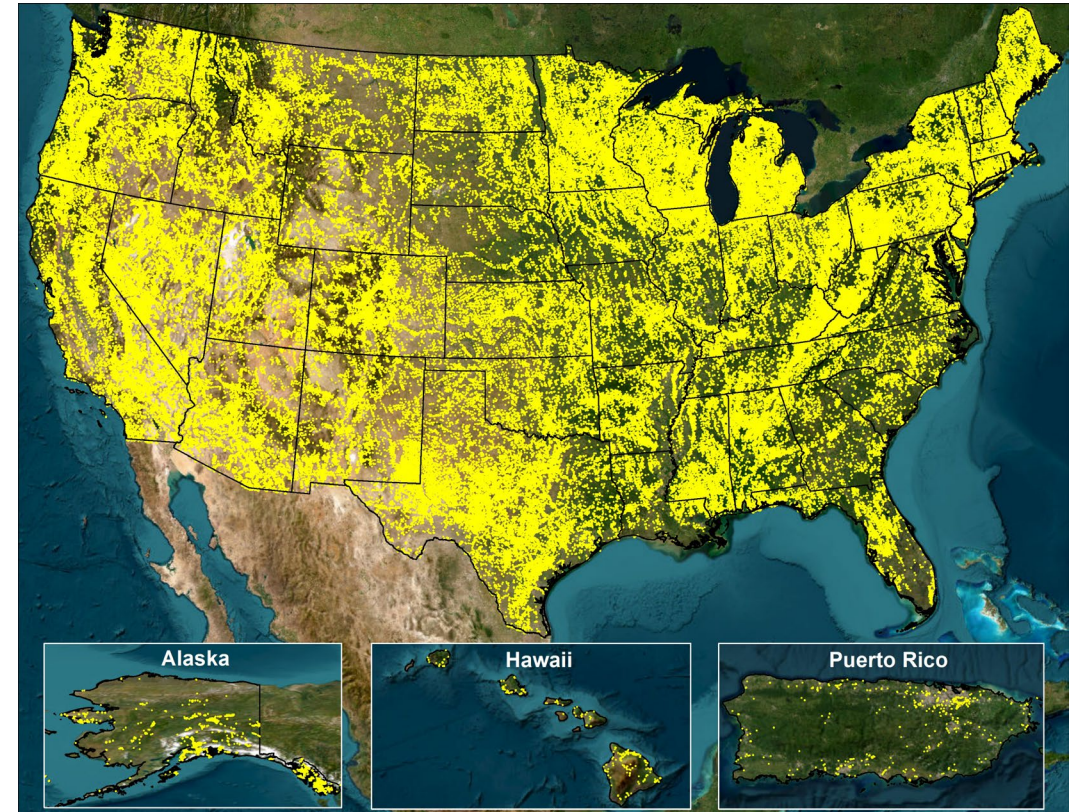


Activities Related to Mine Waste and Earth MRI

Darcy McPhee, Earth MRI Program Manager, Mineral Resources Program
dmcphoe@usgs.gov

Why Study Mine Waste?: Resource Recovery and Remediation

- Mine waste is in every state
 - There is no single authoritative database of all mine locations
- Many legacy mine sites pose environmental and physical hazards
 - There is no single authoritative database of legacy mine status
- Reclaiming mine sites offers co-benefits for remediation and critical mineral recovery
 - Lack of sampling and characterization
 - Lack of methodology for assessing mineral resources in mine waste
 - Lack of definition of sustainability metrics for future mining and mine waste generation and management



New USMIN geospatial database of current and historical mining locations. Yellow dots are mine features captured from historical USGS topographic maps.

Horton, J.D., and San Juan, C.A., 2016, Prospect- and mine-related features from U.S. Geological Survey 7.5- and 15-minute topographic quadrangle maps of the United States (ver. 10.0, May 2023): U.S. Geological Survey data release, <https://doi.org/10.5066/F78W3CHG>.

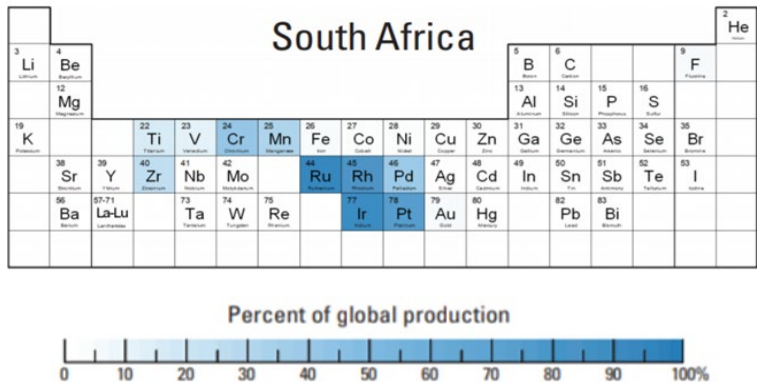
USGS Mine Waste Plan

Goals

- Identification and characterization of **additional domestic sources of critical minerals** to mitigate supply chain challenges,
- Evaluation of the **environmental costs and benefits of extracting resources from mine waste**, and
- Development of **tools to support land-management decisions**, including reclamation of legacy mine sites, at federal and state levels.



USGS Mineral Resources Program



Mineral Intelligence and Supply Chain Analysis

- Analyze global supply, demand, and trade of mineral commodities.
- Forecast supply chain disruptions.
- Develop and update the Nation's critical minerals list.
- Lead a whole-of-government strategy to ensure sustainable and secure mineral supplies.

Research and Assessments

- Understand mineral systems and deposits.
- Understand impacts of mineral development.
- Quantify mineral resources across the resource life cycle and produce mineral resource assessments for Federal, State and international partners.

Earth Mapping Resources Initiative (Earth MRI)

- Data collection, mapping, and synthesis for understanding the Nation's geologic framework and mineral resources, including
 - Mineral resources still in the ground.
 - Above-ground resources in mine wastes and other waste streams.

USGS MINERAL RESOURCES PROGRAM – MINE WASTE STUDIES

Research improves resource assessments and informs Earth MRI mapping efforts. Assessments rely on new Earth MRI data.

Research and Assessments

- Multidisciplinary Lab and Field Mine Waste Studies
- Methods Development
- Data Analysis, Synthesis & Interpretation
- Mine Waste Inventory
- Future: Critical Mineral Resource Assessments in Mine Waste

Supply chain analysis helps prioritize research and assessments. Research improves supply chain analysis and forecasting.

Earth Mapping Resources Initiative (Earth MRI)

- Collects foundational data (topographic, geological, geochemical, hyperspectral and geophysical) and maps the Nation's above- and below-ground mineral resources.
- Mine waste mapping, sampling & characterization
- Mine waste volume determinations
- National Mine Waste Inventory
- State geological survey funding opportunity

Mineral Intelligence and Supply Chain Analysis

- Through a cooperative agreement with Apple Computer, developed a new metric, Rock-to-Metal ratio, to quantify the waste produced by mining.
- For 25 mineral commodities, the study analyzed how much ore is mined and waste rock removed to produce a refined unit of the commodity.
- This metric is vital to understanding mine wastes and potential environmental impacts from mining.
- REE analysis just published.

List of critical minerals and supply chain analysis inform Earth MRI. New Earth MRI data informs long-term supply chain analysis.

MRP Research Example: In-depth Site-Specific Integrated Studies to Characterize Mine Waste Sites

USGS Project leads: Nadine Piatak and Sarah Jane White

- Mineralogical investigations of mine waste inform **critical mineral content, recovery potential, environmental impacts.**
- Microanalytical method development for mine waste characterization (includes **quantitative mineralogy**).
- **Partitioning** of critical minerals is being identified in value and waste streams at active mines (collaborator: **Rio Tinto at Bingham Canyon mine**).
- Critical minerals, toxic elements, and **changes due to weathering and reprocessing** are being examined in mine waste at the **Tar Creek Superfund site**.

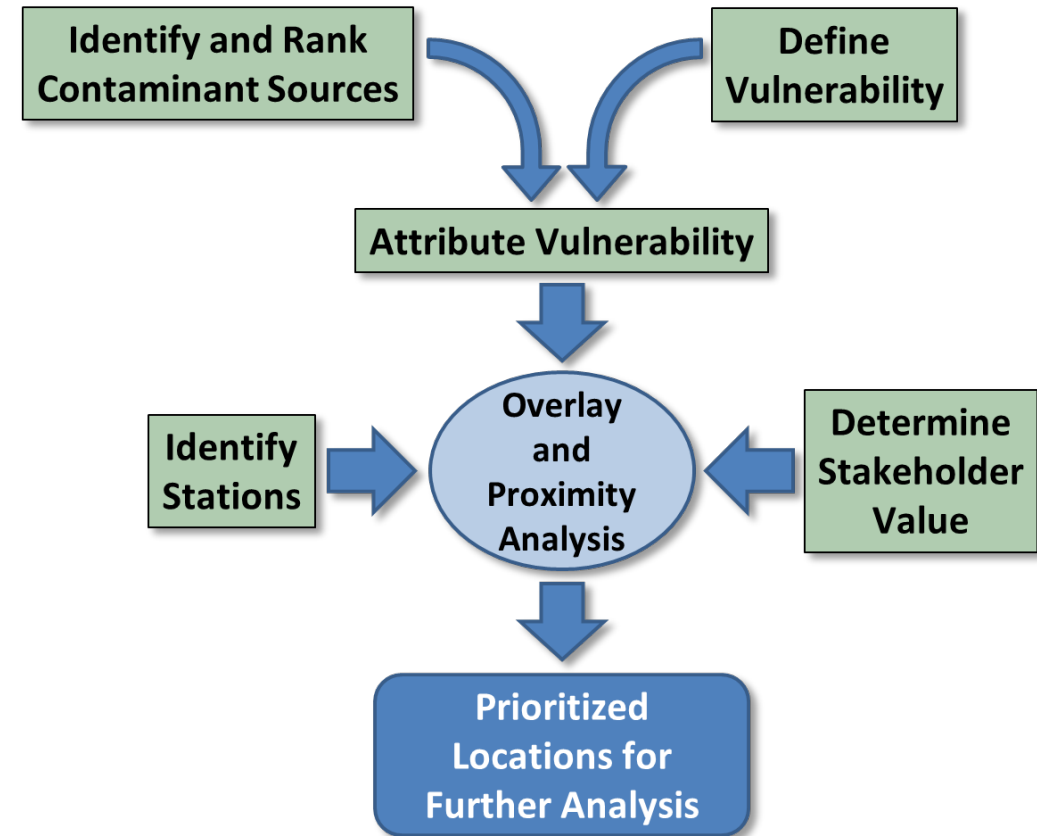
1. White, S.J.O., Piatak, N.M., McAleer, R.J., Hayes, S.M., Seal, R.R. II, Schaidler, L.A., Shine, J.P. (2022) Germanium redistribution during weathering of Zn mine wastes: implications for environmental mobility and recovery of a critical mineral, *Applied Geochemistry*, 143: 105341, <https://doi.org/10.1016/j.apgeochem.2022.105341>.
2. Hayes, S.M., McAleer, R.J., Piatak, N.M., White, S.J.O., Seal, R.R. II. (2023) A novel non-destructive workflow for examining germanium and co-substituents in ZnS. *Frontiers in Earth Science*, special issue: Advances in ore and gem mineral chemistry: Insights into mineral deposit formation and metal cycling in the Earth system. 11.939700. <https://doi.org/10.3389/feart.2023.939700>.
3. Piatak, N.M., Seal, R.R. II, Hoppe, D.A., Bird, T., 2022, The importance of mineralogy in evaluating recovery of critical minerals and other metals from mine waste: An example from a porphyry Cu mine, Geological Society of America Meeting, October 9-12, 2022



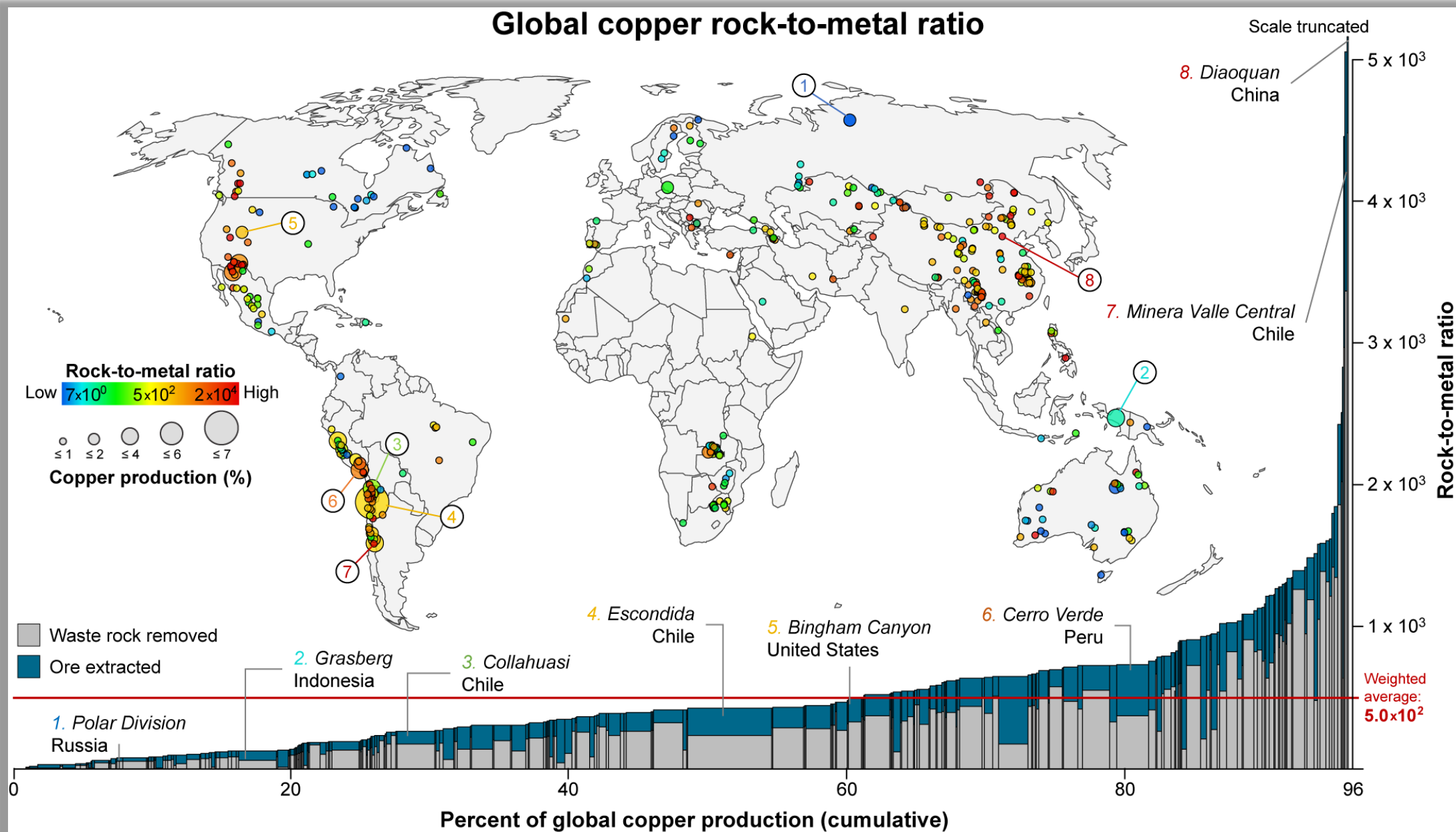
Development of Specialized Decision-Support Tools

PI Contact: Dan Jones, dkjones@usgs.gov

- Geospatial Web Application: **Remediation of Mined Lands.**
- Provides **data visualization** and **data access** for mined land and landscape variables.
- Provides landscape information to:
 - evaluate hazards posed by mined lands,
 - prioritize remediation strategies,
 - document remediation effectiveness across scales.

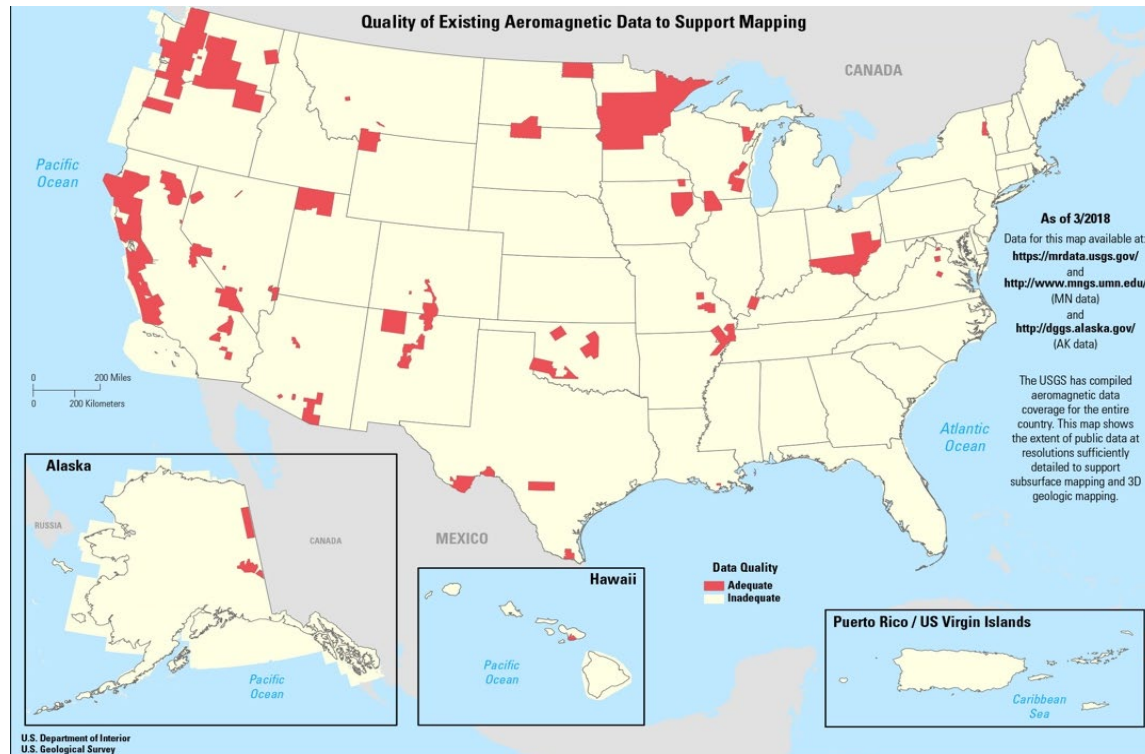


Global Rock-to-Metal Ratio Varies Significantly



Earth Mapping Resources Initiative (Earth MRI) launched in 2019 because the Nation is under-mapped

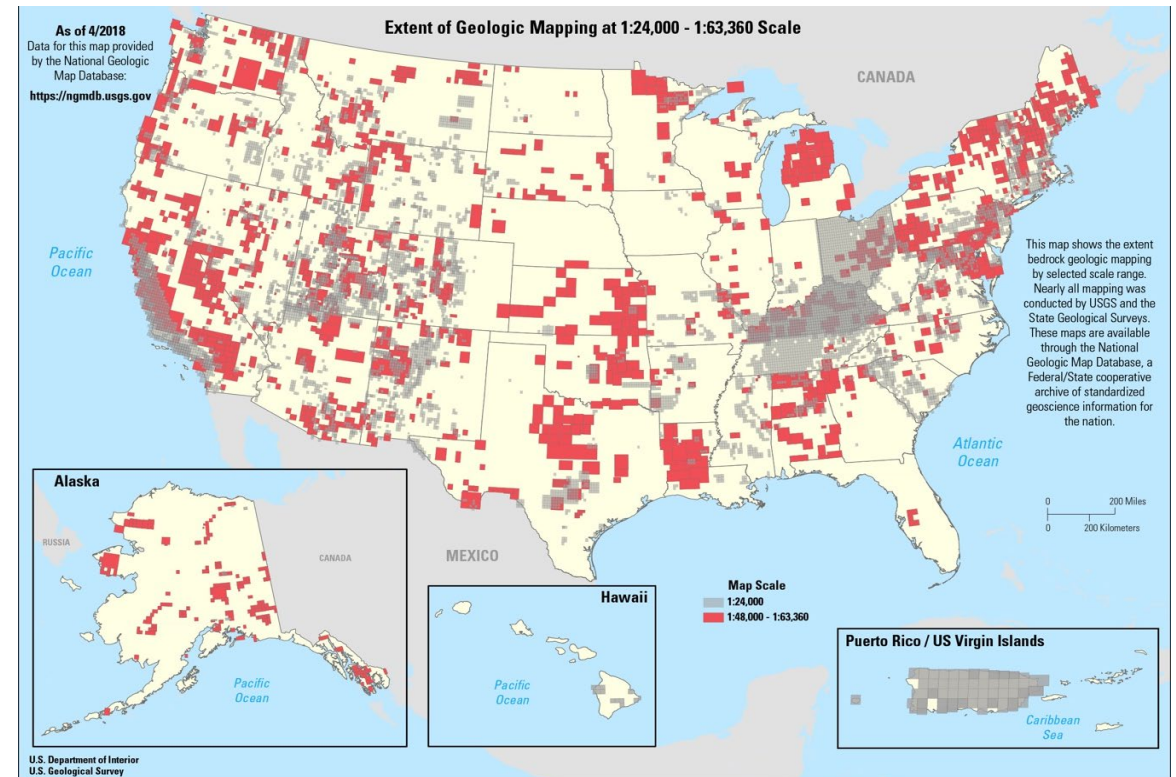
Pre-existing Subsurface Geophysics (2019)



mrdata.usgs.gov,
www.mnsgs.umn.edu,
dggs.alaska.gov

■ Usable quality
($<300\text{m}$ line spacing)

Pre-existing Geologic Mapping (2019)



ngmdb.usgs.gov

■ Moderate (1:40,000-1:63,360)
■ Fine-scale (1:24,000)

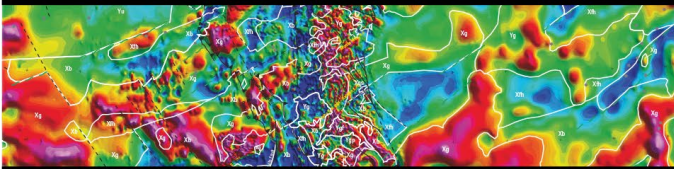
Topography—3D elevation lidar data



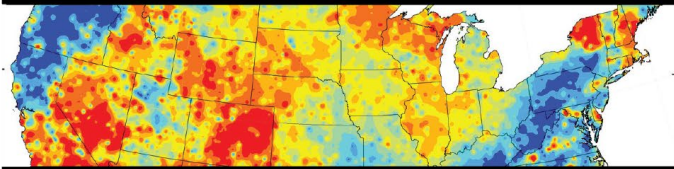
Geology—USGS and State geological survey maps



Geophysics—Aeromagnetic, radiometric, and gravity data



Geochemistry—Rocks, soils, and stream sediments



Mineral deposit databases—USMIN, MRDS, ARDF



Coreholes—Geophysical logs and core samples



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Earth Mapping Resources Initiative (Earth MRI)

Established in 2019 as a partnership between the USGS and State geological surveys to modernize the Nation’s mapping, with a focus on identifying areas that may have the potential to contain mineral resources.

Bipartisan Infrastructure Law: \$64M/year for 5 years in addition to \$10.8M/year appropriation

- Transformational opportunity to increase the Nation’s state-of-the-art data and mapping
- Accelerate existing activities and begin new activities; broaden focus to both **above-ground resources** and below-ground resources

Applications:

- Mineral resources
- Energy resources
- Natural hazards
- Water resources
- Land use planning
- Infrastructure

Partners:

- State geological surveys
- Federal agencies (e.g., DARPA, DOE, NASA, BLM, USFS, NPS)
- Tribes
- Industry
- NGOs
- Academia

Earth MRI– Infrastructure Investment and Jobs Act (IIJA), signed on 11/15/21 (Section 40201) \$320 million over 5 years (FY22-FY26)

“...accelerate efforts to carry out the fundamental resources and mapping mission of the United States Geological Survey by—

- 1) providing integrated topographic, geologic, geochemical, and geophysical mapping;
- 2) accelerating the integration and consolidation of geospatial and resource data; and
- 3) providing interpretation of subsurface and **above-ground** mineral resources data.”

“Not later than 10 years after the date of enactment of this Act, the Initiative shall complete an initial comprehensive national modern **surface** and subsurface mapping and data integration effort.”

Earth MRI Data

Collects fundamental geoscience data including:

- Airborne geophysical surveys (magnetic, radiometric, electromagnetic)
- Hyperspectral surveys
- High-resolution elevation (lidar) surveys
- Geochemical surveys
- Detailed geologic mapping by State geological surveys
- Preservation of minerals data
- Mine waste inventory and characterization with State partners

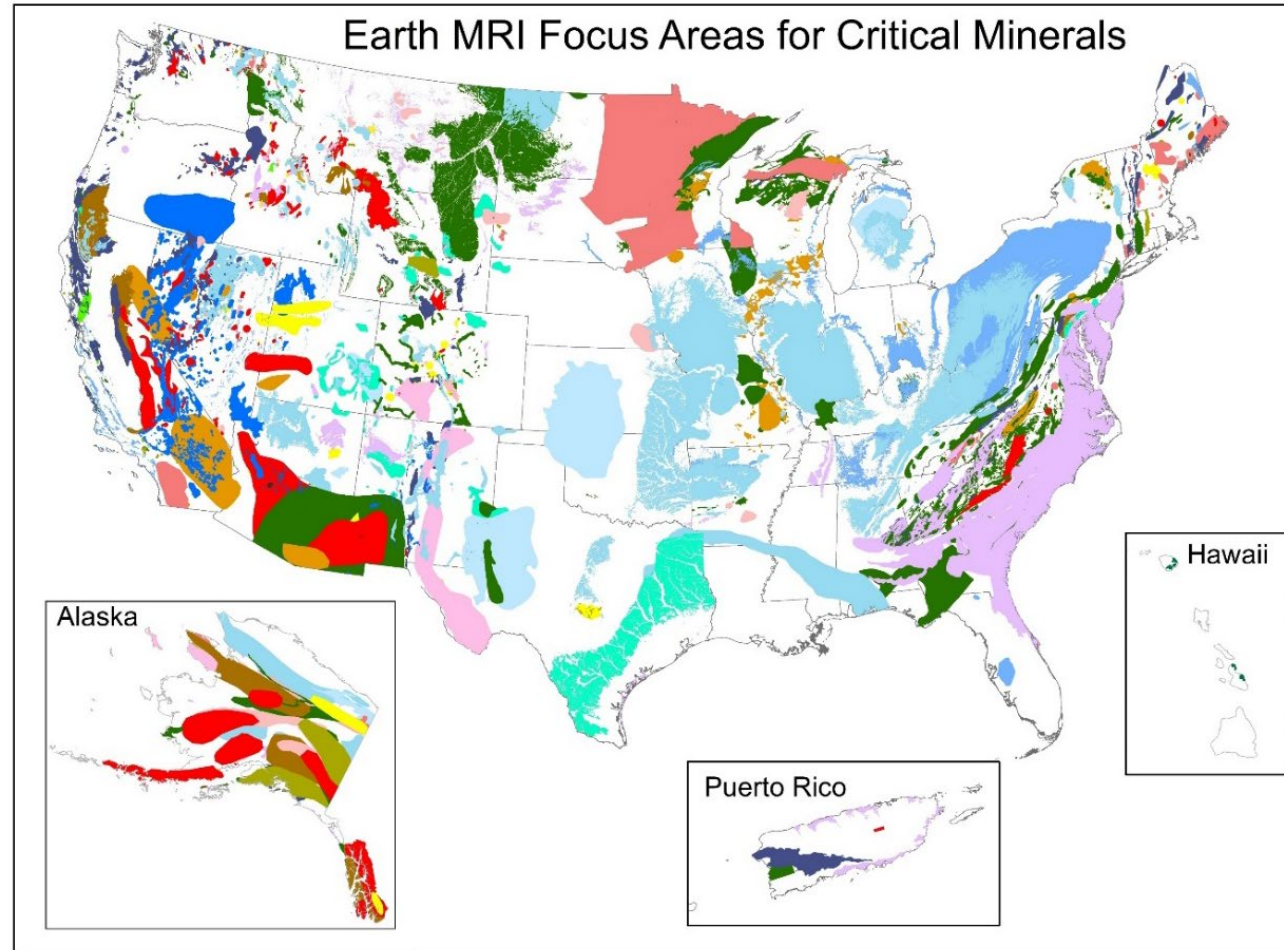
<https://www.usgs.gov/special-topics/earth-mri>



Earth MRI Priorities: Mineral Systems

MRP uses a Mineral Systems approach to:

- Guide Earth MRI data collection
- Accelerate assessing critical mineral resources
- Show resource managers and developers where emerging minerals-dependent technologies may create economic opportunities and/or community concerns



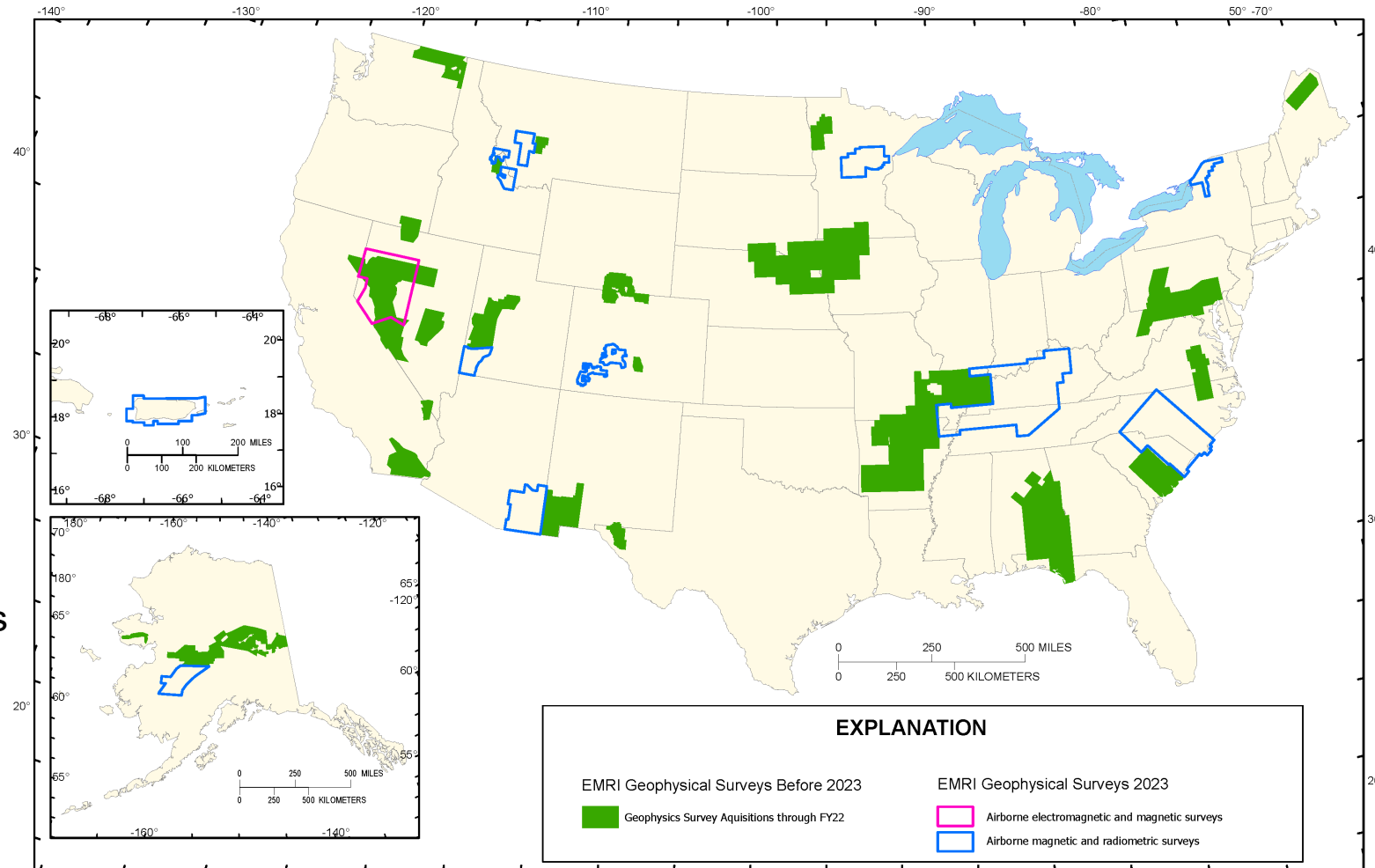
FY23 Earth MRI Airborne Geophysical Surveys

Progress to date:

- FY19-FY22 contracted for area the size of Texas
- FY22 contracted for area greater than area the size of Montana
- FY23 contracted for an area comparable to that covered in FY22- 12 new geophysical surveys!

FY23 survey outlines subject to change due to:

- Tribal engagement processes--must have permission before doing any work on tribal lands
- FFA and DOD restrictions



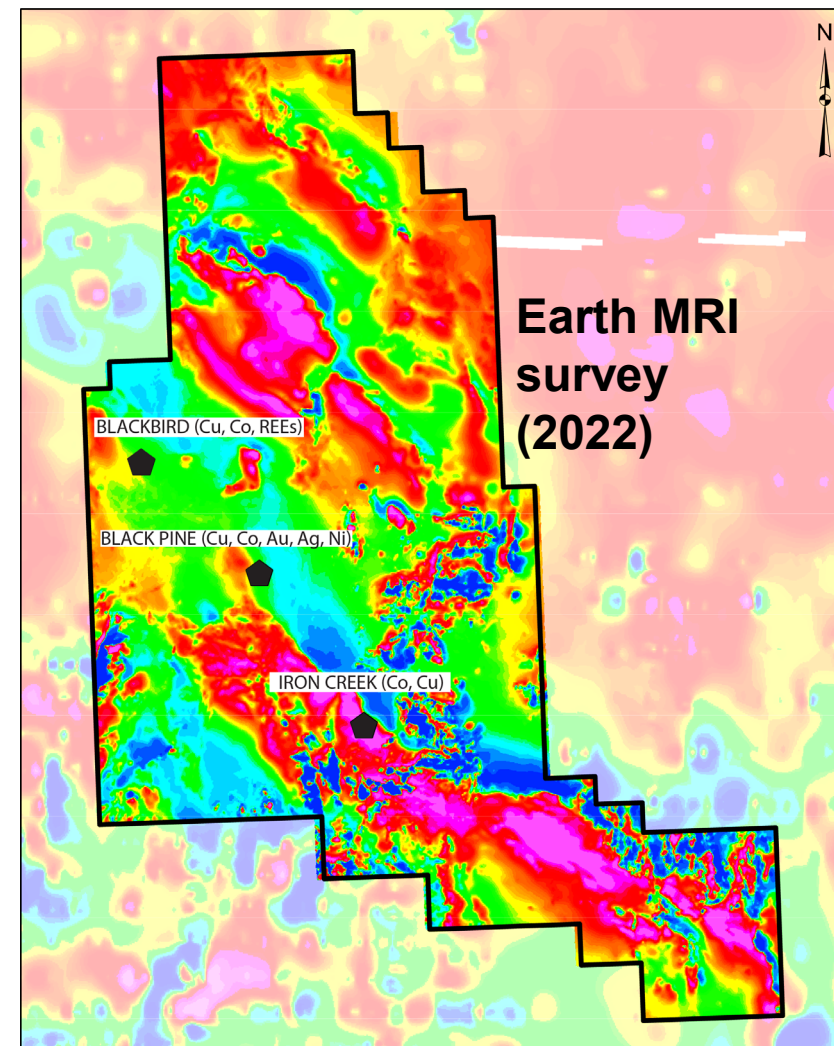
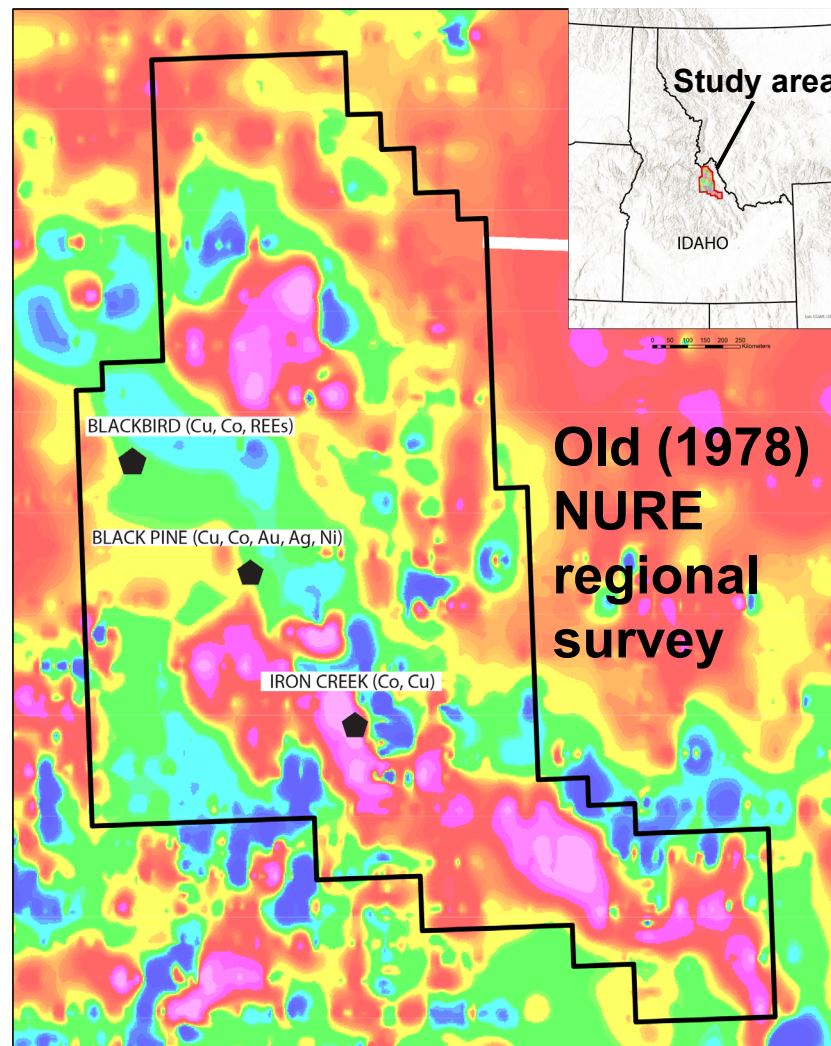
Earth MRI Airborne Magnetic/Radiometric Survey for Idaho Cobalt Belt

The Idaho Cobalt Belt is an active region for exploration and mining for cobalt, copper, and rare earth element resources.

USGS is part of a consortium working on the geology and mineral resources of the district and developing new technologies for mineralogical and geophysical research.

Collaborators:

- Idaho Geological Survey
- Colorado School of Mines
- North Dakota College
- Virginia Tech
- Mining companies:
 - Electra Battery Materials
 - Idaho Strategic Resources
 - Revival Gold
- Analytical companies:
 - Minalyze AB
 - Norsk Electro Optikk AS
 - Hitachi High-Tech
 - National Center for Autonomous Technologies



Geoscience Data Acquisition for Western Nevada (GeoDAWN)

Background

- Region is known to host gold, copper, and many critical mineral resources; Lithium mining ongoing in project area
- DOE Geothermal Technologies Office play fairways analysis identified region has potential for geothermal energy resources

Goal

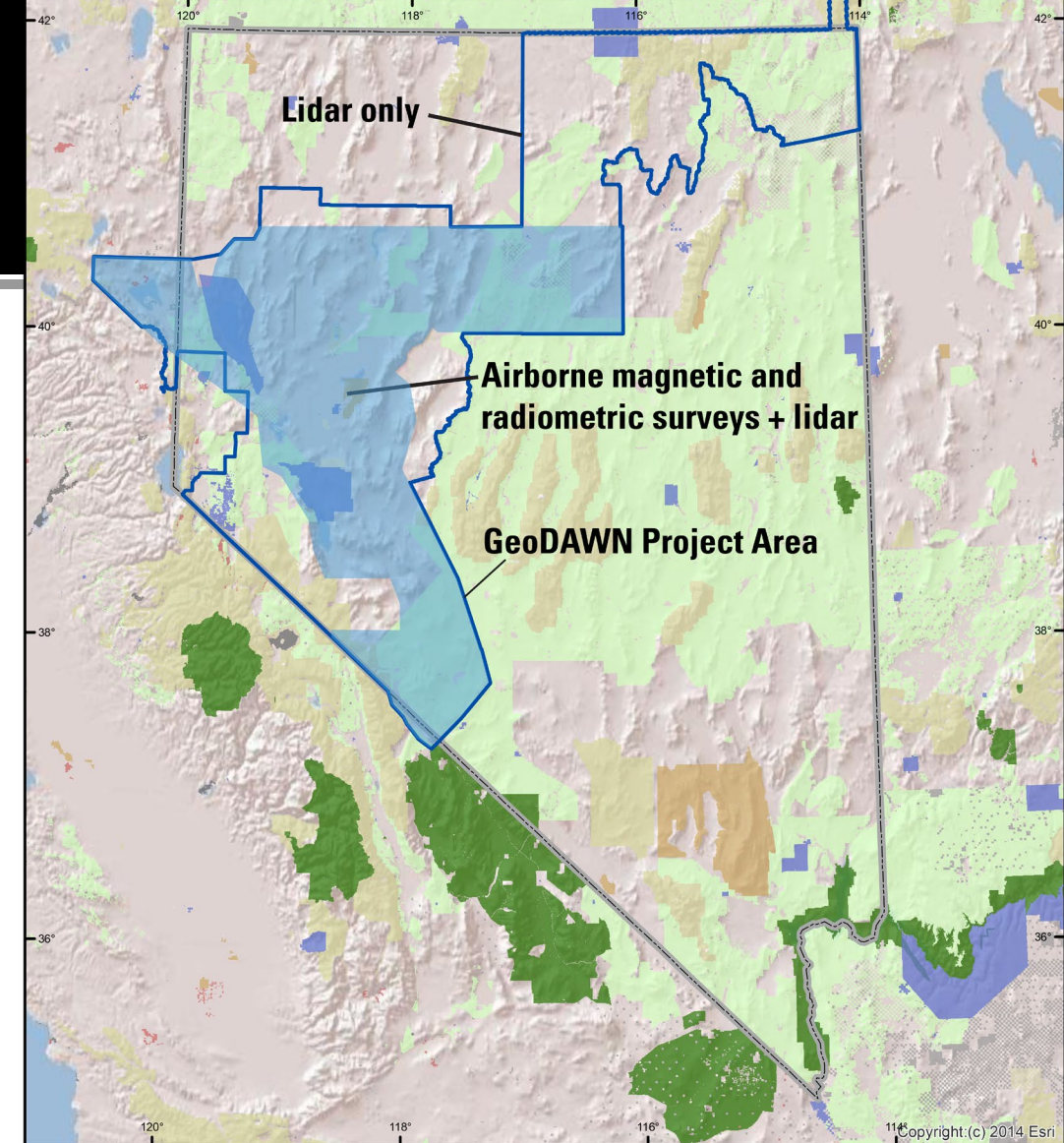
- Collect high-resolution airborne magnetic and radiometric data and lidar data to inform understanding of regional geology, natural resources, and geologic hazards

Details

- Multi-agency partnership includes: USGS, DOE GTO, BLM, NRCS, FEMA, and Nevada Bureau of Mines and Geology
- Total funding: \$10M
- Data collection began in Fall 2021; Survey is complete.

Early Results

- Subtle basin anomalies associated with newly lidar-mapped fault scarps
- Mapping new structure and geology with magnetics



Land Manager

- Tribal lands
- Bureau of Land Management
- National Park Service
- US Fish and Wildlife Service
- Dept of Defense

Land Manager (cont.)

- State Fish and Wildlife
- State Park and Recreation
- State (all classes)
- Federal (all classes)

Earth MRI-NASA A High Altitude Hyperspectral Survey



- AVIRIS-Classic high-altitude visible/infrared imaging spectrometer (17m GSD) and the MASTER thermal infrared multispectral sensor (~50 m GSD)
- Acquisition date range: ~August 20 to September 27, 2023
- New coverage: > 172,500 sq. km.
- Builds on existing 380,000 sq. km. of AVIRISc data
- USGS team collected field reflectance to support ground calibration of airborne data
- FY24: Spring campaign due to start in April 2024 with NASA/JPL's AVIRIS-3 sensor
- District-scale surveys in FL

FY23 Earth MRI Data Acquisition Coverage for the semi-arid Western US.

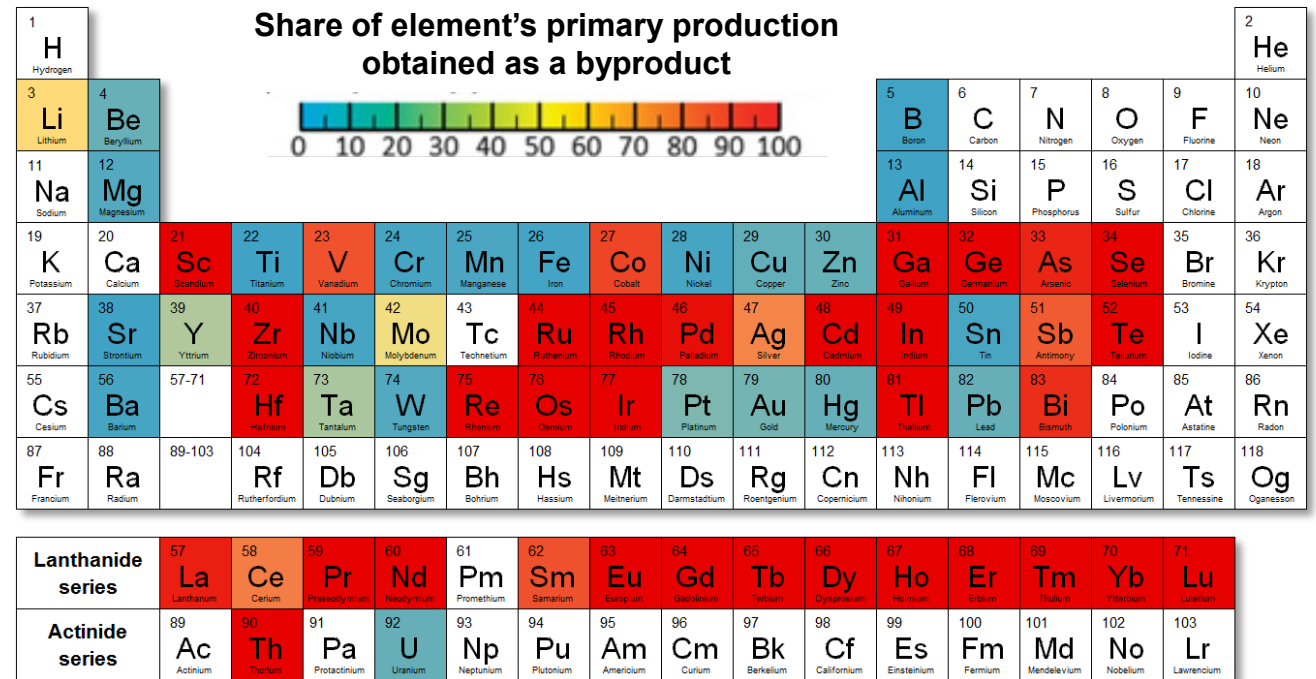


Preliminary information - subject to revision. Not for citation or distribution.

Earth MRI Mine Waste Efforts

Earth MRI supports mapping and collection of mine waste data across the country to support:

- **National mine waste inventory** geospatial database of current and historical mine waste
- **Mine waste characterization** projects to help inform the potential critical mineral endowments of nonfuel hard-rock mine waste materials and reclamation decisions

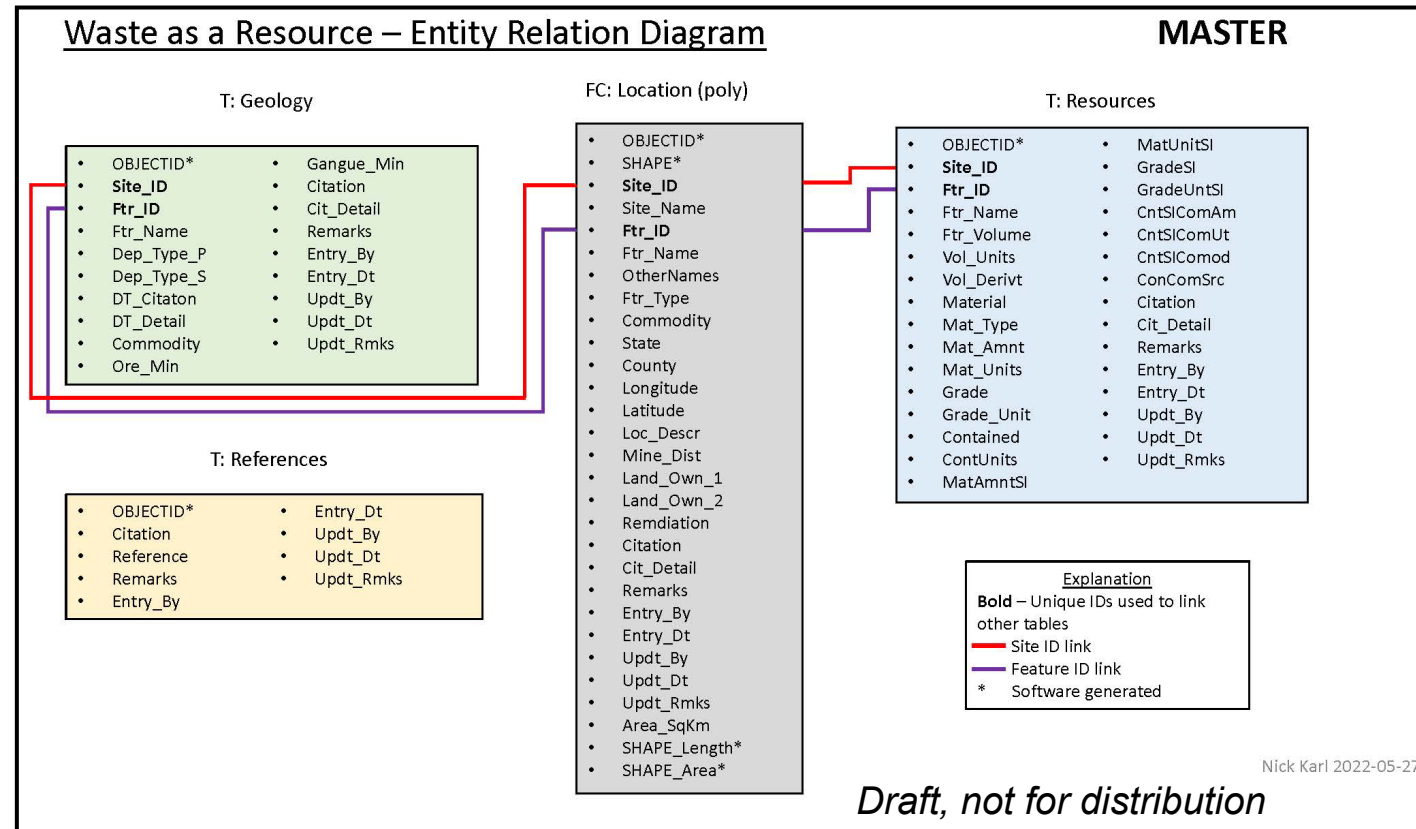


Nassar et al., 2015, By-product metals are technologically essential but have problematic supply, Science Advances 1 (3), e1400180

National Mine Waste Inventory

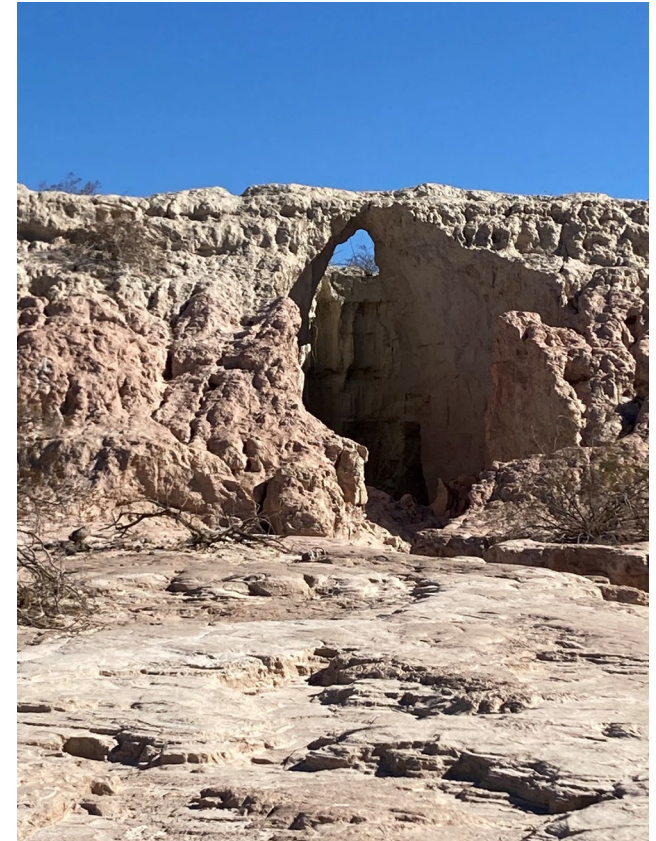
Compilation of mine waste information into a geospatial database helps address the following outstanding questions:

- **How many** mine waste piles are there in the U.S., and **where** are they located?
- **How much material** is available that may contain mineral resources, and what is the **tonnage and grade** of that material?
- What are the **characteristics** of that material (geological, geochemical, mineralogical) that may influence recovery of the commodities of interest?
- How do **land ownership** and other factors influence access to sites for research and (or) reprocessing of mine waste?



Mine Waste Characterization

- Estimate the critical mineral endowment of mine waste
- Identify potential mineral hosts of critical minerals
- Conduct cursory assessment of the environmental characteristics of the mine waste to inform potential reprocessing strategies, environmental management, reclamation, and other attendant costs
- States can help develop a comprehensive and internally consistent database of mine waste locations, masses, geochemical composition, bulk mineralogical composition, and contained commodities
- The USGS is currently developing mine waste site characterization and sampling protocols to guide this effort



Mill Tailings Deposits at the Katherine Mine; photo courtesy of Bob Seal, USGS

Perpetual Water – Tunnel Drainage



Perpetual Water – Pit Lake



Tailings



Mine Waste Types - 2023

Leach Pad Waste (Au)



Slag



Waste Rock and Stockpiles



Leach Pad Waste (Cu)

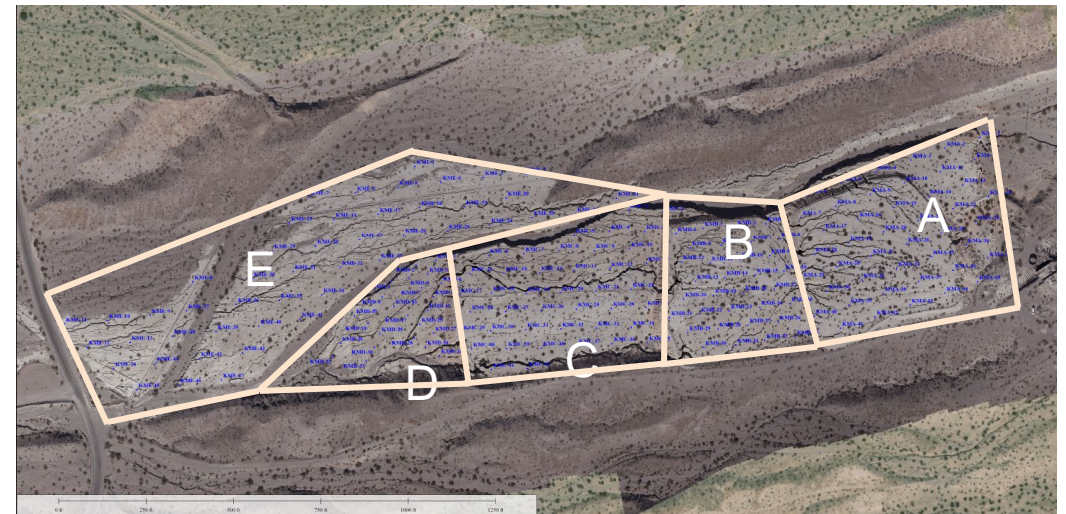


Additional Mine Waste
Types – 2024+ (?)

Sampling Protocols

PURPOSE: Standardized methods across all sampling efforts to produce nationally comparable data set of critical minerals in above-ground waste

- USGS has developed protocols for:
 - How to sample
 - How much sample to collect
 - Blanks and duplicates
 - How to process/preserve samples
 - How to send samples to USGS for analysis
 - Information to be collected in the field
 - Field data
 - Geospatial data
 - Qualitative information
- USGS will provide *in-person training* that must be followed for all sampling efforts



Analytical Scope - solids

Multiple standardized methods to ensure broad coverage of critical minerals

Bulk geochemistry

- 61-element major and trace element (fusion-digestion + ICP-OES/ICP-MS)
- Major elements by wavelength dispersive X-ray fluorescence (WD-XRF)
- Gold, palladium, platinum assay
- Total sulfur, carbon, mercury, carbonate carbon, fluorine
- Inorganic carbon

Mineralogy

- X-ray diffraction (XRD)

Water-rock interaction

- Acid-base accounting



FY22 BIL-Funded State Mine Waste Pilot Projects

- Critical minerals in mine wastes in New Mexico, *New Mexico Bureau of Geology and Mineral Resources*
- Critical Minerals in Mine Waste, Colorado, *Colorado Geological Survey*
- Phosphate waste stream geochemical sampling (pending), *Florida Geological Survey*

Results will help populate the National Mine Waste Inventory and refine methods that can be applied to characterize other mine waste sites.



FY23-26 Mine Waste Notice of Funding Opportunity (NOFO)

- New annual competitive cooperative agreement program for State geological surveys (FY23-FY26)
- Funds 2-year projects focusing on 2 priorities:
 - **Providing existing data for the mine waste inventory (Priority 1) and/or**
 - **Collecting new data for mine waste characterization (Priority 2)**
- In-person training and geochemical analyses provided by USGS
- State geological surveys encouraged to work with other State agencies with mine waste management responsibilities
- Limitations
 - Only geogenic waste (no landfills, sewage)
 - Non-fuel
- Accessibility: Responsibility of the state



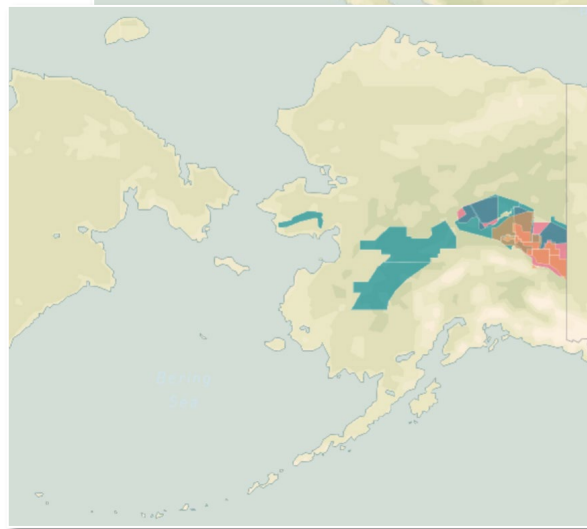
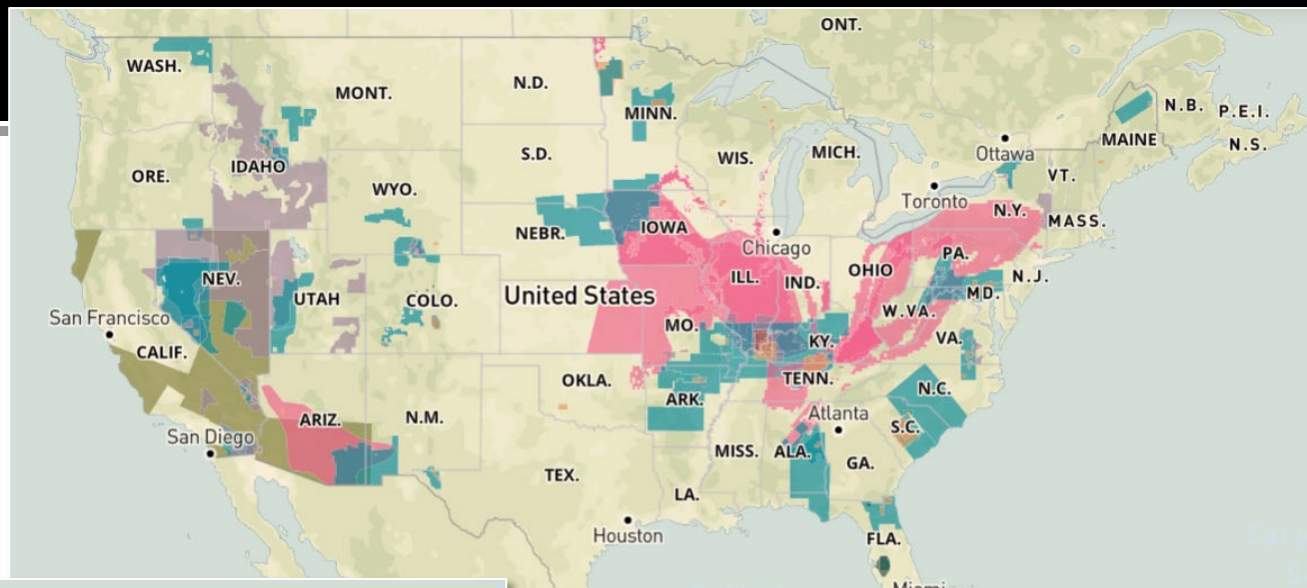
*Chateaugay tailings pile, Adirondack Mountains, NY
Photo by Ryan Taylor, USGS*

2023 State Mine Waste Projects/ Deliverables

- Inventory: GIS database following USGS template
- Geochemical data (which will be released by USGS in data releases)
- Waste feature boundaries
- Volume (or load estimates)
- Final interpretive report provided as a peer-reviewed state publication
- Digital archive of field sheets
- Comprehensive description of any ore hand samples that are collected
- **All Earth MRI deliverables made available to the public**

AZ	Inventory
IA	Characterization
KY	Inventory
MT	Inventory, Characterization
NC	Inventory, Characterization
NV	Inventory
OK	Inventory
WA	Inventory, Characterization
IL	Inventory, Characterization
MI	Inventory
MO	Inventory, Characterization
NM	Inventory
NY	Inventory, Characterization
VA	Inventory

Earth MRI Data and Reports at [Earth MRI | Acquisitions Map \(usgs.gov\)](https://www.usgs.gov/earthmri)



Earth MRI Acquisitions Viewer

Source: [Earth Mapping Resources Initiative \(Earth MRI\)](#)
Metadata & Data Services: [MRData](#), [NGMDB](#)

Earth MRI began in 2019, and is a partnership between the USGS and State Geological Surveys to acquire data in areas across the Nation with potential for hosting critical mineral resources. Click any map area or table record to learn more.

- All
- Geologic Mapping
- Geophysics
- Lidar
- Reconnaissance Geochemistry
- 3D Geological Model

Showing **84** projects on screen.

FY19 Activities:

- 14 geologic mapping projects
- 5 airborne geophysical surveys
- 5 lidar surveys

FY20 Activities:

- 12 geologic mapping projects
- 4 geochemistry projects
- 6 airborne geophysical surveys
- 1 GeoDAWN lidar survey

FY21 Activities

- 14 geologic mapping projects
- 2 geochemistry projects
- 5 airborne geophysical surveys
- 4 lidar surveys

FY22 Activities

- 19 geologic and/or geochemical mapping projects
- 10 airborne geophysical surveys
- 4 lidar surveys
- 3 state mine waste characterization projects

FY23 Activities

- 16 geologic and/or geochemical mapping projects
- 12 airborne geophysical surveys
- 2+ hyperspectral surveys
- 4 lidar surveys
- 7 state mine waste characterization projects
- 13 state mine waste inventory projects

Earth MRI Annual Workshop

October 24-26, 2023, Reston, VA, USGS Headquarters

- USGS and AASG 5th Annual Earth MRI Workshop
- Meeting will be hybrid to allow more staff to join discussions
- Meeting Topics:
 - Review status and discuss future directions of Earth MRI
 - Presentations of Earth MRI projects by USGS and State Geological Survey scientists
 - Jointly plan airborne geophysical surveys, interstate geochemical mapping, and cross border mapping/stratigraphy projects
 - Use “regional” breakout approach
 - Review implementation processes and discuss what needs to be improved
- Poster Session
- Email Patty Loferski for more information; ploferski@usgs.gov

Federal Mining Dialogue (FMD): Critical Minerals Subcommittee

- Interested in demonstrating the idea of extracting critical minerals from mine waste

Land Management



Science & Engineering Research & Application



Regulatory

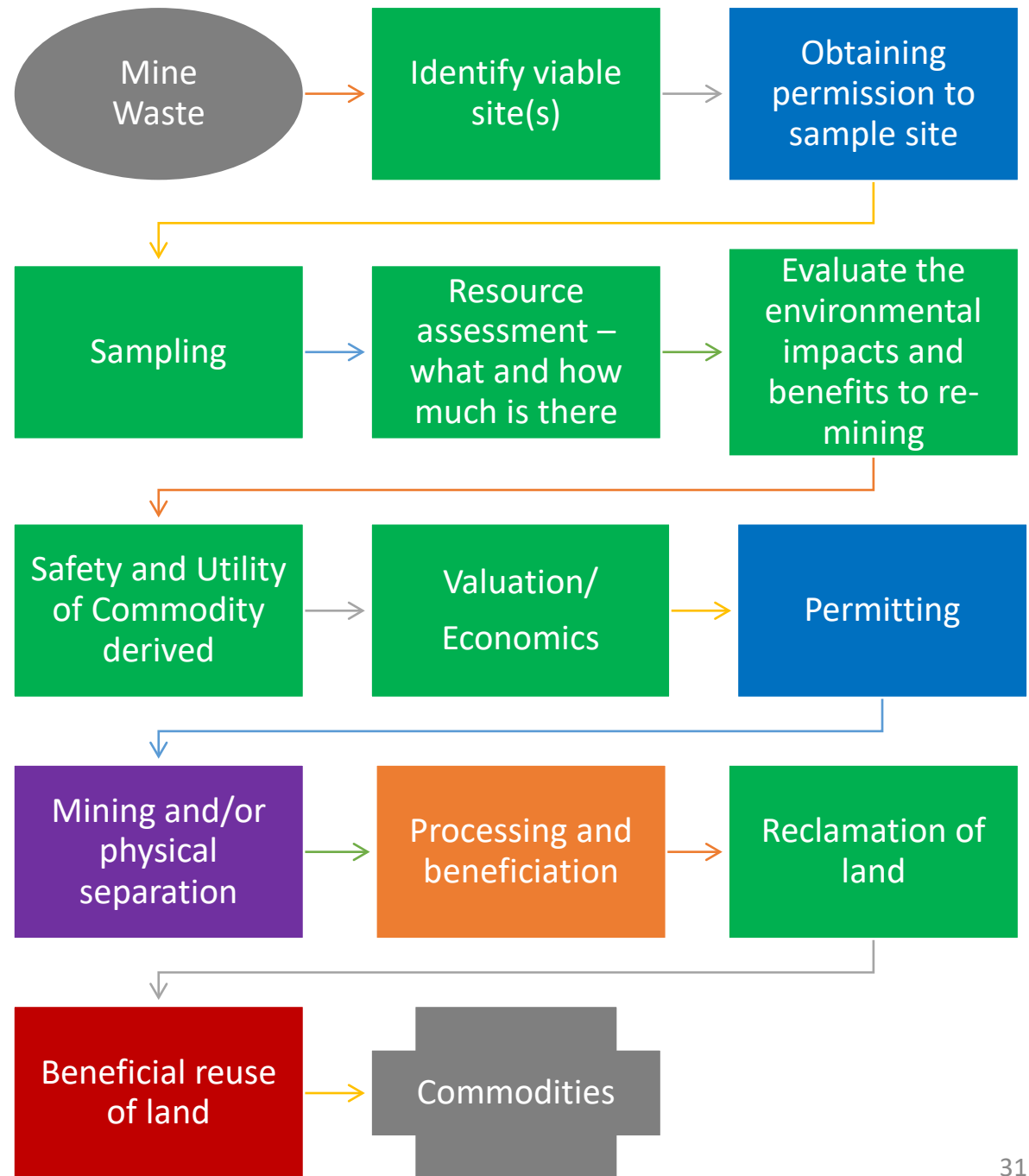


Legal



Demonstrating : “Waste to Commodity Pathway”

- Demonstrating** what it will take to extract commodities from mine waste:
- Existing **processes** exist for each step
 - Identify **gaps** in processes that we need
 - Identify **barriers** to completing step
 - Identify information, **data and/or expertise to fill the gap**
 - Identify Federal agency **roles**



Vision: A Field Site to Demonstrate the Waste to Commodity Pathway

- Scale not yet determined (bench/pilot/full)
- USGS-led with partners
- Relies on multidisciplinary and integrated research
- Multi-agency stakeholders
- Partners across the government, academia, private industry
- Reconnaissance is underway to identify a viable site
- Planning start in early 2024
- Kick off field study in FY25?





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Jamey Jones
Earth MRI Acting Science Coordinator
jvjones@usgs.gov

Bokan Mountain, Alaska (rare earth element deposit)
Photo credit: B. Van Gosen, USGS