Geology of a Cell Phone

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Overview:	Minerals are essential to our everyday lives. Without them, the technology that we've grown dependent on would not exist, the roads we drive on would not be paved, our houses and buildings would not be strong, and our bodies would not function properly. This lesson will introduce minerals used in cell phones - one of the everyday items we've come to rely on which are chock full of mineral components.
Targeted Grade Levels:	9th through 12th (ESS.EES.5, ESS.EES.5.1, ESS.EES.5.5, ESS.EES.5.6, ESS.EES.6)
Objectives:	1. To learn about the minerals that are used to make cell phones 2. To learn about rare earth and critical minerals that are used in cell phones 3. To learn where those geologic materials are found on Earth 4. To learn which cell phone minerals are conflict minerals 5. To learn about reducing technology waste
Estimated Time:	One lesson day plus time for online research
Materials:	Information contained in this lesson, internet access, available minerals
Teacher Background & Prep	The information contained in this activity will allow students to learn about the geologic materials that are components of cell phones. This activity will help students to learn what minerals are used in cell phones and what countries produce them, why some are deemed critical, and how some minerals come from conflict areas. This lesson and activity involve **earth science** (minerals), **geography** (locations of mineral and critical mineral deposits), **critical thinking** (what are conflict minerals and what might be done to combat this issue), and **sustainability** (recycling efforts can lessen our dependence of finding new sources of minerals).
Key Terms	**Mineral**: Solid, inorganic, naturally occurring substance with a defined chemical composition and crystalline structure **Critical Mineral**: Minerals, elements, or materials that 1) are essential to the economic or national security of the United States, 2) the supply chain of which is vulnerable to disruptions, and 3) serve an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economic or national security of the United States **Rare Earth Element**: any of a group of chemically similar metallic elements comprising the lanthanide series; not especially rare but occur together in nature and are difficult to separate from one another **Conflict Mineral**: mineral mined in an area of armed conflict and traded illicitly to finance the fighting

Background

Cell phones (or smartphones) hold a special place in our technology-dependent society. Over 60% of the world's population owns a cell phone or smartphone. (How did we even exist before them?!) Cell phone production has been in full swing since the debut of the first mobile cellular device in 1983. The smartphone as we know it would not exist without minerals and the geologists who find, study, mine, and process them. Over 50% of all components in a smartphone are mineral commodities!

Most people have no idea how the growing demand for electronic devices puts pressure on metal and mineral supply chains AND on planet Earth. The high demand for the metals and minerals that make the technology we use and need (we're going to focus on cell phones) didn't exist 25 years ago. Metals and minerals are natural products – they come from the earth and need to be mined and processed for use. Using education, we hope that more people: 1) become aware of the valuable resources that are needed for technology like cell phones; 2) understand the cost (including human cost) of technology; and 3) reduce technology e-waste.

Minerals in a Cell Phone

On average, our cell phones contain around 42 minerals which are used for electronics, displays, speakers, microphones, vibrations, and more. Many of the metals and minerals are mined and processed in countries other than the United States. Countries such as China, Russia, Chile, Australia, South Africa, and Mexico supply many of the minerals necessary for cell phone production. A few of these minerals include copper, gold, tungsten, silver, magnesium, tin, and aluminum.

The table on Page 4 lists just a few of the minerals needed to make cell phones and what their uses are. For more comprehensive information on cell phone minerals, here are a few resources to get you started:

- https://www.nhm.ac.uk/discover/your-mobile-phone-is-powered-by-precious-metals-and-minerals.html
- https://pubs.usgs.gov/gip/0167/gip167.pdf
- https://www.visualcapitalist.com/visualizing-the-critical-metals-in-a-smartphone/
- https://www.nms.ac.uk/explore-our-collections/resources/from-minerals-to-your-mobile/
- https://www.mecmining.com.au/the-top-10-metals-and-minerals-powering-your-mobile-phone/
- https://www.geolsoc.org.uk/~/media/shared/documents/education%20and%20careers/Resources/Posters/Minerals%20in%20a%20smartphone%20poster.pdf?la=en
- https://mineralseducationcoalition.org/wp-content/uploads/mec_fact_sheet_cell_phone_0.pdf

Critical Minerals in a Cell Phone

As defined on Page 1, critical minerals are minerals, elements, or materials that 1) are essential to the economic or national security of the United States, 2) the supply chain of which is vulnerable to disruptions, and 3) serve an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economic or national security of the United States. There are currently 50 minerals on the critical minerals list, several of which are used in cell phone manufacturing. Of the 50 minerals, the U.S. is 100% import-reliant on at least 14 and more than 50% reliant on at least 31 others.

The U.S. Energy Act of 2020 is legislation that is pushing the U.S. to lessen our imports of these minerals by searching for economic sources of them within our borders. The legislation requires that a list of critical minerals be designated every three years and that the US Geological Survey conduct domestic resource assessments of critical minerals in our country. Additionally, a comprehensive forecast of critical mineral production, consumption, and recycling patterns will be developed over the next one, five, and ten years.

The table on Page 5 lists the current critical minerals and their uses for everyday life. You can also see them on the USGS website. You'll notice an asterisk (*) next to some of the critical mineral names in our table. These critical minerals are used in cell phone manufacturing. Look at how many critical minerals it takes to make a smartphone!

Smartphone Part	Critical Mineral
Touch Screen	Indium
Display	Lanthanum, Gadolinium, Praseodymium, Europium, Terbium, Dysprosium
Electronics	Nickel, Gallium, Tantalum
Casing	Nickel, Magnesium
Battery	Lithium, Nickel, Cobalt
Microphone/speakers vibration	Nickel, Praseodymium, Neodymium, Gadolinium, Terbium, Dysprosium

Here are a few links to information about the Energy Act of 2020 and critical minerals:

- https://www.energy.senate.gov/services/files/847E2D8F-0CED-407E-9D65-C1589C9E1412
- https://www.energy.gov/cmm/critical-minerals-materials-program
- https://www.iea.org/policies/16065-energy-act-of-2020-critical-minerals-provisions
- https://bipartisanpolicy.org/blog/getting-serious-about-critical-materials-the-iija-and-energy-act-of-2020/

A FEW OF THE MINERALS USED IN CELL PHONES/SMARTPHONES

Cell Phone Component	Mineral Name	What it Provides	How It's Used
Display/Screen	Quartz	Silica sand	Glass screen; combined with ceramic materials & potassium for durability
	Cassiterite	Tin	Creates transparent circuits in touch screen display
	Bauxite	Aluminum	LED backlight
	Sphalerite	Indium, germanium, zinc	Screen coating, LED lighting, circuits
	Indium	Tin oxide	Allows touch screen to function
Electronics/Circuitry	Chalcopyrite	Copper	Wires, connectors
	Tetrahedrite	Silver	Electrical pathways
	Arsenopyrite	Arsenic	Radio frequency and power amplifiers
	Tantalite	Tantalum	Added to capacitors to regulate voltage & improve device audio quality
	Wolframite	Tungsten	Acts as heat sink & provides the mass for phone vibration
	Beryl	Beryllium	Wires and connectors
	Nickel	Nickel	Electrical connectors
	Gallium	Gallium	Semiconductors
	Gold	Gold	Circuit boards
Battery	Cobalt	Cobalt	Offers thermal stability to avoid overheating
	Spodumene	Lithium	Cathodes for Li-ion battery
	Graphite	Graphite	Anodes for Li-ion battery
Speakers/Vibration	Bastnaesite	Yttrium, Cerium, Lanthanum	Speaker magnets, microphones, vibration motors
	Nickel	Nickel	Microphone, vibration
	Neodymium, Praseodymium, Gadolinium		Speaker and microphone magnets
Camera	Boron	Borax	Camera chips
Phone Cases	Fluorite	Fluorine	Cell phone case

CRITICAL MINERALS, ELEMENTS, MATERIALS LIST AS OF 2022 AND THEIR USES

CRITICAL MINERAL	USES
Aluminum	LED lighting
Antimony	Lead-acid batteries, flame retardants
Arsenic	Semi-conductors
Barite	Hydrocarbon production
Beryllium	Alloying agent in aerospace and defense industries
Bismuth	Medical and atomic research
Cerium	Catalytic converters, ceramics, glass, metallurgy, polishing compounds
Cesium	Research and development
Chromium	Stainless steel and other alloys
Cobalt*	Rechargeable batteries, superalloys
Dysprosium*	Permanent magnets, data storage devices, lasers
Erbium	Fiber optics, optical amplifiers, lasers, glass colorants
Europium*	Phosphors, nuclear control rods
Fluorspar	In manufacture of aluminum, cement, steel, gasoline, fluorine chemicals
Gadolinium*	Medical imaging, permanent magnets, steelmaking
Gallium*	Integrated circuits, optical devices like LEDs
Germanium	Fiber optics, night vision applications
Graphite	Lubricants, batteries, fuel cells
Hafnium	Nuclear control rods, alloys, high-temperature ceramics
Holmium	Permanent magnets, nuclear control rods, lasers
Indium*	Liquid crystal display screens
Iridium	Coating for anodes for electrochemical processes, chemical catalyst
Lanthanum*	Produce catalysts, ceramics, glass, polishing compounds, metallurgy, batteries
Lithium	Rechargeable batteries
Lutetium	Scintillators for medical imaging, electronics, cancer therapies
Magnesium*	Alloy, metal reducer
Manganese	Steelmaking, batteries
Neodymium*	Permanent magnets, rubber catalysts, medical and industrial lasers
Nickel*	Stainless steel, superalloys, rechargeable batteries
Niobium	Steel, superalloys
Palladium	Catalytic converters
Platinum	Catalytic converters
Praseodymium*	Permanent magnets, batteries, aerospace alloys, ceramics, colorants
Rhodium	Catalytic converters, electrical components, catalyst
Rubidium	Research and development in electronics
Ruthenium	Catalysts, electrical contacts, chip resistors in computers
Samarium	Permanent magnets, absorber in nuclear reactors, cancer treatments
Scandium	Alloys, ceramics, fuel cells
Tantalum*	Electronic components, capacitors, superalloys
Tellurium	Solar cells, thermoelectric devices, alloying additive
Terbium*	Permanent magnets, fiber optics, lasers, solid-state devices
Thulium	Metal alloys, lasers
Tin	Protective coatings, steel alloys
Titanium	White pigment, metal alloys
Tungsten	Wear-resistant metals
Vanadium	Alloying agent for iron and steel
Ytterbium	Catalysts, scintillometers, lasers, metallurgy
Yttrium	Ceramics, catalysts, lasers, metallurgy, phosphors
Zinc	Metallurgy to produce galvanized steel
Zirconium	High temperature ceramics, corrosion-resistant alloys

Rare Earth Elements

Rare Earth Elements (REE) are metallic elements on the periodic table. They include two transition metals and all metals in the Lanthanide series (atomic numbers 57-71). Here's a link to more information. They allow technology like smartphones to be made smaller and lighter. They're used in modern medical devices, in satellite communications, and in aircraft and their guidance systems. These elements have unique magnetic, phosphorescent, and catalytic properties and make our technology-enabled society possible. REEs are actually NOT rare in nature, but it IS rare to find them in quantities that would be economical to extract (i.e. it's expensive).

The REEs are yttrium, lanthanum, cesium, praseodymium, scandium, terbium, neodymium, dysprosium, gadolinium, europium, samarium, thulium, holmium, lutetium, ytterbium, erbium, and promethium.

This website from Canadian Geographic has a great, interactive way to learn about the REEs in a smartphone.

Conflict Minerals

Unfortunately, some of the minerals used to manufacture cell phones are called conflict minerals, meaning they're mined in areas of armed conflict and are traded illicitly to finance fighting. Conflict minerals fund rebel groups, contribute to political and economic instability, neglect workers' rights, safety, and the ability to earn a fair wage. Countries and rebel groups that mine and sell conflict minerals have committed war crimes and human rights violations. Groups in the Democratic Republic of Congo, Bolivia, and Indonesia reportedly produce Coltan, tungsten, and tin with forced labor and/or child labor.

Some of the conflict minerals used in cell phones are: cassiterite (provides tin), gold, Coltan (provides niobium and tantalum), tantalite (provided tantalum), cobalt, and wolframite (provides tungsten).

You can find more information using these links:

- https://verite.org/project/coltan-tungsten-tin-2/
- https://www.mining.com/conflict-minerals-entering-tech-supply-chains-from-countries-beyond-africa-report/
- https://www.state.gov/conflict-minerals/
- https://www.gao.gov/products/gao-23-106295

Cell Phone Recycling

Cell phone recycling is a matter of both economics and environmental responsibility. Recapturing critical minerals and rare earth elements helps to reduce technology waste and lessens our need to find new sources of these components. According to Earth911, the U.S. is responsible for more e-waste (electronic waste) than any other country.

- Around 350,000 cell phones are disposed every day (152 million per year)
- There are 7.2 billion active mobile devices in the U.S. – larger than the U.S. population
- Only 12.5% of e-waste is recycled
- One million recycled cell phones yield: 35,274 pounds of copper, 772 pounds of silver, 75 pounds of gold, and 33 pounds of palladium

Here are some resources for you to check out:

- https://www.verizon.com/articles/trade-in-to-trade-up/cell-phone-recycling/
- https://earth911.com/recycling-guide/how-to-recycle-cell-phones/
- https://earth911.com/inspire/we-earthlings-for-every-million-cellphones-recycled/

Activity Ideas

Here are activity ideas and critical thinking questions based on this lesson, the resources provided, or any other resources you find.

Elements, Minerals & Rocks

- Learn about the relationship between elements, minerals, and rocks.
- How do elements combine to form minerals? How do minerals combine to form rocks?

Minerals in Cell Phones (ESS.EES.5.1, ESS.EES.5.5, ESS.EES.5.6)

- Geography & critical thinking:
  - Have your students make a comprehensive list of all the minerals used to make cell phones. Based on that information, have them do the following:
  - Find the countries that produce cell phone minerals.
  - Use a Google map or paper maps to locate the countries. Label them and answer the following:
    - Are there any countries that produce cell phone minerals that have ongoing conflict (war)?
    - Are there any countries that produce multiple cell phone minerals?
    - Is there a region of the world that produces more cell phone minerals than other regions?
    - Make a list of reasons why importing so many important minerals from other countries could present issues for the U.S.
- Environment & Critical thinking:
  - Research the various ways minerals are mined. What are the environmental impacts from the various mining processes (land disturbance, air pollution, water pollution, ecosystem disturbance, etc.)?
  - Why do you think it's important to find more than one use for a mineral? In what ways can multi-use minerals affect mining, processing, e-waste, and the environment?
  - Research minerals found in/on the ocean floor? Do you think it's environmentally responsible for humans to mine the ocean floors for minerals? Explain your answer.

Conflict Minerals in Cell Phones (ESS.EES.5.1, ESS.EES.5.5, ESS.EES.5.6, ESS.EES.6.1)

- Research the current conflict minerals that are in cell phones. What countries are providing these minerals and why are those minerals considered to be conflict minerals?
- How does the mining of conflict minerals impact human populations, some more than others?
- Do the mining techniques used for conflict minerals negatively impact natural resources, ecosystems, and/or human health? If so, how?
- Are there any tech companies who are changing their policies and production methods to ensure they don't use conflict minerals?
- Is there anything you can think of that might lessen the tech industry's reliance on conflict minerals?

Sustainability and Your Cell Phone (ESS.EES.5.1, ESS.EES.5.5, ESS.EES.5.6, ESS.EES.6.1)

- Assign students one mineral from the list of cell phone minerals and research its uses for technologies other than cell phones.
    - Are any of the uses for that mineral included in green energy or green technology?
- Research what can you do to extend the life of your cell phone.
- Have students survey school administrators to find out if the school's e-waste is recycled. If so, where does it go? If not, they can try to start a campaign to have their school's e-waste sent to a certified recycler.
- Have students start a campaign in their school to 1) advocate for individual cell phone recycling, 2) increase awareness of extending the life of cell phones and its importance for our environment, and 3) highlight eco-friendly phones and accessories.
- Research the cell phone recycling process to find out how much of a cell phone can be recycled.
    - How much (in weight or volume) can be recovered from cell phones that have been turned in?
- Recovering metals and minerals during cell phone recycling can reduce the need to mine for new sources. Research into why is this important to humans and to the environment.
- What are some ways that our environment can be harmed during mineral mining?
- Are there populations of people who might be more affected from these mining processes than others? Explain your answer.