

The Principal Types of Rare Earth Elements Deposits



Mountain Pass mine, California
MP Materials



Bokan Mountain, Alaska
Ucore Rare Metals

Brad Van Gosen



Periodic Table of the Elements

1 H 1.01																	18 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.30											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (97.91)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (208.98)	85 At (209.99)	86 Rn (222.02)
87 Fr (223.02)	88 Ra (226.03)	89 Ac (227.03)	104 Rf (261.11)	105 Ha (262.11)	106 Sg (263.12)												

Atomic number

Light rare earths

Heavy rare earths

Lanthanides
(Rare Earth Elements)

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (144.91)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237.05)	94 Pu (244.06)	95 Am (243.06)	96 Cm (247.07)	97 Bk (247.07)	98 Cf (251.08)	99 Es (252.08)	100 Fm (257.10)	101 Md (258.10)	102 No (259.10)	103 Lr (262.11)



Rare Earth Elements (REEs) deposit types

- **Carbonatites (global light rare earth source)**
- **“South China clays” (global heavy rare earth source)**

- **Alkaline igneous intrusions**
 - Vein deposits
 - Layered alkaline intrusions
- **Magmatic iron bodies**
- **Coastal sand deposits**
- **Sedimentary phosphate deposits**

Carbonatite: A rare igneous **carbonate** rock containing 50 percent or more carbonate minerals.

Mountain Pass mine

**Sulphide Queen carbonatite
(Mountain Pass deposit)**

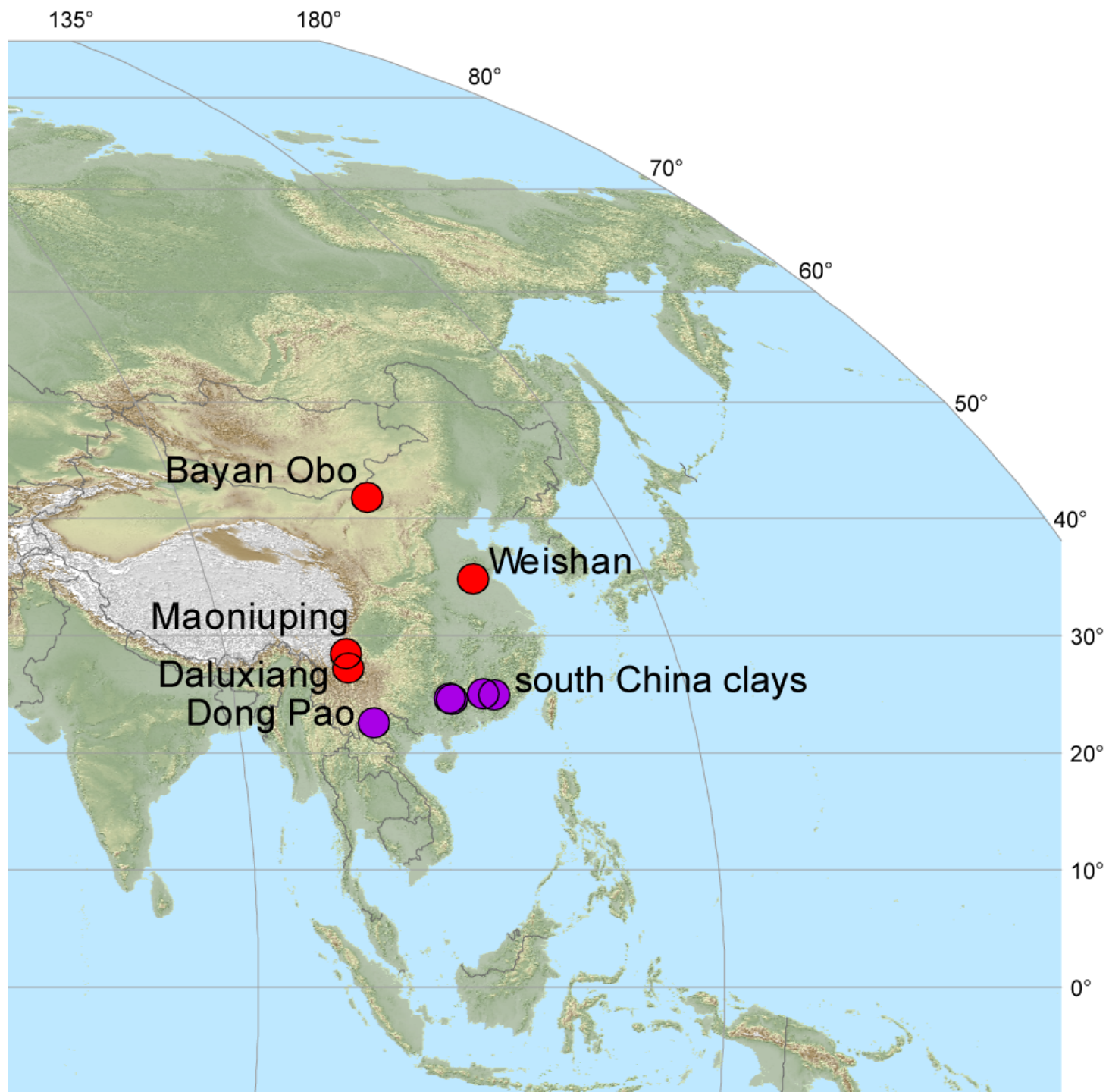
REE oxide content of
7.98 percent

Dominantly light REEs





Mountain Pass processing facilities
on-site



Longnan, China



“South China clays”

0.03 to 0.5 % total REE oxide

The Telegraph,
March 2012

Bokan Mountain alkaline igneous intrusive complex



Dotson Ridge

- 5.8 million metric tons of mineable resource
- avg. grade of 0.6% total REE oxide
- ~ 40 % heavy REE

vein

vein

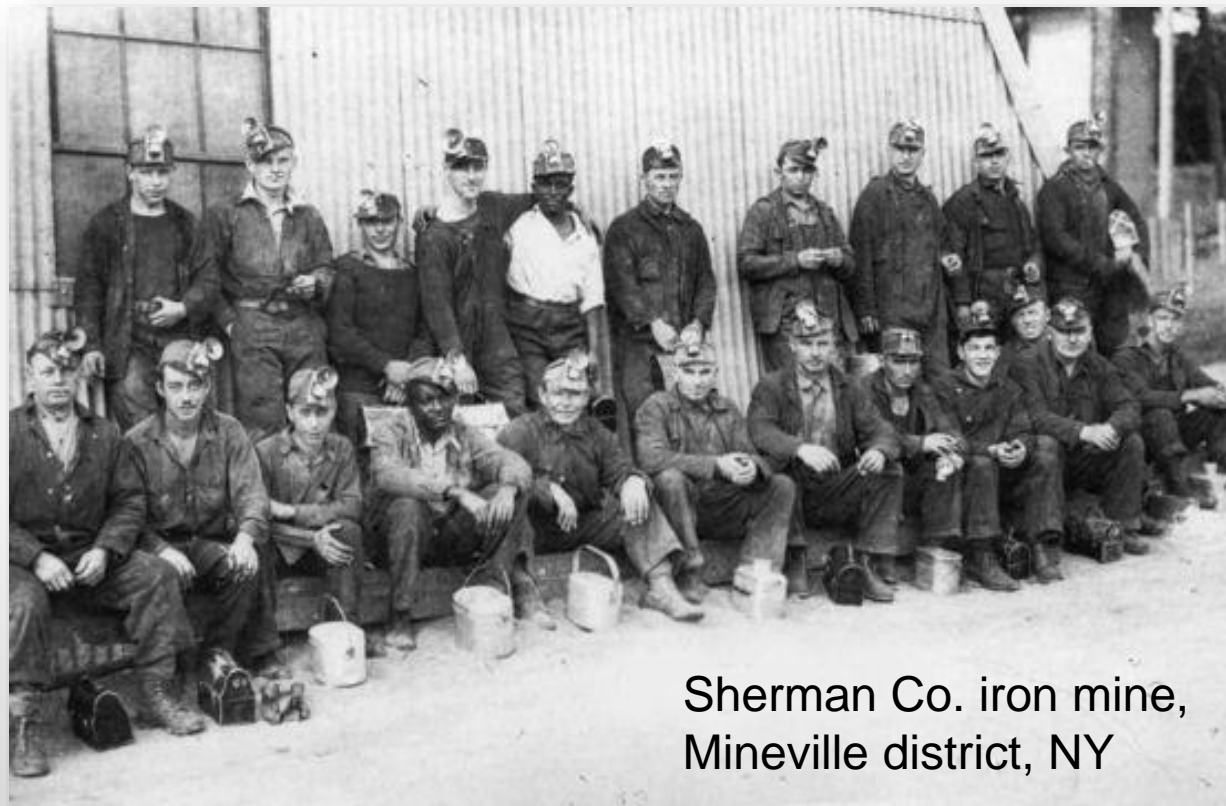


Layered alkaline igneous intrusions



Magmatic magnetite-hematite (iron) bodies

- Pea Ridge iron mine, southeastern Missouri
- Mineville iron mining district, upstate New York



Sherman Co. iron mine,
Mineville district, NY

Mineville iron mining district,
northeast New York,
active 1804 - 1971



Large iron tailings piles



2/3^{rds} of tailings from apatite-rich ores



Represents ~9 million metric tons of tailings



Average grade of ~8 % apatite



~726,000 metric tons of apatite in tailings



Apatites average 11.14 % REE oxide



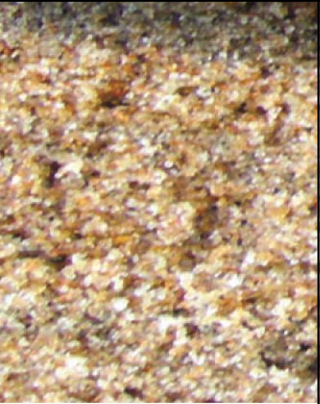
~80,700 metric tons of REE oxide

Zircon
 $ZrSiO_4$



3rd most

Coastal deposits of Heavy-Mineral Sands



Rutile
 TiO_2

2nd most



Ilmenite
 $Fe^{2+}TiO_3$

Most abundant heavy mineral

Monazite
 $(REE,Th)PO_4$

Trace to minor amounts
of heavy mineral suite

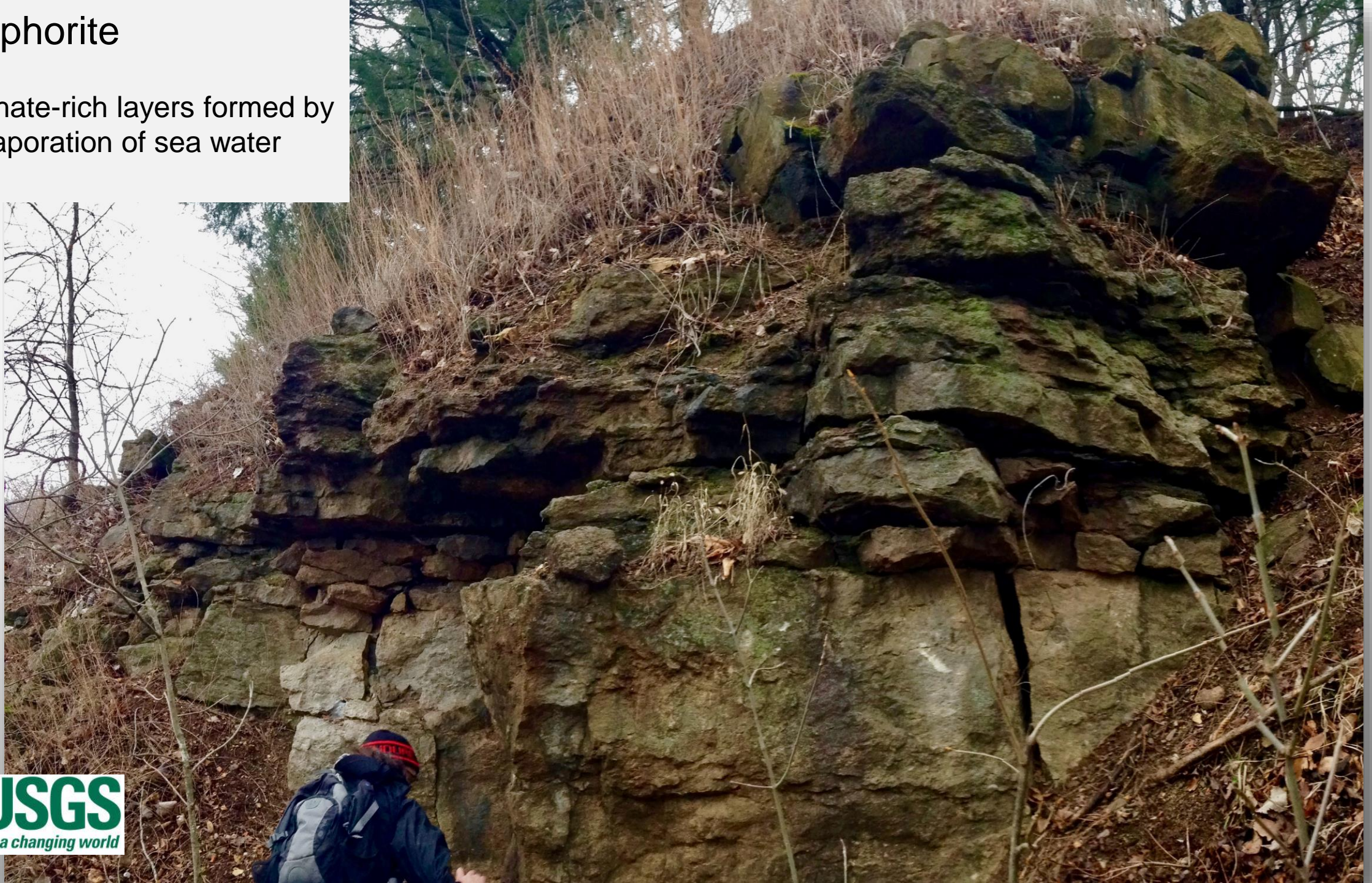


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Phosphorite

Phosphate-rich layers formed by the evaporation of sea water



Critical mineral resources of the United States

Google: “**USGS Professional Paper 1802**”

The principal rare earth elements deposits of the United States

Google: “**USGS SIR 2010-5220**”

Rare earth element mineral deposits in the United States

Google: “**USGS Circular 1454**”

Rare earth elements in coal and coal fly ash

Google: “**USGS Fact Sheet 2019-3048**”

Earth MRI Initiative

Google: “**USGS Earth MRI**”

