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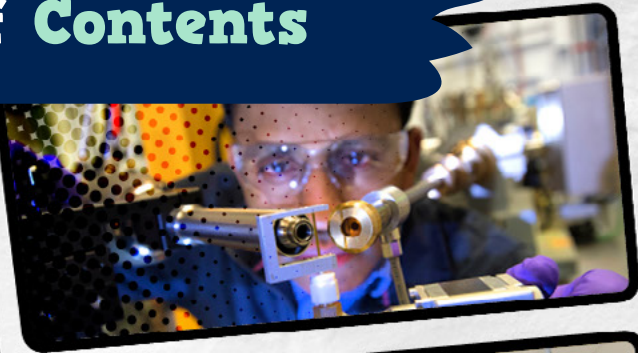
24 Cr Chromium 52	53 I Iodine 127	22 Ti Titanium 48	6 C Carbon 11	13 Al Aluminum 27
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MINERALS

*THE CURIOUS MIND'S GUIDE TO STUDYING,
USING, AND FINDING CRITICAL MINERALS.*



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Why do we need critical minerals?

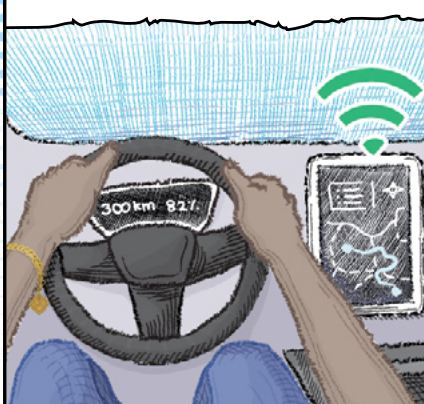
Throughout our day, we are surrounded by critical minerals. How do we interact with them and why are they so critical?

Let's find out!

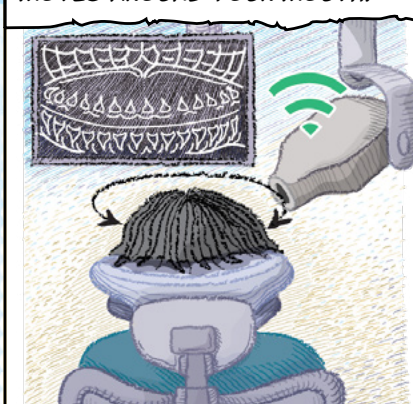
AS SUNLIGHT FILLS YOUR BEDROOM, YOU CHECK YOUR CELLPHONE FOR THE TIME AND QUICKLY GET READY FOR THE DAY.



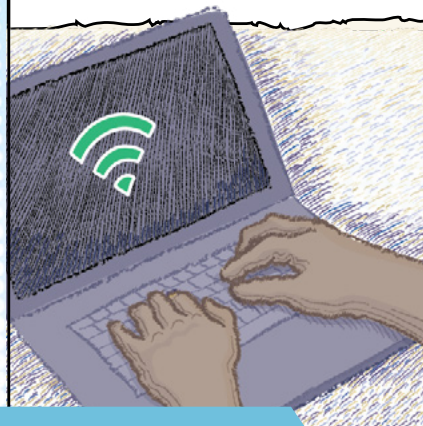
YOU HOP IN AN ELECTRIC CAR AND TURN ON SOME MUSIC AS YOUR SISTER DRIVES YOU TO YOUR ANNUAL DENTIST VISIT.



ONCE IN THE EXAMINING CHAIR, YOU BRACE YOURSELF AS THE X-RAY MACHINE AWKWARDLY MOVES AROUND YOUR MOUTH.

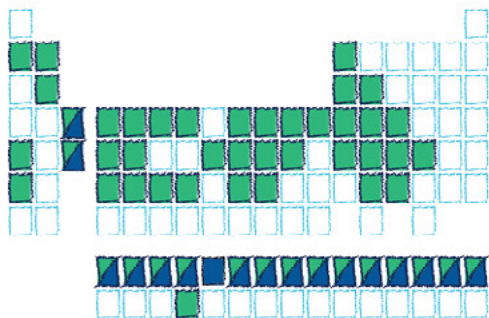


AFTER LEAVING THE DENTIST AND ARRIVING AT SCHOOL, YOU POWER ON YOUR LAPTOP AND CONNECT TO WI-FI.



CELL PHONES, WI-FI ROUTERS, CARS, AND X-RAY MACHINES ARE JUST A FEW EXAMPLES OF HOW MANY PRODUCTS RELY ON CRITICAL ELEMENTS AND MINERALS.

CRITICAL MINERAL ELEMENT OR METAL?



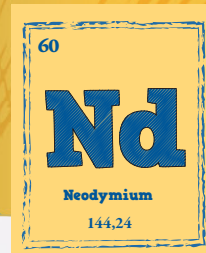
□ Element
■ Critical Element
■ Rare Earth Element

A critical element is an element on the periodic table that is critical to our economy or national defense.

- Some elements are also metals (meaning they can conduct electricity or heat), so we call them **critical metals**.
- If a mineral contains a critical element or critical metal, it becomes a **critical mineral**.

- > Smart phone touch screens contain europium and indium.
- > Car batteries contain lithium, cobalt, and nickel.
- > X-ray machines contains tungsten.
- > Laptops contain lithium, cobalt, and rare earth elements.

FOR EXAMPLE, **NEODYMIUM** IS A **CRITICAL METAL** THAT CAN BE INCORPORATED INTO THE MINERAL MONAZITE, MAKING IT A **CRITICAL MINERAL**. **NEODYMIUM IS USED FOR SUPER-STRONG MAGNETS**



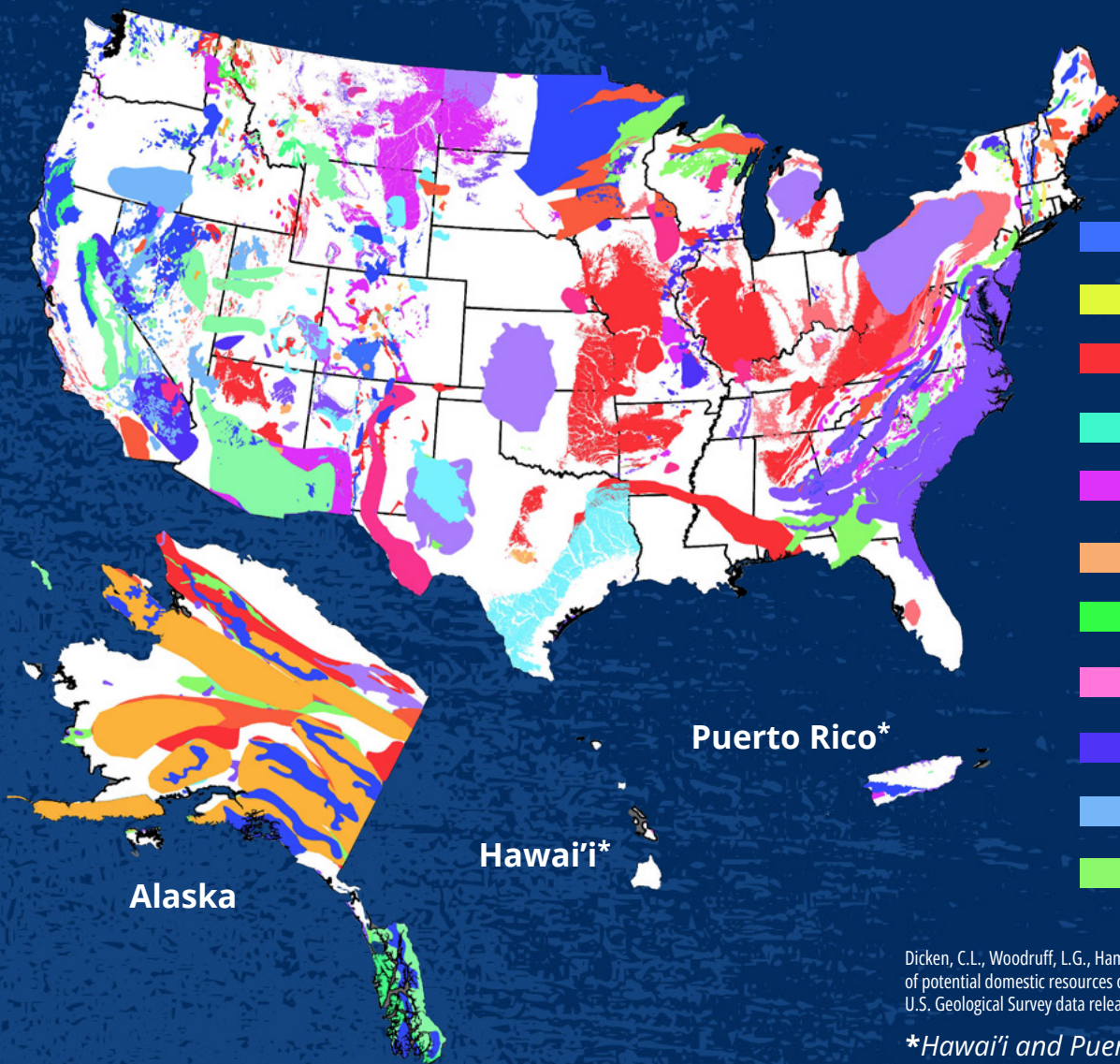
Areas with Potential to Host Subsurface Critical Minerals



U.S. Department of the Interior
U.S. Geological Survey

The U.S. has a variety of geologic deposits that have the potential to include critical minerals. The types of deposits shown on the map can be broadly grouped.

- **Magmatic** deposits form when fluids in volcanic or plutonic systems concentrate metals in minerals and veins.
- **Evaporite** deposits host metals and other minerals that crystallize as water evaporates.
- **Metamorphic** systems concentrate metals when minerals recrystallize during metamorphism caused by high pressure, temperature, and the presence of fluids.
- **Marine** deposits form when seawater evaporates in arid environments or chemically precipitates new minerals.
- **Meteoric** (surface) water can concentrate critical minerals when streams erode rocks with critical minerals or when rainwater chemically alters metal-bearing rocks. Surface water or groundwater can also percolate through magmatic systems to concentrate metals.



Deposit Types (Critical Minerals)

Magmatic (Al, As, Bi, fluorspar, Ga, Ge, In, Mn, PGE, Sb, Sc, V, W, Zn)	Magmatic (Be, Hf, Nb, REE, Sc, Sr, Ta, Te, Ti, V, Zr)
Evaporite (As, Bi, Co, Ni, Sb)	Marine (Co, Cr, F, Mn, Ni, PGE, REE, V)
Evaporite (Co, Cs, Ga, Ge, In, Li, Mg, PGE, REE, Sc, Sn, Zn)	Marine (Mg)
Magmatic (As, Sb)	Metamorphic (Graphite, Mg, REE)
Meteoric (Al, Bi, Co, Ga, Ge, In, Li, Mn, Nb, Ni, PGE, REE, Sc, Zn)	Meteoric (Sb, Te)
Magmatic (Al, As, Be, Bi, Ga, Ge, In, Li, Mn, Nb, REE, Sb, Sc, Sn, W, Zn)	Meteoric (Co, Mg, Mn, PGE, REE, Sc, Sr, V)
Metamorphic (Co, Ga, Ge, In, Sb, Zn)	Metamorphic (As, graphite, Sb, Te, W)
Magmatic-Brine Hybrid (Be, Nb, REE, Ti)	Meteoric (Hf, Nb, Mn, PGE, REE, Sc, Sn, Ta, Ti, W, Zr)
Magmatic (As, Bi, Co, Ga, Ge, In, Mn, Ni, Re, Sb, Zn)	Magmatic (Al, As, Bi, Co, Ga, Ge, In, Mg, Mn, PGE, Sb, Sc, Sn, Te, W, Zn)
Evaporite (Cs, Li, Mg, Mn, Rb, W, Zn)	Magmatic (Al, As, Be, Bi, Cs, Ga, Ge, In, Li, Mn, Nb, Sb, Sc, Sn, Ta, Te, W, Zn)
Magmatic (Co, Cr, NiO, PGE, REE, Te, Ti, V)	Magmatic (As, Be, Bi, Cs, Ga, graphite, In, Li, Mn, Nb, Sb, Sc, Sn, Ta, Te, W, Zn)
	Magmatic (As, Bi, Co, Ga, Ge, In, Mn, Ni, REE, Sb, Sc, Sn, Te, Zn)

Dicken, C.L., Woodruff, L.G., Hammarstrom, J.M., and Crocker, K.E., 2022, GIS, supplemental data table, and references for focus areas of potential domestic resources of critical minerals and related commodities in the United States and Puerto Rico (ver. 2.0, April 2024): U.S. Geological Survey data release, <https://doi.org/10.5066/P9DIZ9N8>.

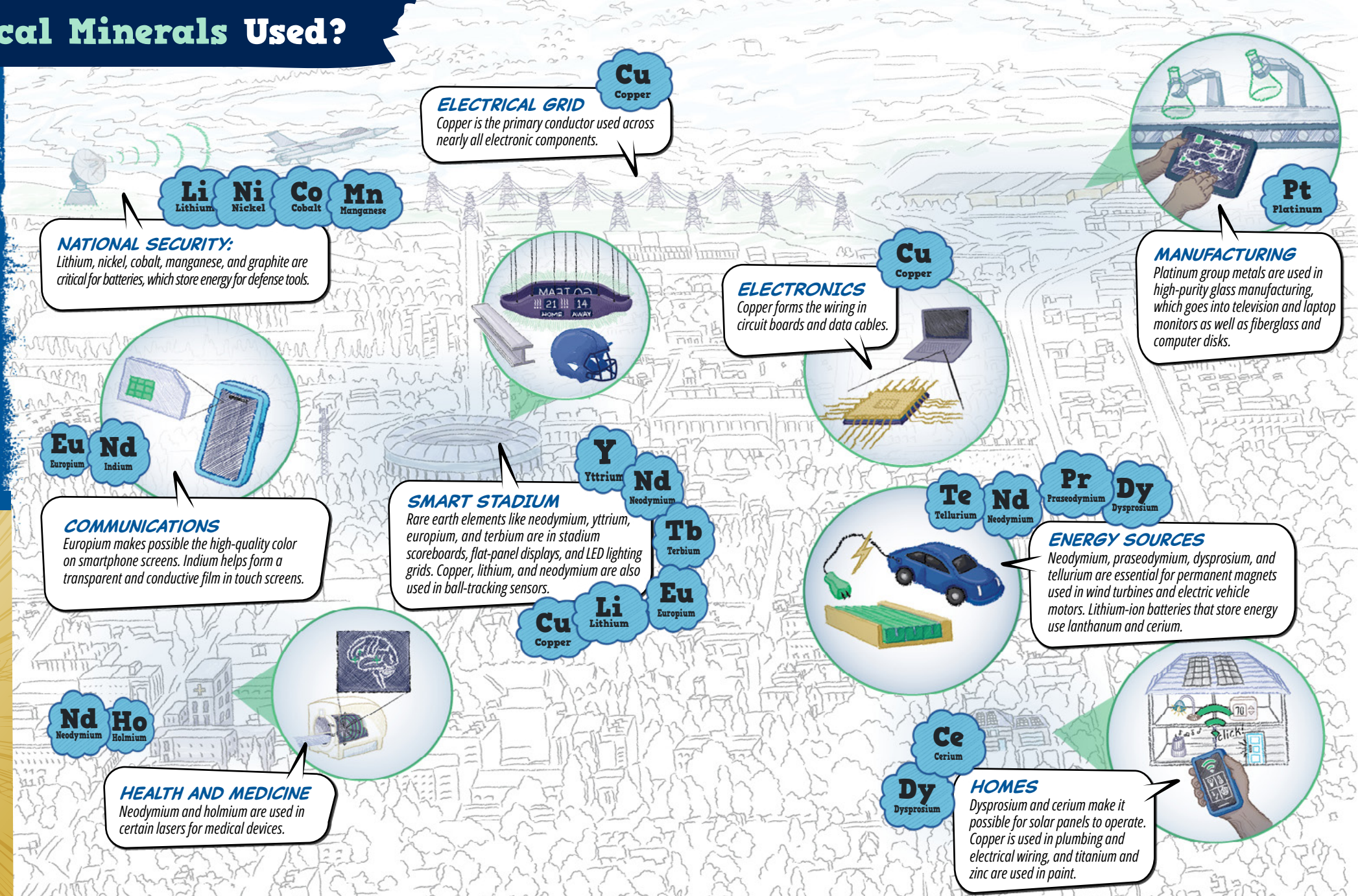
**Hawai'i and Puerto Rico are not to scale*

How are Critical Minerals Used?

We call these minerals critical because they're in high demand but have limited or vulnerable supply. The latest list of critical minerals to the U.S. changes over time.

For example, people used to think table salt, or halite, was a critical mineral (can you imagine a bland chip?), but now we think palladium is critical (for smartphones, among other tech).

We rely on critical minerals in almost every aspect of our lives. From electrical grids to car engines, these materials do it all.

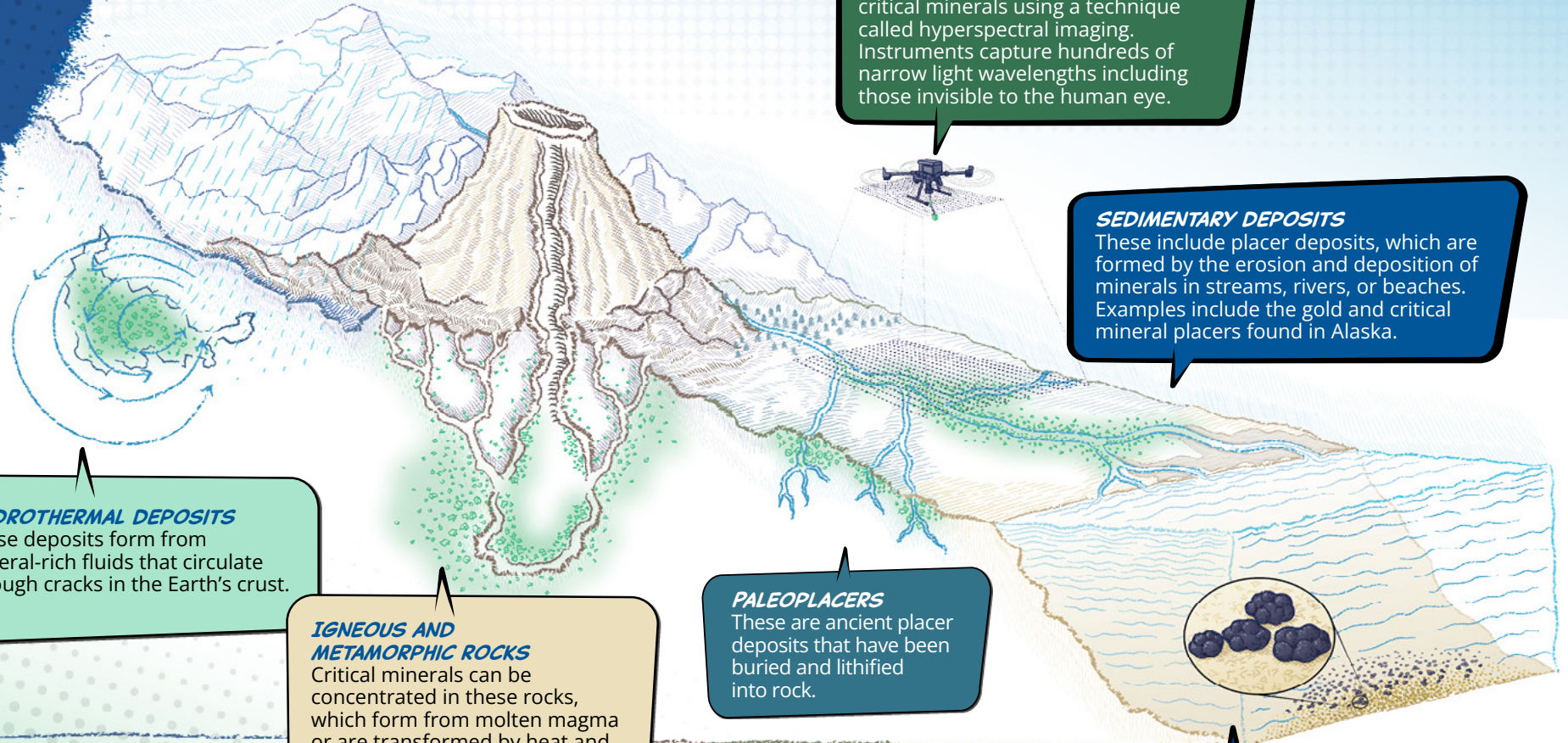


Exploring Geologic Settings

Many critical minerals form in and around igneous systems, where there is or used to be magma. Critical minerals can accumulate when magma cools and crystallizes, concentrating metals into specific minerals.

There are lots of places in the nation where geoscientists are actively exploring and studying critical mineral sources, like igneous rocks in **Butte, Montana, the Copper Mountain Mining District in Arizona,** and **sedimentary deposits in Alaska.**

Some are also investigating new ways to recover critical minerals from materials that were once thought to be mining waste, including in Arizona, Montana, and Alaska.



MAPPING BY AIR

Drones and satellites are used to map critical minerals using a technique called hyperspectral imaging. Instruments capture hundreds of narrow light wavelengths including those invisible to the human eye.

SEDIMENTARY DEPOSITS

These include placer deposits, which are formed by the erosion and deposition of minerals in streams, rivers, or beaches. Examples include the gold and critical mineral placers found in Alaska.

HYDROTHERMAL DEPOSITS

These deposits form from mineral-rich fluids that circulate through cracks in the Earth's crust.

IGNEOUS AND METAMORPHIC ROCKS

Critical minerals can be concentrated in these rocks, which form from molten magma or are transformed by heat and pressure. For example, some rare earth elements (REEs) are found in intrusive igneous rocks.

PALEOPLACERS

These are ancient placer deposits that have been buried and lithified into rock.

SEAFLOOR EXPLORATION

Over time, metals in seawater such as manganese, iron, copper, nickel, cobalt, and sometimes rare earth elements accumulate in layers on the outside of other particles. Trying to access these nodules in ways that don't disturb seafloor environments is a major challenge.

Once **Critical Minerals** are found...

After geoscientists have located potential environments to find critical minerals, they collaborate with experts in other fields to extract those minerals.



INDUSTRY PROFESSIONALS

Mining companies and investors determine if the minerals can be produced in a profitable way. They decide if they need to build a new mine or focus on older mine tailings — the finely ground rock, water, and trace chemical waste leftover after the valuable minerals or metals have been extracted from mined ore.



ENVIRONMENTAL IMPACT ASSESSORS

Experts determine how the mining efforts will impact the environment and local communities.



COMMUNITY OUTREACH TEAMS

Researchers connect with the people who live in impacted communities to hear their ideas and concerns about new mines being located nearby.

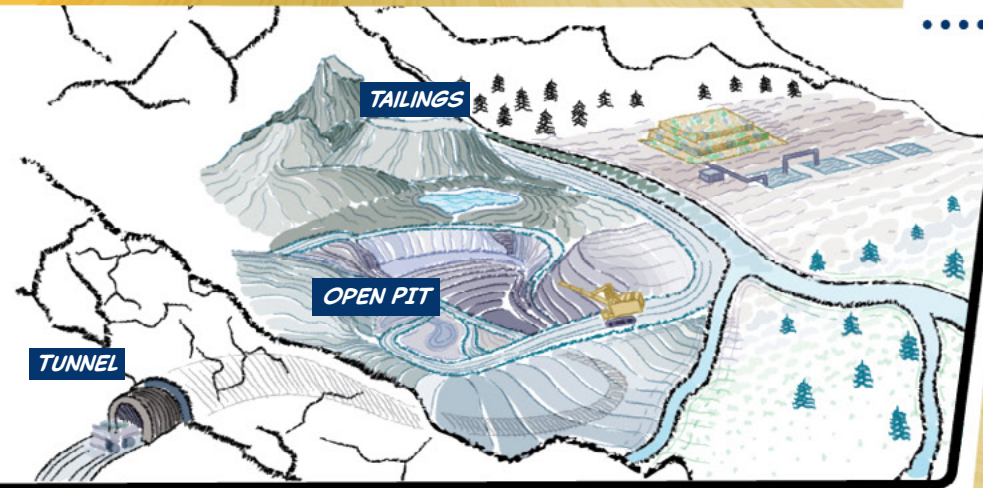


LAWYERS

Lawyers and local governments must submit requests for permits to begin any mining activities.

From Mining to Minerals

ONCE WE KNOW WHERE THE MINERALS ARE, HOW DO WE GET TO THEM?

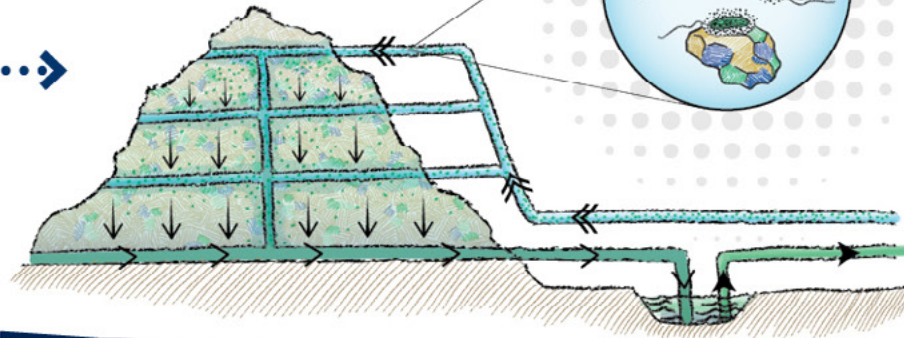


Critical minerals are found in rocks below the Earth's surface. We can take them out by digging large open pits or by digging tunnels into the rock formations.

The rocks that are removed in the process of digging that don't have the minerals we want are called "waste" material. We crush this material up and move it into giant piles outside of the mine called tailings.

However, we've realized that those tailings often contain critical minerals we didn't consider to be valuable or we didn't have the technology to extract at the time they were mined. Researchers are now using creative methods to extract valuable critical minerals from what we used to consider waste.

NEW WAYS OF EXTRACTING AND SEPARATING CRITICAL MINERALS



One process to remove critical minerals from the tailings is to pump fluids through the piles so that chemical reactions can collect material that is rich in critical minerals. Fluids can include acids that must be carefully collected so they are not released into the environment.

In another process, microscopic organisms (microbes) are distributed into tailings piles to collect critical elements. Some microbes break down rocks, releasing critical minerals. Metabolic processes generate energy for some microbes, which helps process critical minerals like lithium, copper, and rare earth elements.

Purifying

Purification processes include a combination of physical processes (e.g. mining and crushing) as well as chemical and sometimes biological processes. Once material is collected from mines or from tailings piles, additional purification processes separate critical elements from each other and lead critical minerals from rocks to pure materials that can be used to improve the efficiency, sustainability, and performance of products like batteries.

PURIFYING CRITICAL MINERALS FOR MANUFACTURING.

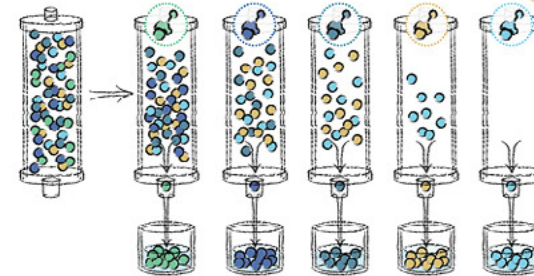
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Purification processes can include a combination of physical processes (e.g. mining and crushing), as well as chemical and sometimes biological processes.

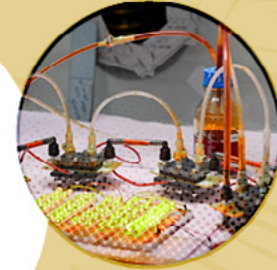
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CRITICAL MINERALS SEPARATION



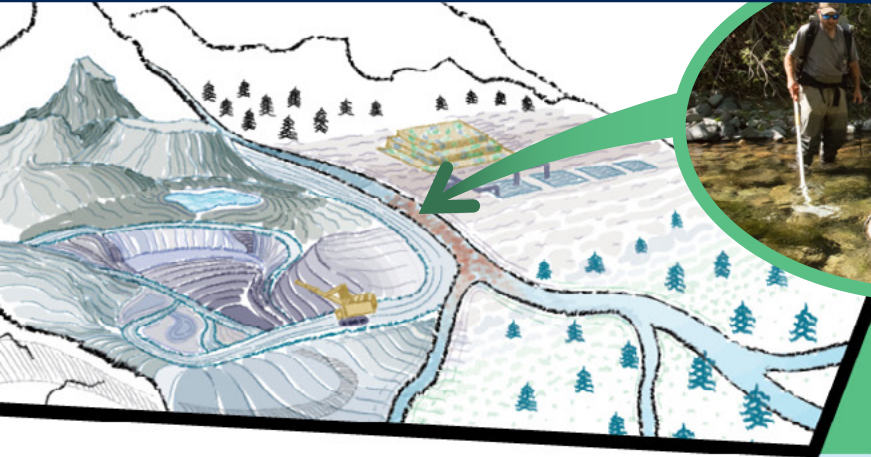
Crushed rock material can be dissolved in fluids that chemically purify and separate critical elements from each other.

3



The final purified product improves the efficiency, sustainability, and performance of items like this experimental battery.

What happens after we mine?



Mining geologists and environmental scientists carefully monitor streams and soils to make sure contamination doesn't happen. They also work to remove any impacts of contaminants if they are detected. After mining processes end, mined areas can be restored by planting vegetation. Mine sites are sometimes repurposed for wildlife and parks.

Cellphones, computers, and other electronics contain a lot of critical minerals. Engineers have developed ways to remove these critical minerals from our old devices, making it really important to recycle anything we want to toss.



Mining and purification processes at mines can release extra sediment into streams, which makes it hard for fish and other life to survive. Chemical processes may also unintentionally release chemicals into the environment.

TIMELINE FOR HOW WE RECYCLE E-WASTE (ELECTRONIC-WASTE):

1 E-DUMPING OLD ELECTRONICS:

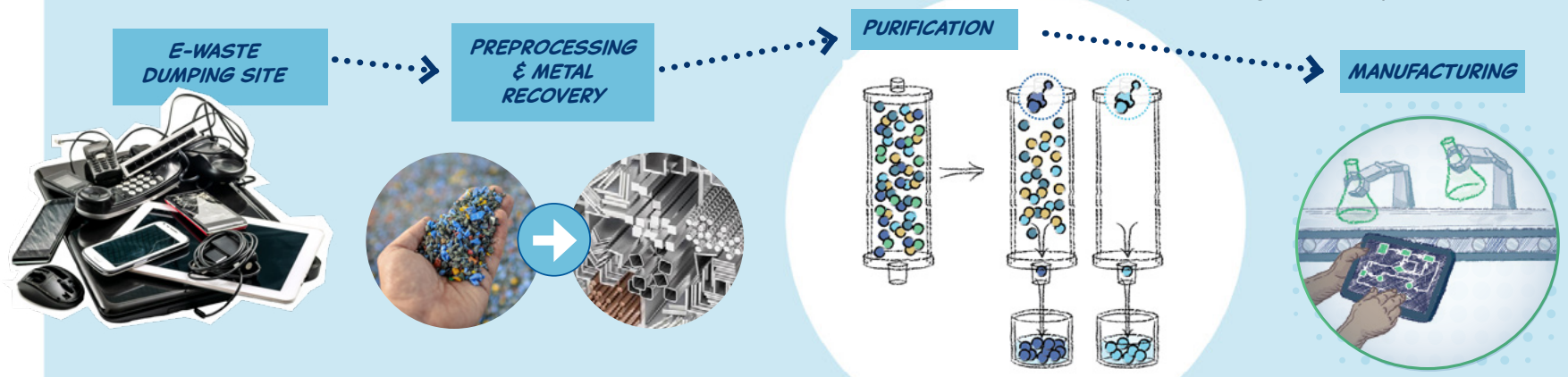
E-waste can be deposited in E-waste sites (in many communities).

2 PREPROCESSING AND METAL RECOVERY:

E-waste is precisely broken down to separate plastics from metals.

3 PURIFICATION AND MANUFACTURING:

Recycled critical minerals are purified and distributed to manufacturing facilities where they are used again in new products.



Critical Minerals Science Ecosystem

Scientific discoveries happen at all stages of the critical minerals ecosystem. From the first stages of **exploration** to the **extraction** processes and finally to the **purification** and **manufacturing** processes, researchers are adding to the growing scientific literature on critical minerals.

Ultimately, critical minerals benefit all of us by providing economic benefits, supporting communication networks, and strengthening national defense. It is also critical that we educate and train the next-generation workforce to continue improving the critical minerals ecosystem.



Be a part of the

WORKFORCE

Scientists often work in teams at universities or companies. For example, an exploration geologist who looks for rocks with critical minerals will work with lab technicians who use microscopes and chemical analyses to determine how much critical material is in the rocks. They then bring this information to the mining engineers and mining company owners who make business decisions at the mine.



UPSTREAM

Geoscientists locate areas with critical minerals, sometimes with drones or by collecting rock samples.

Geoscientists work in labs to find and remove critical minerals from rocks. Biologists work with microbes to extract the minerals. Chemists, biochemists, and technicians work in labs to remove, concentrate, and purify critical minerals so they can be used in products.

Environmental scientists and biologists monitor water and habitats before, during, and after mining.



MIDSTREAM & DOWSTREAM

Engineers develop and improve on ways to build products like cell phones and batteries that use critical minerals.

Researchers use artificial intelligence and advanced computational models to better understand the critical mineral supply chain.

Technicians build products like magnets and batteries that use critical minerals. Researchers build new tools to recycle critical minerals from discarded material.



WORKFORCE TRAINING

Two-year colleges, internships, and apprenticeships offer programs that providing training and education to begin a career supporting the critical minerals ecosystem.

Undergraduate coursework supports all scientific disciplines related to critical minerals and materials.

Graduate coursework provides students with opportunities to deeply study and innovate aspects of the critical minerals ecosystem.



Get Involved

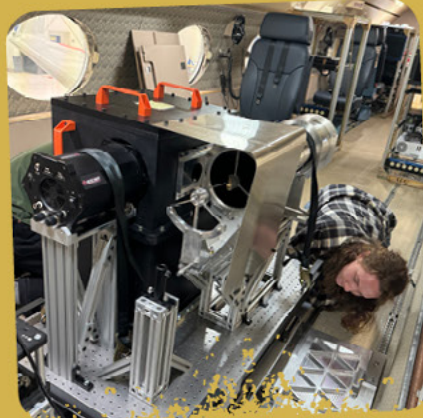


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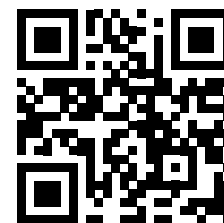
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