping, remotely operated vehicles, chemical and physical analytic tools, and high-bandwidth satellite communications to gather information about the region that will catalyze further exploration and research, and help guide future management activities.

For more information about NOAA Ship *Okeanos Explorer*, her expeditions and exploration strategies, please see http://oceanexplorer.noaa.gov/okeanos/about.html and the *NOAA Ship Okeanos Explorer Education Materials Collection* http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html.

In this lesson, students will investigate ecosystems associated with cobalt-rich ferromanganese crusts, and evaluate ways to protect these ecosystems from potential human impacts.

Learning Procedure

1. To prepare for this lesson, review background information about the Hohonu Moana: Exploring Deep Waters Off Hawaii Expedition 2015 [http://oceanexplorer.noaa.gov/okeanos/explorations/ex1504/welcome.html], "Exploration of the two largest marine protected areas of the United States," by Daniel Wagner and Samantha Brooke [http://oceanexplorer.noaa.gov/okeanos/explorations/ex1504/background/mpas/welcome.html], and "Cobalt-Rich Ferromanganese Deep-Sea Crust Deposits in the Hawaiian and Johnston Island Exclusive Economic Zone," by Charles Morgan [http://oceanexplorer.noaa.gov/okeanos/explorations/ex1504/background/crusts/welcome.html]. You may also want to review essays about seamounts, and/or the NOAA Ship *Okeanos Explorer* exploration strategy referenced above.

2. Briefly introduce the NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge. Describe the purpose of marine national monuments, and the variety of biological, geological, and cultural resources found in the PMNM and PRIMNM. Mention cobalt-rich ferromanganese crusts as one of the important geological resources, but do not describe these in detail at this point.

3. Provide each student or student group with a copy of the *Deep-sea Minerals Investigation*, tell them that their assignment is to investigate cobalt-rich ferromanganese crusts, and develop best practices to minimize impacts from mining these resources. Make sure students understand that a key purpose of the Hohonu Moana: Exploring Deep Waters Off Hawaii Expedition 2015 is to provide baseline information about biological communities in proximity to mineral resources that have potential economic importance, because while mining is prohibited in the PMNM and PRIMNM, important biological resources also exist in many other unprotected areas where deepsea mineral resources are found.

   Students will need to use Internet resources to complete Part I of the *Investigation*.

   Reports from the Secretariat of the Pacific Community on cobalt-rich Ferromanganese Crusts [www.sopac.org/dsm/public/files/meetings/TrainingWorkshop4/UNEP_vol1C.pdf], and the 2014 World Ocean Review on "Marine Resources – Opportunities and Risks" [http://worldoceanreview.com/wp-content/downloads/wor3/WOR3_english.pdf] will be particularly useful for this task. You may wish to provide these references, or allow students to discover them on their own.

   Part II of the *Investigation* requires students to synthesize information obtained in Part I to develop best practices to minimize impacts from mining cobalt-rich ferromanganese crusts. This may be done individually, in small groups, or as a whole-class activity; a more interactive approach will help build students' collaborative skills as well as achieve the learning objectives of this lesson.

4. Facilitate a discussion of students' research results. This may occur as a series of reports by individual students or student groups, or may take place in the context of ongoing collaboration among the entire class as described above. Key points related to Part I of the Inquiry Guide include:
   1) Reasons for concerns about future supplies of important industrial metals include:
      - Rising demand caused by development of new technologies (some rare earth metals, for example, are important for the construction of electric engines, generators, and solar panels);
      - Rising demand due to economic development in countries such as Brazil, India, China, and Russia, as well as global population growth and increased demand for technological products;
      - Limited availability from traditional sources (for example, germanium and indium are by-products of lead and zinc

mining so increased production of these metals would require increased production of lead and zinc, but demand for the latter metals is not high enough to justify increased production);
- State monopolies for important resources (for example, 97 percent of the worldwide production of rare earth metals comes from China);
- Corporate monopolies or oligopolies for resources that are mined by only a few companies; and
- Political instabilities in countries that have high concentrations of key resources (for example, the Democratic Republic of the Congo which accounts for 40 percent of worldwide cobalt production, but is unstable due to ongoing civil warfare).

2) The International Seabed Authority (ISA), grants licenses for exploration and mining in specific areas of the deep sea outside the jurisdictions of individual countries. The overall objective of the ISA is to ensure that the profits from deep-sea mining are shared equitably.

3) Three main types of deep-sea mineral deposits that are presently the focus of interest for seafloor mining are:
- Manganese nodules—lumps of baseball to soccer ball-sized minerals—are found at depths below 3500 meters over extensive areas of the Pacific and Indian Ocean seabeds. They contain manganese, iron, copper, nickel, cobalt, molybdenum, zinc, and lithium.
- Cobalt-rich ferromanganese crusts are found at depths between 400 and 4,000 meters with the richest crusts between 800 and 2,500 meters on the sides of underwater mountain ranges and seamounts in the western Pacific, and contain manganese, iron, cobalt, nickel, platinum and rare earth elements.
- Massive sulfides accumulate primarily at the openings of hydrothermal vents where cold seawater entering cracks in the seafloor is heated to 400 C or more and dissolves minerals in Earth's crust; when the heated fluid rises back into the cold seawater dissolved minerals precipitate around the vents openings to form massive ore deposits. Massive sulfides are found around the world in areas that are presently or once were volcanic, and may contain copper, zinc, lead, gold, silver, indium, germanium, tellurium, and/or selenium depending upon their location.

4) Plans for mining massive sulfide deposits in the Bismarck Sea off Papua New Guinea are already at an advanced stage, and mining operations are expected to begin around 2016. The

proposed mining area is within the territorial sea regulated by the government of Papua New Guinea.

5) Technical problems involved with mining cobalt-rich ferromanganese crusts include:
- To date, there have been no field tests of equipment capable of mining cobalt-rich ferromanganese crusts.
- Recovering minerals from these crusts first requires some way to peel the crusts from the underlying stone. (One concept is to use caterpillar-type vehicles that use a type of chisel to separate the crusts.)
- Once the crusts are removed, some method is needed for transporting the broken crust rocks to ships at the ocean surface.
- Pumps, hoses, or other transport equipment will have to withstand severe wear from moving rocks, and no such equipment has been tested under actual mining conditions.

6) The biology of seamounts where cobalt-rich ferromanganese crusts are most abundant has not been well-studied, and the relationships between seamounts and other marine ecosystems are even less well-known. Even with few studies, it is clear that seamount species vary significantly from one region to the next, so it may be difficult to predict the impacts of mining specific seamounts based on information from seamounts in other areas. Studies to date suggest that many seamount species have very slow growth rates and produce relatively few offspring, which means that these species are especially vulnerable to overharvest or habitat destruction. This prediction is consistent with studies of seamounts of Australia and New Zealand that were fished with bottom-trawl nets. Even after 10 to 30 years, there were far fewer animal species than on seamounts that had not been trawled. Specific studies of cobalt-rich ferromanganese crusts have found highly diverse communities of many species, particularly filter-feeders that are well-adapted to seamount habitats. Seamounts have been identified as hotspots for pelagic fish biodiversity, and are well-known for large aggregations of sharks, fishes, seabirds, and marine mammals.

7) Environmental concerns related to mining cobalt-rich ferromanganese crusts include:
- clouds of rocks and particulates resulting from stripping crusts from underlying rock, and secondary sediment clouds from transportation of crust fragments to the surface;
- destruction of all organisms living on crusts that are mined;
- noise and vibrations from machinery that might affect marine mammals;

- potential disturbance to birds, mammals, and fishes from lights on harvesting vessels and equipment; and
- pollution from various waste discharges from mining ships.

These impacts may affect pelagic species as well as benthic species directly associated with crusts.

5. Discuss students' ideas about policies and best practices to minimize impacts from mining cobalt-rich ferromanganese crusts. Simply rejecting the concept of deep-sea mining is not an adequate response, unless this approach is supported by a detailed cost benefit analysis. Given the limitations of present data, the emphasis should be on practices that minimize large-scale impacts and that help maintain overall biodiversity and health and function of marine ecosystems. It is reasonable for students to assume that mining operations driven by commercial interests will not take place unless there is reasonable certainty that these operations will be financially profitable. It is also reasonable to assume that environmental concerns and management measures may not be adequately considered in commercial cost/benefit calculations.

   Following are some features and concepts that may be included in student-generated policies and best practices.

   Environmental management programs include several of the following approaches:
   - ecosystem approaches that consider human needs and requirements to use natural resources as well as the need to maintain the biological diversity and ecological processes that sustain the composition, structure and function of the habitats or ecosystems that provide these resources;
   - precautionary approaches that apply cost-effective measures to prevent environmental degradation, even if there is not "scientific certainty" that degradation will occur from proposed activities;
   - adaptive management, in which environmental data are collected as resources are being exploited, and managers have the flexibility to act rapidly in response to these data to ensure that conservation objectives are met; and
   - marine spatial planning that identifies specific locations where various resource use activities may take place as a means of managing potential conflicts among activities that seek to use the same resources for different purposes;
   - environmental baseline studies that define conditions before resource development activities take place, and subsequent ongoing monitoring studies that compare baseline conditions to conditions as development activities are implemented.

   Other options include:
   - establishing conservation areas that can contain species and ecosystems that are representative of areas being exploited;

whether these can actually contribute to restoration of impacted areas depends upon the relative size of the conservation areas, their connectivity to impacted areas, and the reproductive characteristics of individual species; "upstream" locations may be desirable to lessen the impacts of sediment plumes from impacted areas, and to facilitate the distribution of larvae from conservation areas into impacted areas;

- active mitigation of impacted areas, such as installation of artificial substrates to stimulate re-colonization, or re-locating representatives of rare species prior to exploitation;
- evaluating options for discharging wastewater to minimize environmental impact (for example, considering impacts of discharging at the surface vs. discharging at various depths).

The BRIDGE Connection

www.vims.edu/bridge/ - Scroll over "Ocean Science Topics," and click on select "Geology" for activities and links about marine geology.

The "Me" Connection

Have students write a brief essay discussing how deep-sea mining might affect them personally.

Connections to Other Subjects

English/Language Arts, Social Studies

Assessment

Responses to *Inquiry Guide* questions and participation in class discussions provide opportunity for assessment.

Extensions

Visit http://oceanexplorer.noaa.gov/okeanos/explorations/explorations.html for links to individual voyages of discovery by NOAA Ship *Okeanos Explorer*.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lesson 14 for interactive multimedia presentations and Learning Activities on seamounts.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Round and Round (Grades 9-12)
(from the 2003 Mountains in the Sea Expedition)
[http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_round.pdf]

Focus: Circulation cells in the vicinity of seamounts (Earth Science)

Students interpret data from a three-dimensional array of current monitors to infer an overall pattern of water circulation, hypothesize what effect an observed water circulation pattern might have on seamount fauna that reproduce by means of floating larvae, and describe the importance of measurements to verify theoretical predictions.

Mapping Deep-sea Habitats in the Northwestern Hawaiian Islands
(Grades 7-8)
(from the 2002 Northwestern Hawaiian Islands Expedition)
[http://oceanexplorer.noaa.gov/explorations/02hawaii/background/education/media/nwhi_mapping.pdf]

Focus: Bathymetric mapping of deep-sea habitats (Earth Science)

Students create a two-dimensional topographic map given bathymetric survey data, create a three-dimensional model of landforms from a two-dimensional topographic map, and interpret two- and three-dimensional topographic data.

No Escape (grades 9-12)
(from the 2003 Mountains in the Sea Expedition)
[http://oceanexplorer.noaa.gov/explorations/06davidson/background/edu/escape.pdf]

Focus: Fate of benthic invertebrate larvae in the vicinity of seamounts (Earth Science)

Students use field data to evaluate an hypothesis about the influence of a water circulation cell on the retention of benthic invertebrate larvae in the vicinity of a seamount, describe some potential advantages and disadvantages to species whose larvae are retained in the vicinity of seamounts where the larvae are produced, and describe the consequences of partial or total larval retention on the biological evolution of species producing these larvae.

Watching in 3D (grades 9-12)
(from *The NOAA Ship Okeanos Explorer Education Materials Collection Volume 2: How Do We Explore?*)
[http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-MM3D912.pdf]

Focus: Multibeam Sonar (Physics)

Students explain how multibeam sonar uses the properties of sound waves in water for scientific research about topography of the ocean floor; and analyze and interpret multibeam sonar data to identify patterns in the distribution of seafloor features that contribute to scientific research about large-scale interactions in Earth's systems.

Other Resources

The Web links below are provided for informational purposes only. Links outside of the Ocean Explorer web site have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html – Web page for the *Okeanos Explorer Education Materials Collection*

http://oceanexplorer.noaa.gov/facts/seamounts.html – Seamount fact sheet

http://oceanexplorer.noaa.gov/edu/themes/seamounts/welcome.html -Ocean Explorer Seamount theme page

Hein, James R. Seamounts and Cobalt-Rich Ferromanganese Crusts. U.S. Geological Survey for the ISA. July 2006. A slide show. [https://www.isa.org.jm/files/documents/EN/Workshops/Jul06/J-Hein.pdf]

Secretariat of the Pacific Community (2013). Deep Sea Minerals: Cobalt-rich Ferromanganese Crusts, a physical, biological, environmental, and technical review. Baker, E. and Beaudoin,Y. (Eds.) Vol. 1C, Secretariat of the Pacific Community [www.sopac.org/dsm/public/files/meetings/TrainingWorkshop4/UNEP_vol1C.pdf]

Lange, E., S. Peersen, L. Rüpke, E. Söding, and K. Wallmann. 2014. World Ocean Review 3: Marine Resources – Opportunities and Risks. Chapter 2. Mineral Resources. maribus gGmbH, Pickhuben 2, D-20457 Hamburg, Germany. [http://worldoceanreview.com/wp-content/downloads/wor3/WOR3_english.pdf]

Next Generation Science Standards

HS. Human Sustainability

Performance Expectation:

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

Science and Engineering Practices

Engaging in Argument from Evidence

- Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).

Disciplinary Core Ideas

ESS3.A: Natural Resources

- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

Crosscutting Concepts

Influence of Engineering, Technology, and Science on Society and the Natural World

- Engineers continuously modify these systems to increase benefits while decreasing costs and risks.
- Analysis of costs and benefits is a critical aspect of decisions about technology.

Connections to Nature of Science

Science Addresses Questions About the Natural and Material World

- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

Common Core State Standards Connections:

ELA/Literacy -

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Mathematics -

MP.2 Reason abstractly and quantitatively

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 6:
The ocean and humans are inextricably interconnected.

Fundamental Concept b. The ocean provides food, medicines, and mineral and energy resources. It supports jobs and national economies, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept d. Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (point source, nonpoint source, and noise pollution), changes to ocean chemistry (ocean acidification), and physical modifications (changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, experimentation, and discovery are required to better understand ocean systems and processes. Our very survival hinges upon it.

Fundamental Concept c. Over the last 50 years, use of ocean resources has increased significantly; the future sustainability of ocean resources depends on our understanding of those resources and their potential.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, physicists, animators, and illustrators. And these interactions foster new ideas and new perspectives for inquiries.

Send Us Your Feedback

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

Acknowledgements

This lesson was developed and written for NOAA's Office of Ocean Exploration and Research (OER) by Dr. Mel Goodwin, PhD, Marine Biologist and Science Writer.
Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

Credit

Deep-sea Minerals Investigation

Part I

1. One of the major motivations for deep-sea mining is the concern that the supply of important industrial metals could become more uncertain in the future. What are some reasons for this concern?

2. Ocean mineral resources may be mined within the territorial waters of individual nations, or may be mined in the deep sea, which is considered to be a resource that should be shared among all nations. Individual countries are responsible for regulating the mining activity in their own sovereign territory. What authority regulates mining activities in the deep sea? What is the overall objective of this authority?

3. What are the three main types of deep-sea mineral deposits that are presently the focus of interest for seafloor mining? Where are these deposits found, and what are some of the important minerals that they contain?

4. Which of these three types of deepsea mineral deposits is most likely to be mined in the near future?

5. What are some of the technical problems (not including environmental concerns) involved with mining cobalt-rich ferromanganese crusts?

6. What are some features of biologic communities in areas where cobalt-rich ferromanganese crusts are found?

7. What are some environmental concerns related to mining cobalt-rich ferromanganese crusts?

Part II

What policies and best practices should be adopted to minimize impacts from mining cobalt-rich ferromanganese crusts? Discuss the policies you recommend from the standpoint of available evidence as well as costs and benefits (costs and benefits may include values other than strictly monetary ones). At a minimum, the objectives of these policies and practices should include maintaining overall biodiversity and health and function of marine ecosystems as mandated by international law.