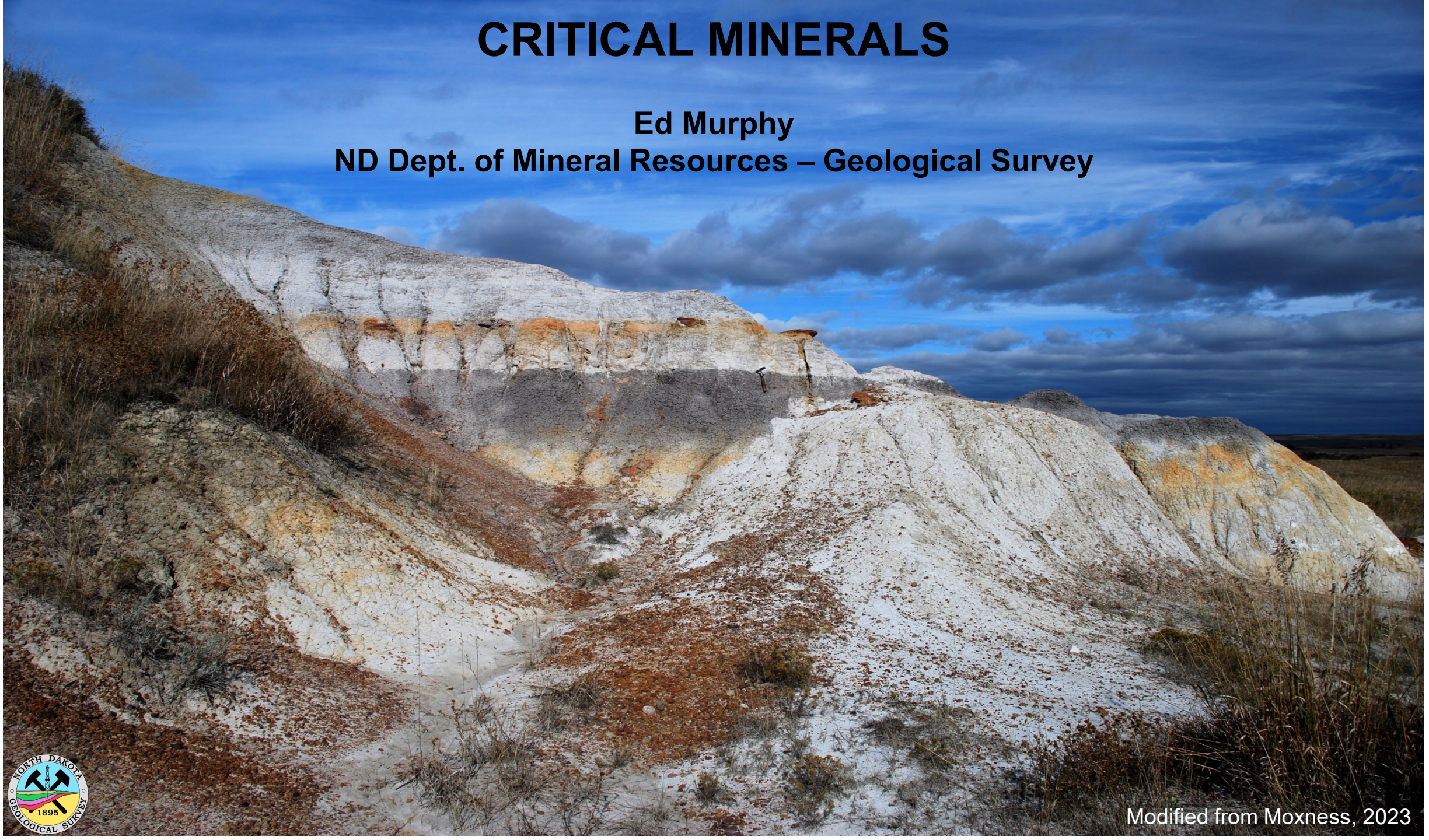
CRITICAL MINERALS

Ed Murphy
ND Dept. of Mineral Resources – Geological Survey



Modified from Moxness, 2023

Critical Minerals

Critical minerals are defined as:

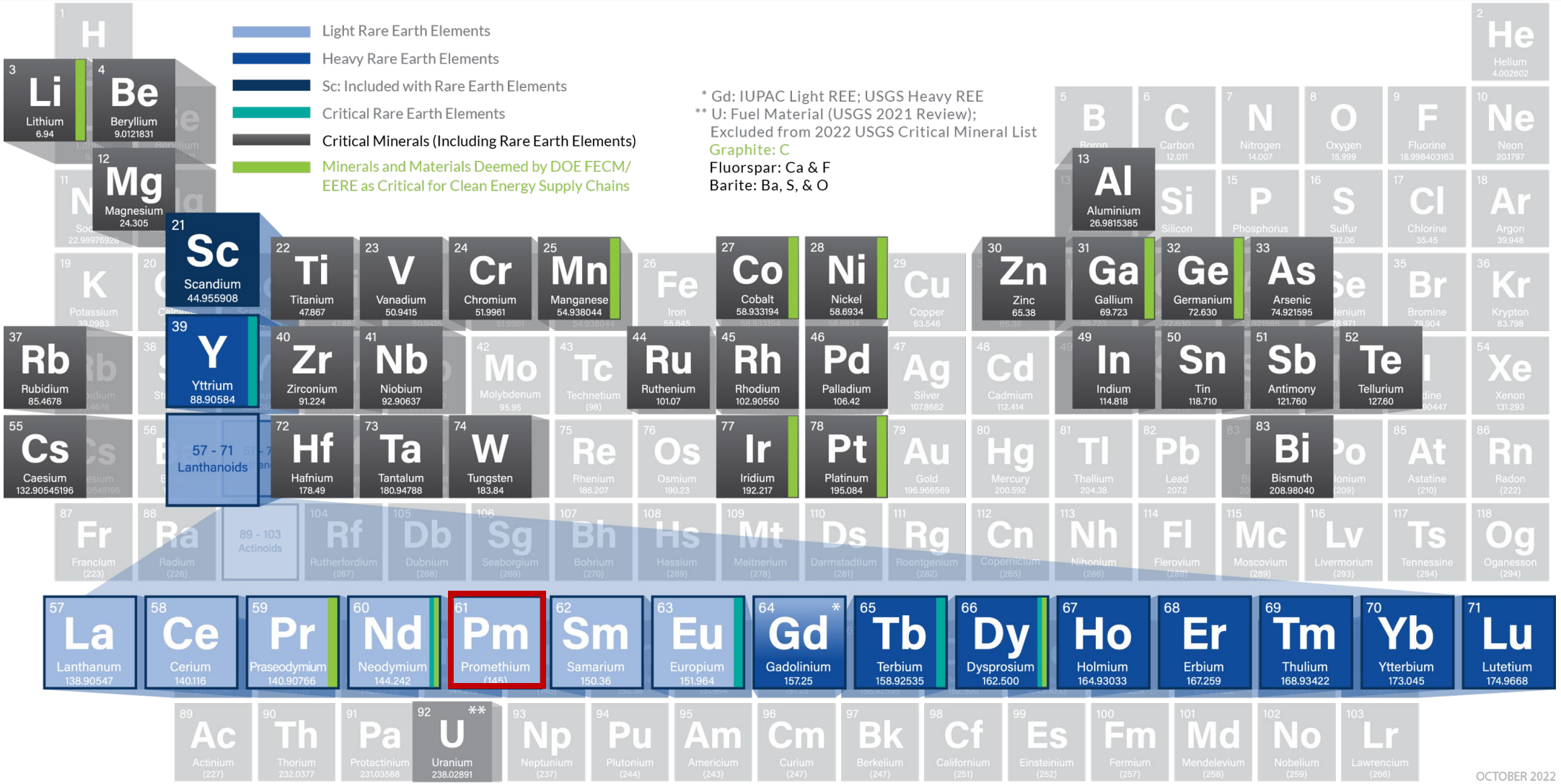
1) those that are essential to the economic or national security of the United States;

2) have a supply chain that is vulnerable to disruption;

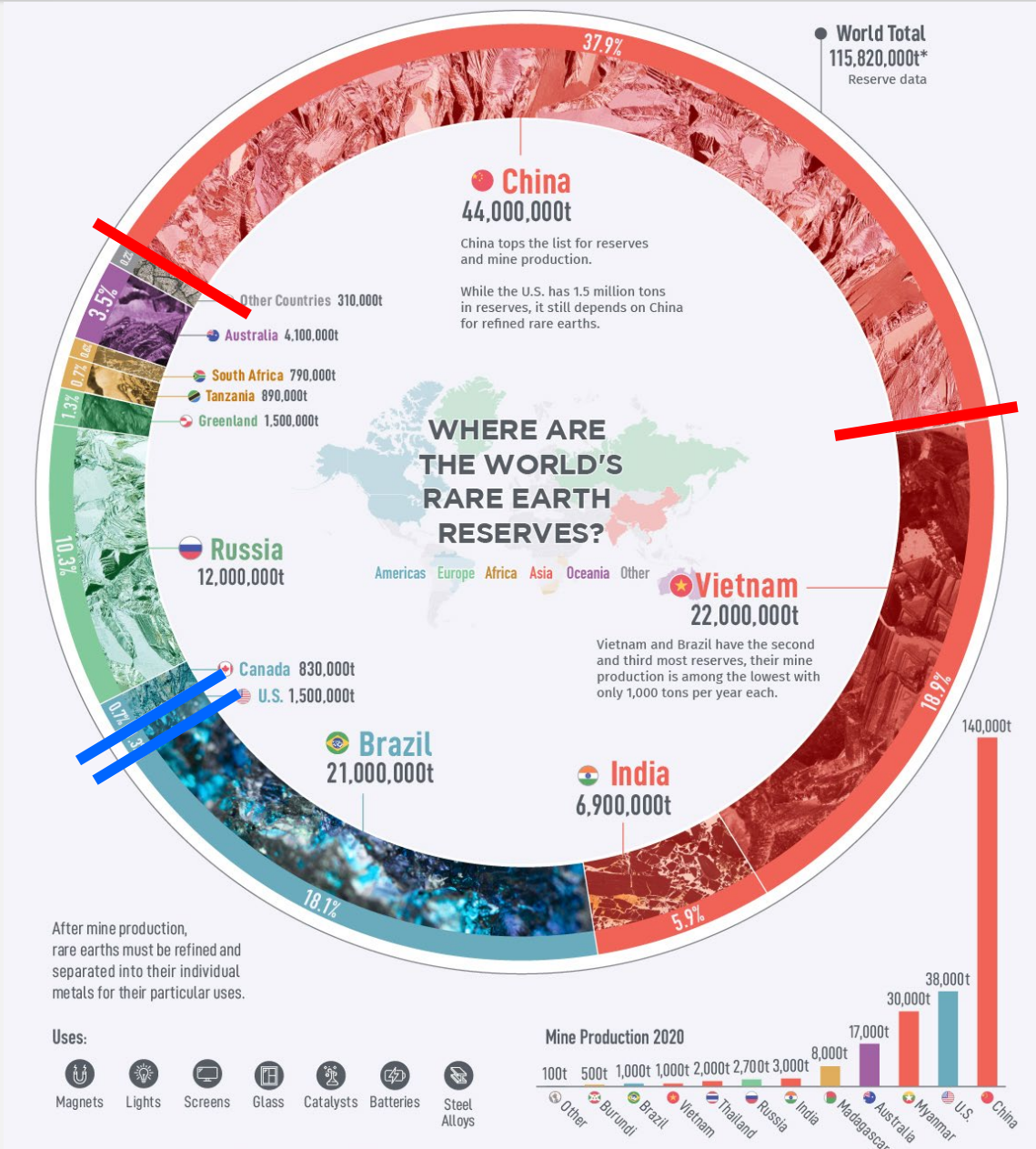
3) and serve an essential function in the manufacturing of a product – the absence of which would have significant consequences for the economic or national security of the U.S.

Definitions by the Energy Act of 2020 and USGS (2022)

PERIODIC TABLE



RARE EARTH ELEMENT RESERVES



REE Reserves

China	**37.9%**
Vietnam	18.9%
Brazil	18.1%
Russia	10.3%
India	5.3%
Australia	3.5%
Greenland	1.3%
U.S.	**1.3%**
Canada	0.7%
Tanzania	0.7%
South Africa	0.6%
Others	0.2%

Mining.com, 2021

Rare Earth Elements

Rare earth elements have gotten the most attention of the critical minerals because in 2010 China cut off rare earth elements to Japan for two months over a fishing dispute and in recent years have leveraged exports to U.S. defense contractors during trade negotiations.

Between 2010 and 2023, China's share of global rare earth element production fell from **92%** to **69%** as other countries ramped up production.

USGS, 2024

And it is not just about consumer electronics…

Energy generation

49 In Indium

31 Ga Gallium

34 Se Selenium

Thin-film solar PV

Photo credit: Testbourne, Ltd.

Offshore direct drive wind turbine

Photo credit: US DOE

60 Nd Neodymium

66 Dy Dysprosium

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.

Gen. III Ground Panoramic Night Vision Goggles

Photo credit: L3 Technologies, Inc.

32 Ge Germanium

31 Ga Gallium

33 As Arsenic

Healthcare

64 Gd Gadolinium

63 Eu Europium

71 Lu Lutetium

PET/CT diagnostic imaging

Photo credit: GE Healthcare

58 Ce Cerium

65 Tb Terbium

39 Y Yttrium

Transportation

3 Li Lithium

27 Co Cobalt

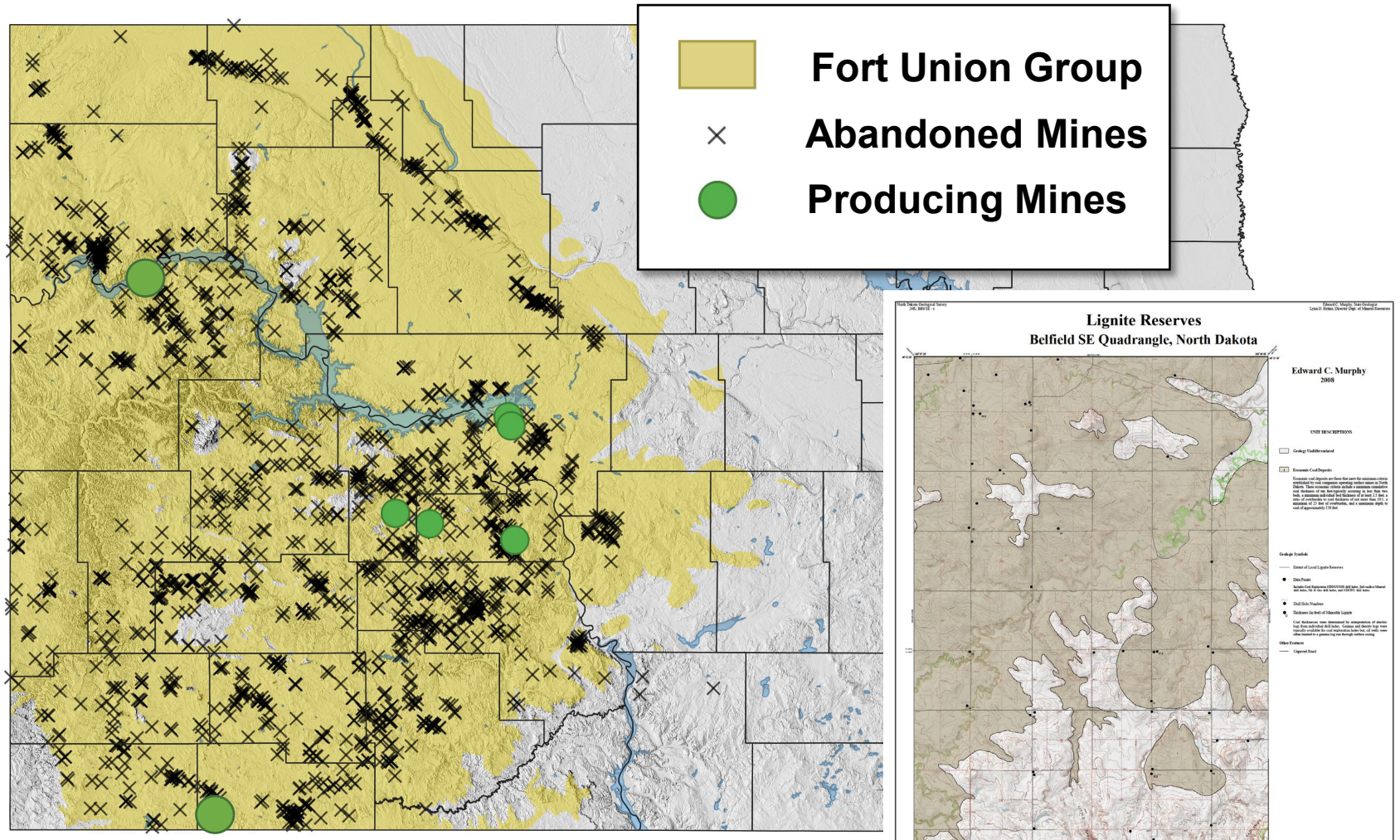
Electric and hybrid vehicles

Photo credit: Telsa, Inc.

Nassar, USGS, 2018

Abundant North Dakota Lignite

Near the surface at active mines and elsewhere



1.3 trillion tons

Total lignite resources

25 billion tons

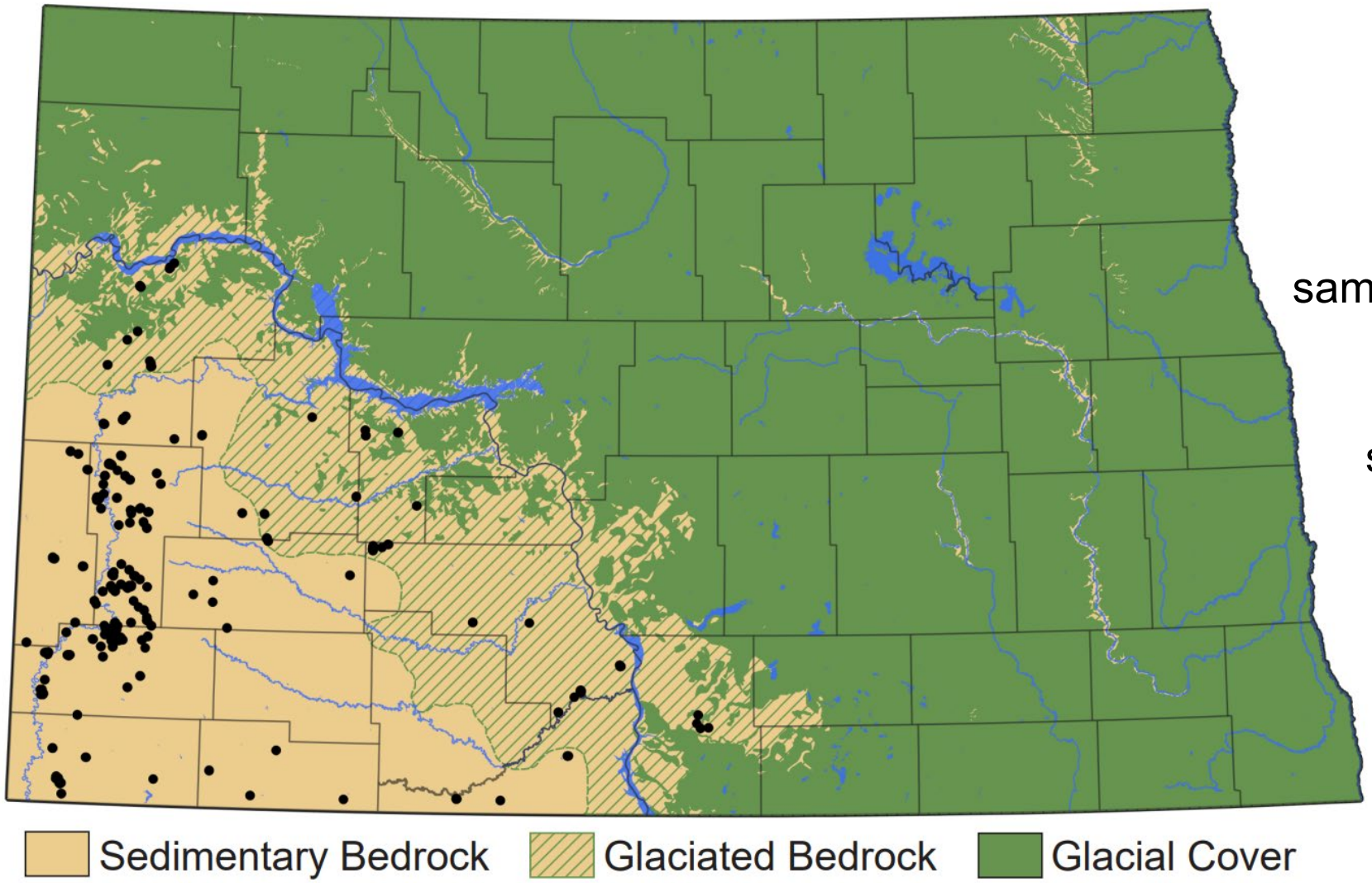
Economically recoverable lignite

1800 ft

Lignite-bearing sedimentary rock

NDGS Characterization Study: 2015 to 2024 (ongoing)

Rare earth and other critical element concentrations in ND lignites



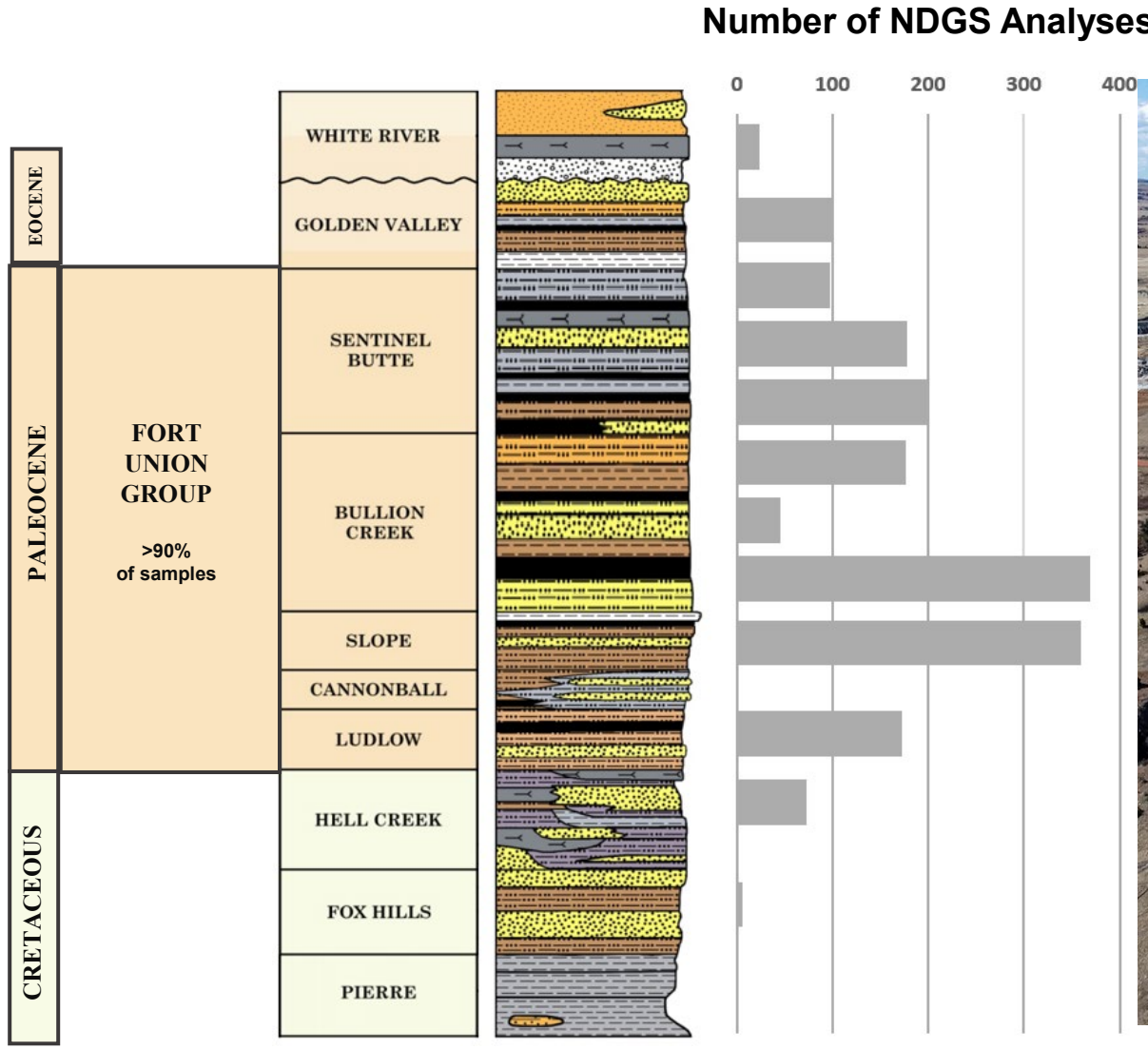
2,175
samples collected

1,829
samples submitted for ICP-MS analysis

321
stratigraphic sections measured

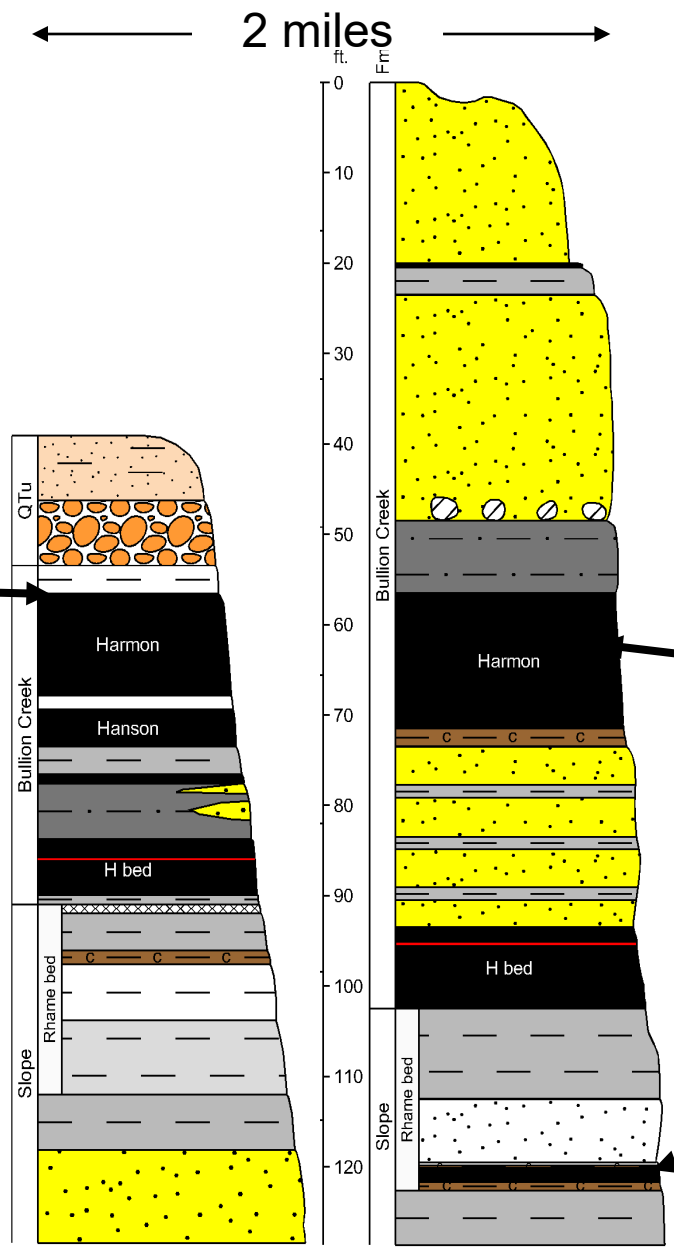
NDGS Characterization Study: 2015 to 2024 (ongoing)

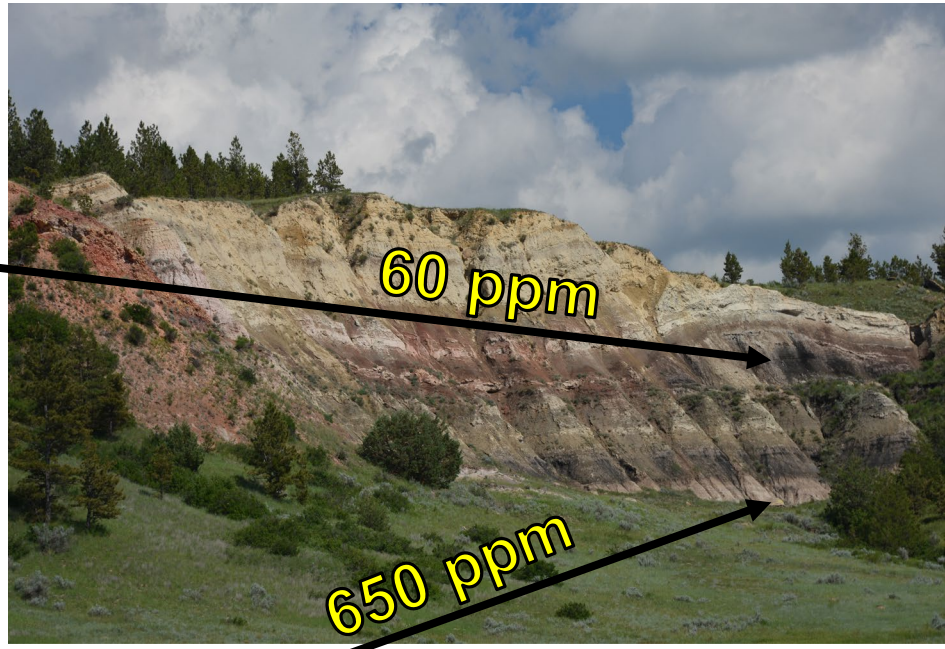
Rare earth and other critical element concentrations in ND lignites



NDGS Characterization Study: 2015 to 2024 (ongoing)

Rare earth element concentrations in ND lignites

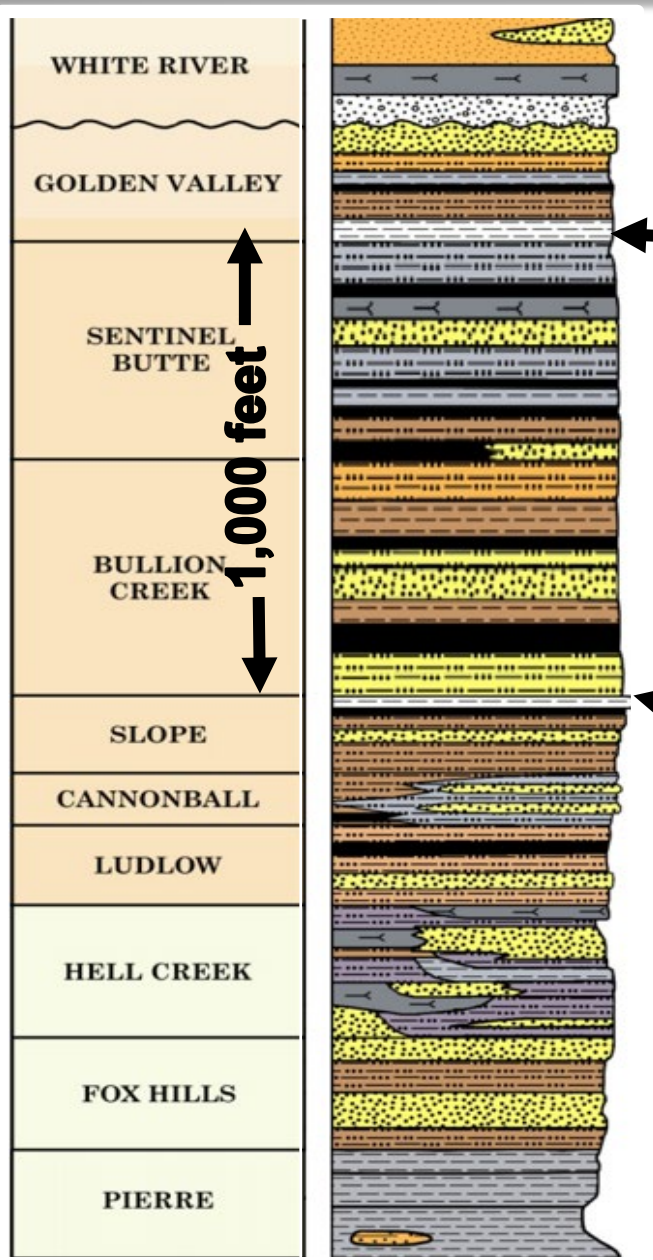


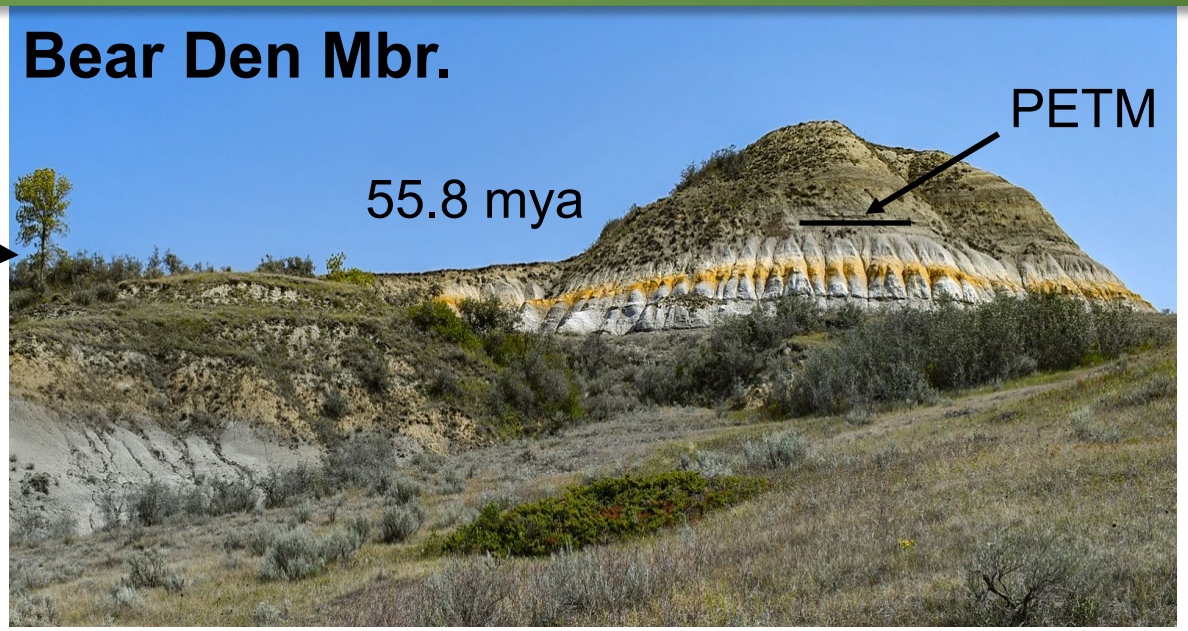


3 tons of 250 ppm REE (2018)

3 tons of 800 ppm REE (2018)
44 tons of 650 ppm REE (2020)

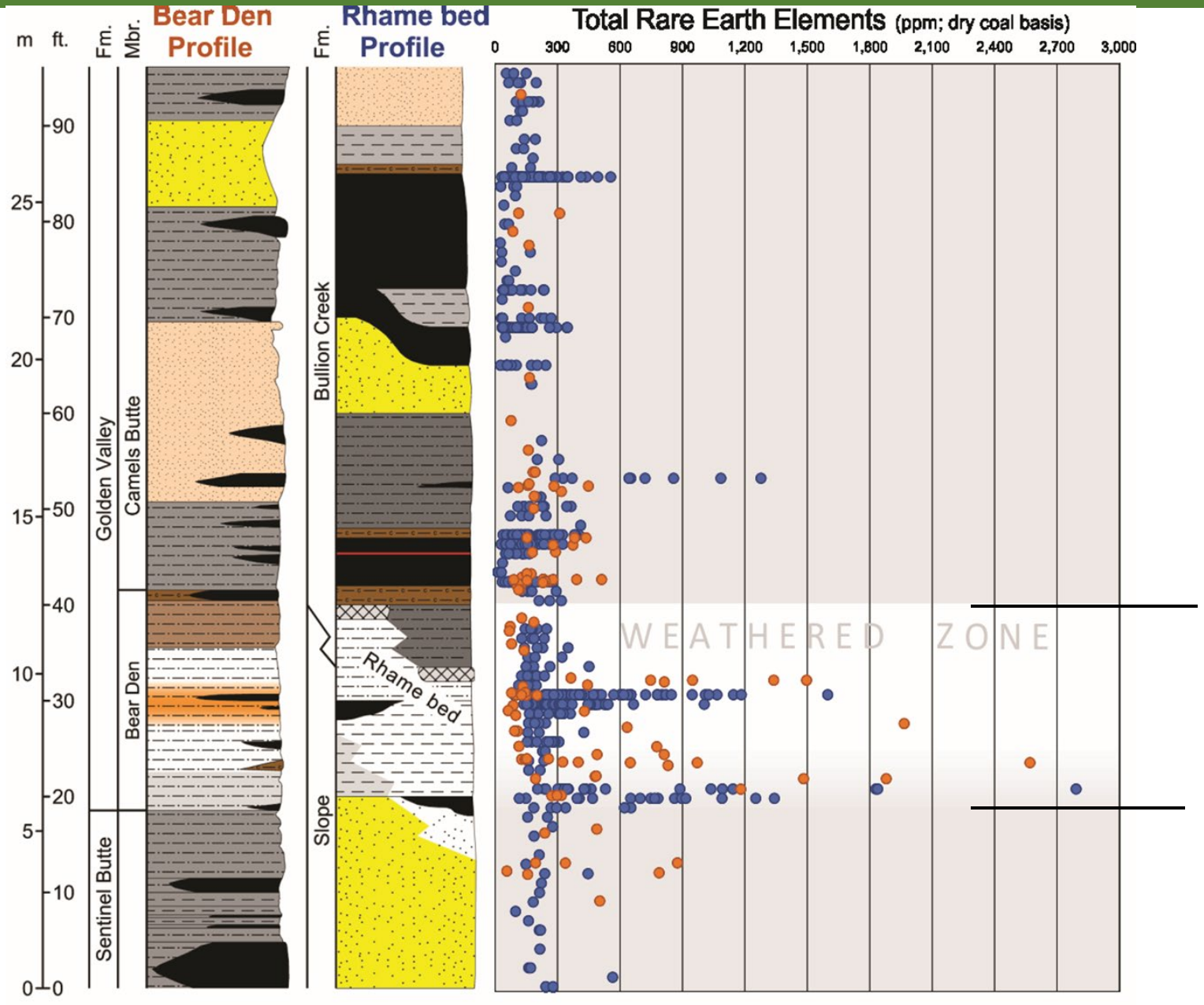
NDGS Characterization Study: 2015 to 2024 (ongoing)

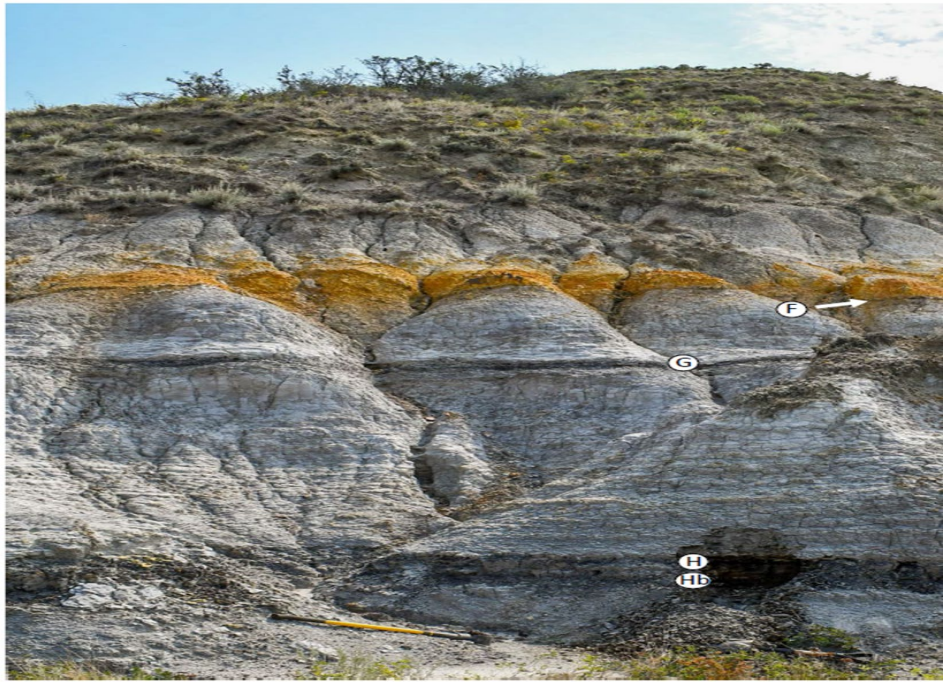




NDGS Characterization Study: 2015 to 2024 (ongoing)

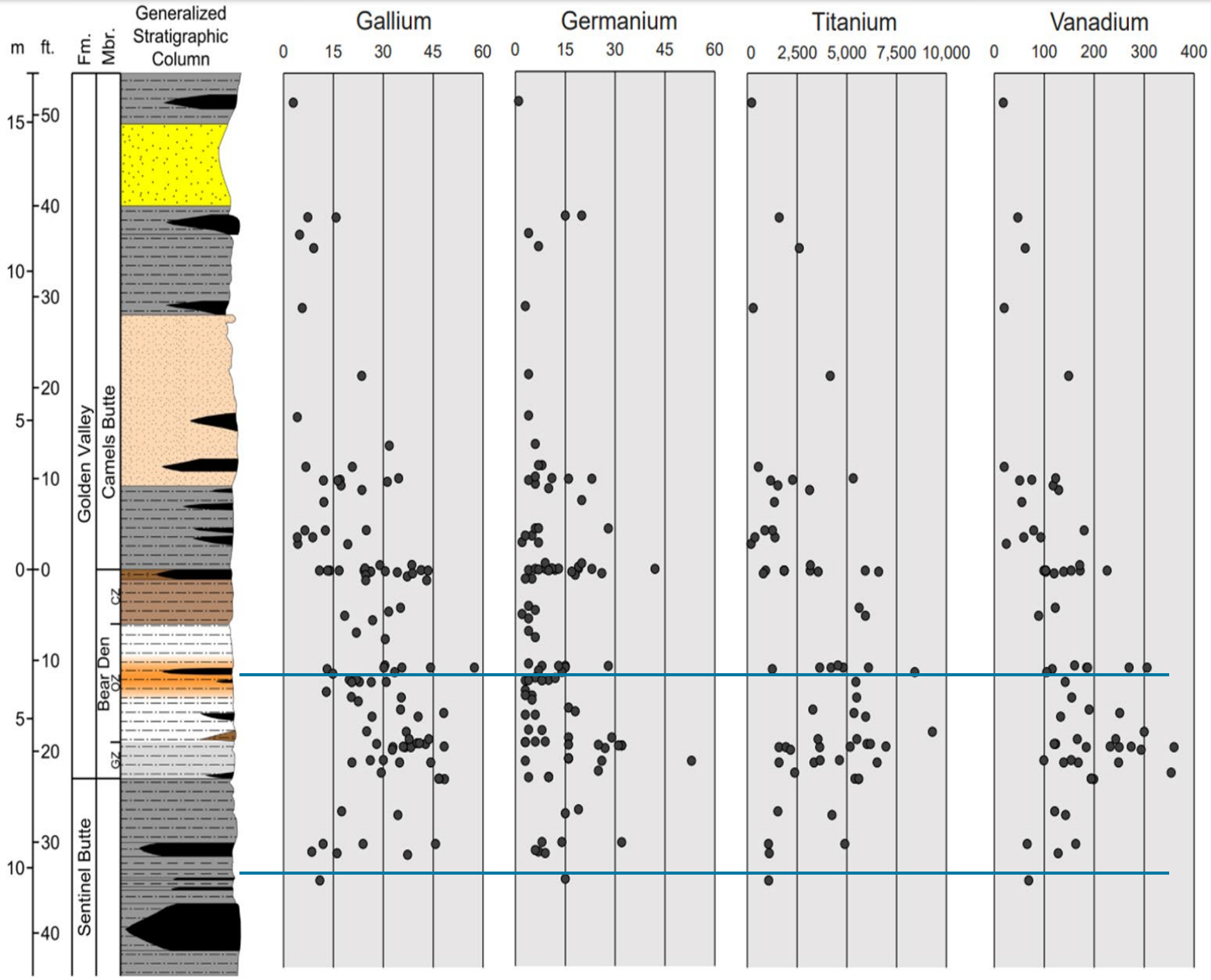
Rare earth element concentrations in ND lignites





NDGS Characterization Study: 2015 to 2024 (ongoing)

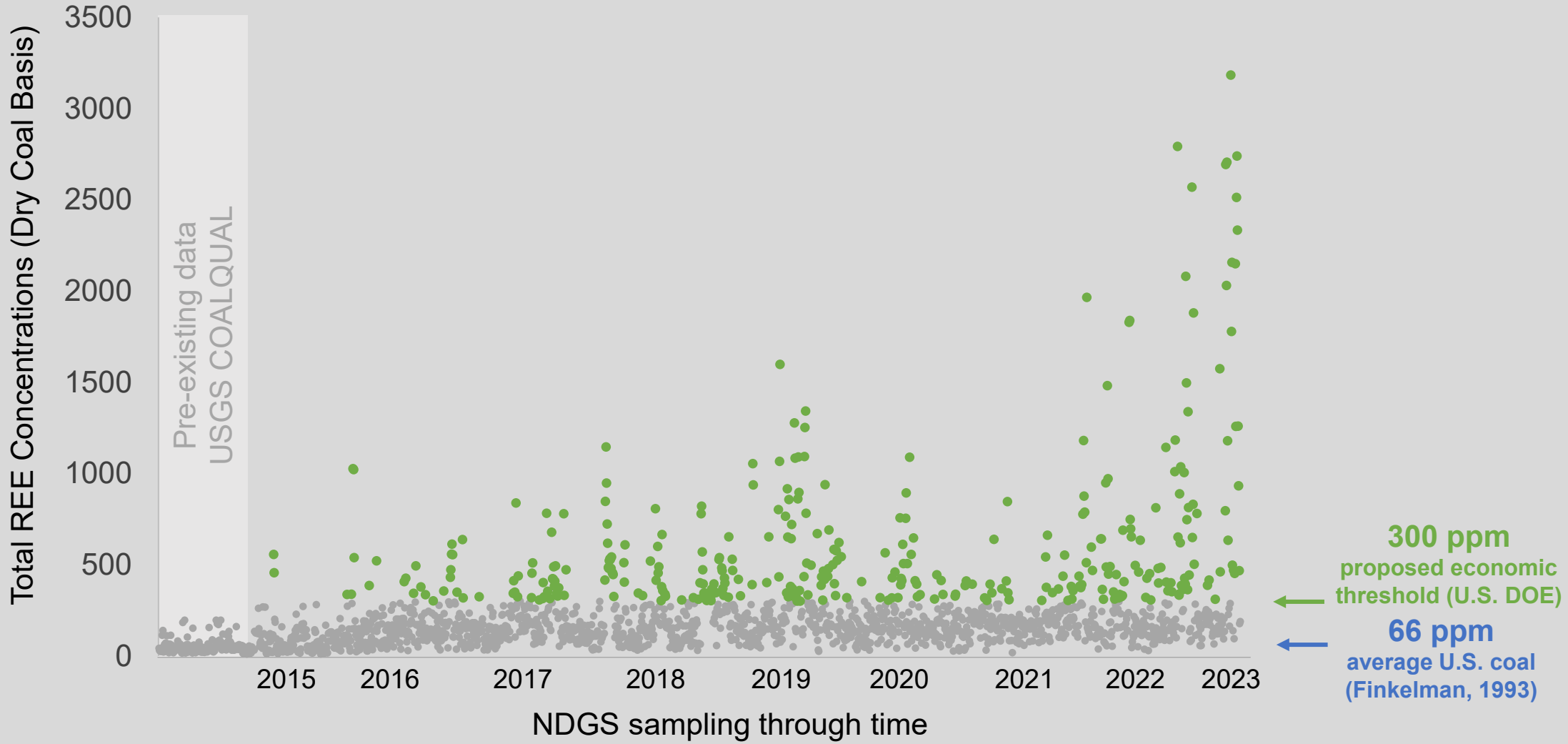
Critical element concentrations in ND lignites



Enriched Zone

NDGS Characterization Study: 2015 to 2024 (ongoing)

Rare earth element concentrations in ND lignites



Rare Earth Element Concentrations in Fort Union and Hell Creek Strata in Western North Dakota

by

Ned W. Kruger, Levi D. Moxness, and Edward C. Murphy

REPORT OF INVESTIGATION NO. 117
North Dakota Geological Survey
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2017

Rare Earth Element Concentrations in the Harmon, Hanson, and H Lignites in Slope County, North Dakota

by

Edward C. Murphy, Levi D. Moxness, Ned W. Kruger, and Christopher A. Maike

REPORT OF INVESTIGATION NO. 119
North Dakota Geological Survey
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2018

Rare Earth and Other Critical Element Concentrations in the Sentinel Butte Formation, Tracy Mountain, North Dakota

by

Levi D. Moxness, Edward C. Murphy, and Ned W. Kruger

REPORT OF INVESTIGATION NO. 128
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2021

Critical Elements in North Dakota Lignites

Lignite Research Council White Paper

North Dakota Department of Mineral Resources
Geological Survey

Levi D. Moxness
Ned W. Kruger
Edward C. Murphy

February 3, 2022

CRITICAL MINERALS IN THE FOX HILLS (CRETACEOUS), HELL CREEK (CRETACEOUS) AND LUDLOW (PALEOCENE) FORMATIONS IN NORTH DAKOTA

by

Levi D. Moxness, Edward C. Murphy, and Ned W. Kruger

REPORT OF INVESTIGATION NO. 130
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2022

Rare Earth and Other Critical Element Concentrations in the Sentinel Butte and Bullion Creek Formations (Paleocene), Billings, McKenzie, and Golden Valley Counties, North Dakota

by

Ned W. Kruger, Levi D. Moxness, and Edward C. Murphy

REPORT OF INVESTIGATION NO. 131
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2022

ELEVATED CRITICAL MINERAL CONCENTRATIONS ASSOCIATED WITH THE PALEOCENE-EOCENE THERMAL MAXIMUM, GOLDEN VALLEY FORMATION, NORTH DAKOTA

by

Edward C. Murphy, Levi D. Moxness, and Ned W. Kruger

REPORT OF INVESTIGATION NO. 133
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2023

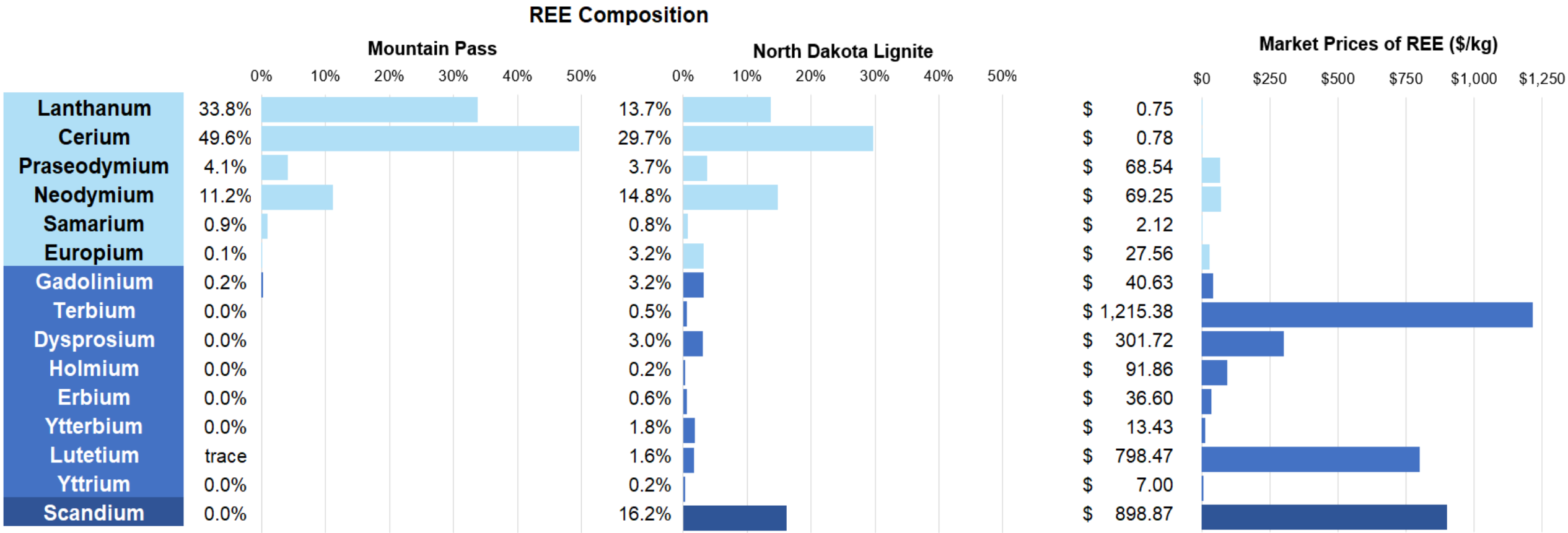
CRITICAL MINERAL ENRICHMENT IN LIGNITES BENEATH THE RHAME BED (PALEOCENE) OF THE SLOPE FORMATION IN THE WILLISTON BASIN OF NORTH DAKOTA

by

Levi D. Moxness, Edward C. Murphy, and Ned W. Kruger

REPORT OF INVESTIGATION NO. 134
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2023

Rare Earth Elements

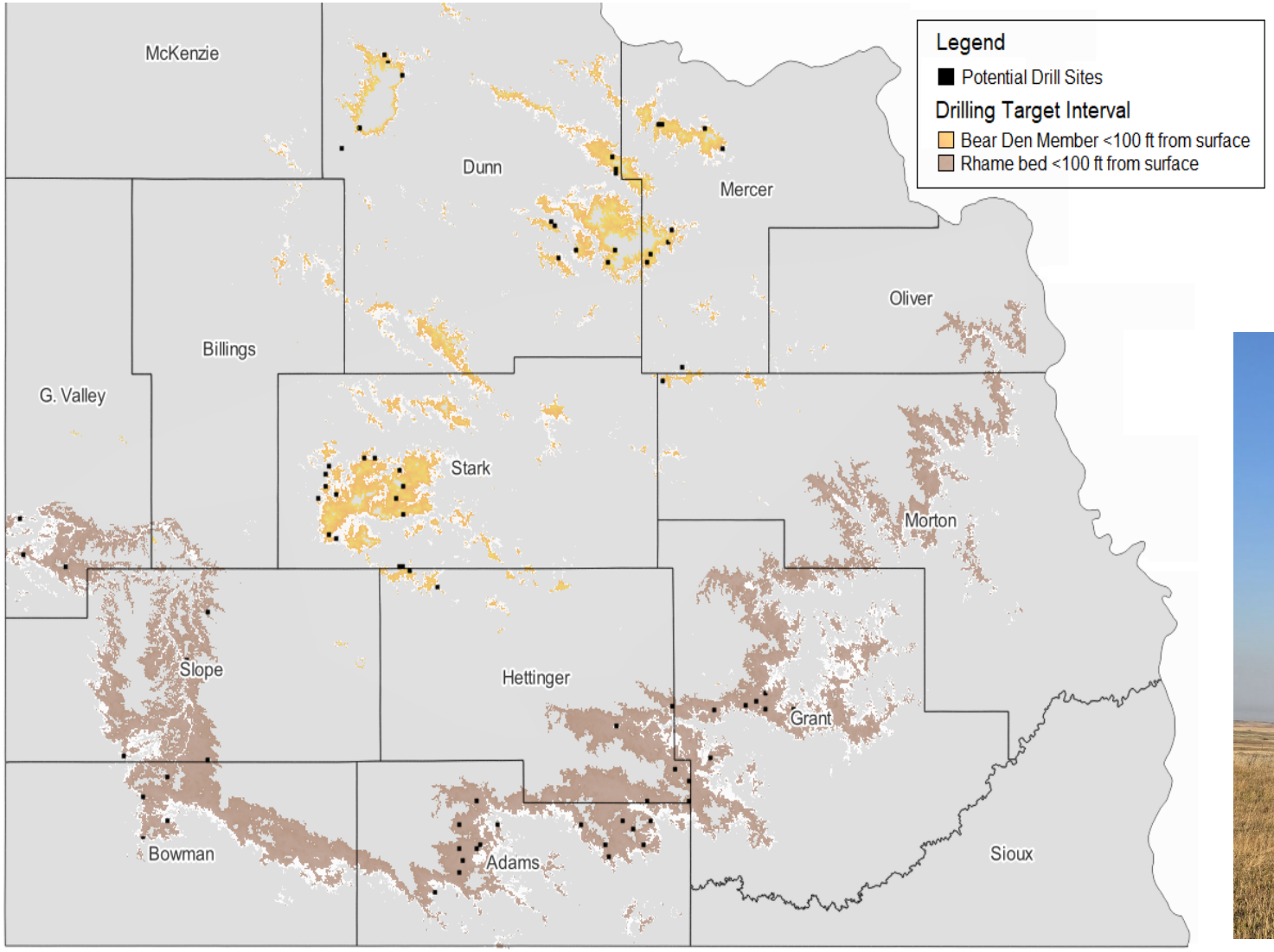


(Gschneidner and Pecharsky, 2019)

NDGS Critical Minerals Study

https://www.metal.com/Rare-Earth-Oxides, June 2023

2024 Critical Minerals Drilling Project



53 holes
8,600 feet drilled
1,040 feet cored

2024 Critical Minerals Drilling Project

Portable X-Ray Fluorescence (XRF) Analyzer

Critical Minerals in Produced Water in the Williston Basin

1) 2015: couldn't find an aqueous laboratory willing to work with produced waters with high total dissolved solids (TDS).

2) Lithium, potassium, strontium, magnesium, and manganese (Feng Xiao, 2021).

3) Lithium, magnesium, manganese, cobalt, and nickel (Smith et.al.,2024).

4) Lithium concentrations in southeastern Saskatchewan in the Duperow Fm. up to 148 - 259 mg/l (ROK Resources - Wright, 2024).

USGS science for a changing world

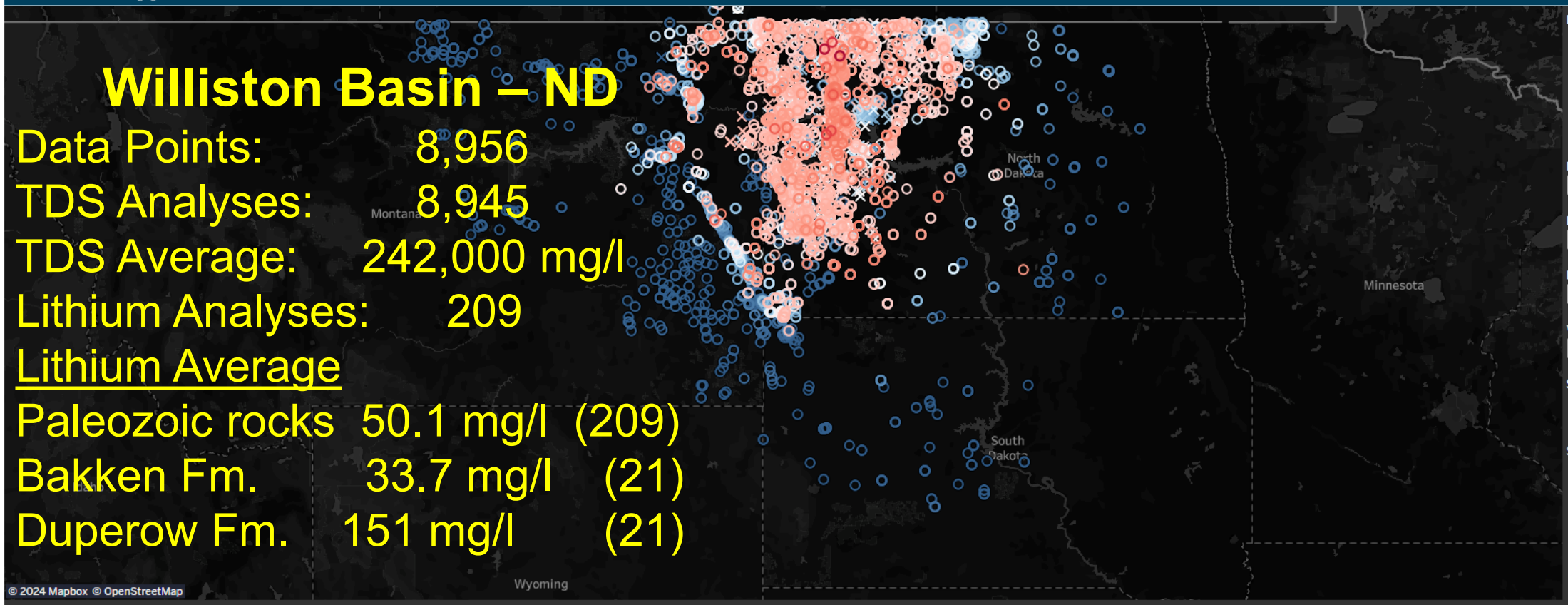
U.S. Geological Survey National Produced Waters Geochemical Database, version 3.0

Williston Basin – ND

Data Points: 8,956
TDS Analyses: 8,945
TDS Average: 242,000 mg/l
Lithium Analyses: 209

Lithium Average

Paleozoic rocks	50.1 mg/l	(209)
Bakken Fm.	33.7 mg/l	(21)
Duperow Fm.	151 mg/l	(21)



PLAYTYPE
- (All)
- Coal
- Geothermal
- Injection
- Sedimentary
- Shale

REGION: (All)

BASIN: Williston

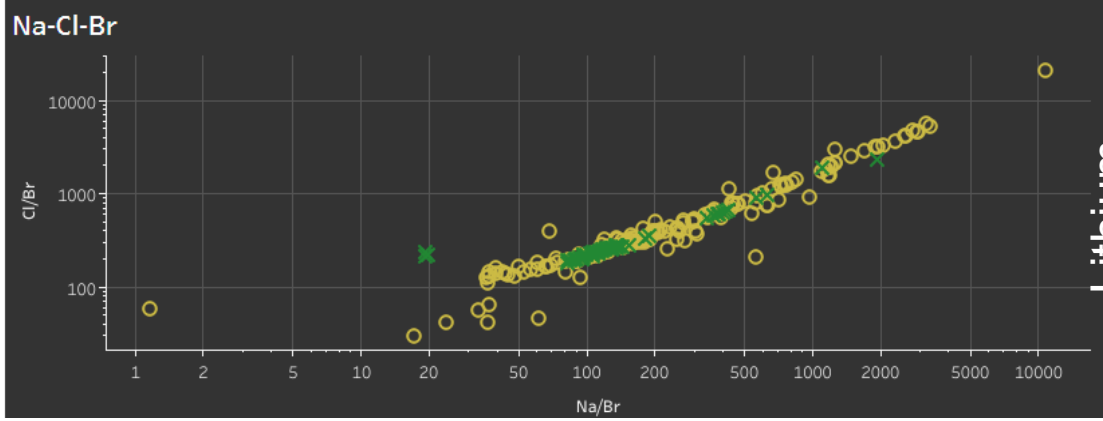
FORMSIMPLE: (All)

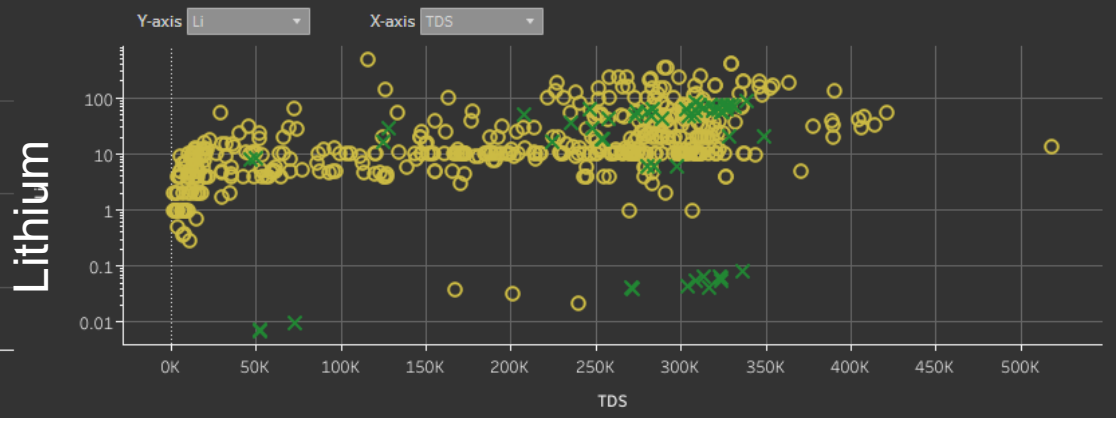
Variable: All

Salinity (TDS, mg/L): 0 – 530,000

Salinity (TDS, mg/L): 0 – 530,000

PLAYTYPE
- Sedimentary
- Shale





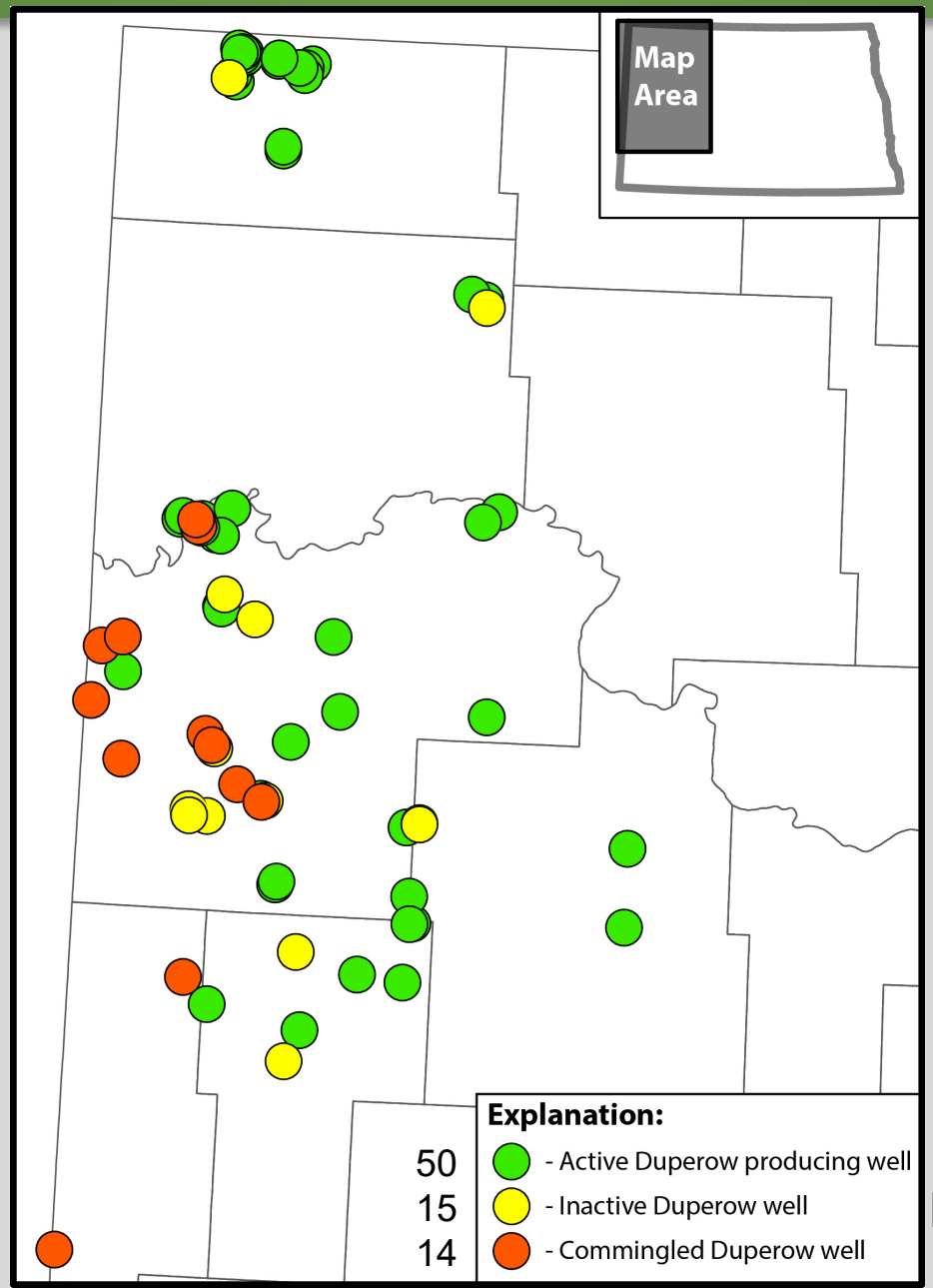
Oil and Gas Waters Project

Data Dictionary & Data Download

Reference: Madalyn S. Blondes, Katheri..

Disclaimer: Although the data have bee..

Duperow Wells



Lithium concentrations up to 400 mg/l

THE HILL

Researchers say Arkansas may have 19M tons of lithium critical for battery power

by Tara Suter - 10/21/24 7:22 PM ET

Researchers said in a recent article that Arkansas may have **19 million tons of lithium**, which is used in rechargeable batteries for important products like phones and electric cars.

The researchers said in their article released last month in the journal Science Advances they had “calculated that there are **5.1 to 19 million tons** of lithium in **Smackover Formation** brines in southern Arkansas,” making up “35 to 136% of the current US lithium resource estimate.”

> 400 mg/l

Ownership of Critical Minerals in North Dakota

1) At this time, if critical mineral mining were to occur in North Dakota, it would likely involve coal.

2) Critical minerals are separate minerals from the coal (coal vs coalbed methane).

3) Did not see a benefit of mining critical minerals as a by-product of coal mining.

4) The ownership of the critical minerals would not change if they were extracted pre-combustion or post-combustion.

5) A federal coal lease only covers coal, not any critical minerals found within.

6) Coal mining regulated by the ND Public Service Commission and critical minerals by the ND Industrial Commission.

B. Bjella Memo, 9/19/23


natural coal ash

LITHOLOGY	NUMBER OF SAMPLES		REE maximum (ppm)
Lignite	1,232	(67%)	4,443
Carbonaceous Mudstone	429	(23%)	2,570
Clay/Mudstone	43		485
Bentonite	25		639
Tonstein	25		325
Nodules and Concretions	24		190
Volcanic Ash	20		195
Natural Coal Ash	12		236
Sandstone	9		155
Coalified Wood	6		781
K\Pg Ejecta	3		261


barite nodule


bentonite


volcanic ash


iron nodules


manganese nodules


tonstein

Ownership of Critical Minerals in North Dakota

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2) Critical minerals are separate minerals from the coal (coal vs coalbed methane).

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4) The ownership of the critical minerals would not change if they were extracted pre-combustion or post-combustion.

5) A federal coal lease only covers coal, not any critical minerals found within.

6) Coal mining regulated by the ND Public Service Commission and critical minerals by the ND Industrial Commission (Subsurface Minerals Program).

B. Bjella Memo, 9/19/23

Mineral Ownership in North Dakota

1) **Prior to July 1, 1955:** a conveyance or reservation of minerals included all minerals.

2) **July 1, 1955 – July 1, 1983:** a conveyance of severed minerals transferred all minerals except for coal, uranium, gravel or clay unless the intent to convey these was included.

3) **July 1, 1975 – July 1, 1983:** a deed conveying or reserving minerals had to name each one.

4) **Since July 1, 1983:** a deed conveying or reserving minerals includes all minerals unless otherwise specified.

B. Bjella Memo, 9/19/23

Leasing of Critical Minerals in North Dakota

1) **Prior to July 1, 1955:** a mineral lease included oil, gas, coal, and any other mineral, but an oil and gas or coal lease did not cover other minerals unless stated.

2) **July 1, 1955 – July 1, 1957:** a lease of minerals covered oil, gas, and other minerals, but did not include coal, uranium, gravel or clay unless stated in the lease.

3) **July 1, 1957 – July 1, 1969:** a lease only covered those minerals named in the lease.

4) **Since July 1, 1969:** a lease only covers those minerals named in the lease, including all compounds and byproducts of those named minerals.

Gravel, clay, and scoria are considered part of the surface and not minerals.

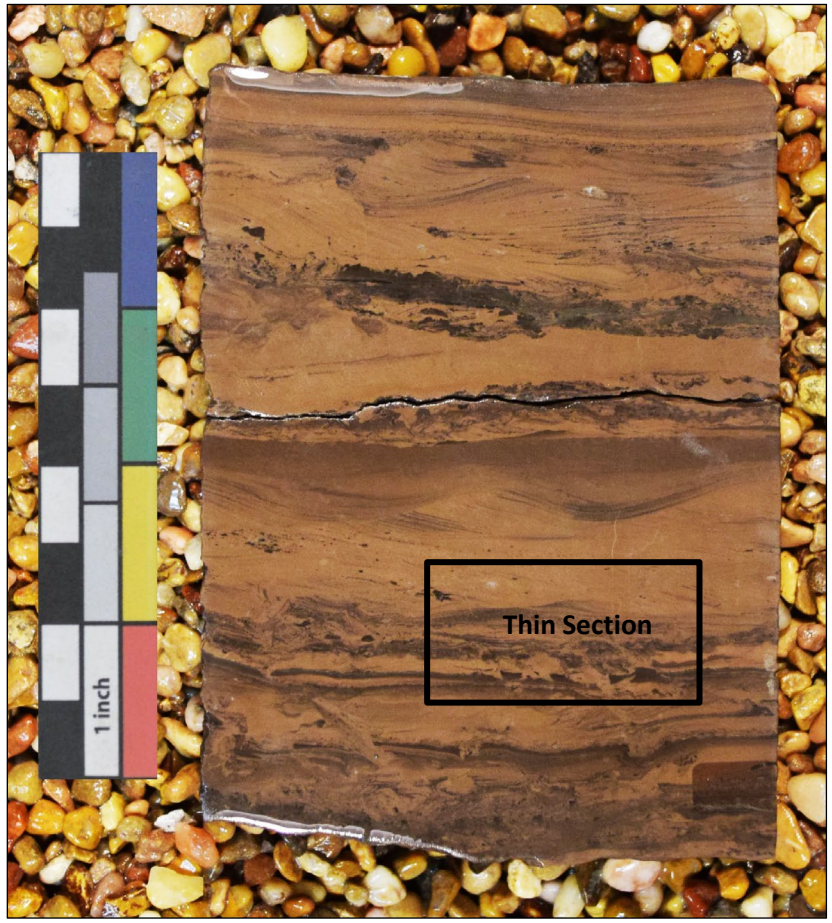
B. Bjella Memo, 9/19/23

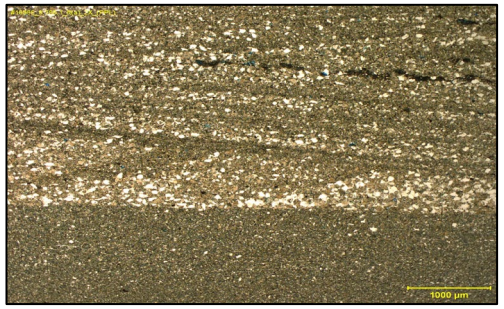
Wilson M. Laird Core & Sample Library

41,000 ft^2 warehouse
5,000 ft^2 of laboratories

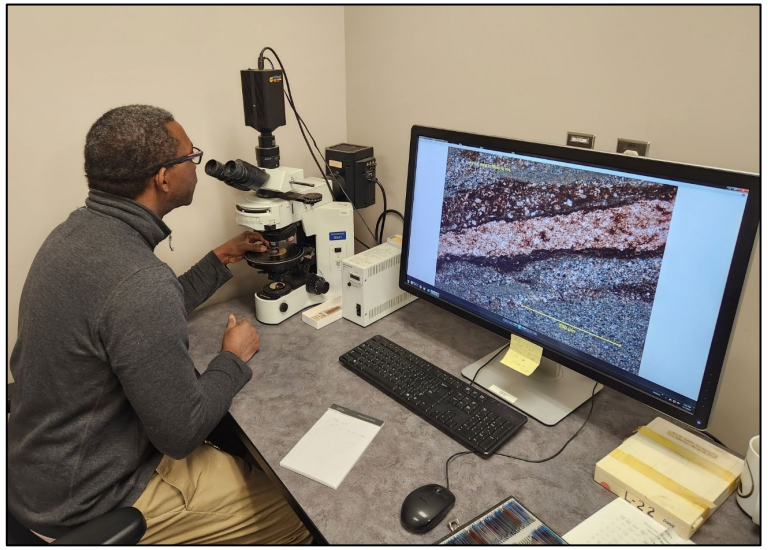
CORE AND THIN SECTION PHOTOGRAPHY PROGRAM

Wilson M. Laird Core and Sample Library





Total core (one set) in the core library =	486,000 feet (92 mi.)
Total photographed =	263,000 feet (54%)
Core photographs =	402,000
Total thin sections in the core library =	20,000
Thin section photographs =	151,000
Total photographs on website =	**553,000**



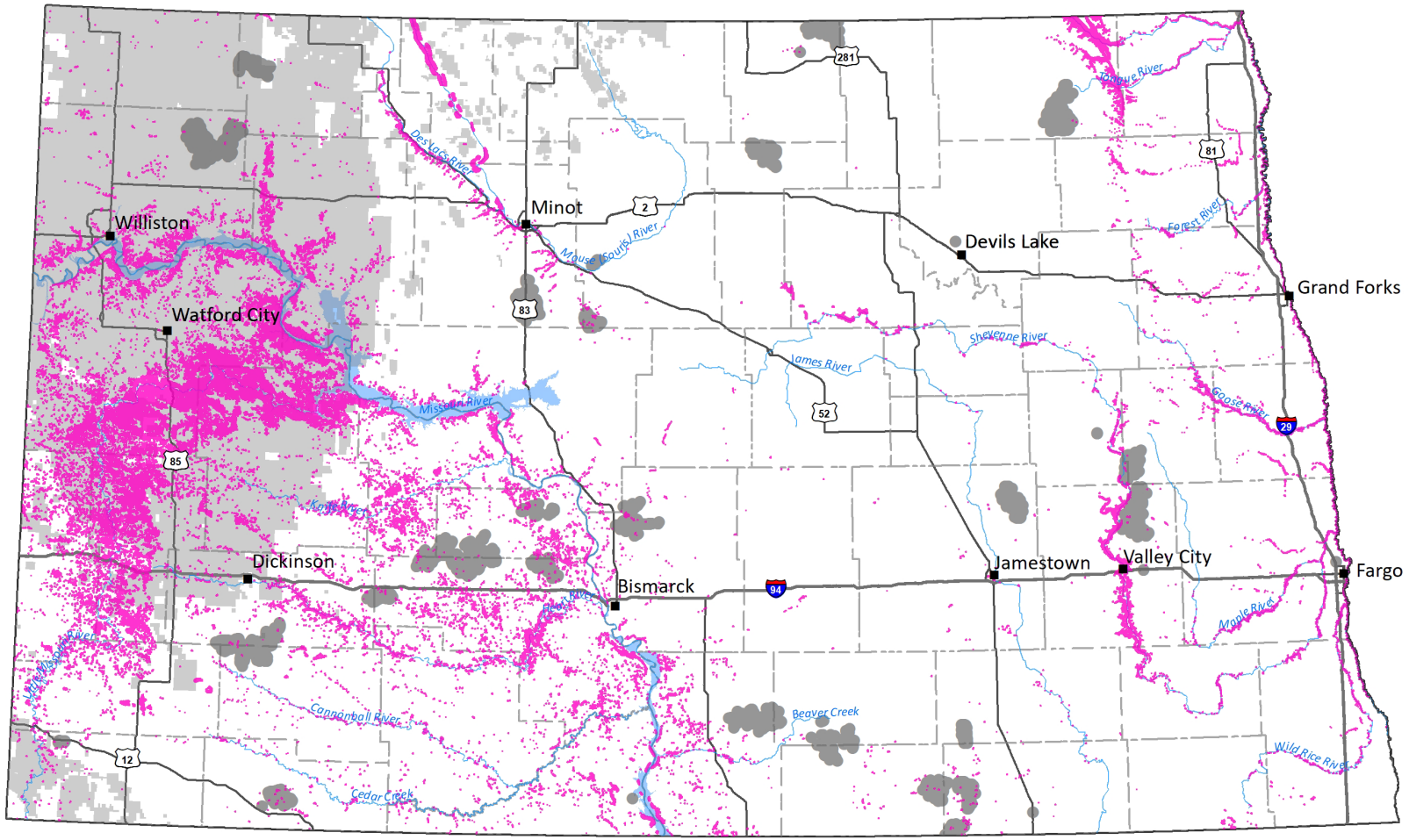
CORE AND THIN SECTION PHOTOGRAPHY PROGRAM

Wilson M. Laird Core and Sample Library

Total core (one set) in the core library	=	486,000 feet (92 mi.)
Total photographed (tripod)	=	67,000 feet (14%)
Tripod photographs	=	8,900

LANDSLIDE PROGRAM

77,000 Landslides Mapped (Phase III)



Landslide Deposits | Oil/Gas Field | Water | Wind Turbines