USGS
science for a changing world

US Geological Survey Critical Minerals Efforts

Oklahoma Geological Survey Critical Minerals Workshop

November 10, 2021

Warren Day, USGS Earth MRI Science Coordinator, Mineral Resources Program, Golden, CO

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

Critical minerals support the global economy

Future technologies require increased supply

Energy generation

49 **In** Indium

31 **Ga** Gallium

34 **Se** Selenium

Thin-film solar PV

Photo credit: Testbourne, Ltd.

60 **Nd** Neodymium

66 **Dy** Dysprosium

Offshore direct drive wind turbine

Photo credit: US DOE

Healthcare

64 **Gd** Gadolinium

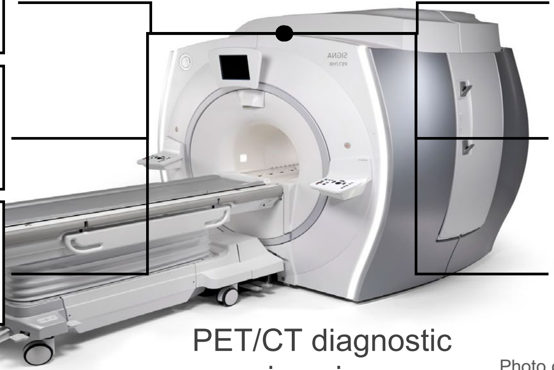
63 **Eu** Europium

71 **Lu** Lutetium

58 **Ce** Cerium

65 **Tb** Terbium

39 **Y** Yttrium



PET/CT diagnostic imaging

Photo credit: GE Healthcare

Defense and national security

75 **Re** Rhenium

U.S. Air Force F-35A Lightning II Joint Strike Fighter

Photo credit: Master Sgt. John R. Nimmo, Sr.

32 **Ge** Germanium

31 **Ga** Gallium

33 **As** Arsenic

Gen. III Ground Panoramic Night Vision Goggles

Photo credit: L3 Technologies, Inc.

Transportation

3 **Li** Lithium

6 **C** Carbon

27 **Co** Cobalt

28 **Ni** Nickel

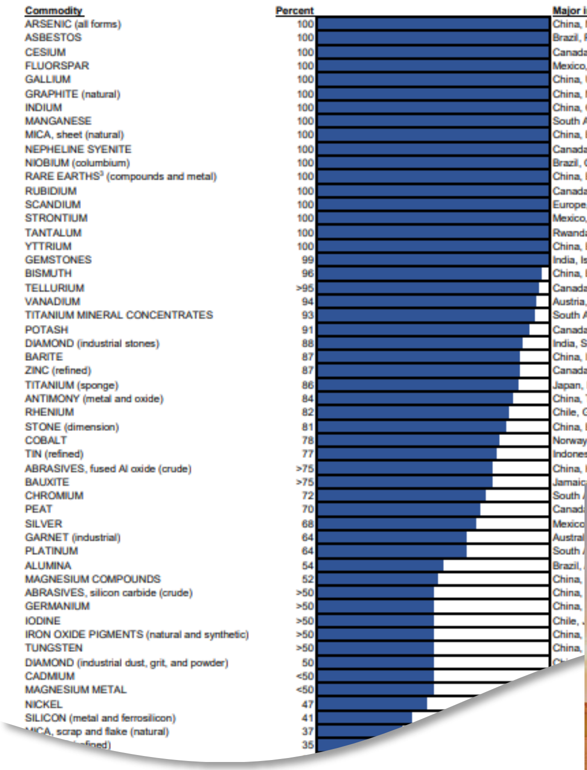
Photo credit: Telsa, Inc.

Electric and hybrid vehicles

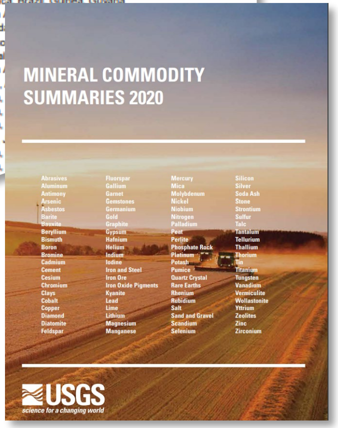
USGS National Minerals Information Center

The US is highly import reliant for a large and growing number of mineral commodities

2019 U.S. net import reliance

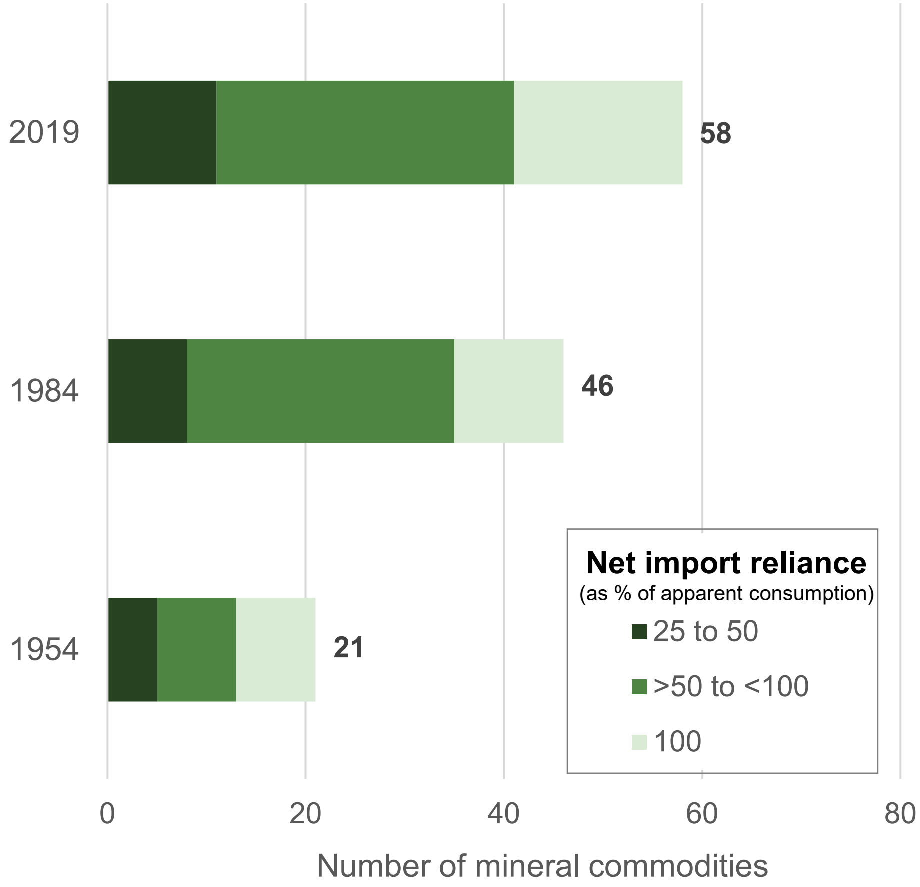


Commodity	Percent	Major import sources (2015–18)[2]
ARSENIC (all forms)	100	China, Morocco, Belgium
ASBESTOS	100	Brazil, Russia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, Vietnam, South Africa, China
GALLIUM	100	China, United Kingdom, Germany, Ukraine
GRAPHITE (natural)	100	China, Mexico, Canada, India
INDIUM	100	China, Canada, Republic of Korea, Taiwan
MANGANESE	100	South Africa, Gabon, Australia, Georgia
MICA, sheet (natural)	100	China, Brazil, Belgium, Austria
NEPHELINE SYENITE	100	Canada
NIOBIUM (columbium)	100	Brazil, Canada, Russia, Germany
RARE EARTHS[3] (compounds and metal)	100	China, Estonia, Japan, Malaysia
RUBIDIUM	100	Canada
SCANDIUM	100	Europe, China, Japan, Russia
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	Rwanda, Brazil, Australia, Congo (Kinshasa)
YTTRIUM	100	China, Estonia, Republic of Korea, Japan
GEMSTONES	99	India, Israel, Belgium, South Africa
BISMUTH	96	China, Belgium, Mexico, Republic of Korea
TELLURIUM	>95	Canada, China, Germany
VANADIUM	94	Austria, Canada, Russia, Republic of Korea
TITANIUM MINERAL CONCENTRATES	93	South Africa, Australia, Canada, Mozambique
POTASH	91	Canada, Russia, Belarus, Israel
DIAMOND (industrial stones)	88	India, South Africa, Botswana, Australia
BARITE	87	China, India, Morocco, Mexico
ZINC (refined)	87	Canada, Mexico, Australia, Peru
TITANIUM (sponge)	86	Japan, Kazakhstan, Ukraine, China, Russia
ANTIMONY (metal and oxide)	84	China, Thailand, Belgium, India
RHENIUM	82	Chile, Germany, Kazakhstan, Canada
STONE (dimension)	81	China, Brazil, Italy, Turkey
COBALT	78	Norway, Japan, China, Canada
TIN (refined)	77	Indonesia, Malaysia, Peru, Bolivia
ABRASIVES, fused Al oxide (crude)	>75	China, Hong Kong, France, Canada
BAUXITE	>75	Jamaica, Brazil, Guinea, Guyana
CHROMIUM	72	South [illegible]
PEAT	70	Canad[illegible]
SILVER	68	Mexico[illegible]
GARNET (industrial)	64	Austral[illegible]
PLATINUM	64	South [illegible]
ALUMINA	54	Brazil, [illegible]
MAGNESIUM COMPOUNDS	52	China, [illegible]
ABRASIVES, silicon carbide (crude)	>50	China, [illegible]
GERMANIUM	>50	China, [illegible]
IODINE	>50	Chile, [illegible]
IRON OXIDE PIGMENTS (natural and synthetic)	>50	China, [illegible]
TUNGSTEN	>50	China, [illegible]
DIAMOND (industrial dust, grit, and powder)	50	[illegible]
CADMIUM	<50	[illegible]
MAGNESIUM METAL	<50	[illegible]
NICKEL	47	[illegible]
SILICON (metal and ferrosilicon)	41	[illegible]
MICA, scrap and flake (natural)	37	[illegible]
[illegible]fined)	35	[illegible]



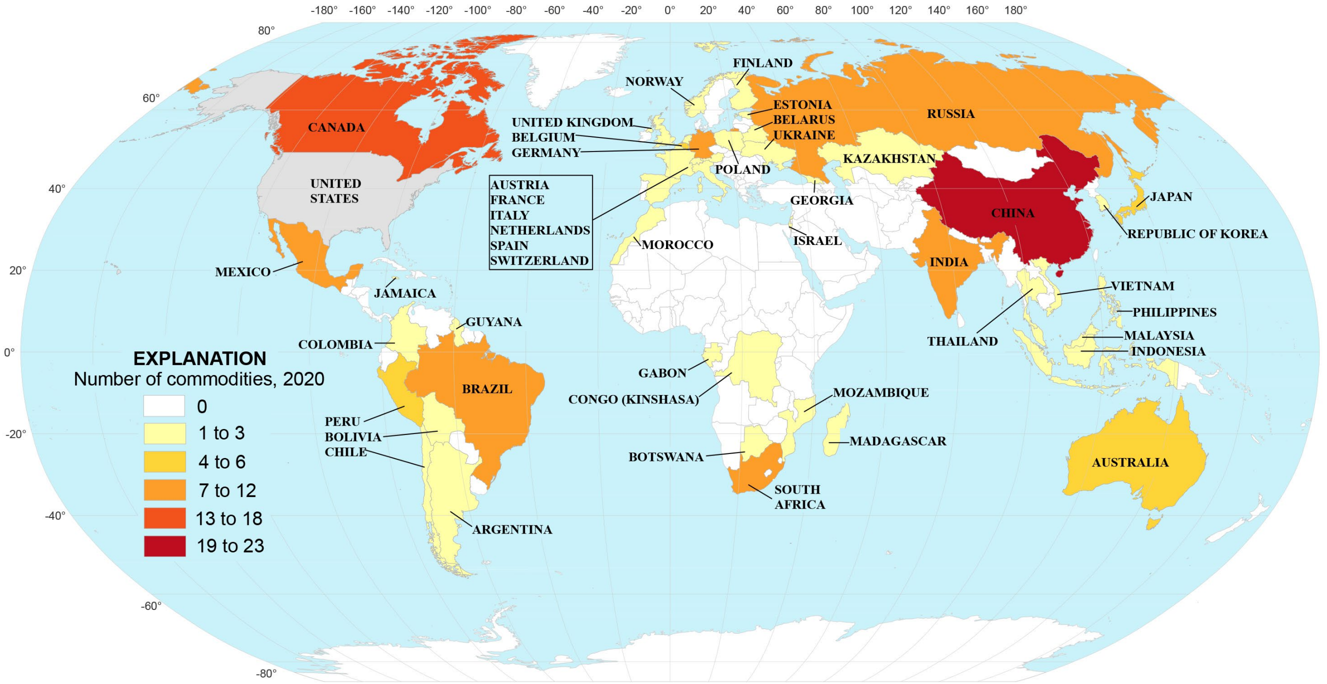
>90% import reliant for 23 critical minerals
> 50% import reliant for 46 critical minerals

Growing U.S. net import reliance



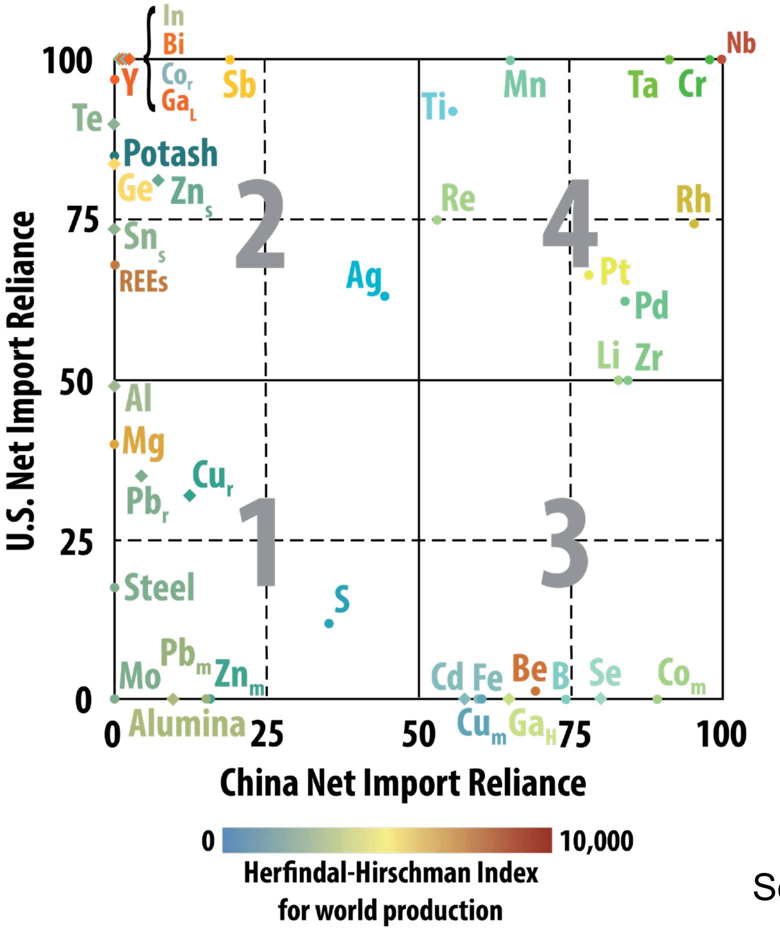
US Net Import Reliance: Sources by Country

Major Import Sources of Nonfuel Mineral Commodities for which the United States was greater than 50% Net Import Reliant in 2020



Source: USGS National Minerals Information Center

US vs. China Net Import Reliance



Key for symbols/letters tied to commodities

H = high-purity production
L = low-purity production
m = mine production
r = refinery production
s = smelter production

Circles = mine production
Rhombuses = refinery or smelter production

Andrew L. Gulley, Nedal T. Nassar, Sean Xun, China, the United States, and competition for resources that enable emerging technologies, 2018: Proceedings of the National Academy of Sciences, 201717152; DOI:10.1073/pnas.1717152115

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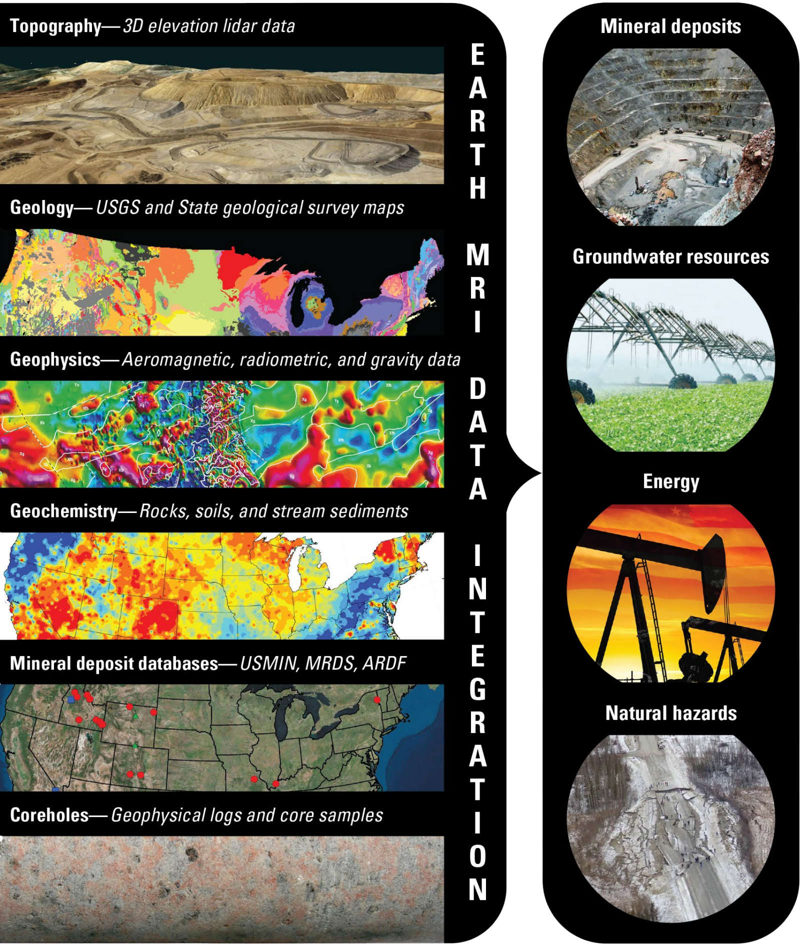
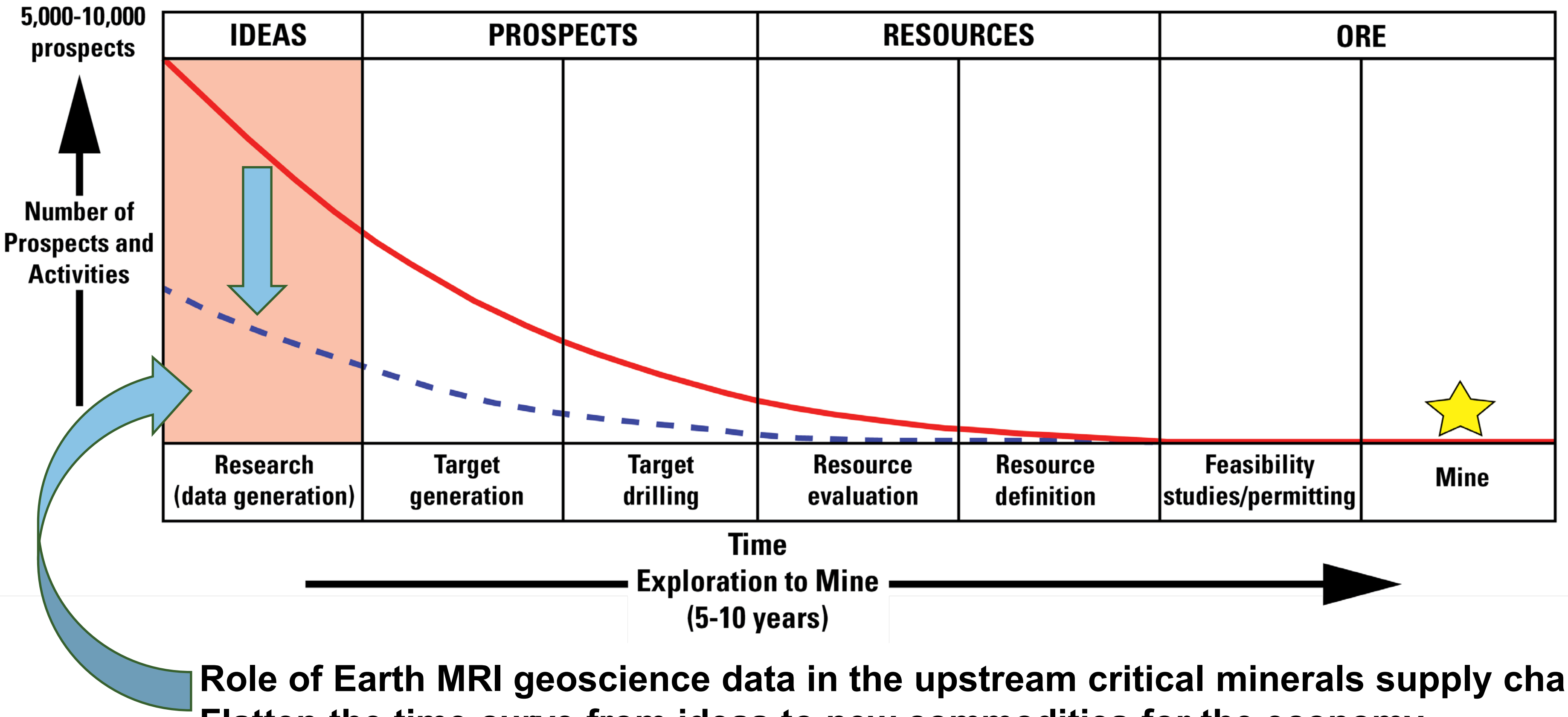
Source: USGS National Minerals Information Center

USGS Earth Mapping Resources Initiative (Earth MRI)



- Established in 2019 under Executive Order 13817 and Secretarial Order 3359 to address the shortfall in the critical minerals supply needed for National defense and economic security.
- Goal: Improve our knowledge of the geologic framework of the United States in areas permissive for hosting undiscovered critical mineral resources.
- Partnership between the USGS, State Geological Surveys, and the private sector to generate state-of-the-art surface geologic maps, geophysical surveys, and elevation (lidar) data in areas with critical mineral potential.
- Multiple stakeholders and applications that include energy, groundwater, natural hazards, and other vital geoscience issues.

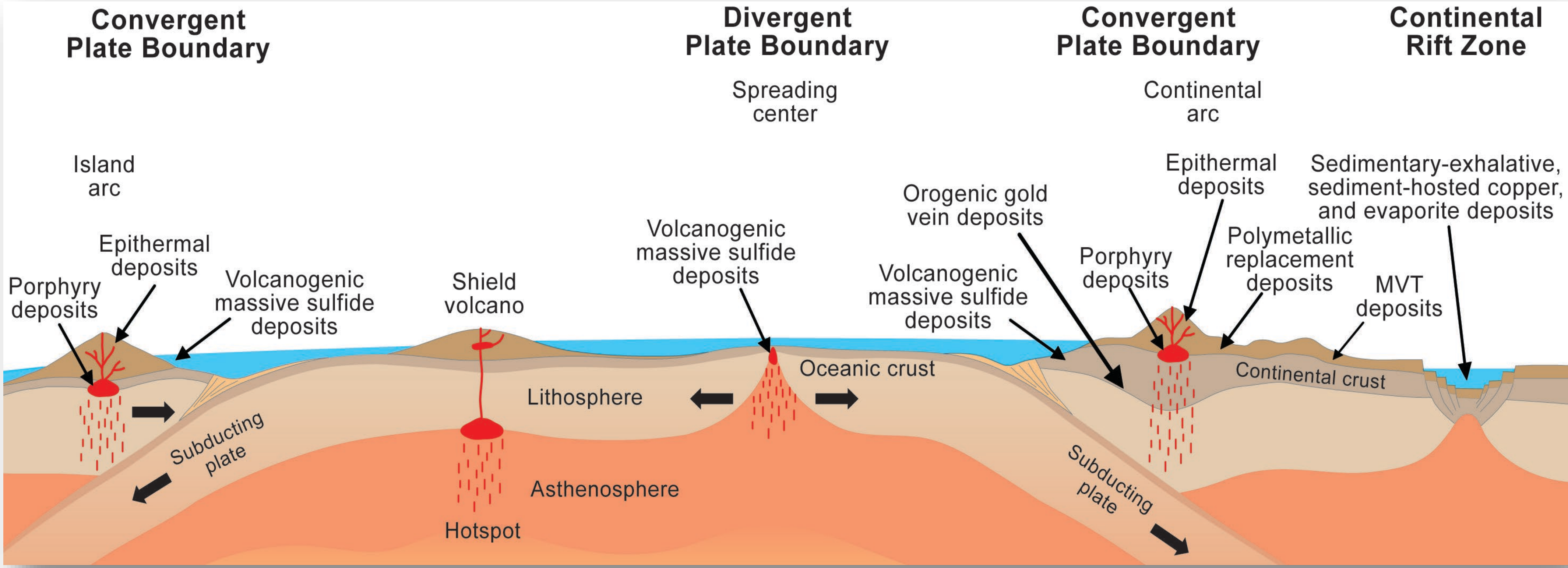
Role of Geoscience Data in Upstream Part of Critical Mineral Supply Chain



Role of Earth MRI geoscience data in the upstream critical minerals supply chain: Flatten the time curve from ideas to new commodities for the economy

Mineral Systems Framework

Mineral system: family of ore deposit types genetically linked in time, space, and shared tectonic processes



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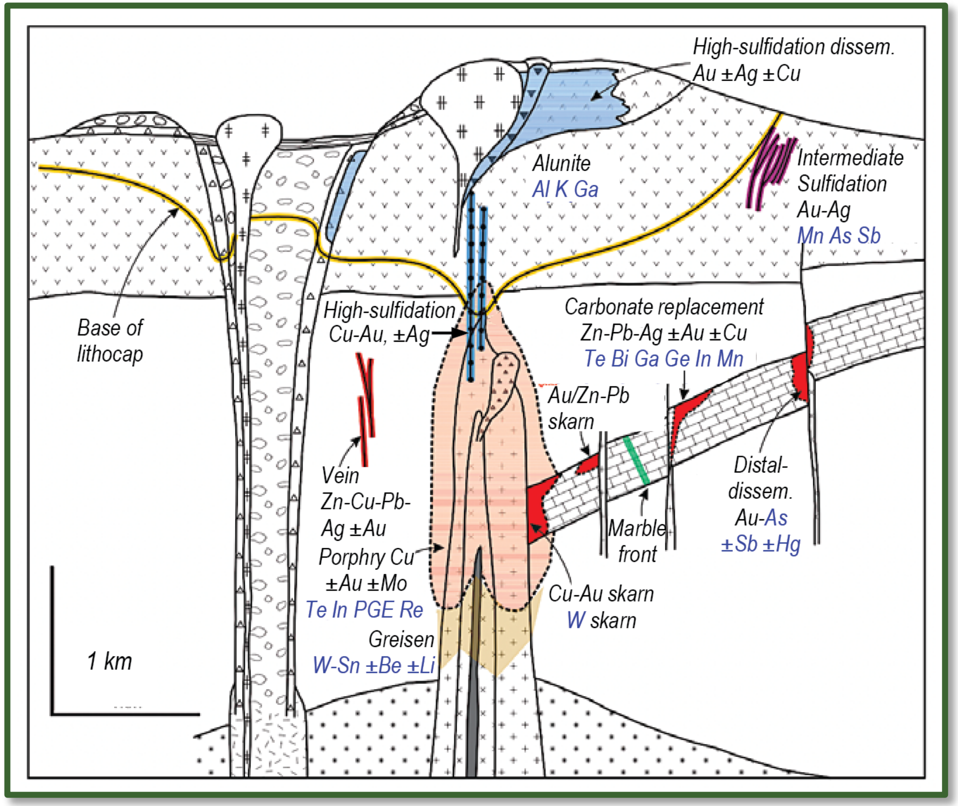
Mineral Systems Approach

Example: Porphyry Copper-Molybdenum-Gold System

Mineral system: family of ore deposit types genetically linked in time, space, and shared tectonic processes



System Name	Deposit type	Principal commodities	Critical commodities
Porphyry Cu-Mo-Au	Greisen	Mo, W, Sn	W, Sn
	S-R-V tungsten	W	W, Bi, Mn, Sc
	Porphyry/skarn molybdenum	Mo, W, Sn	W, Re, Bi
	Porphyry/skarn copper	Cu, Au, Ag, Mo	PGE, Te, Re, U, Sc, Co, Bi
	Skarn iron	Fe, Cu	Ge
	Skarn magnesite	Mg	Mg
	R-V manganese	Mn	Mn, Co
	Polymetallic sulfide S-R-V-IS	Cu, Zn, Cd, Pb, Ag, Au	Mn, Ge, Ga, In, Bi, Sb, As, W, Te
	Distal disseminated silver-gold	Ag, Au	Sb, As
	High sulfidation gold-silver	Cu, Ag, Au	As, Sb, Te, Bi, Sn, Ga
	Intermediate sulfidation antimony	Sb, Hg	Sb, As
	Lithocap alunite	Al, K_2SO_4 (potash)	Al, K_2SO_4, Ga
	Lithocap kaolinite	Kaolin	Ga

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Project Phase by Critical Mineral Commodity
2018 U.S. list of 35 critical minerals

Earth MRI needs national-scale maps showing where critical minerals may occur to drive science-based funding decisions.

- **Phase 1:** Rare earth elements.
- **Phase 2:** Primary and co-product critical mineral commodities for which new geologic information will impact discovery and production.
- **Phase 3:** Co-products and by-product commodities for which new geologic information will impact discovery and production.
- **Remaining mineral** commodities are primarily by-products from mining of other commodities. Their recovery is largely dependent on the economics of recovery and market forces.

Phase 1
Rare earth element group

Phase 2
Aluminum
Cobalt
Graphite (natural)
Lithium
Niobium
Platinum group elements
Rare earth element group
Tantalum
Tin
Titanium
Tungsten

Phase 3
Antimony
Barite
Beryllium
Chromium
Fluorspar
Hafnium
Helium
Magnesium
Manganese
Potash
Uranium
Vanadium
Zirconium

Phase 4
Arsenic
Bismuth
Cesium
Gallium
Germanium
Indium
Rhenium
Rubidium
Scandium
Strontium
Tellurium

Department of Interior, 2018, Federal Register Notice 2018-10667

Project Phase by Critical Mineral Commodity

2021 Updated USGS List

Earth MRI needs national-scale maps showing where critical minerals may occur to drive science-based funding decisions.

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Phase 2
Aluminum
Cobalt
Graphite (natural)
Lithium
Niobium
Platinum group elements
Rare earth element group
Tantalum
Tin
Titanium
Tungsten

Phase 3
Antimony
Barite
Beryllium
Chromium
Fluorspar
Hafnium
~~Helium~~
Magnesium
Manganese
~~Potash~~
Uranium
Vanadium
Zirconium

Phase 4
Arsenic
Bismuth
Cesium
Gallium
Germanium
Indium
~~Rhenium~~
Rubidium
Scandium
~~Strontium~~
Tellurium

Added: zinc and nickel
Uranium not reviewed. Considered a fuel mineral (not critical mineral)

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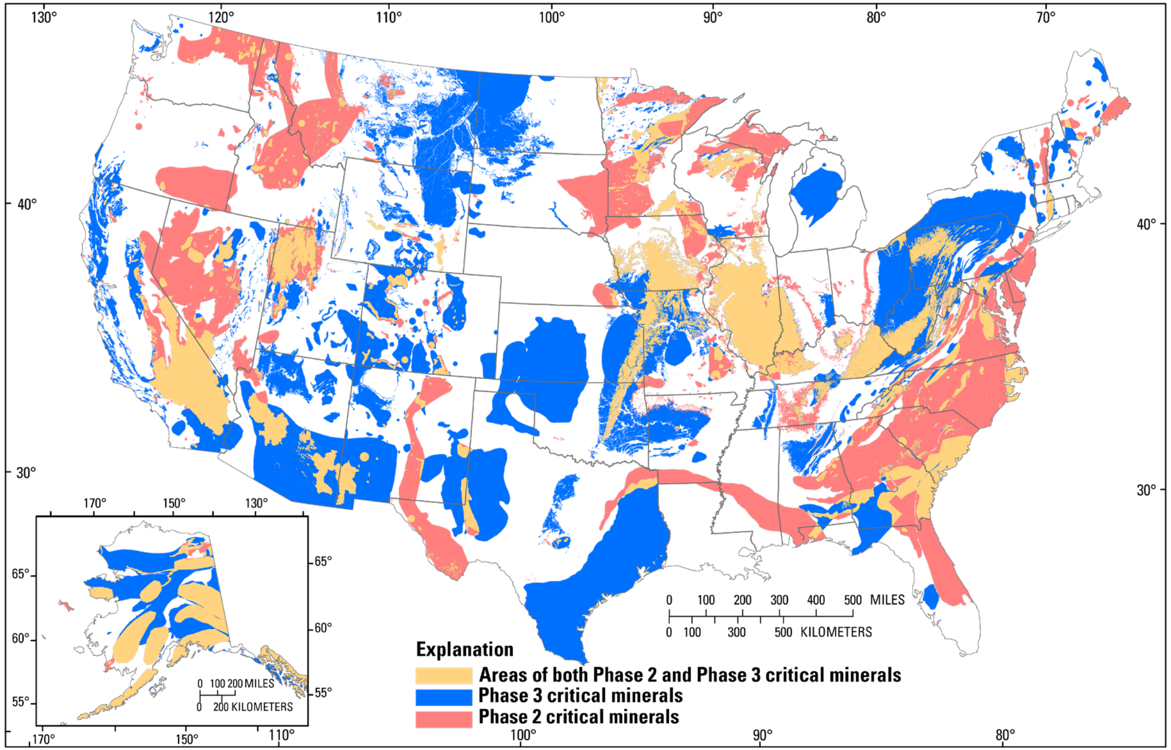
Nassar, N.T., and Fortier, S.M., 2021, USGS Open-File Report 2021–1045, 31 p., https://doi.org/10.3133/ ofr20211045.

Permissive Areas for Mineral Systems with Critical Minerals



Earth MRI Project Phase Critical Minerals

Phase 2	**Phase 3**
Aluminum	Antimony
Cobalt	Barite
Graphite (natural)	Beryllium
Lithium	Chromium
Niobium	Fluorspar
Platinum group elements	Hafnium
Rare earth element group	Helium
Tantalum	Magnesium
Tin	Manganese
Titanium	Potash
Tungsten	Uranium
	Vanadium
	Zirconium

Sources:
Dicken and others, 2021, USGS data release, https://doi.org/10.5066/P9WA7JZY
Dicken and Hammarstrom, 2020, USGS data release, https://doi.org/10.5066/P95CO8LR

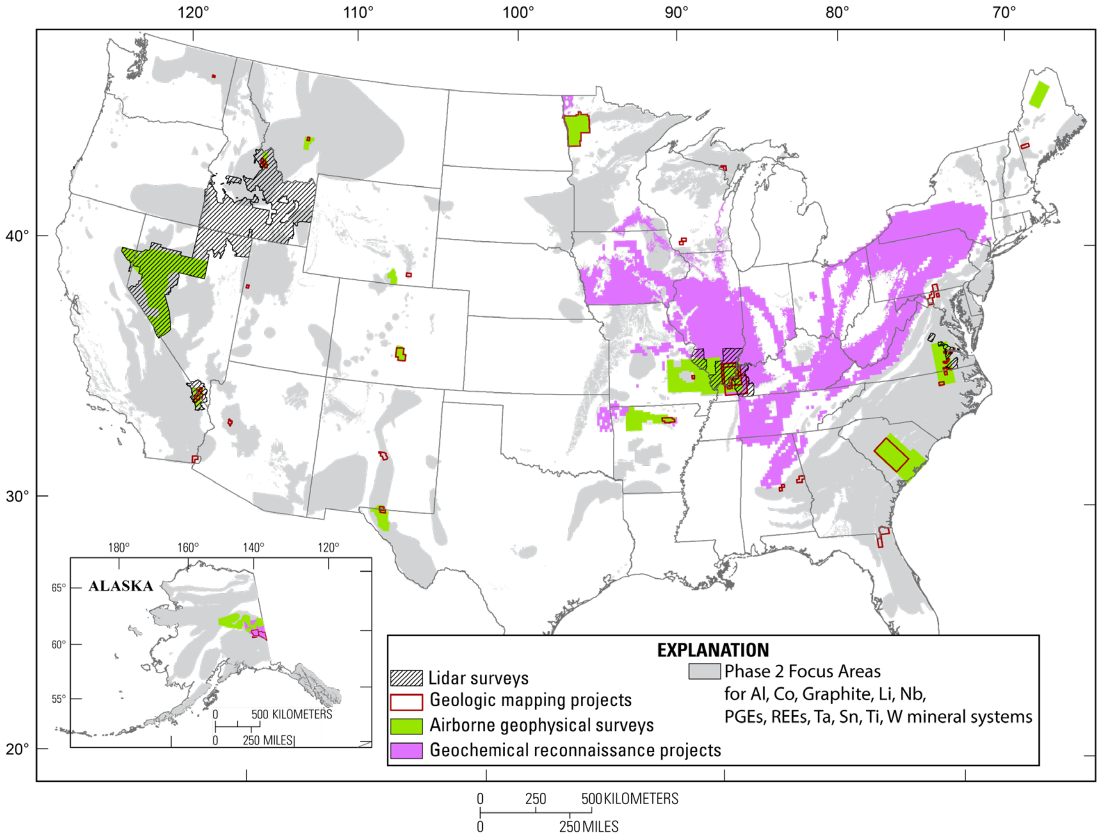
Prioritization Criteria for Projects

- The area contains or has reasonable potential for hosting critical mineral deposits.
- The proposed area contains or has reasonable potential for hosting overlapping critical mineral systems.
- New framework geologic data will materially increase understanding of geologic processes that influence the distribution of mineral systems and concentration of critical minerals.
- ***The land status will allow for mineral exploration and development for the reasonably foreseeable future.***
  - *Avoid National Parks, FWS Wildlife Refuges, state parks, urban areas, BLM Wilderness Study Areas, USFS Roadless Areas, etc.*
  - *If near Tribal or ceded lands, need to have USGS work with Tribes to secure agreement for new work.*

Supporting criteria:

- The project will support other geoscience information needs, such as groundwater, natural hazards, and(or) energy resources.
- Stakeholders offer funding to help support the costs of new data acquisition.
- The project supports ongoing or future USGS, federal and state agency, and tribal activities.

Earth MRI FY2019-FY2021 Projects



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
- 1-2 large lidar surveys

Data available at https://www.usgs.gov/earthmri

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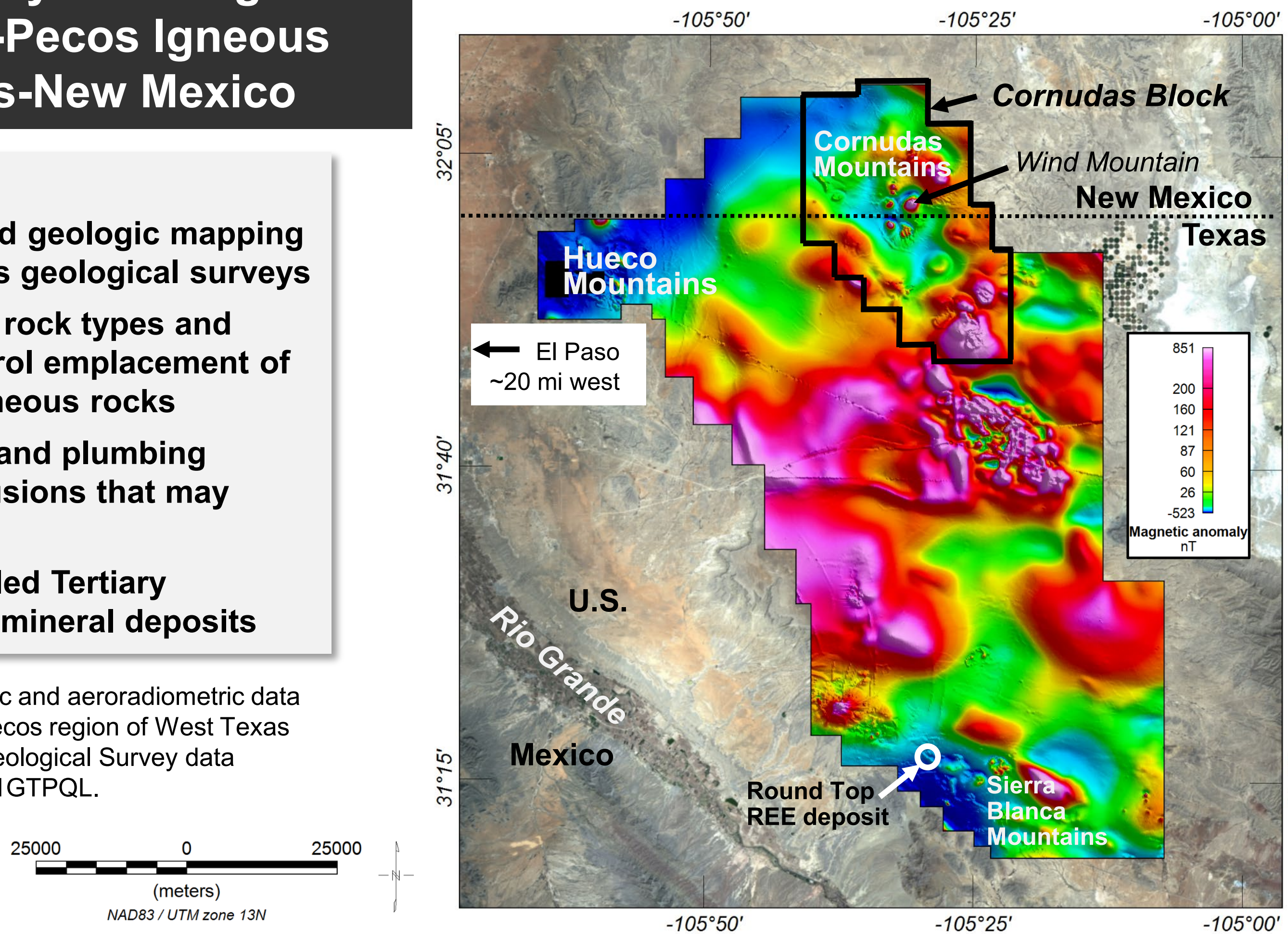
Example: Preliminary Aeromagnetic Map of the Trans-Pecos Igneous Province, Texas-New Mexico

Objectives

- **Support Earth MRI-funded geologic mapping by New Mexico and Texas geological surveys**
- **Detect regional trends in rock types and structures that may control emplacement of mineral-bearing alkali igneous rocks**
- **Identify magma sources and plumbing systems for Tertiary intrusions that may control mineralization**
- **Identify potential concealed Tertiary intrusions that may host mineral deposits**

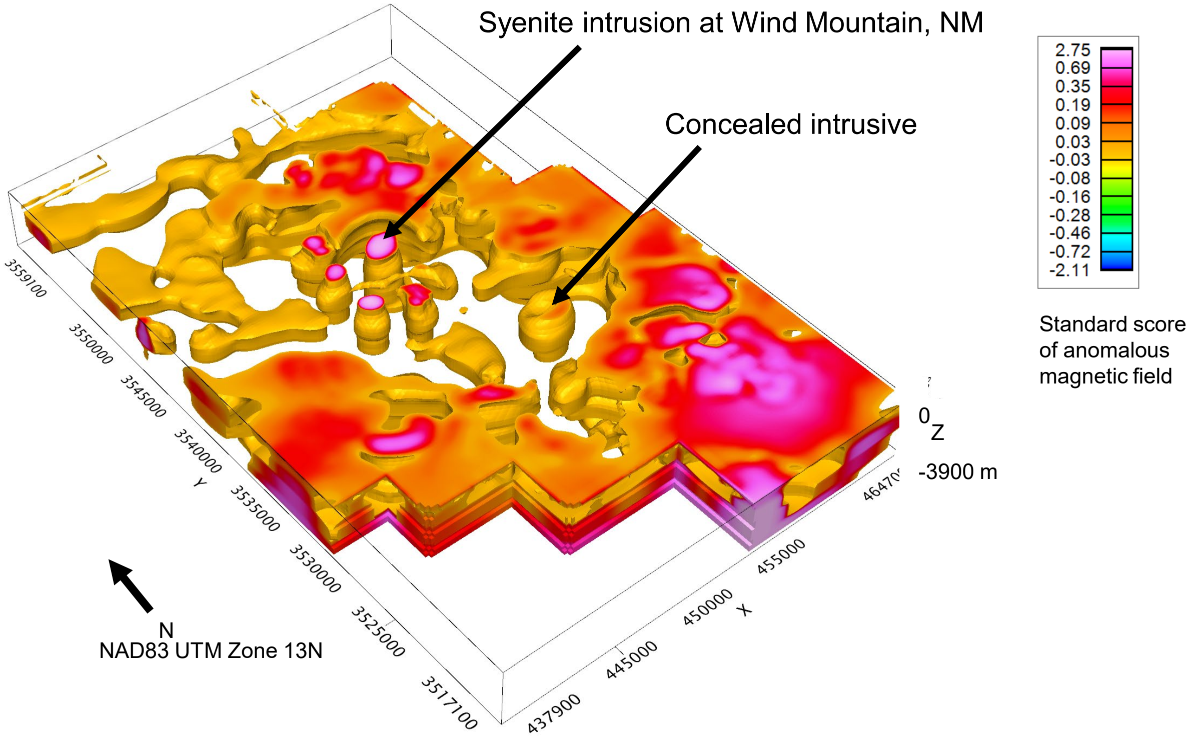
Bultman, M.W., 2021, Aeromagnetic and aeroradiometric data acquired over parts of the Trans-Pecos region of West Texas and Southern New Mexico: U.S. Geological Survey data release, https://doi.org/10.5066/P91GTPQL.

Map courtesy of Mark Bultman, USGS



3D Model of High magnetic Susceptibility Rocks in the Cornudas Block, Trans-Pecos aeromagnetic survey

- **Earth MRI data is allowing scientists to integrate geologic, geophysical, and lidar data to gain new insights into geologic settings commonly concealed by soils and overburden**
- **Enhancing process-level research on ore-forming systems**
- **All data are publicly available at www.usgs.gov/special-topic/earthmri**



Model courtesy of Mark Bultman, USGS

Bultman, M.W., 2021, to be given at Critical Minerals: from discovery to supply chain, Workshop organized by British Columbia Geological Survey, Geological Survey of Canada, Geoscience Australia, and Geological Association of Canada-Pacific Section, Nov. 16-18, 2021.

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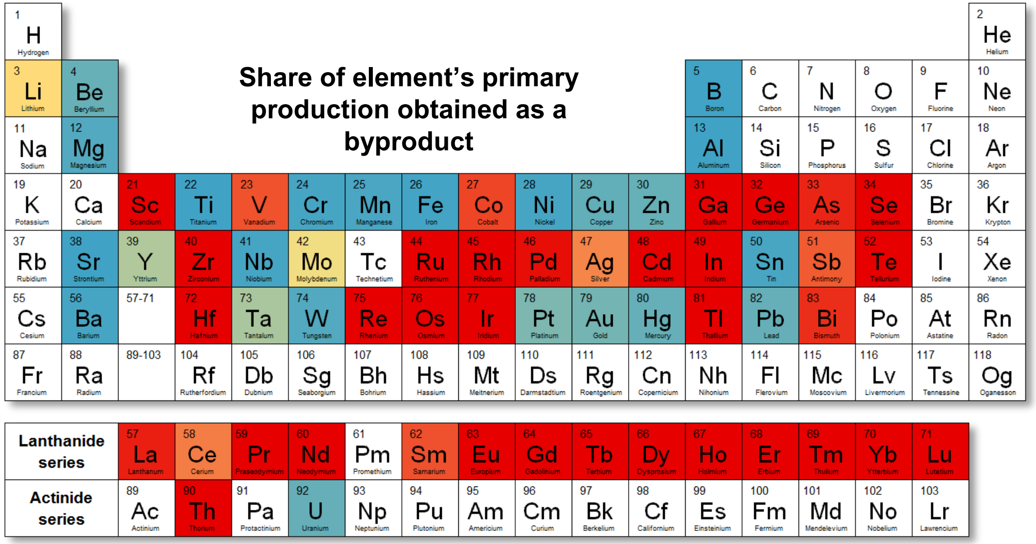
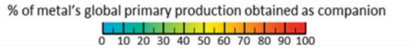
Unconventional Mineral Resources: Mine Wastes

Reclaiming mine sites offers co-benefits for remediation and critical mineral recovery.

USGS and partners are planning a national mine waste inventory





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

New USMIN geospatial database of current and historical mining locations. Yellow dots are mine features captured from historical USGS topographic maps. (A collaboration with BLM and State geological surveys)

Horton, J.D., and San Juan, C.A., 2021, Prospect- and Mine-Related Features from U.S. Geological Survey 7.5- and 15-Minute Topographic Quadrangle Maps of the United States (ver. 6.0, April 2021): U.S. Geological Survey data release, https://doi.org/10.5066/F78W3CHG.

USGS

All Earth MRI data at usgs.gov/special-topics/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 new geologic maps, geophysical surveys, and lidar data to better understand the fundamental geologic framework of areas across the Nation with potential for hosting critical mineral resources. Click any map area or table record to learn more.

All | Geology | Geophysics | Lidar | Geochemistry

Showing 73 projects on screen.

Filter by project, year, affiliation, or state name

Project | Affiliation | Theme | Year

Adams County Mesozoic Basin, Pennsylvania | Pennsylvania Department of Conservation & Natural Resources, Bureau of Geological Survey | Geologic mapping
Year Started: 2020 | Year Complete: In Progress — GE

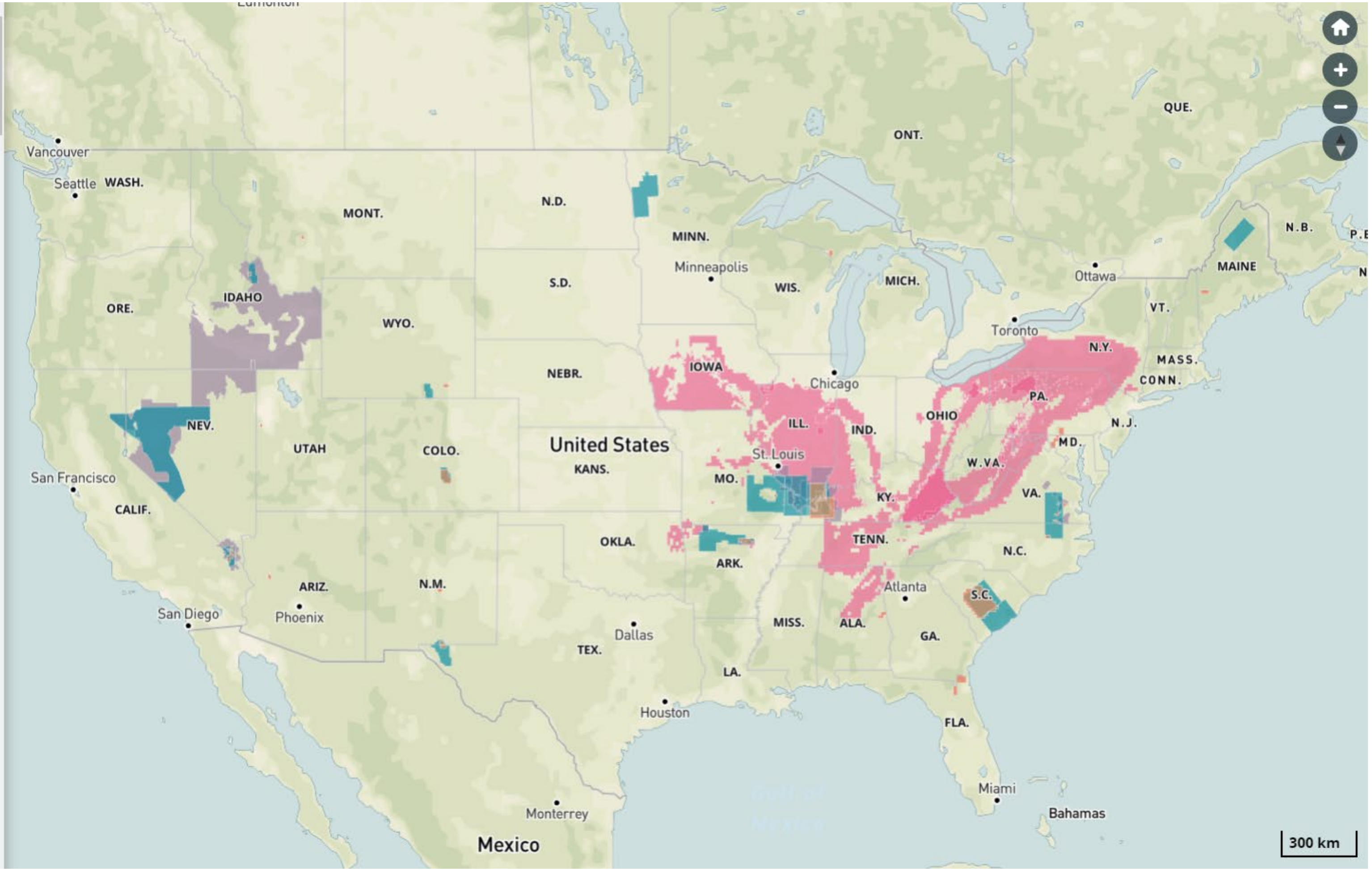
Adams County Mesozoic Basin, Pennsylvania | Pennsylvania Department of Conservation & Natural Resources, Bureau of Geological Survey | Geochemistry
Year Started: 2020 | Year Complete: In Progress — GC

Big Sandy Valley, Arizona | Arizona Geological Survey | Geologic mapping
Year Started: 2020 | Year Complete: In Progress — GE

Big Sandy Valley, Arizona | Arizona Geological Survey | Geochemistry
Year Started: 2020 | Year Complete: In Progress — GC

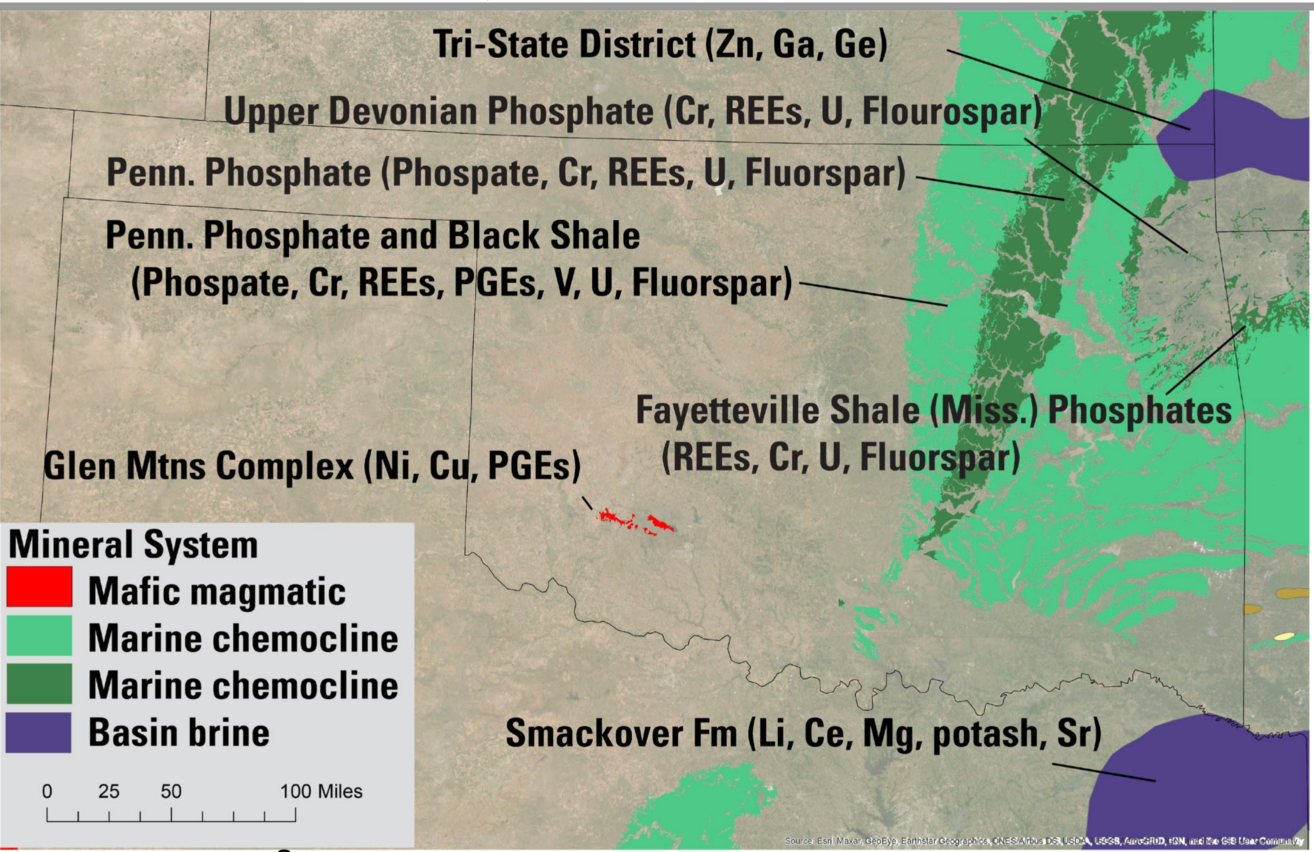
Blue Ridge area, Maryland | Maryland Geological Survey | Geologic mapping
Year Started: 2019 | Year Complete: In Progress — GE

Blue Ridge area, Maryland | Maryland Geological Survey



Current Earth MRI Focus Areas and Mineral Systems in Oklahoma

(Phase 2 and 3 Critical Mineral Commodities)



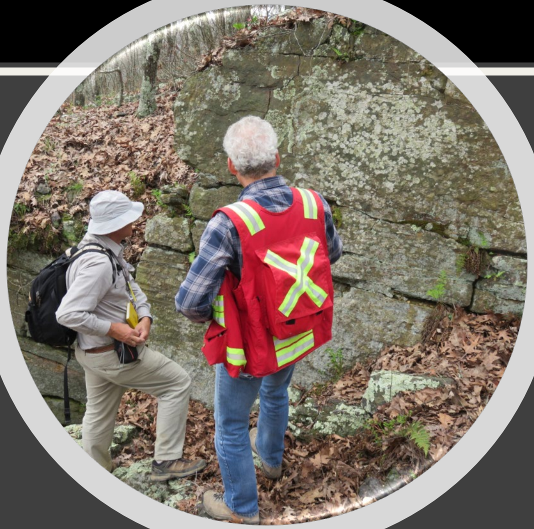
Map will change after:

1) Focus areas for Phase 4 mineral systems as included
2) States help with border faults, revise Phase 2&3 focus areas
3) Improvements on the way from OK GS

Note: Helium, uranium, and potash not shown. Dropped from 2021 CM list

Sources:
Dicken and others, 2021, USGS data release, https://doi.org/10.5066/P9WA7JZY
Dicken and Hammarstrom, 2020, USGS data release, https://doi.org/10.5066/P95CO8LR

USGS



Questions?