Economic Geology: Managing Critical Resources in a Changing World

Companion Lesson X-STEM All Access Episode "Rockhounding Rare Earths"

Grade Band: Middle School - High School	**Topic:** Earth & Space Science

Brief Lesson Description: Students investigate Earth's critical minerals and responsible resource use.

Performance Expectation(s):

MS-ESS3-1: Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.
MS-ESS3-2: Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.
HS-ESS3-1: Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios

Specific Learning Outcomes:

Students will be able to:

- Explain why some minerals are considered critical or rare
- Identify regions where critical minerals are concentrated and explain why they are not evenly distributed
- Relate geologic processes to the formation of economically valuable mineral deposits
- Explore tradeoffs between technology, environment, and geopolitics
- Analyze environmental and economic implications of mineral extraction and resource use
- Connect mineral properties to their technological applications
- Use data, evidence, and reasoning to justify claims in peer discussions or presentations

Narrative / Background Information

Modern life depends on materials pulled from the Earth—from copper and lithium to rare earth elements that power phones, wind turbines, and electric vehicles—yet these resources form through complex geological processes and are not easy to find. Economic geologists study how heat, pressure, fluids, and time concentrate valuable minerals into deposits and determine whether they can be responsibly extracted. In this lesson, students investigate what makes certain minerals critical, why rare earth elements are essential to modern technology, and how geologists evaluate Earth materials, connecting Earth systems, resource distribution, and human needs to understand how geology shapes technology and global decision-making.

Prior Student Knowledge: Before engaging in this lesson, students should be familiar with:

- *Rock and Mineral Properties:* Minerals have identifiable physical properties (such as hardness, luster, color, streak, density, and magnetism) that allow geologists to classify and identify them.
- *Rock Cycle and Earth Processes:* Basic understanding of how igneous, sedimentary, and metamorphic processes form different rocks, and how heat, pressure, and fluids contribute to mineral formation and concentration.
- *Matter and Its Properties:* Matter has physical and chemical properties that determine how it can be used, extracted, or processed.
- *Earth's Resources and Human Use:* Many of the materials we use every day come from the Earth, but these materials are found in specific places due to geologic processes rather than everywhere on the planet.
- *Cause and Effect in Earth Systems:* Geological processes (such as volcanism, weathering, erosion, and deposition) influence where minerals are found and how they accumulate into usable deposits.
- *Mineral Structure and Function:* Recognizing that the internal structure and composition of a material influence its function and usefulness, especially in technological and industrial applications.

Science & Engineering Practices:	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Constructing Explanations and Designing Solutions Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (MS-ESS3-1) (HS-ESS3-1) **Analyzing and Interpreting Data** Analyze and interpret data to determine similarities and differences in findings. (MS-ESS3-2) **Engaging in Argument From Evidence** Evaluate competing design solutions to a real-world problem based on scientific	**ESS3.A: Natural Resources** Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes. (MS-ESS3-1) Resource availability has guided the development of human society. (HS-ESS3-1) All forms of energy production and other resource extraction have associated	**Cause and Effect** Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-ESS3-1) **Patterns** Graphs, charts, and images can be used to identify patterns in data. (MS-ESS3-2) **Connections to Engineering, Technology, and Applications of Science** **Influence of Science, Engineering, and Technology on Society and the Natural World** All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. (MS-ESS3-1)

ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). (HS-ESS3-2)	economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2)	The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-ESS3-2)

Possible Preconceptions/Misconceptions:

- **Rare earth elements are extremely rare in the Earth's crust:** In reality, many are relatively abundant but difficult to concentrate and extract economically.
- **If a mineral is critical, it must be running out:** Students may not understand that "critical" often refers to supply risk, geopolitical factors, or processing challenges—not just scarcity.
- **Finding minerals is mostly luck:** Students may overlook the scientific investigation required before mining ever begins and may not recognize the role of data, observation, mapping, and geologic reasoning.
- **Mining is always harmful and never managed responsibly:** Students may view mining as purely negative without understanding regulation, reclamation, or decision-making tradeoffs.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:

Purpose: To spark curiosity, activate student wonder, and connect everyday technologies to Earth materials.

Opening Hook:

1. Display 5–7 everyday objects or images of these objects:
    - Smartphone
    - Electric vehicle or battery
    - Wind turbine
    - Headphones or speaker
    - MRI or X-ray tubes
    - LED light
    - Credit card or computer chip
2. Ask students: "Every object you see here depends on something hidden inside the Earth. What do you think it is?"
    - Have students discuss with their table groups and then form a list of guesses on the board. Expect answers like: electricity, metal, energy, plastics, wires, etc.
3. Once the list is complete (you've gathered all their thoughts), then reveal: "Each of these objects depends on minerals that had to be found, identified, and mined — many of them are rare earth elements and some of them considered critical minerals."

Curiosity spark and 'wow' moment:

1. Show dramatic images of the 17 rare earth elements, an active or abandoned REE mine, create and print "What's Inside?" cards for a few of the objects, or one of Elley Ringo's field photos.
2. Tell students: "There are geologists whose job is to hike into remote areas, explore abandoned mines, identify tiny mineral clues, and decide whether an area might contain materials essential for modern technology. One of those geologists is Elley Ringo — an economic geologist who explores mineral deposits around the world and shares how geologists read the Earth to understand where valuable resources come from."

Discussion Questions:

"How do people even know where to look for rare earth elements or critical minerals?"
"How can a rock found at the surface tell you what's hidden underground?"
"Why would some minerals be so important that entire countries compete for them?"
"What skills do you think an economic geologist might need?"

Lesson Anchor Question:

How do geologists figure out where rare earth elements or critical minerals are found — and why do those materials matter so much to modern life?

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:

Purpose: Students investigate functional material properties and global distribution patterns to identify why certain minerals are considered critical and how geologic materials enable modern technologies.

Stage 1: Magnetic Properties Investigation

Why is neodymium such a powerful material?

Materials (per group):

- Neodymium magnet
- Ceramic (ferrite) magnet
- Paperclips or steel washers
- Ruler or scale (optional)

Student Task- Students compare the strength of neodymium and ceramic magnets by:

1. Counting how many paperclips each magnet can lift
2. Observing attraction distance
3. Noting magnet size vs strength

4. Answer the following questions:
    - Which magnet is stronger? Does the size of the magnet matter?
    - What evidence supports your claim?
    - Why might strong magnetism be useful in technology?

Key Student Takeaway:
Some materials have exceptional properties that make them more useful than others.

Stage 2: Resource Distribution & Geologic Context

If critical minerals, like neodymium, are essential to modern technology, where are they found—and why?

Materials:

- Global or regional maps of rare earth element and critical mineral deposits (https://apps.usgs.gov/critical-minerals/critical-minerals-atlas.html)

Students analyze maps to:

1. Identify regions rich in critical minerals and/or rare earth elements
2. Look for patterns or clustering in resource locations
3. Infer the geologic processes or environments associated with these deposits
4. Answer the following questions:
    - Are critical mineral deposits evenly distributed around the world?
    - What types of geological settings appear common (e.g., igneous, sedimentary, hydrothermal)?
    - Why might the location of these resources matter for technology, economies, and global decision-making?

Key Student Takeaway:
Critical minerals are tied to specific geological conditions and are not found everywhere.

Guiding Questions:

Which properties make some materials better for electronics or motors?
Why might strong magnetism be especially valuable in modern technology?
Why would a material with unique properties be considered critical, even if it's not rare?
How do material properties connect to where minerals are found?
How does location affect how minerals are extracted?

Record student ideas in a clearly visible anchor chart— these become anchor ideas for Explain.

EXPLAIN:

Purpose: Students develop a shared understanding of critical minerals, rare earth elements, and economic geology by connecting their observations to geologic processes and professional field practices, including those used by Elley Ringo.

Teacher-Facilitated Explanation / Mini Lecture:

1. Introduce key concepts:
    - What are critical minerals?
        - Minerals essential to modern technology & national security
        - Have supply chain risks
        - A mineral becomes critical because of the combination of its properties, limited locations, extraction challenges, and importance to technology — not just because it's scarce.
    - What are rare earth elements (REEs)?
        - 17 metallic elements used in magnets, electronics, lasers, and energy technologies
        - Not actually rare—just hard to mine economically
    - Basics of economic geology
        - The study of Earth materials that can be used for economic/industrial purposes
        - Focus on ore formation, mineral identification, deposit types, and extraction feasibility
    - Tie in Elley Ringo:
        - Elley is an economic geologist specializing in:
            - Field identification of ore minerals
            - Placer mining (minerals in stream deposits)
            - Hard-rock mining (minerals in bedrock)
            - Global exploration of abandoned mines and mineral systems
            - Communication of real-world geology to the public through @elleyknowsrocks
        - Her work demonstrates how geological science connects directly to energy, electronics, manufacturing, and sustainability.
        - **Show the Companion X-STEM Video** "Rockhounding Rare Earths" starring Elley Ringo (14 minutes)
            - Ask students to reflect on the following questions:
                - What skills does Elley use to investigate mineral deposits?
                - What evidence does she look for in the field?
                - How does her work connect to the properties and locations you explored earlier?

Part 2: Deepening Understanding — Student Investigation

1. Students now apply their understanding using a structured resource such as: "Science of Rare Earth Elements" (Science History Institute)
2. Students work in groups to:
    - Examine background information on REEs

- Analyze competing perspectives (technology, environment, national security, economics)
- Use evidence to explain why REEs are both valuable and controversial

Discussion Questions:
Why are rare earth elements essential to modern technology?
What challenges exist in mining and processing REEs?
Why do supply chains and geography matter?
How do decisions about mining involve more than just science?

ELABORATE: Applications and Extensions:
Purpose: Students apply their understanding of rare earth elements and critical minerals to evaluate and propose strategies that reduce environmental impacts and improve the sustainability of resource use.
Sustainable Critical Minerals Proposal
Scenario: Rare earth elements like neodymium are essential to modern technology, but mining and processing them can produce large amounts of waste and environmental harm. Scientists, engineers, and policymakers are actively researching ways to reduce these impacts while still meeting society's needs.
The student's task is to develop a short, evidence-based proposal that suggests one strategy for reducing the environmental footprint associated with the use of rare earth elements.
Proposal Focus Options (Choose One)- Students select one of the following pathways:
Option A: Improving Ore Processing & Separation
- Reducing waste during ore processing
- Improving efficiency of REE separation
- Lowering the amount of toxic byproducts

Option B: Recycling Rare Earth Elements
- Recovering REEs from old electronics (phones, batteries, motors)
- Reducing the need for new mining
- Challenges and limitations of recycling

Option C: Alternative Sources
- Recovering REEs from coal ash or mining waste
- Using secondary sources instead of new mines
- Environmental tradeoffs

Research Component- Students use teacher-approved resources (articles, short videos, case studies) to research their chosen strategy. (Starter REE and Critical Minerals Research Resource Set)
Required Evidence:
- At least two sources
- Evidence that explains how the strategy reduces environmental impact
- Evidence that explains why the strategy is challenging or limited

Proposals should include:
1. *Problem Statement*: Why rare earth elements are necessary and problematic.
2. *Proposed Solution*: Description of the chosen strategy.
3. *Scientific Reasoning*: How this approach reduces waste, pollution, or environmental harm.
4. *Limitations & Tradeoffs*: Why this solution doesn't fully replace mining (yet).
5. *Connection to Society*: How this solution supports technology, energy, or sustainability goals.

Format Options:
- One-page written proposal
- Infographic or poster
- Short slide presentation
- CER-style written response (Claim–Evidence–Reasoning)

Discussion Questions:
"How can scientific understanding of Earth materials help reduce environmental impacts while still supporting modern technology?"

EVALUATE:
Formative Monitoring (Questioning / Discussion):
Questions in bold/italics can be used to check student understanding throughout the lesson.
Summative Assessment (Quiz / Project / Report): Students will present their Sustainable Critical Minerals Proposal in teams using one of the formats described in the Elaborate section (e.g., slide deck, poster, brief written proposal, or short presentation). Student understanding will be assessed through peer evaluation and self-evaluation using a rubric that emphasizes scientific accuracy, use of evidence, feasibility, and systems-level reasoning about Earth resources, technology, and human impacts.

EXTEND: Students may apply their engineering and science understanding to real-world technological challenges through one of the following extension activities:
Invite students to explore: Earth vs Space Mining
1. Students work in pairs or small groups and choose one off-Earth mining environment to explore:
    - Moon (lunar regolith)
    - Asteroids (metal-rich bodies)
    - Mars (igneous and sedimentary rocks)
2. Students investigate how mining in their chosen/assigned environment would differ from Earth by considering:

- Gravity
- Atmosphere
- Geological Processes
- Accessibility
- Environmental Impact

Optional Product:

- Concept sketch + caption ("Mining on the Moon in 2050")
- Mini science brief (½ page)
- One-slide pitch comparing Earth vs space mining
- Exit-ticket style CER answering: *"Could space mining change how we manage Earth's resources?"*

Discussion Questions:

How might lower gravity change extraction or transport?
How does the lack of atmosphere or water affect processing?
Would mining in space reduce environmental impacts on Earth—or create new ones?
Could space resources replace Earth mining, or only supplement it?

CAREER CONNECTIONS

From economic geologists identifying ore deposits to materials scientists engineering ultra-pure semiconductors, the critical minerals and microelectronics industries sit at the forefront of modern science and technology. Professionals in these fields blend geology, chemistry, physics, and engineering to locate, extract, process, and transform Earth materials into components that power everything from smartphones and renewable energy systems to medical devices and national infrastructure. Their work spans mineral exploration, sustainable mining practices, materials processing, and chip fabrication—each essential to balancing technological advancement with environmental responsibility. As innovations in recycling, advanced materials, and semiconductor manufacturing reshape global supply chains, careers in economic geology, materials science, mining engineering, and microelectronics offer students the opportunity to help secure critical resources, reduce environmental impacts, and shape the future of technology in an increasingly interconnected world.

1. **Explore Career Clusters**: Have students visit USA Science Festival Resources and explore careers in the Critical Minerals and Microelectronics industry clusters to discover opportunities in these growing fields.
2. **Choose a Career**: Students will select one career from the chosen industry cluster that interests them.
3. **Research the chosen Career**: Using the provided graphic organizer or a class notebook, students will gather the following information about their chosen career:
    - Job description: Typical responsibilities and duties.
    - Education and training required: Degrees, certifications, or technical training.
    - Skills and qualities needed: Key traits for success in the field.
    - Average salary: Typical earnings for the role.
    - Work environment and schedule: Typical working conditions and hours
    - Professional Organizations, Educational Programs, and Internship & Apprentice Opportunities
4. Students will select one of the following choice board activities to synthesize their research:

Career in Action Find a reliable video or article about someone working in this career. Summarize what you learned and how it aligns with your expectations.	**Job Skills Match** List at least five skills needed for this career. Identify which of these skills you already have and which ones you need to develop.	**Future You** Write a letter to your future self explaining why this career interests you and what steps you plan to take to pursue it.

5. **Share findings**: Provide an opportunity for students to share their findings. This could be a class presentation, a gallery walk with posters or a peer discussion group.

FUTURE-READINESS TOOLKIT

Competency Addressed: Responsible & Strategic Thinking
Purpose: Students explore how responsible decisions require thinking beyond immediate outcomes, considering impacts on people, systems, and the future. Through a low-stakes scenario and structured reflection, students practice evaluating options, identifying tradeoffs, and explaining their reasoning—skills essential for future careers, civic life, and complex problem-solving.

1. **The No-Perfect-Answer Question**
    a. Display this prompt: "Some decisions don't have a 'right' answer—only better or worse tradeoffs."
    b. Ask students to:
        - Do a silent think for 30 seconds
        - Turn and talk: Do you agree or disagree? Why?
    c. Follow with a quick whole-class share: *(No need to correct answers—this is about surfacing thinking.)*
        - What makes decisions hard?
        - Why do people sometimes avoid thinking about long-term consequences?
2. **Strategic Thinking Scenario**
    a. Scenario: Your school has received a one-time grant that can only be used for one major improvement.

- Option A: Make quick repairs to several aging classrooms (new furniture, fresh paint, minor fixes). These improvements will be noticeable immediately but may need to be redone in a few years.
- Option B: Invest the money into upgrading one major system (such as heating/cooling, internet infrastructure, or safety systems). This will take longer to implement and won't be as visible right away but could improve conditions for many years.

b. In small groups students discuss:
- What problem does each option solve now?
- What problems might appear later?
- Who benefits most from each choice?
- What information would help you make a more responsible decision?
- Is there a way to combine ideas or reduce negative impacts?

3. **Introduce the concept explicitly**: What Is Responsible & Strategic Thinking?

a. Responsible & Strategic Thinking means:
- Looking beyond immediate outcomes
- Considering impacts on people, systems, and the future
- Weighing tradeoffs instead of searching for a "perfect" answer
- Using evidence and values to guide decisions

b. Connect to real-world contexts (without content dependence):
- Technology choices
- Environmental decisions
- Career planning
- Community rules or policies

4. **Decision Defense**

a. Students individually choose one option from the strategic thinking scenario and write or discuss:
- Why they chose it
- What tradeoffs they accepted
- One possible unintended consequence
- How they might reduce negative impacts

b. Students may:
- Write a short paragraph
- Create a decision flowchart
- Share a brief verbal "defense" in pairs

5. Reflection & Self-Assessment

a. Students respond to 2–3 prompts:
- What makes a decision responsible, not just convenient?
- How did your thinking change during this activity?
- Where might you need strategic thinking outside of school?

Materials Required for This Lesson/Activity	
Quantity	**Description**
1 per class	Computer with Projector and Internet Access Whiteboard space or chart paper for anchor charts
1 per student	Rubrics as found in the Evaluate section Computer with Internet Access for Research
Explore Stages: One complete set of materials is needed for each group	***Stage 1 materials***: Neodymium magnets (small discs or bars), ceramic (ferrite) magnets, paper clips, washers, or small steel objects, thin cardboard or paper (for distance testing).
	Stage 2 materials: Printed or digital maps of critical mineral / REE deposits, colored pencils or markers (optional for pattern highlighting on printed maps)
1 set per group	Materials for the **Engage** section: Real tech objects, printed object cards, *optional*: printed "What's Inside?" cards-- especially for the cell phone, printed mineral cards, photos of Elley Ringo in the field

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