

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.



PERIODIC TABLE

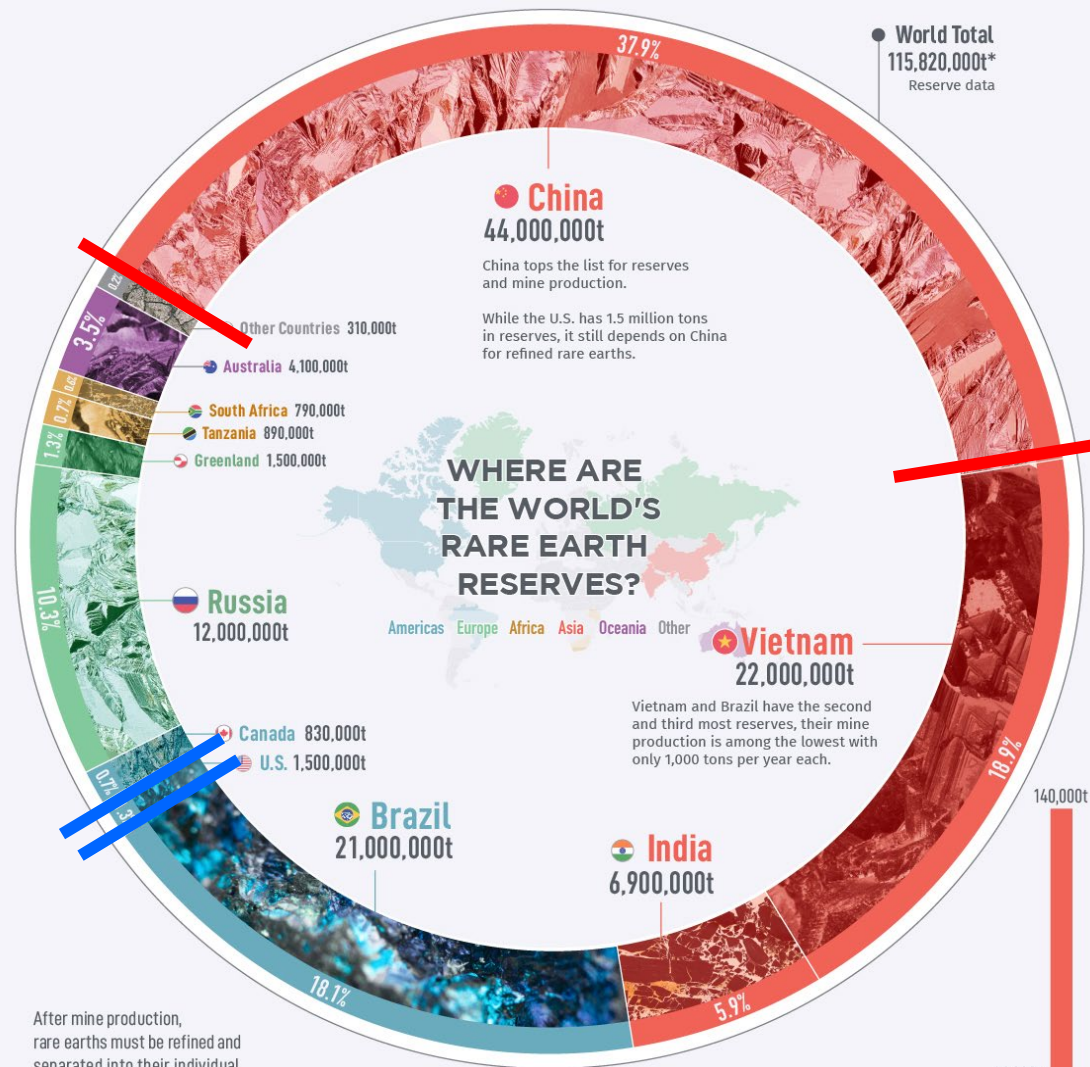
1 H Hydrogen 1.00794	2 He Helium 4.002602																
3 Li Lithium 6.94	4 Be Beryllium 9.0121831	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998403163	10 Ne Neon 20.1797										
11 Na Sodium 22.98976928	12 Mg Magnesium 24.305	13 Al Aluminium 26.9815385	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948										
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955908	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933194	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.921595	34 Se Selenium 78.9718	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90637	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90547	54 Xe Xenon 131.293
55 Cs Caesium 132.90545196	56 Ba Barium 137.327	57-71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.592	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89-103 Actinoids	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (269)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)
57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93033	68 Er Erbium 167.259	69 Tm Thulium 168.93422	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.9668			
89 Ac Actinium (227)	90 Th Thorium 232.0377	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	**	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)		

- Light Rare Earth Elements
- Heavy Rare Earth Elements
- Sc: Included with Rare Earth Elements
- Critical Rare Earth Elements
- Critical Minerals (Including Rare Earth Elements)
- Minerals and Materials Deemed by DOE FECM/EERE as Critical for Clean Energy Supply Chains

* Gd: IUPAC Light REE; USGS Heavy REE
** U: Fuel Material (USGS 2021 Review); Excluded from 2022 USGS Critical Mineral List
Graphite: C
Fluorspar: Ca & F
Barite: Ba, S, & O

OCTOBER 2022

RARE EARTH ELEMENT RESERVES

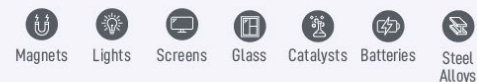


REE Reserves

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%

After mine production, rare earths must be refined and separated into their individual metals for their particular uses.

Uses:



Mine Production 2020



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.

And it is not just about consumer electronics...

Energy generation

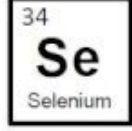
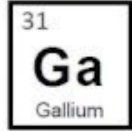
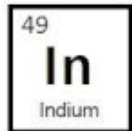
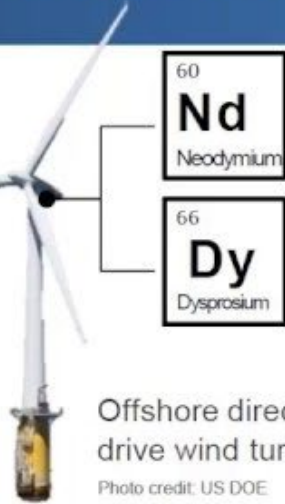
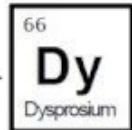
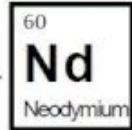


Photo credit: Testbourne, Ltd.



Offshore direct drive wind turbine
Photo credit: US DOE



Defense and national security

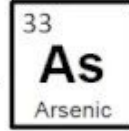
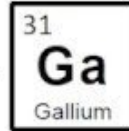
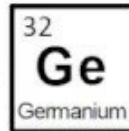


U.S. Air Force F-35A
Lightning II Joint Strike
Fighter

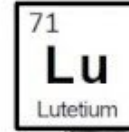
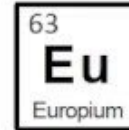
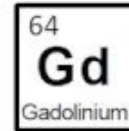
Photo credit: Master Sgt. John R. Nimmo, Sr.

Gen. III Ground Panoramic
Night Vision Goggles

Photo credit: L3 Technologies, Inc.

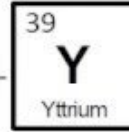
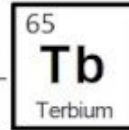
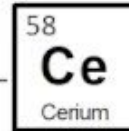


Healthcare

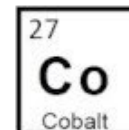
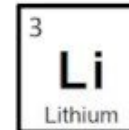


PET/CT diagnostic
imaging

Photo credit: GE Healthcare



Transportation



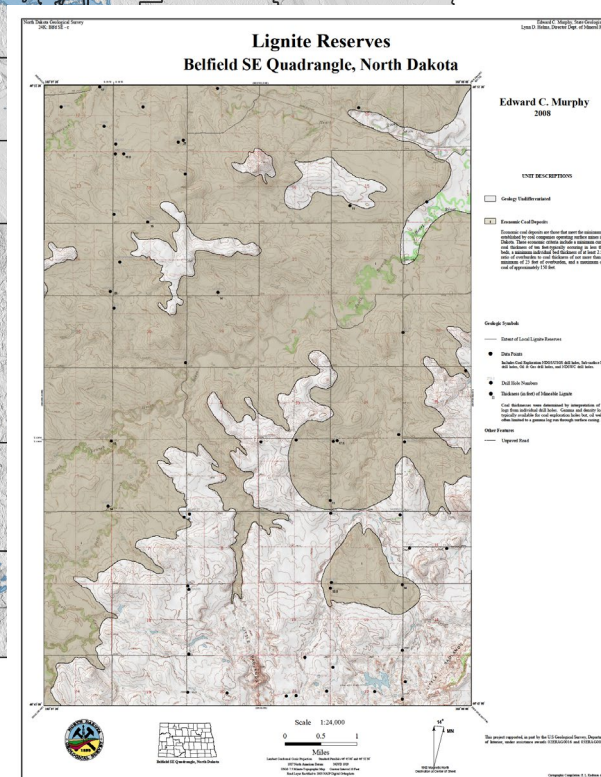
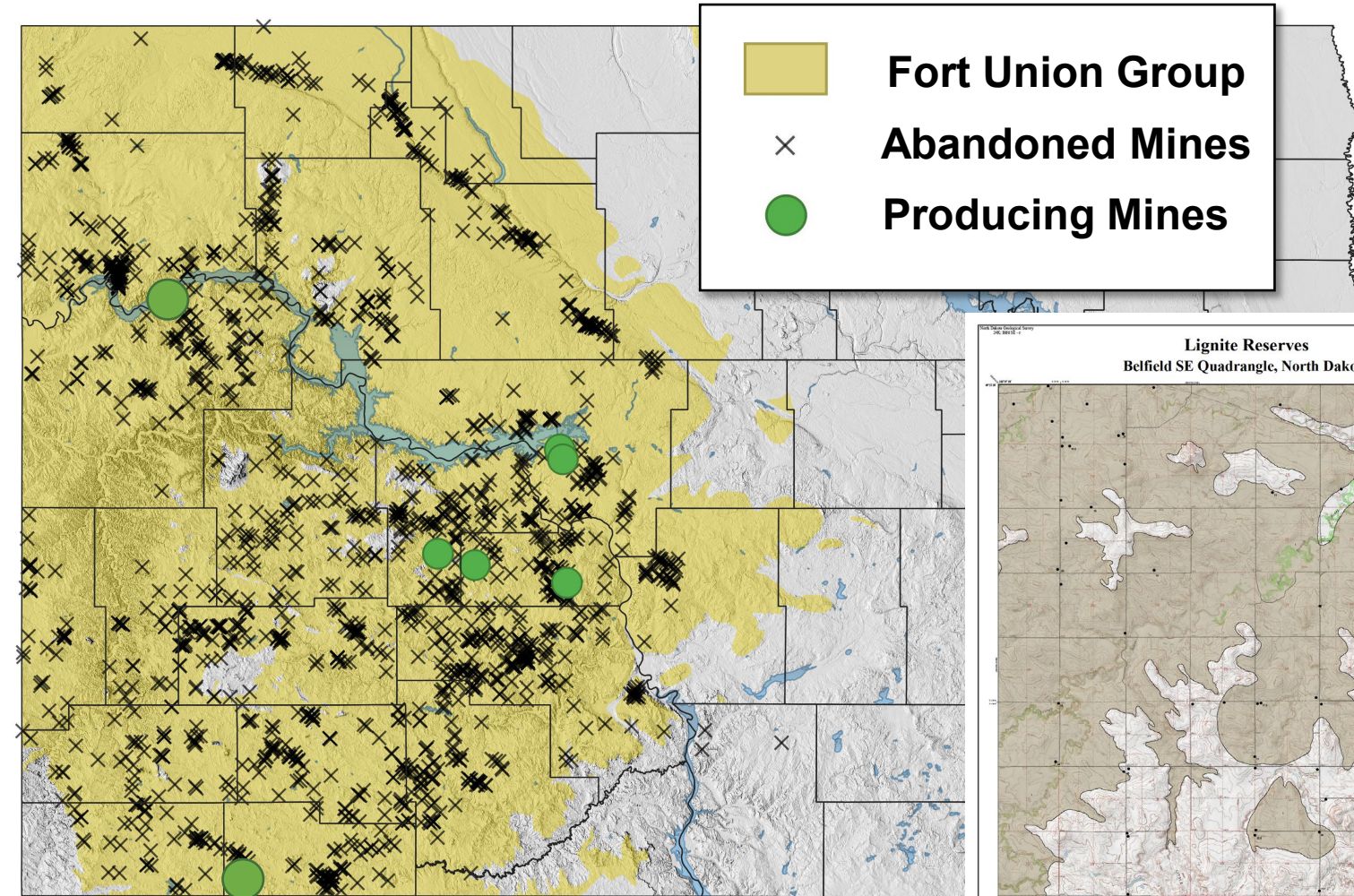
Electric and hybrid
vehicles

Photo credit: Tesla, Inc.



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

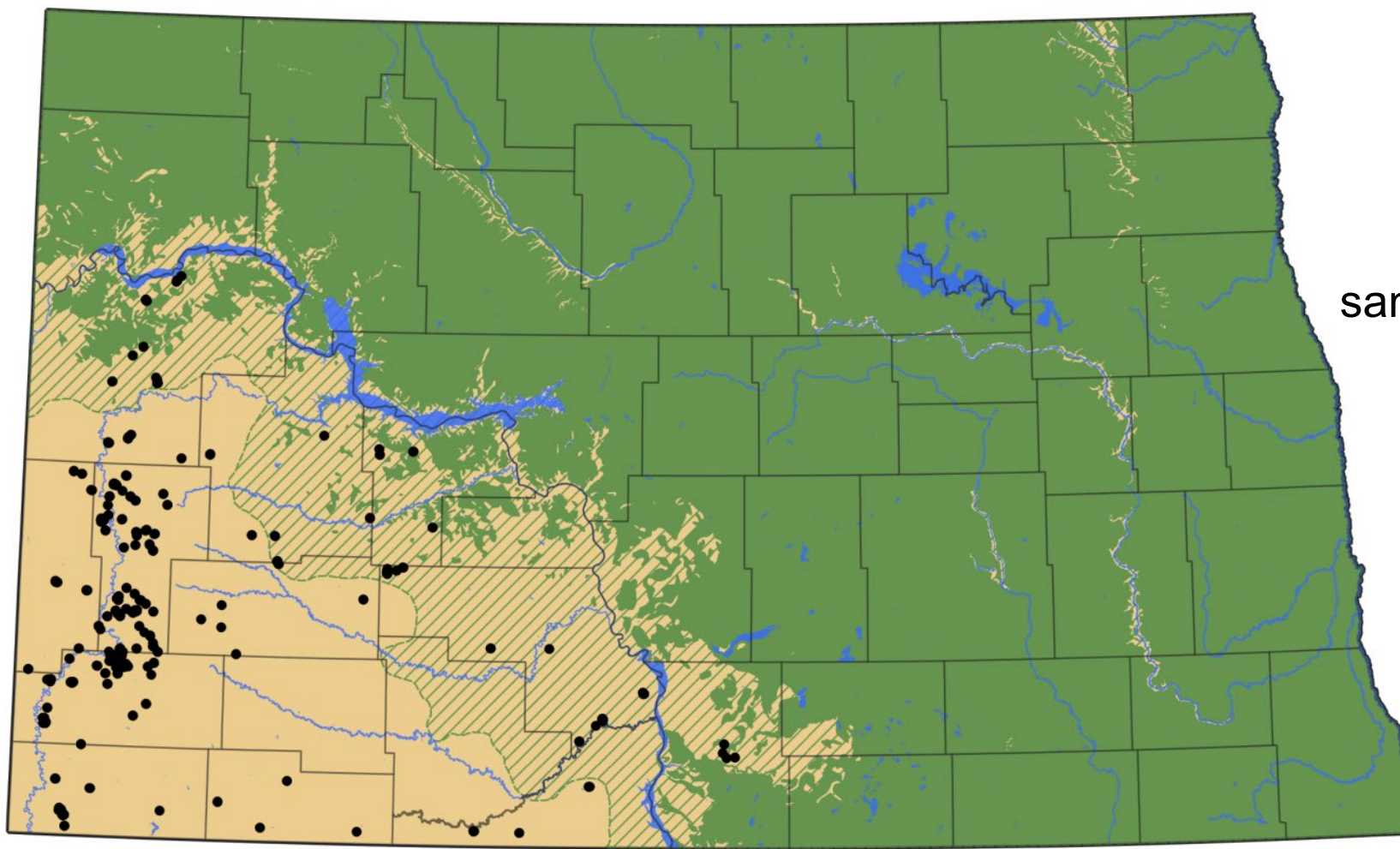
samples collected

1,829

samples submitted for ICP-MS analysis

321

stratigraphic sections measured

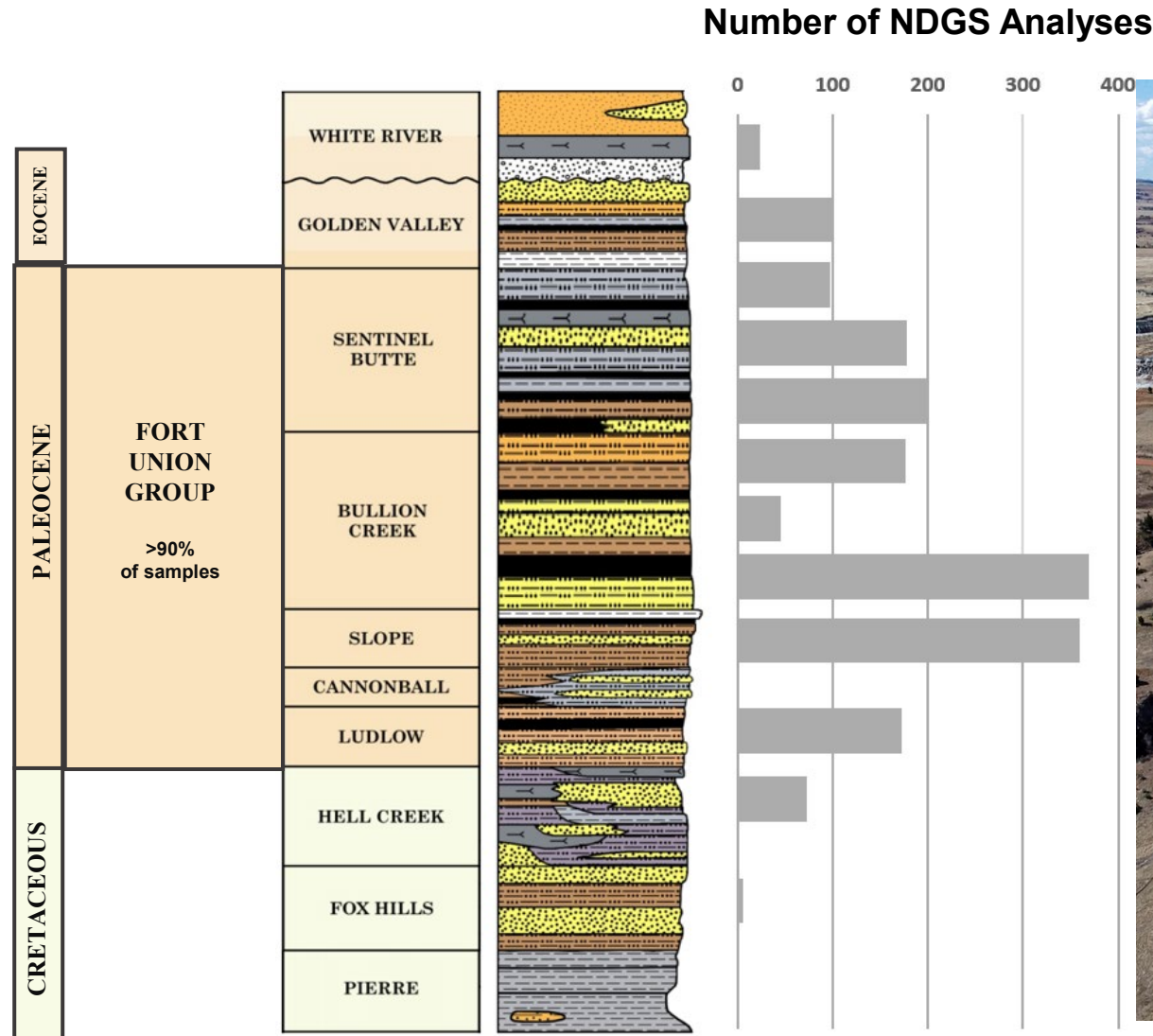


 Sedimentary Bedrock  Glaciated Bedrock  Glacial Cover



NDGS Characterization Study: 2015 to 2024 (ongoing)

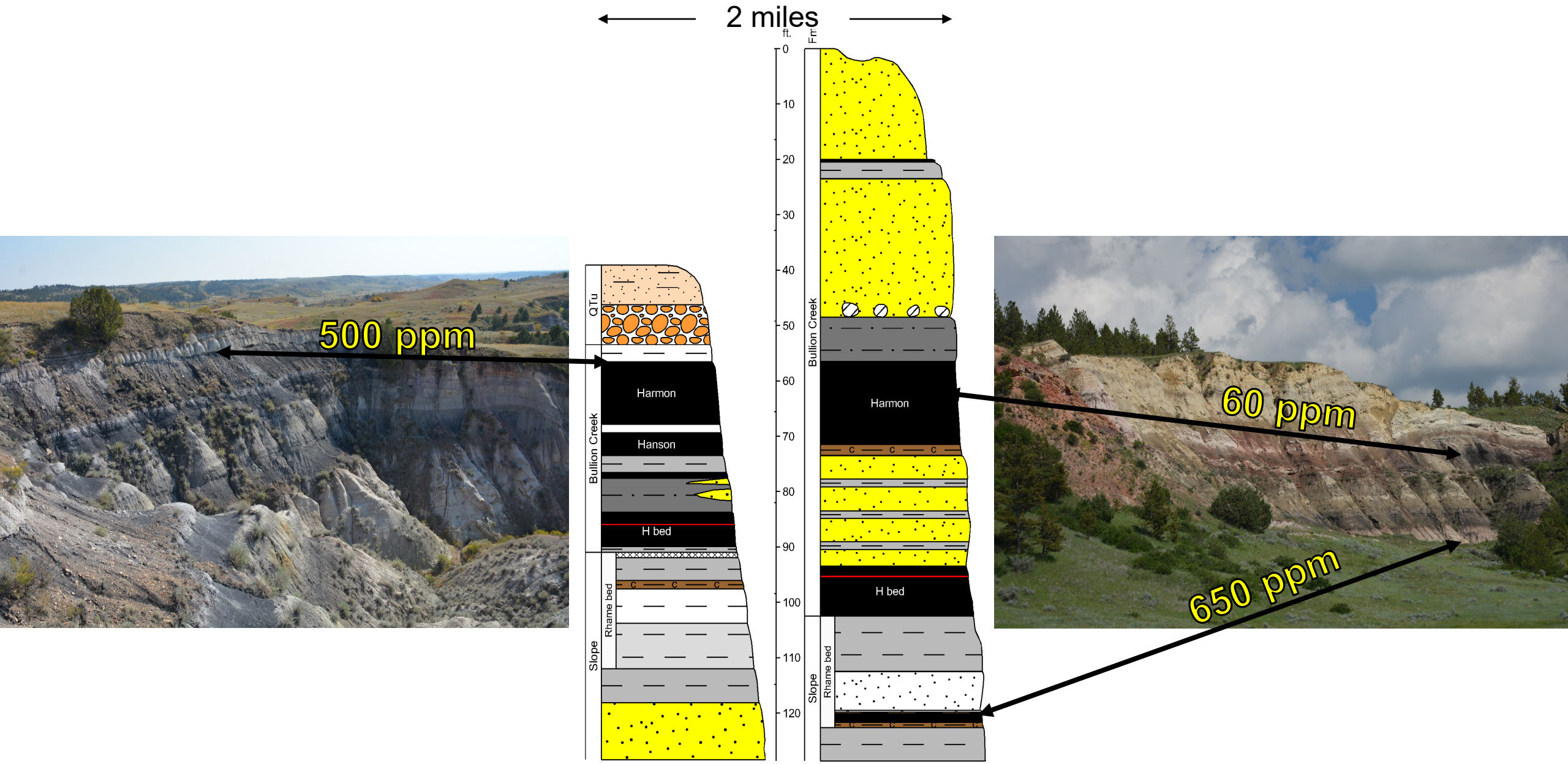
Rare earth and other critical element concentrations in ND lignites





NDGS Characterization Study: 2015 to 2024 (ongoing)

Rare earth element concentrations in ND lignites



3 tons of 250 ppm REE (2018)

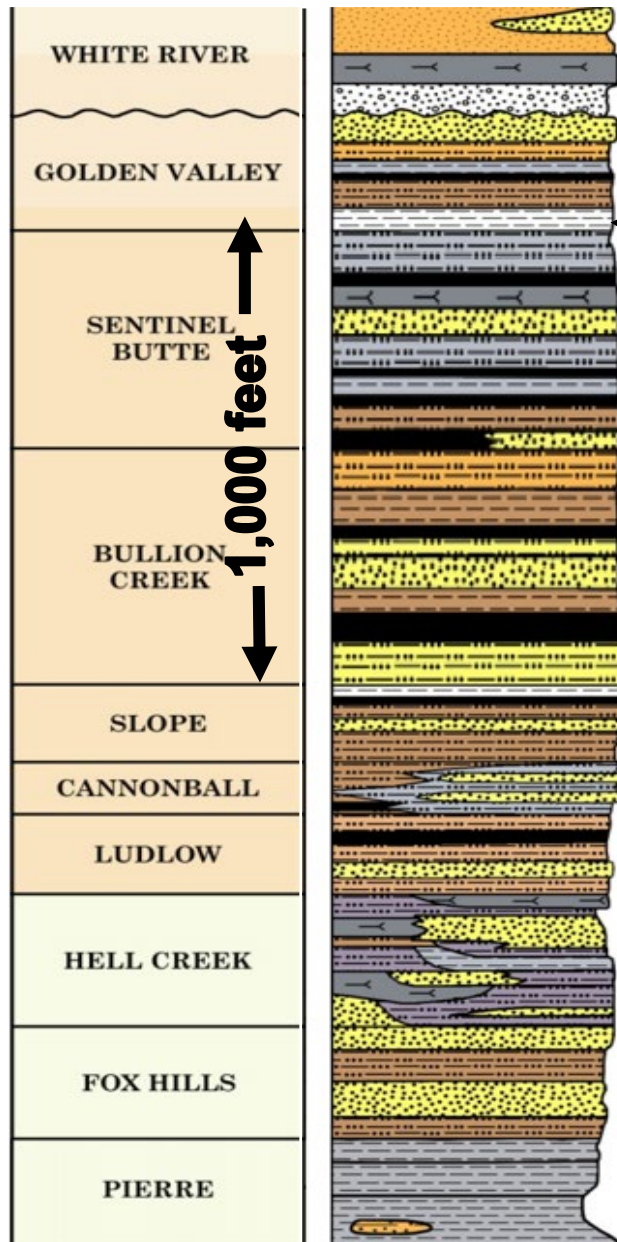


3 tons of 800 ppm REE (2018)
44 tons of 650 ppm REE (2020)

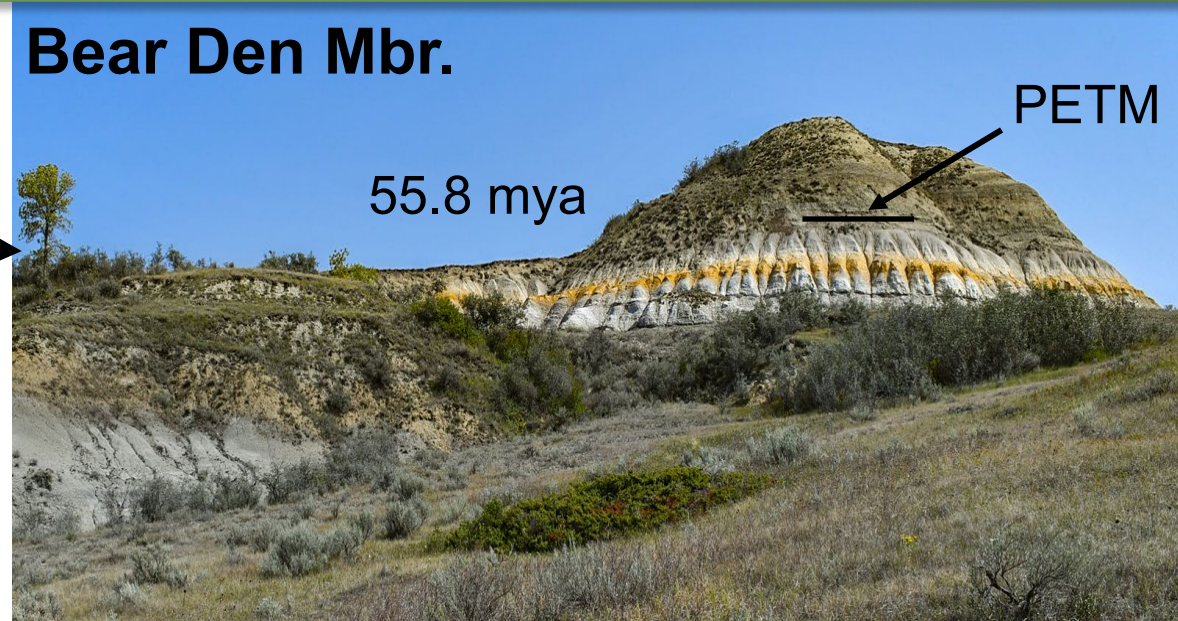




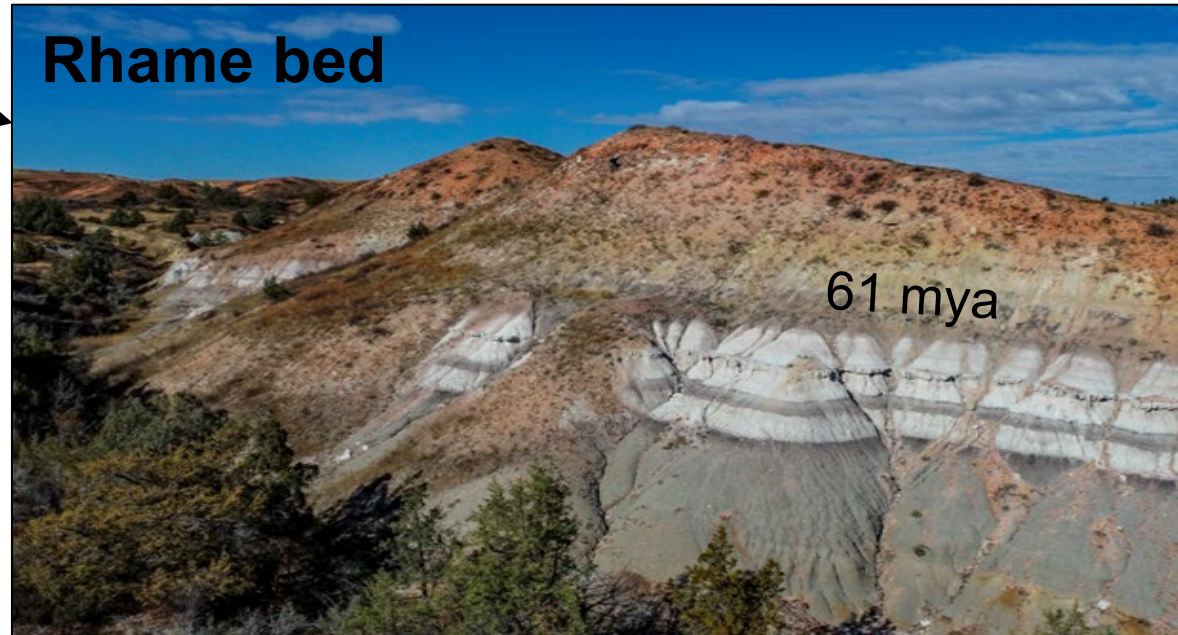
NDGS Characterization Study: 2015 to 2024 (ongoing)



Bear Den Mbr.



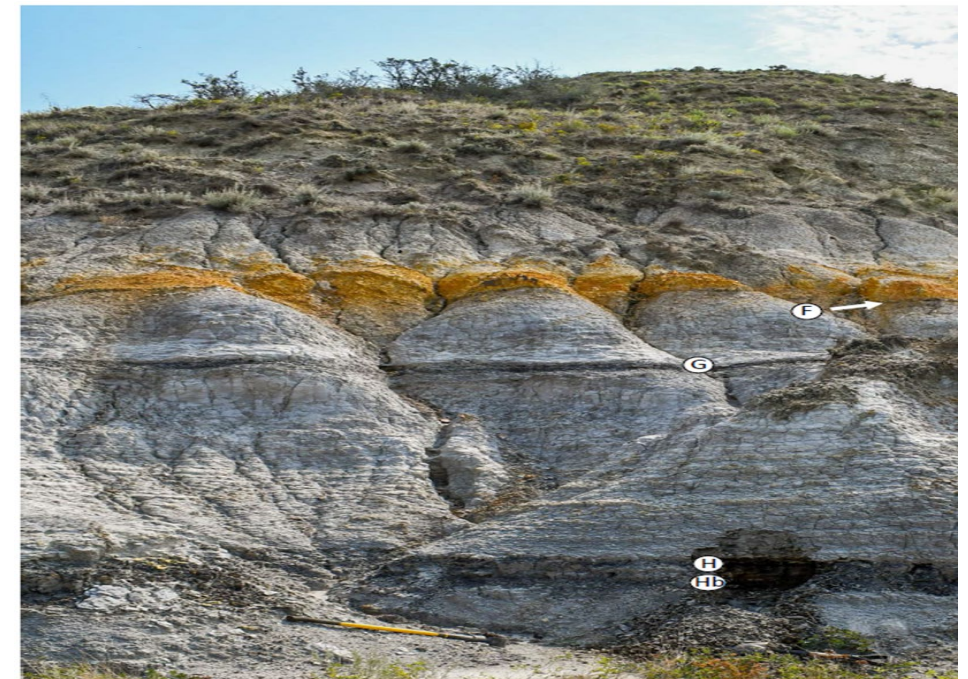
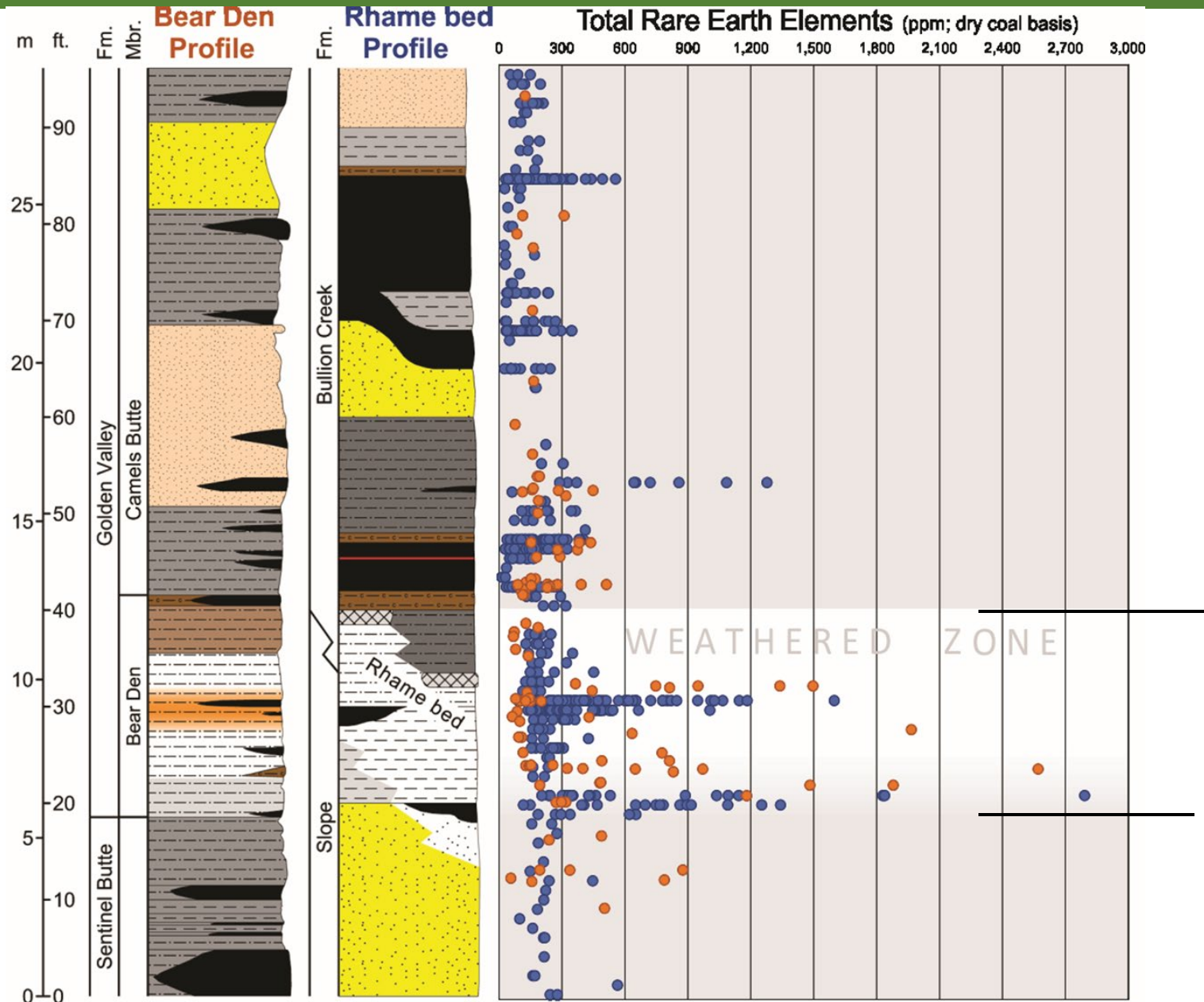
Rhame bed





NDGS Characterization Study: 2015 to 2024 (ongoing)

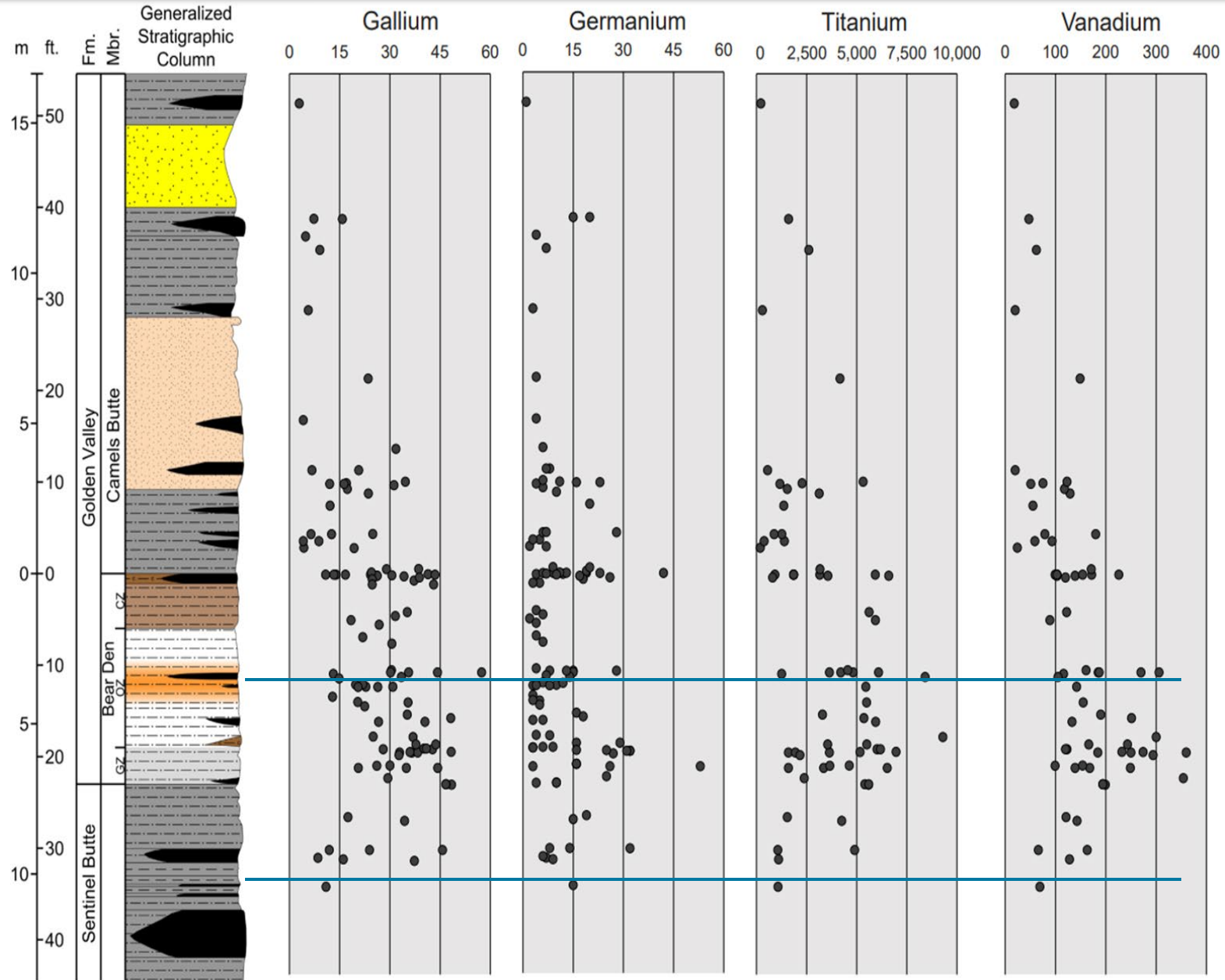
Rare earth element concentrations in ND lignites





NDGS Characterization Study: 2015 to 2024 (ongoing)

Critical element concentrations in ND lignites

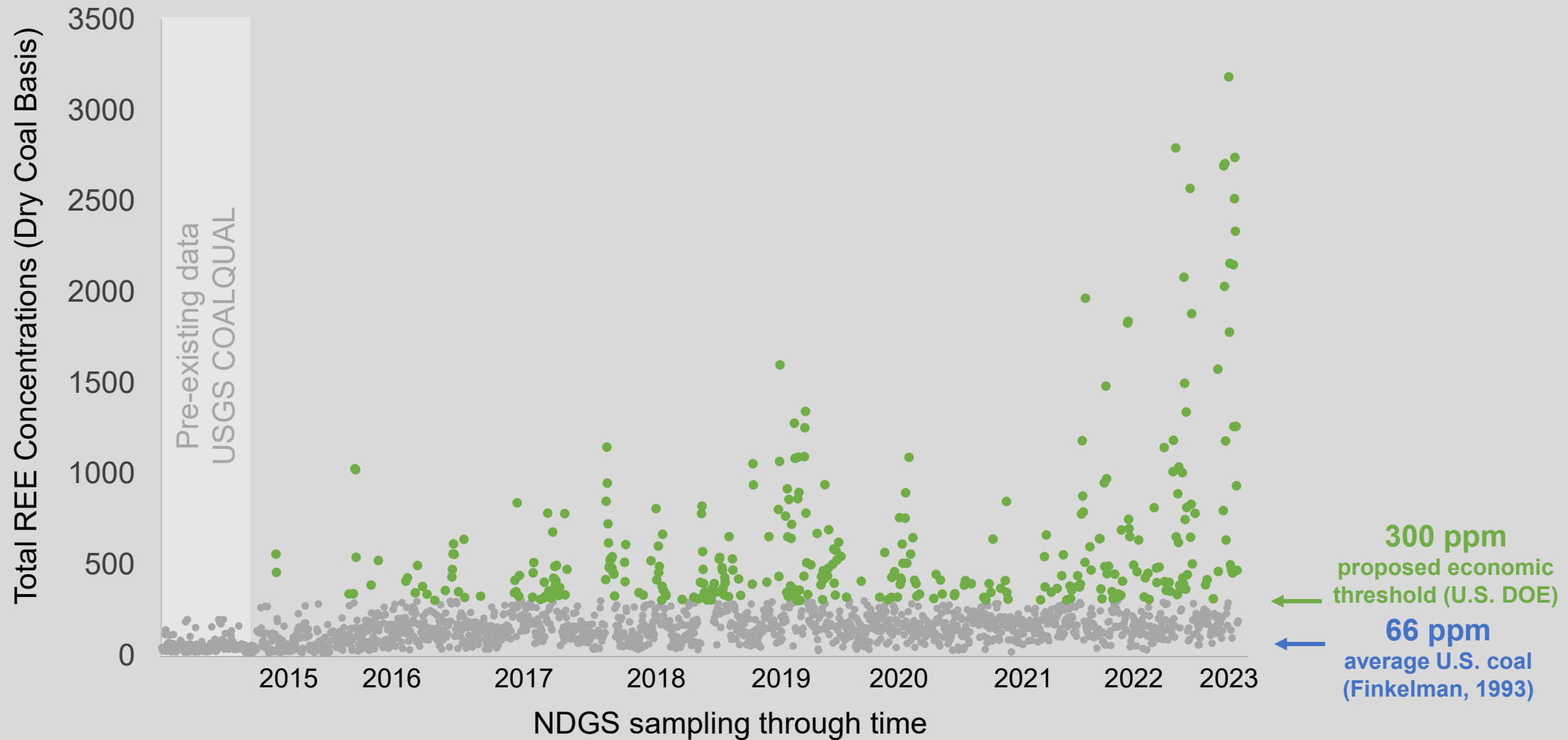


Enriched Zone



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. Maiké



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

REE Composition

Mountain Pass

0% 10% 20% 30% 40% 50%

North Dakota Lignite

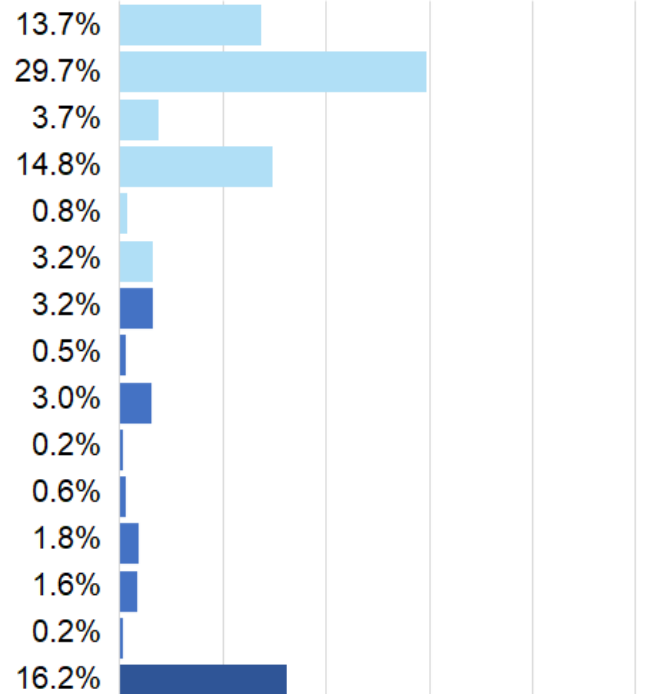
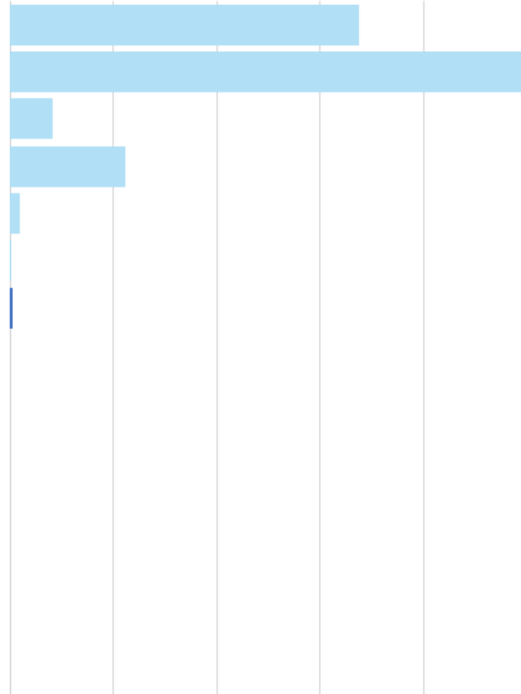
0% 10% 20% 30% 40% 50%

Market Prices of REE (\$/kg)

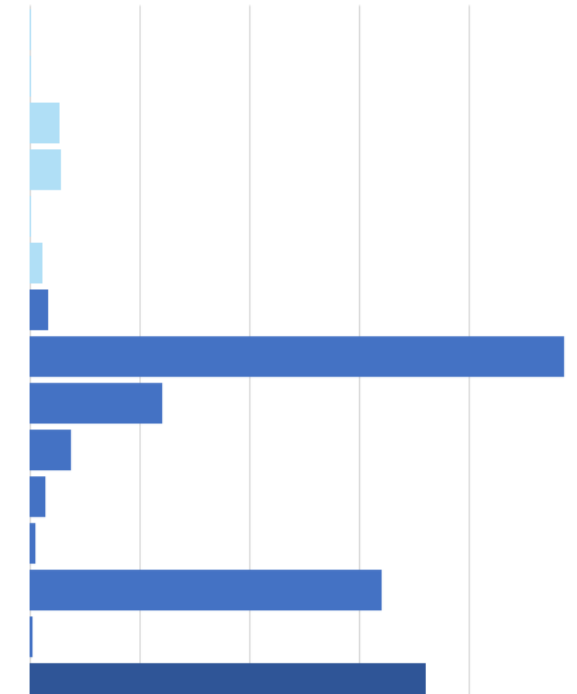
\$0 \$250 \$500 \$750 \$1,000 \$1,250

Lanthanum
Cerium
Praseodymium
Neodymium
Samarium
Europium
Gadolinium
Terbium
Dysprosium
Holmium
Erbium
Ytterbium
Lutetium
Yttrium
Scandium

33.8%
49.6%
4.1%
11.2%
0.9%
0.1%
0.2%
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%



\$ 0.75
\$ 0.78
\$ 68.54
\$ 69.25
\$ 2.12
\$ 27.56
\$ 40.63
\$ 1,215.38
\$ 301.72
\$ 91.86
\$ 36.60
\$ 13.43
\$ 798.47
\$ 7.00
\$ 898.87



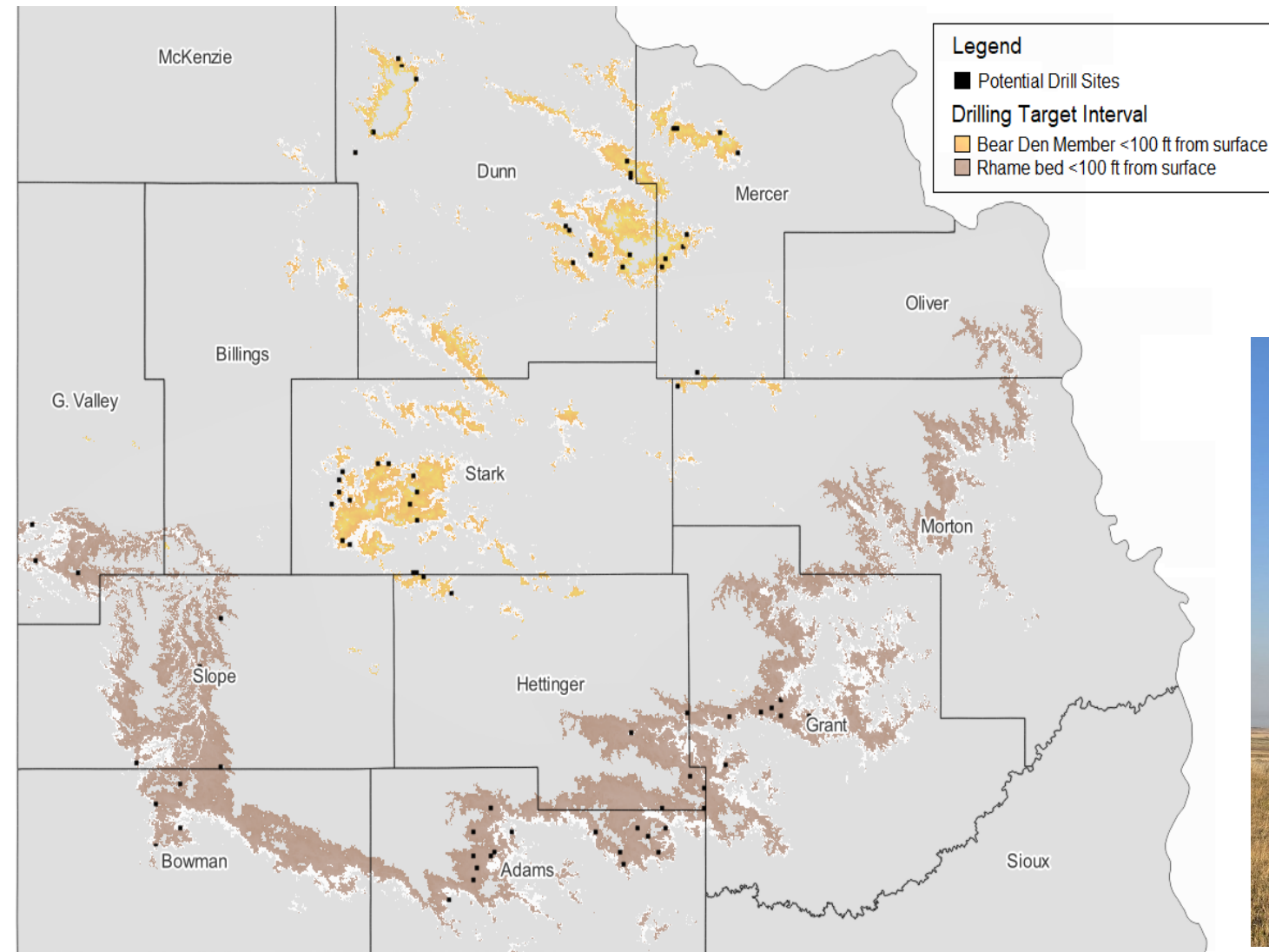
(Gschneidner and Pecharsky, 2019)

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



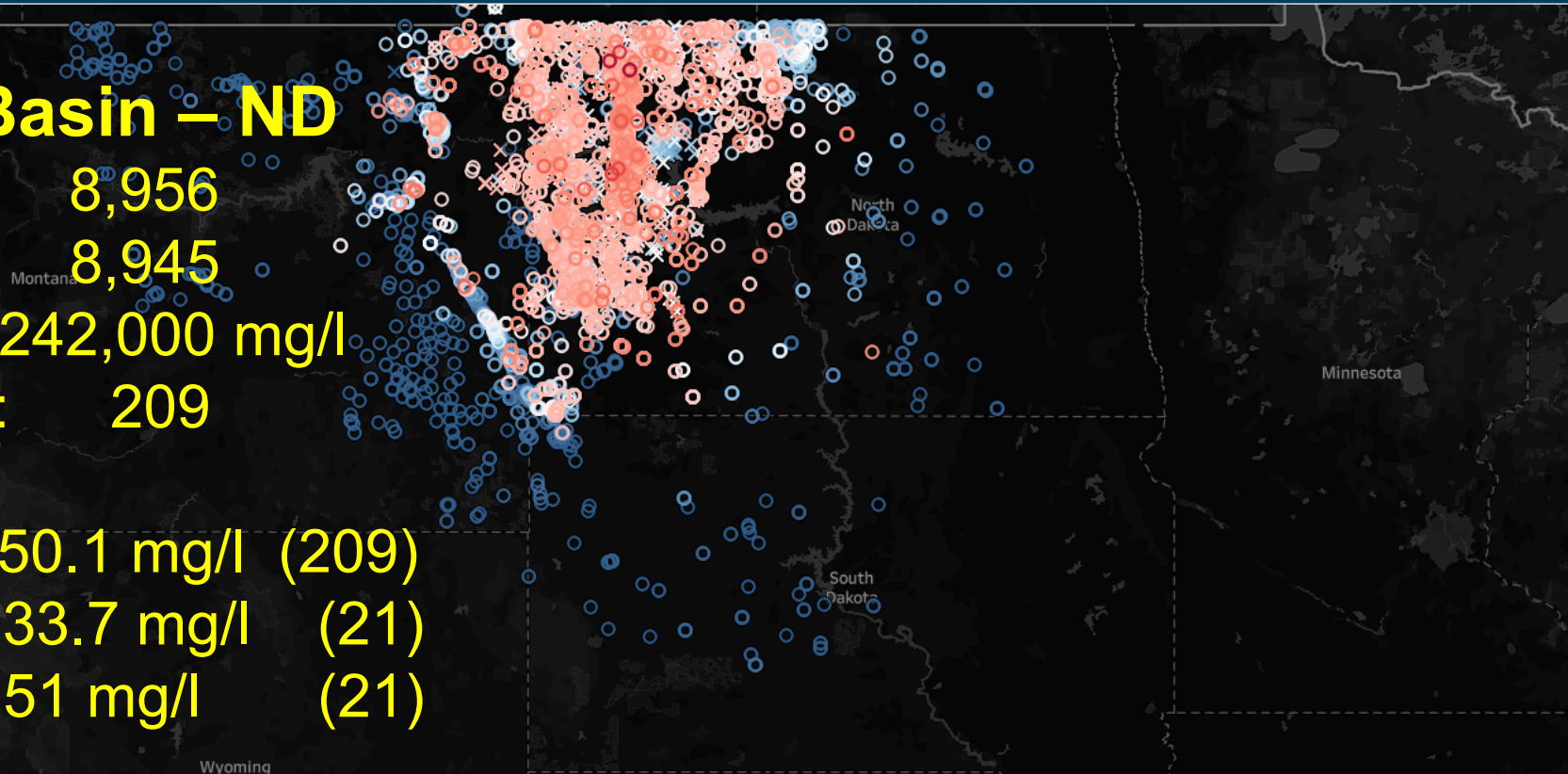


Critical Minerals in Produced Water in the Williston Basin

- 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).

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)

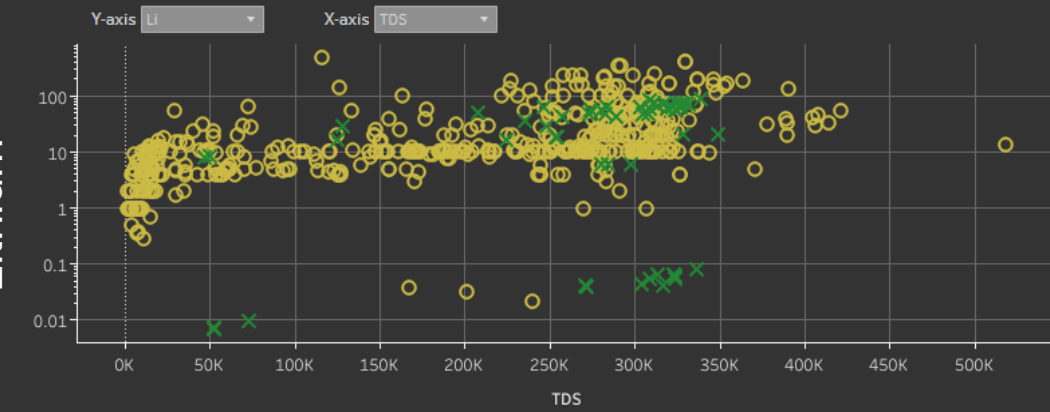
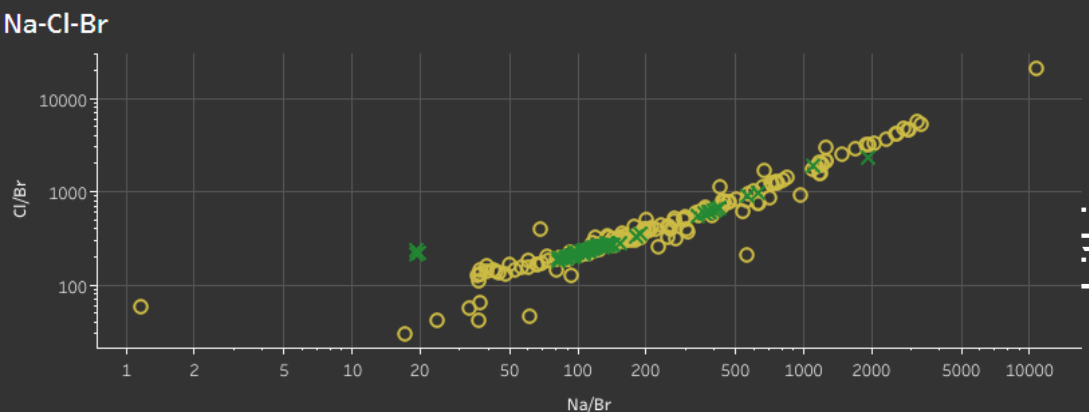
Variable
All

Salinity (TDS, mg/L)
0 530,000

Salinity (TDS, mg/L)
0 530,000

PLAYTYPE

- Sedimentary ○
- Shale ×



Oil and Gas Waters Project

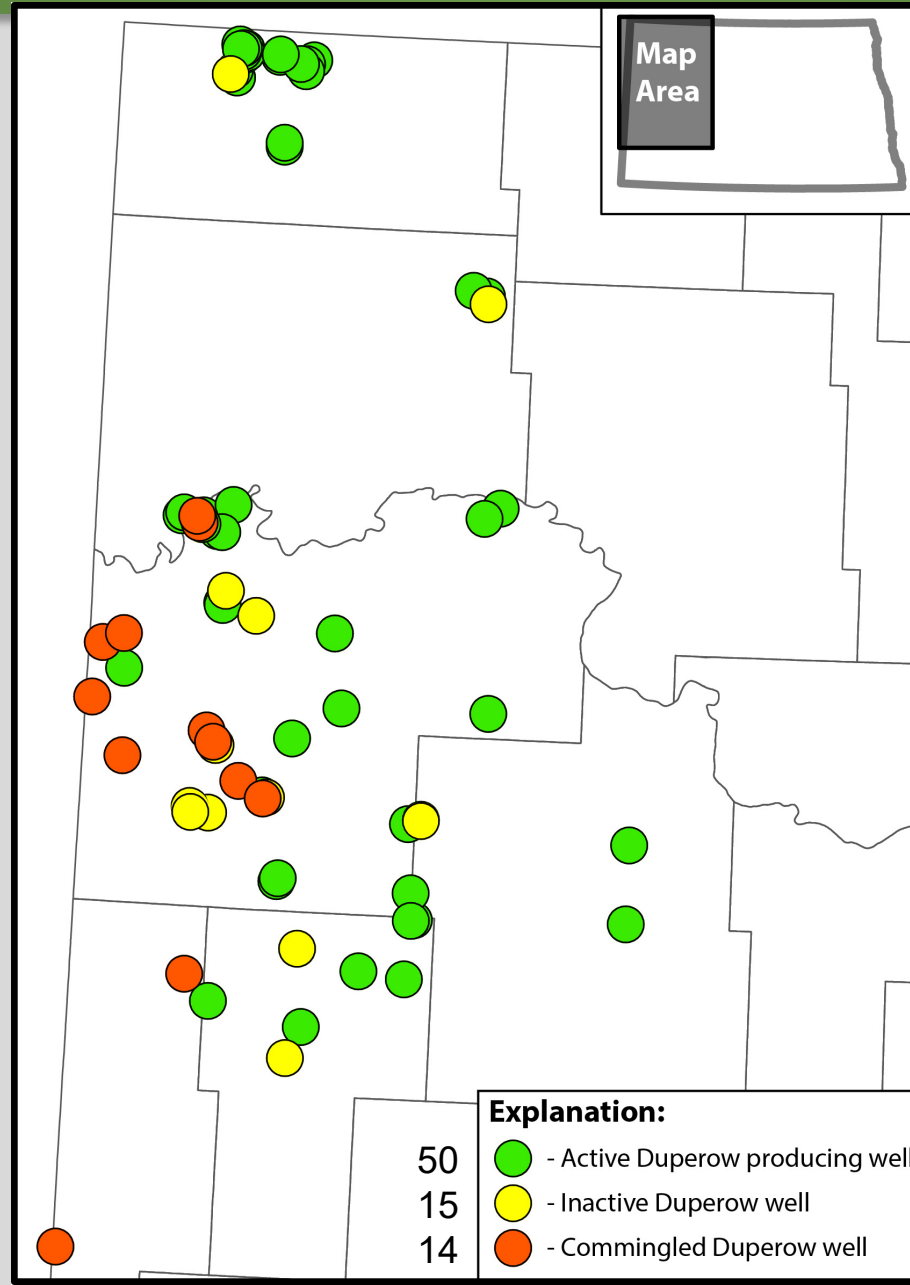
Data Dictionary & Data Download

Reference Madalyn S. Blondes, Katheri..

Disclaimer Although the data have bee..



Duperow Wells



Lithium concentrations up to 400 mg/l

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.”

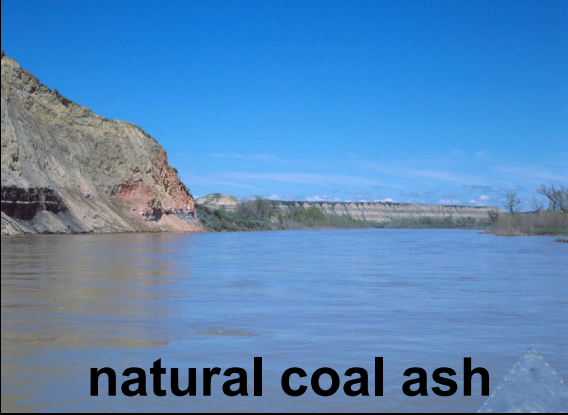


> 400 mg/l



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.



natural coal ash



bentonite

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



volcanic ash



iron nodules



manganese nodules



tonstein



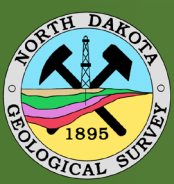
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- 5) A federal coal lease only covers coal, not any critical minerals found within.
- 6) Coal mining regulated by the ND Public Service Commission and critical minerals by the ND Industrial Commission (Subsurface Minerals Program).



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.



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.



Wilson M. Laird Core & Sample Library



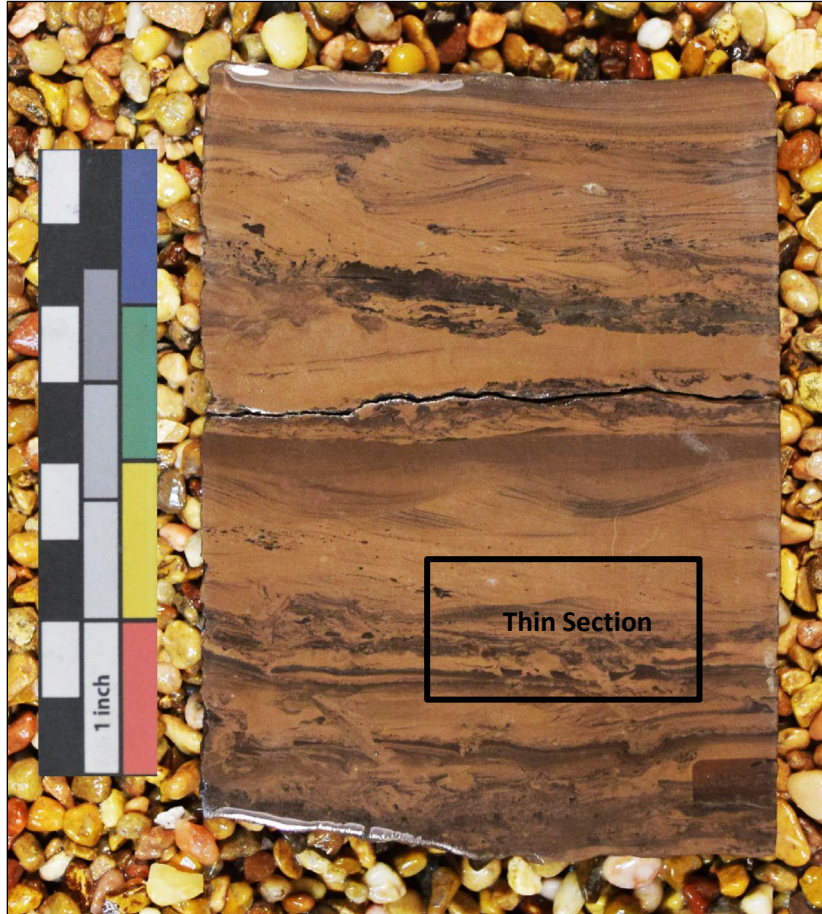
41,000 ft² warehouse
5,000 ft² of laboratories





CORE AND THIN SECTION PHOTOGRAPHY PROGRAM

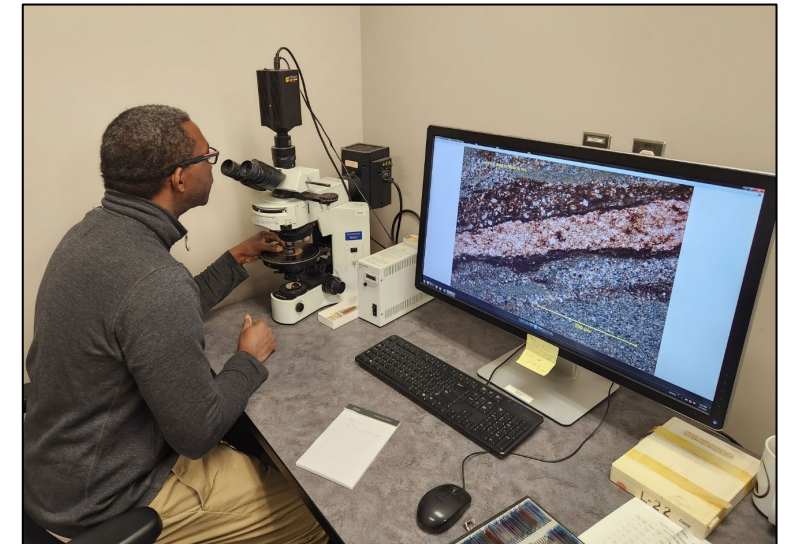
Wilson M. Laird Core and Sample Library



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

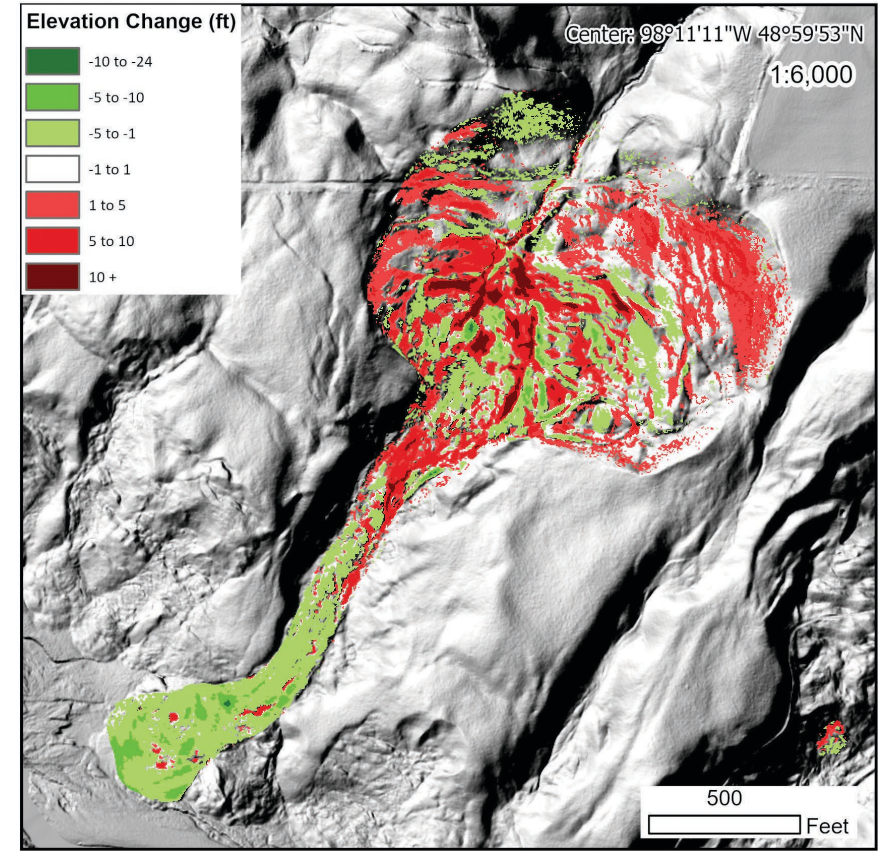
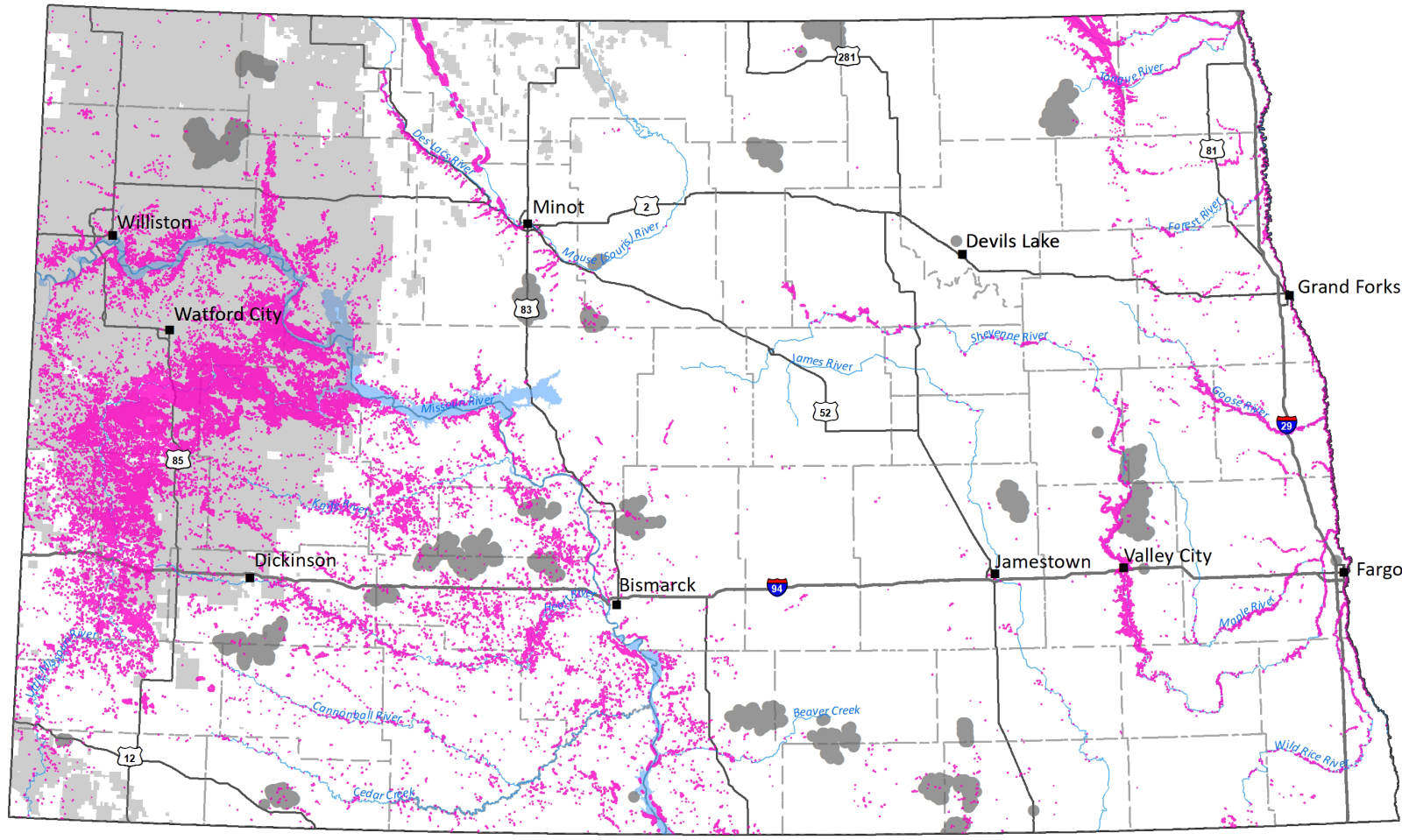
Total core (one set) in the core library = 486,000 feet (92 mi.)
Total photographed (tripod) = 67,000 feet (14%)
Tripod photographs = 8,900





LANDSLIDE PROGRAM

77,000 Landslides Mapped (Phase III)



Landslide Deposits Oil/Gas Field Water Wind Turbines

