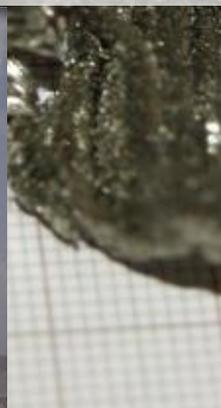


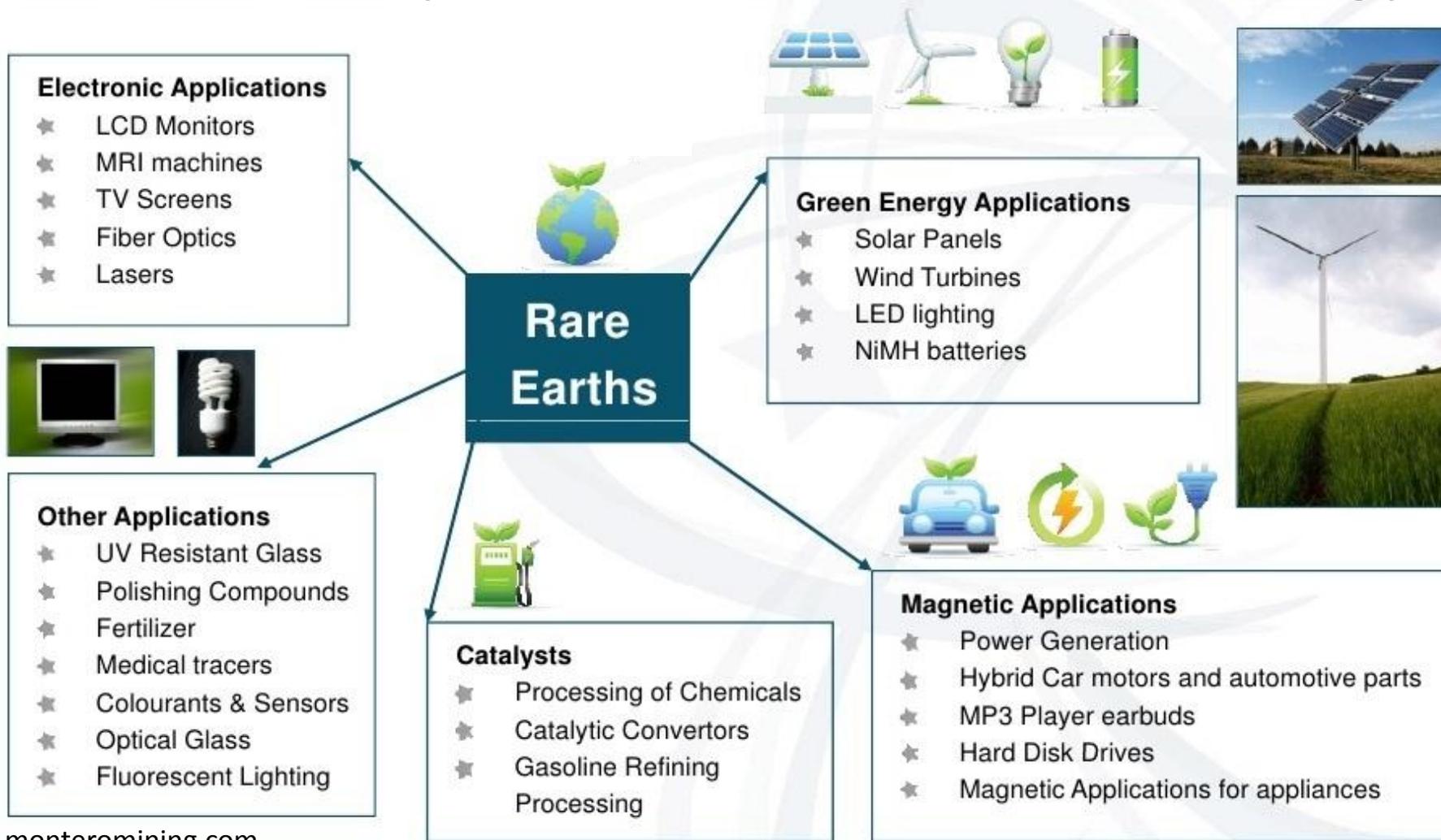
Characterization of Rare Earth Elements in WV Coal Measures

Jessica Moore

West Virginia Geological and Economic Survey



Rare Earth Elements: Essential Components of Modern Technology



Rare Metals in a smart phone



<http://www.outsiderclub.com/report/how-to-invest-in-rare-earth-metals-and-profit/1446>

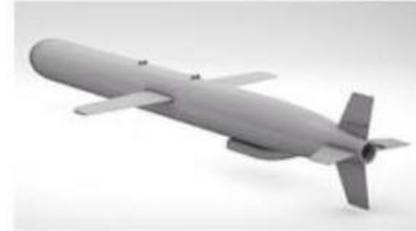
Homeland Security & Advanced Military Applications



Predator Drone
Neodymium, Samarium
Electric Motors and Guidance



Smart Bomb
Neodymium, Samarium
Electric Motors and Guidance



Tomahawk Cruise Missile
Neodymium, Samarium
Electric Motors and Guidance



Night Vision Goggles
Terbium, Erbium, Gadolinium
Optical Lenses



F-22 Fighter Jet
Europium, Yttrium, Terbium, Erbium
Optical Systems, Visuals and Fiber Optics



Bullet Proof Vest
Yttrium
Hardened Ceramics



Bradley Tank
Yttrium
Hardened Ceramics



Radar Detection
Europium, Lutetium
Signal Amplification

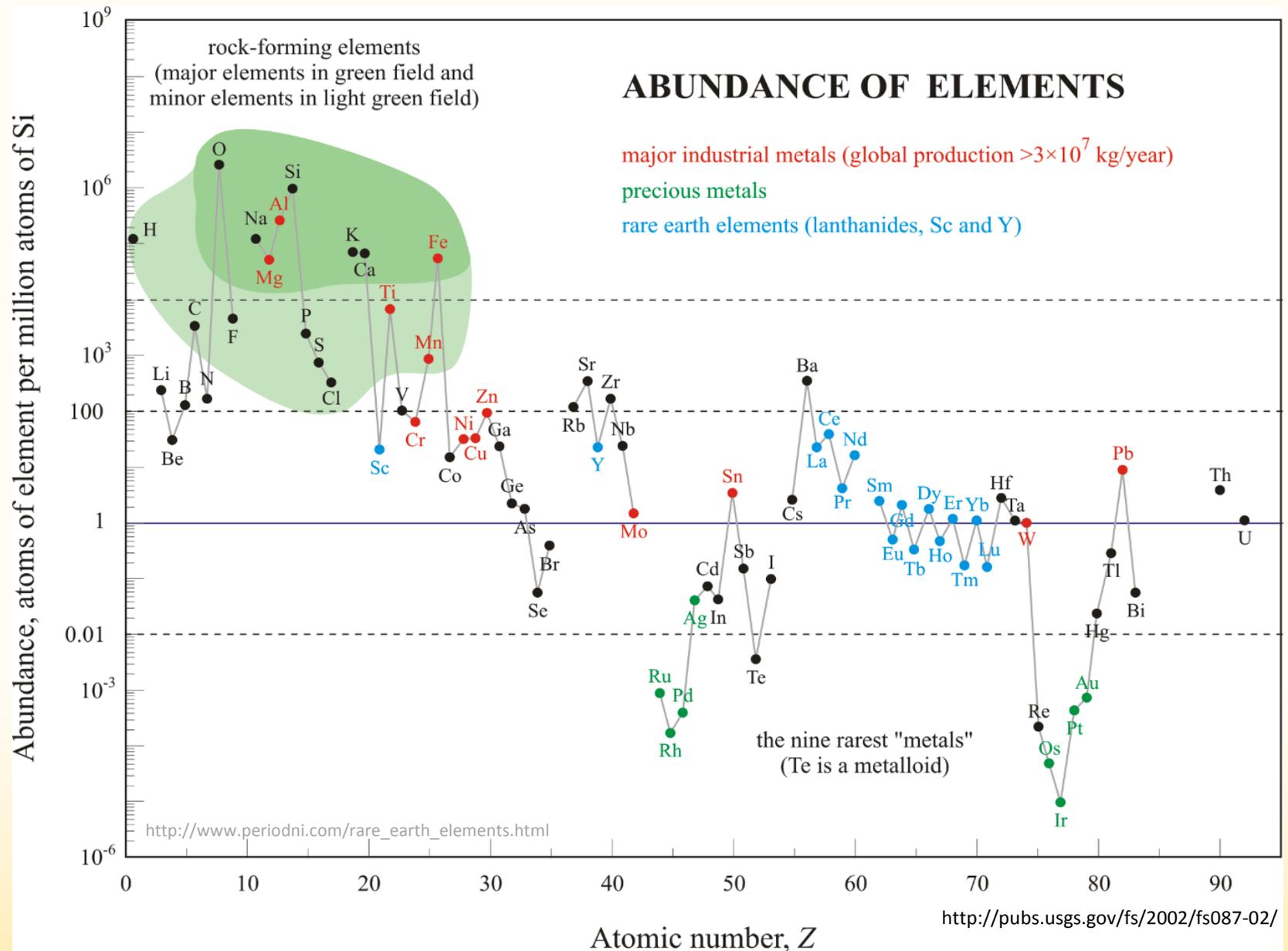


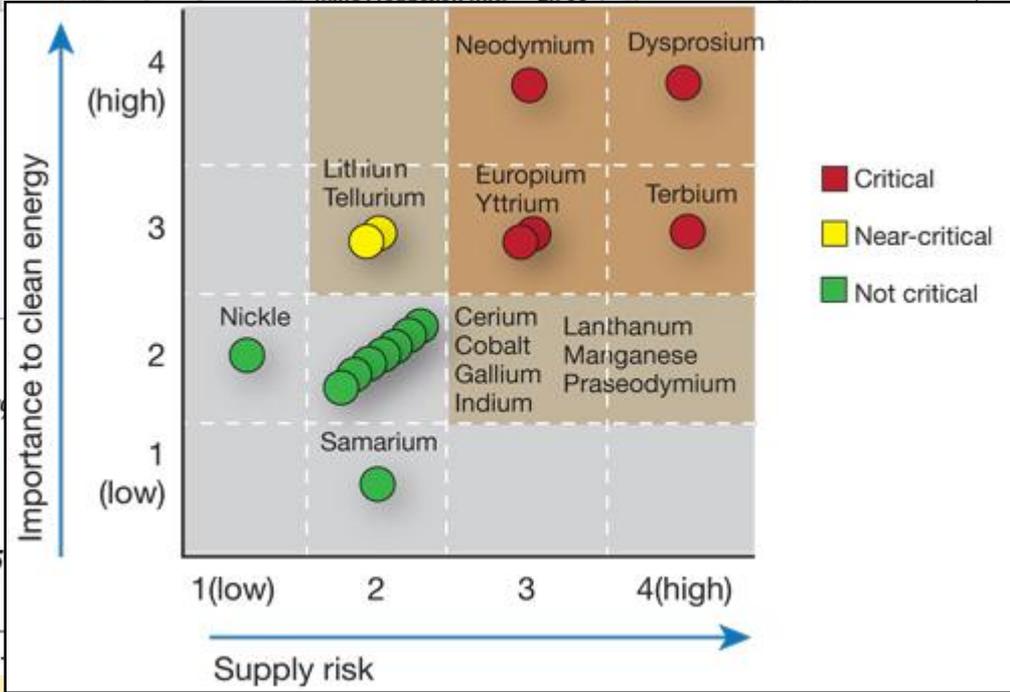
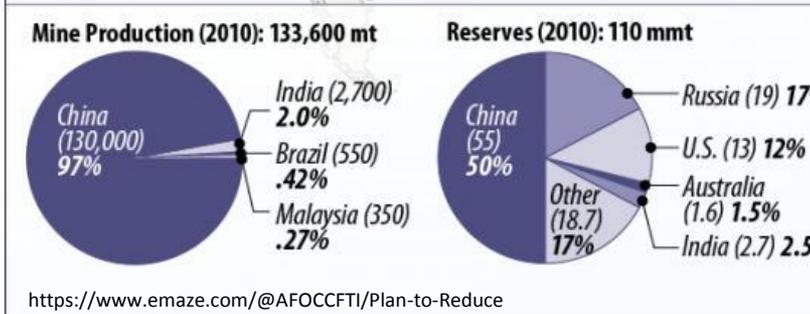
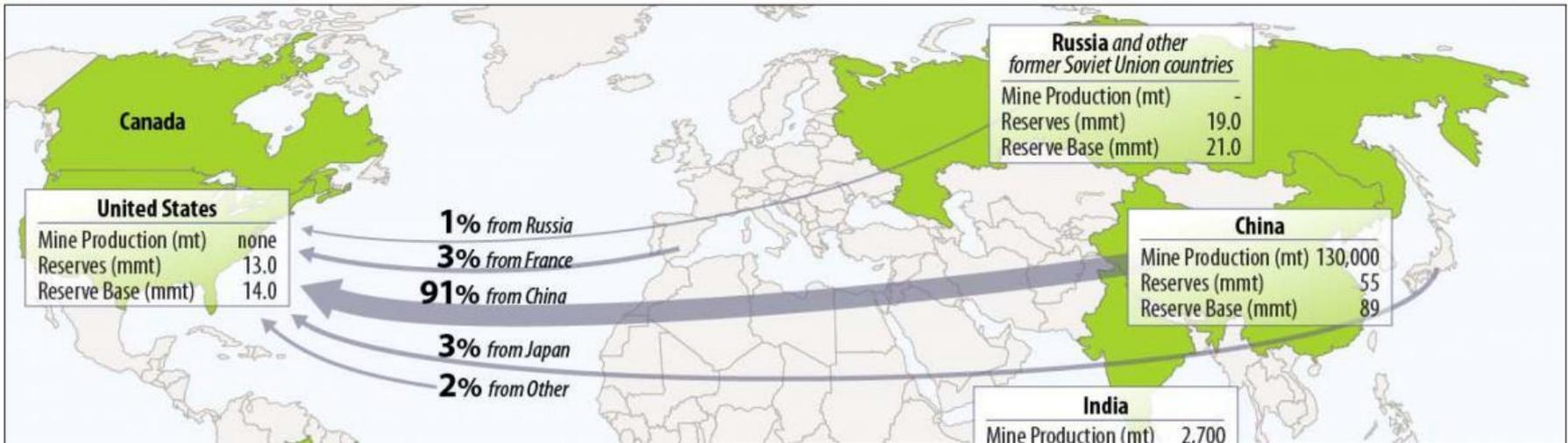
Nuclear Submarine
Europium, Lutetium
Sonar Detection

The Elements

H 1 Hydrogen																	He 2 Helium						
Li 3 Lithium	Be 4 Beryllium																	B 5 Boron	C 6 Carbon	N 7 Nitrogen	O 8 Oxygen	F 9 Fluorine	Ne 10 Neon
Na 11 Sodium	Mg 12 Magnesium																	Al 13 Aluminum	Si 14 Silicon	P 15 Phosphorus	S 16 Sulfur	Cl 17 Chlorine	Ar 18 Argon
K 19 Potassium	Ca 20 Calcium	Sc 21 Scandium	Ti 22 Titanium	V 23 Vanadium	Cr 24 Chromium	Mn 25 Manganese	Fe 26 Iron	Co 27 Cobalt	Ni 28 Nickel	Cu 29 Copper	Zn 30 Zinc	Ga 31 Gallium	Ge 32 Germanium	As 33 Arsenic	Se 34 Selenium	Br 35 Bromine	Kr 36 Krypton						
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54						
La 57 Lanthanum	Ce 58 Cerium	Pr 59 Praseodymium	Nd 60 Neodymium	Pm 61 Promethium	Sm 62 Samarium	Eu 63 Europium	Gd 64 Gadolinium																
Tb 65 Terbium	Dy 66 Dysprosium	Ho 67 Holmium	Er 68 Erbium	Tm 69 Thulium	Yb 70 Ytterbium	Lu 71 Lutetium																	
Ac 89 Actinium	Th 90 Thorium	Pa 91 Protactinium	U 92 Uranium	Np 93 Neptunium	Pu 94 Plutonium	Am 95 Americium	Cm 96 Curium	Bk 97 Berkelium	Cf 98 Californium	Es 99 Einsteinium	Fm 100 Fermium	Mendelevium	Nobelium	Lawrencium									

<http://sun-bin.blogspot.com/2010/10/rare-earth-elements-what-do-they-look.html>





Commodity Prices vary, but can be significant

RARE EARTH METALS

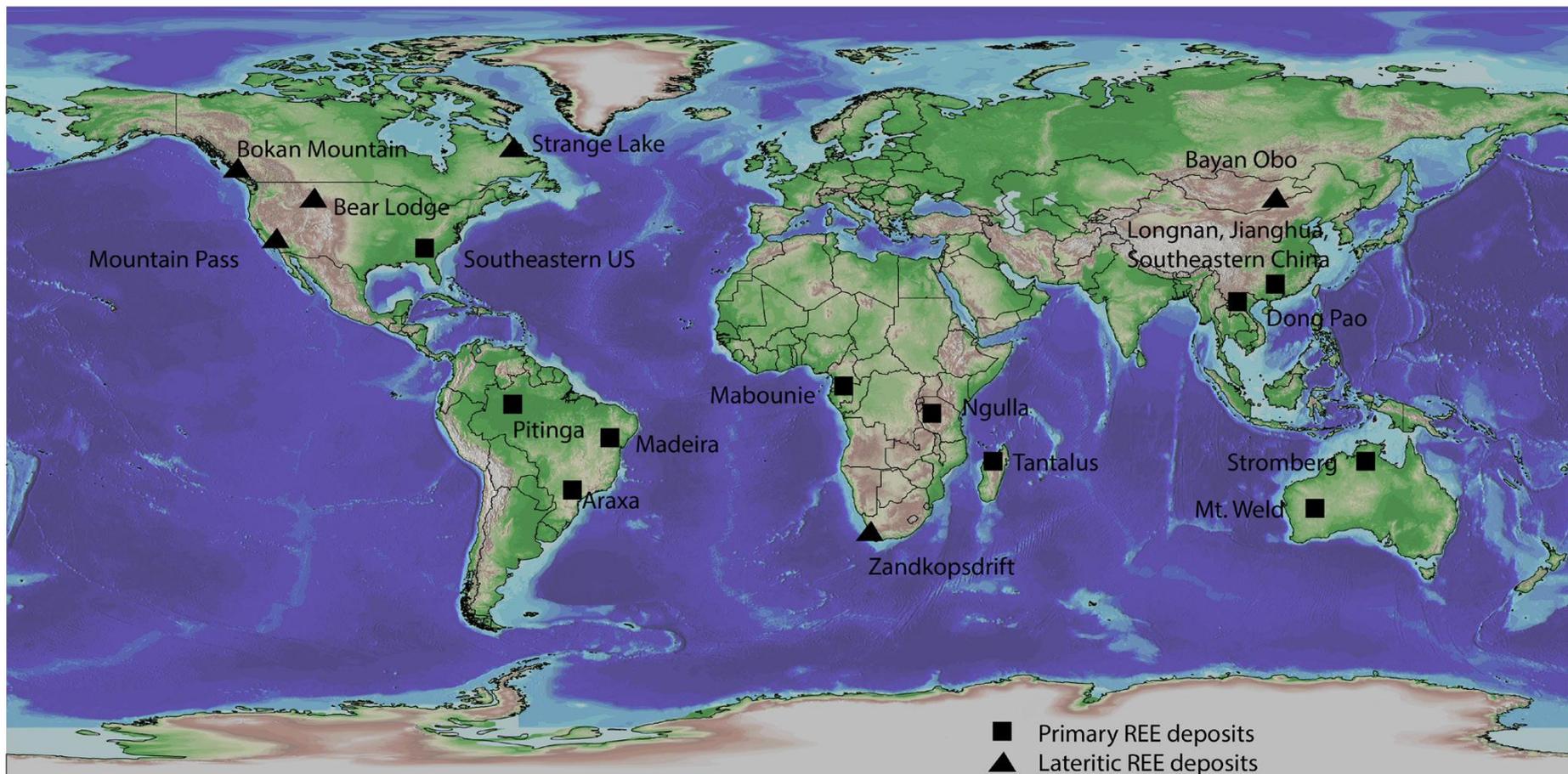


HEFA Rare Earth *Providing quality rare earth products and more*

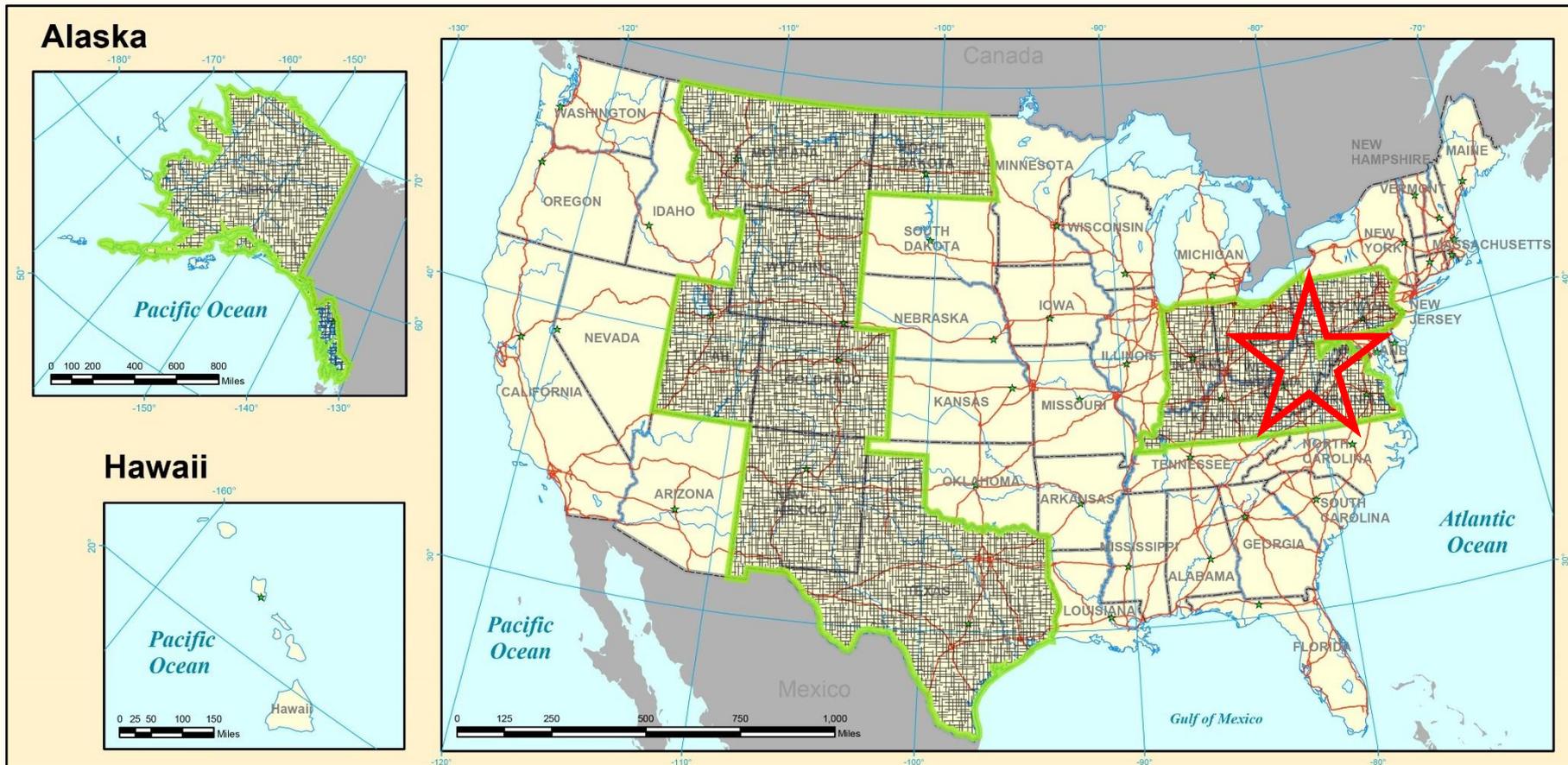
Source	Time	LIGHT RARE EARTH METALS		Last Price	% Week	% Year	31.Dec.2015	Units
mineralprices.com	05 Jul 2016	Lanthanum metal ≥ 99%	-3.0	7.00	-30.0%	-30.0%	10.00	US\$/kg
mineralprices.com	05 Jul 2016	Lanthanum Oxide ≥ 99.5%	-2.8	2.00	-58.3%	-58.3%	4.80	US\$/kg
mineralprices.com	05 Jul 2016	Cerium metal ≥ 99%	-3.0	7.00	-30.0%	-30.0%	10.00	US\$/kg
mineralprices.com	05 Jul 2016	Cerium Oxide ≥ 99.5%	-2.4	2.00	-54.5%	-54.5%	4.40	US\$/kg
mineralprices.com	05 Jul 2016	Praseodymium metal ≥ 99%	-90.0	85.00	-51.4%	-51.4%	175.00	US\$/kg
mineralprices.com	05 Jul 2016	Praseodymium Oxide ≥ 99.5%	-53.0	52.00	-50.5%	-50.5%	105.00	US\$/kg
mineralprices.com	05 Jul 2016	Neodymium metal ≥ 99.5%	-27.0	60.00	-31.0%	-31.0%	87.00	US\$/kg
mineralprices.com	05 Jul 2016	Neodymium Oxide ≥ 99.5%	-17.0	42.00	-28.8%	-28.8%	59.00	US\$/kg
mineralprices.com	05 Jul 2016	Samarium metal ≥ 99.9%	-13.0	7.00	-65.0%	-65.0%	20.00	US\$/kg
Source	Time	HEAVY RARE EARTH METALS		Last Price	% Week	% Year	31.Dec.2015	Units
mineralprices.com	05 Jul 2016	Europium Oxide ≥ 99.99%	-530.0	150.00	-77.9%	-77.9%	680.00	US\$/kg
mineralprices.com	05 Jul 2016	Gadolinium metal 99.9%	-40.0	55.00	-42.1%	-42.1%	95.00	US\$/kg
mineralprices.com	05 Jul 2016	Gadolinium Oxide ≥ 99.5%	-7.0	32.00	-17.9%	-17.9%	39.00	US\$/kg
mineralprices.com	05 Jul 2016	Terbium metal ≥ 99.9%	-260.0	550.00	-32.1%	-32.1%	810.00	US\$/kg
mineralprices.com	05 Jul 2016	Terbium Oxide ≥ 99.5%	-200.0	400.00	-33.3%	-33.3%	600.00	US\$/kg
mineralprices.com	05 Jul 2016	Dysprosium metal ≥ 99%	-120.0	350.00	-25.5%	-25.5%	470.00	US\$/kg
mineralprices.com	05 Jul 2016	Dysprosium Oxide ≥ 99.5%	-110.0	230.00	-32.4%	-32.4%	340.00	US\$/kg
mineralprices.com	05 Jul 2016	Erbium metal ≥ 99.9%	-70.0	95.00	-42.4%	-42.4%	165.00	US\$/kg
mineralprices.com	05 Jul 2016	Erbium Oxide ≥ 99.5%	-43.0	34.00	-55.8%	-55.8%	77.00	US\$/kg
mineralprices.com	05 Jul 2016	Yttrium metal ≥ 99.9%	-42.0	35.00	-54.5%	-54.5%	77.00	US\$/kg
mineralprices.com	05 Jul 2016	Yttrium Oxide ≥ 99.99%	-9.0	6.00	-60.0%	-60.0%	15.00	US\$/kg
mineralprices.com	05 Jul 2016	Scandium metal 99.9%	-3000.0	15,000.00	-16.7%	-16.7%	18,000.00	US\$/kg
mineralprices.com	05 Jul 2016	Scandium Oxide ≥ 99.95%	-3000.0	4,200.00	-41.7%	-41.7%	7,200.00	US\$/kg
mineralprices.com	05 Jul 2016	Mischmetal ≥ 99%	-2.0	6.00	-25.0%	-25.0%	8.00	US\$/kg

<http://www.baotou-rareearth.com/>

Resources distributed between two main types of deposits: Primary Ores and Lateritic Soils/Paleosols



http://repository.azgs.az.gov/sites/default/files/dlio/files/nid1570/ree_cocker_chp4.pdf



<https://www.netl.doe.gov/research/coal/rare-earth-elements>

U.S. Department of Energy analyzed hundreds of coal and coal by-product samples and found highest rare-earth assays in the northern Appalachian region

RARE EARTH ELEMENTS

Home > Research > Coal

REE Home

Overview

Key Focus Areas

Project Information

News Center

Publications

REE-EDX

Key Contacts

FAQ

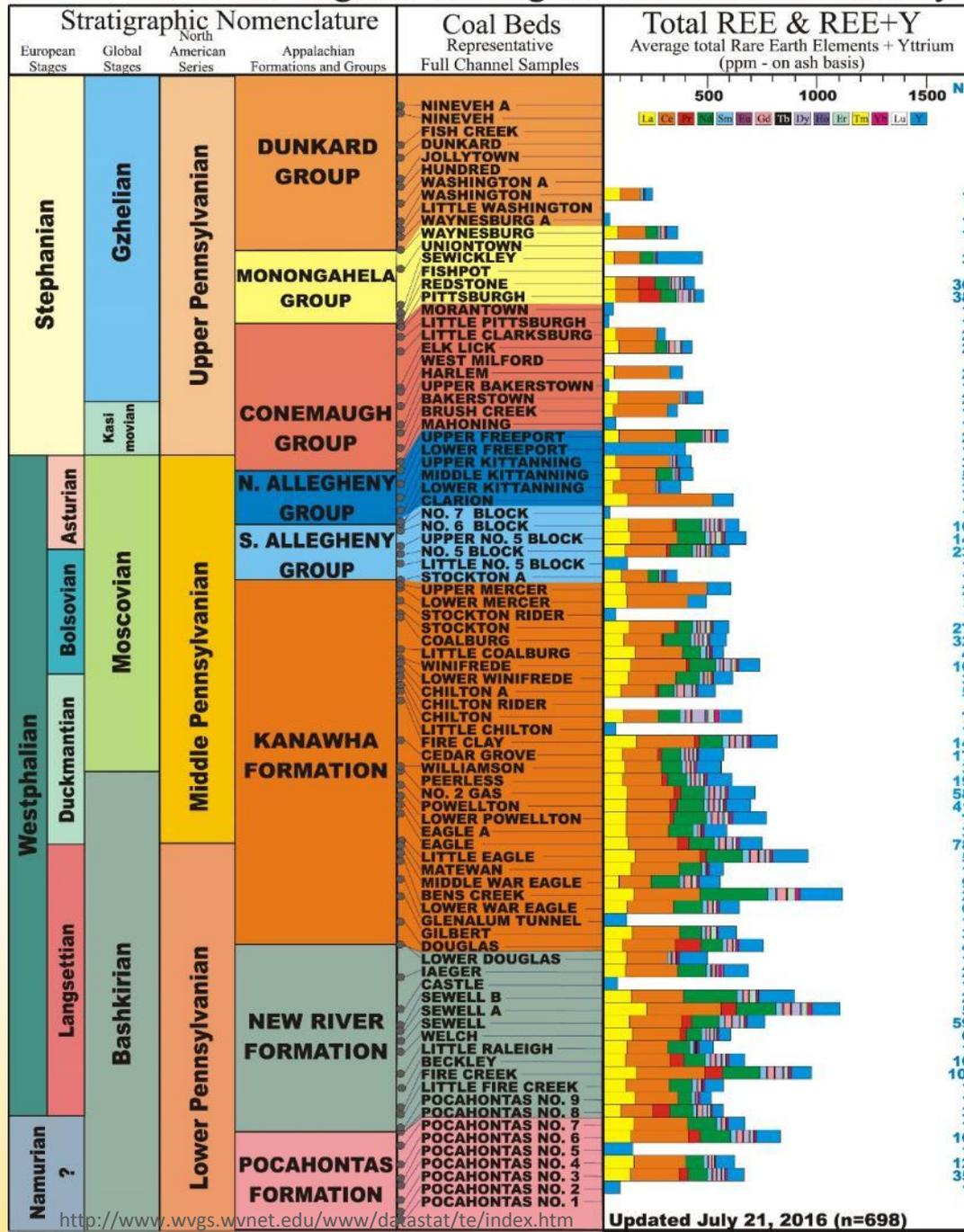


RARE EARTH ELEMENTS FROM COAL AND COAL BY-PRODUCTS

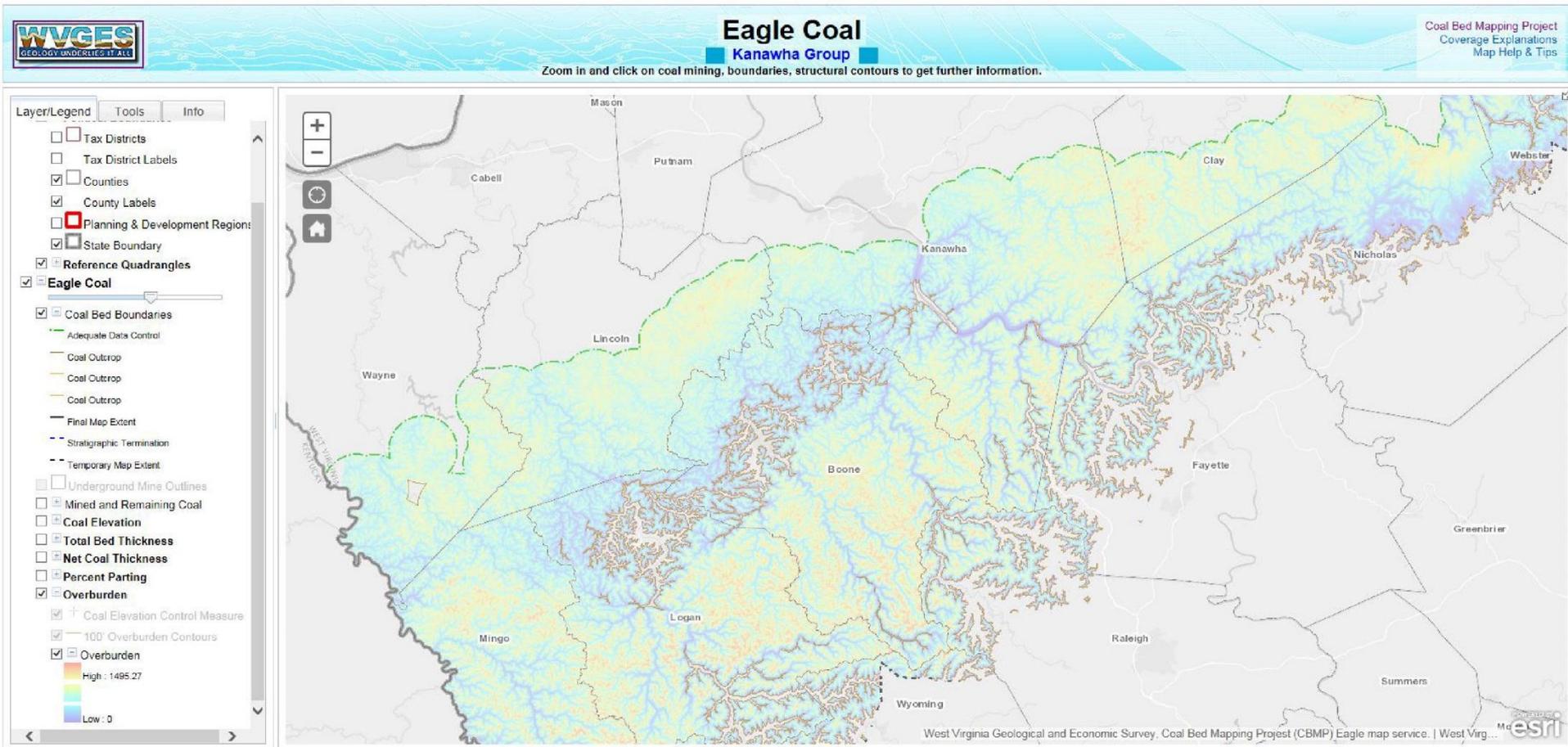
Comprising 17 elements from the periodic table, the group known as rare earth elements (REEs) provide significant value to our national security, energy independence, environmental future, and economic growth. REEs are important elements used in high-technology products such as catalysts, cell phones, hard drives, hybrid engines, lasers, magnets, medical devices, televisions, and other applications. The development of an economically competitive domestic supply of REEs will help to maintain our nation's economic growth and national security.



<https://www.netl.doe.gov/research/coal/rare-earth-elements>

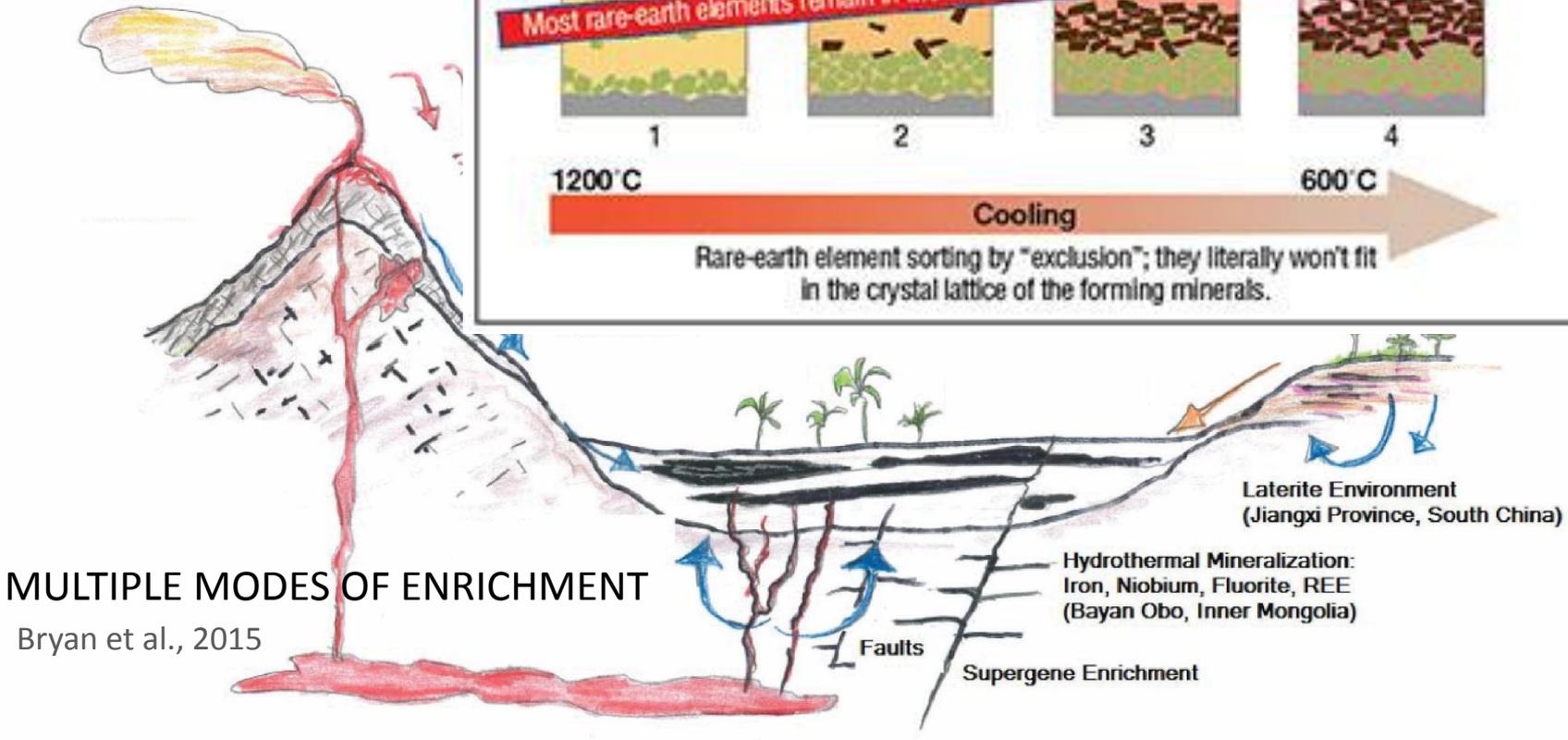
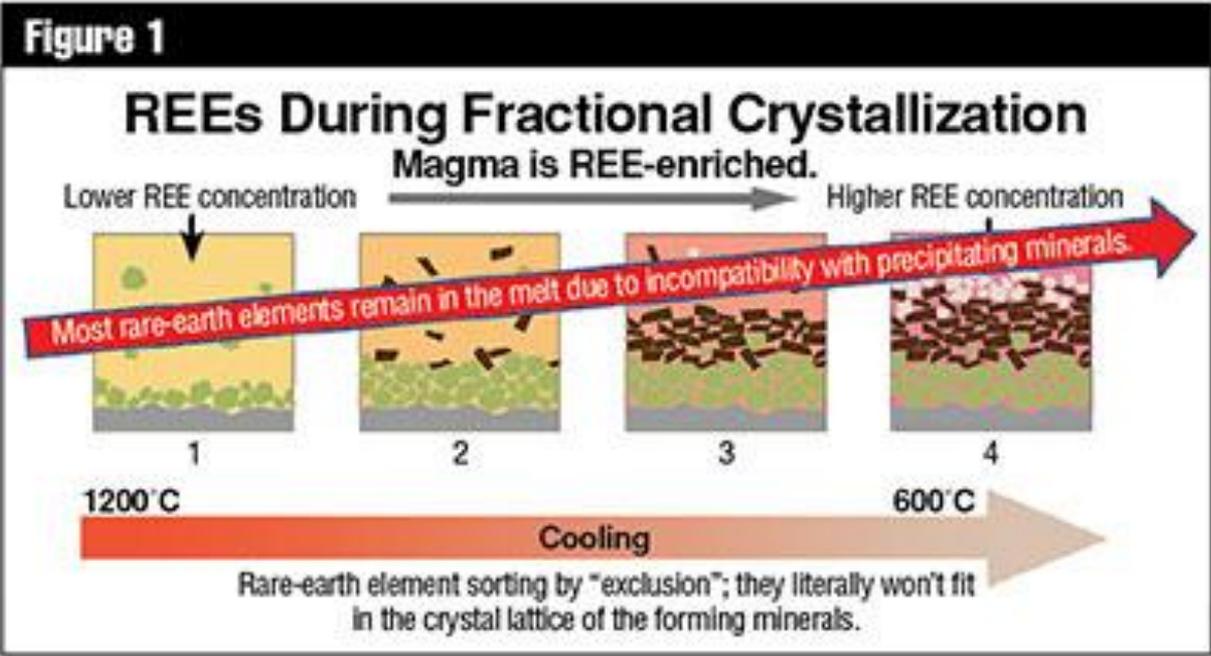


WVGES Coal Program Interactive Mapping Application: Decades of Coal Research and Field Study



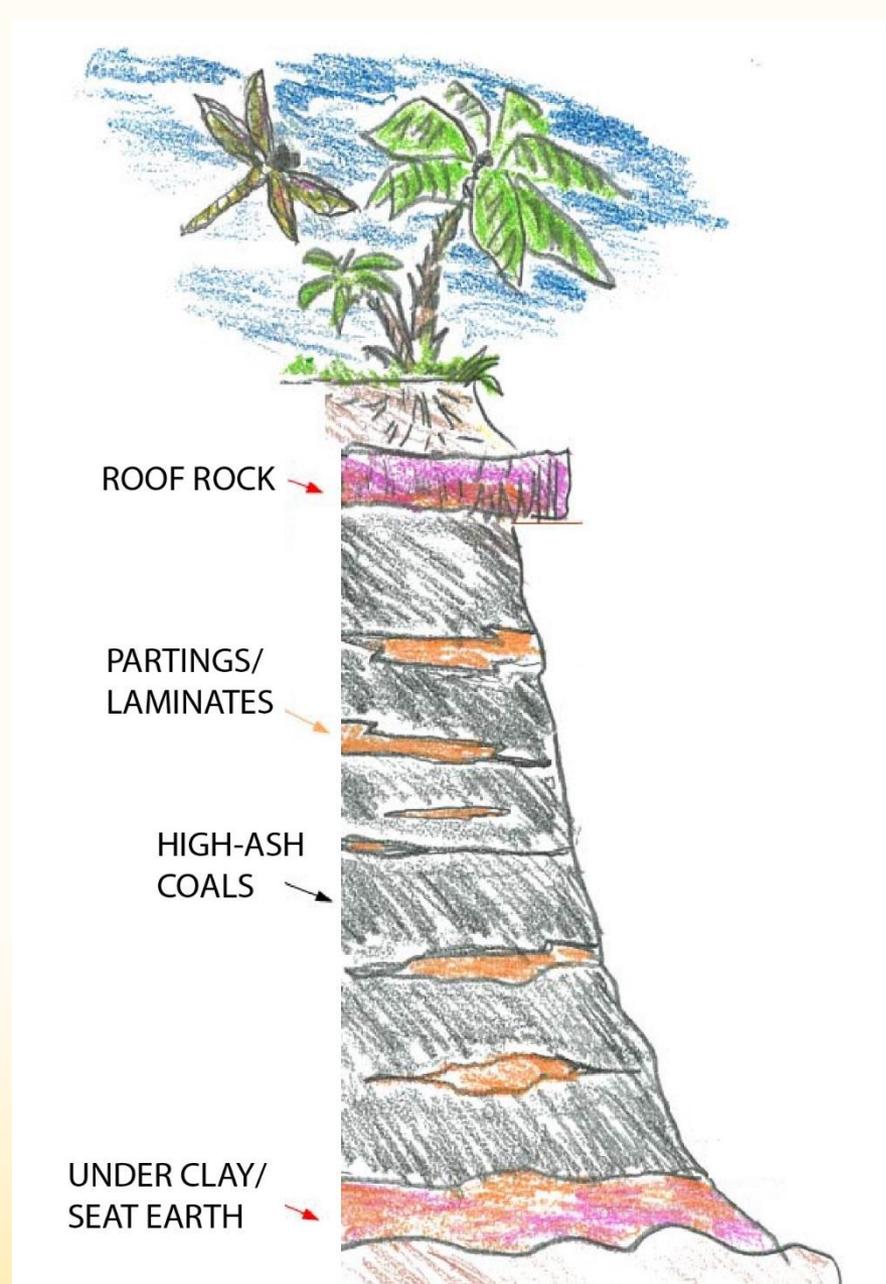
<http://www.wvgs.wvnet.edu/www/coal/cbmp/coalims.html>

Challenge 1: Identify Prime Feedstocks



Multiple Enrichment Modes: several possibilities for concentration within coal measures

Bryan et al., 2015



Enrichment in Roof Rock and Underclay: Lower Kittanning, Clarion Co. PA

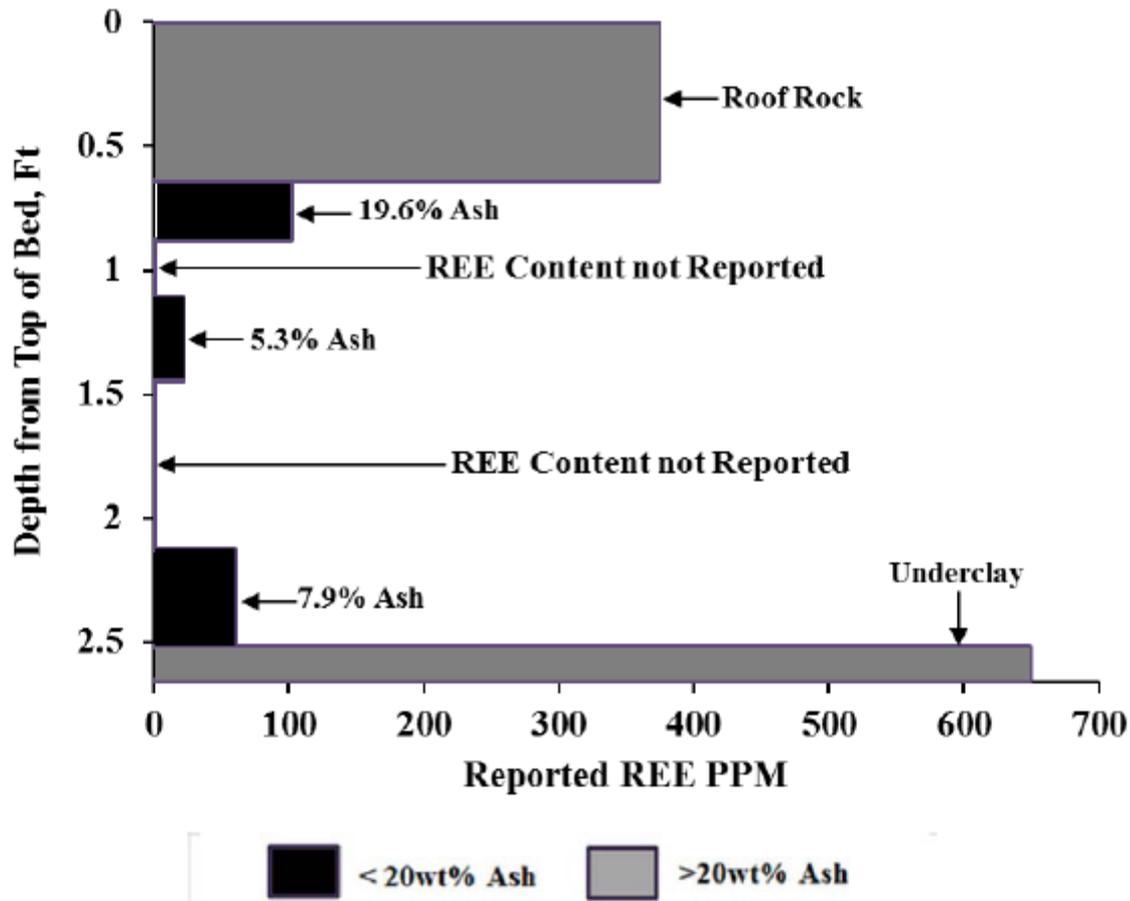


Figure 18: Stratigraphic Distribution of REE Content, Lower Kittanning Bed, Clarion County, Pennsylvania, Data from Schatzel and Stewart⁴².

Bryan et al., 2015

Enrichment in High-Ash Coals: Fire Clay Coal Bed, Letcher Co., KY

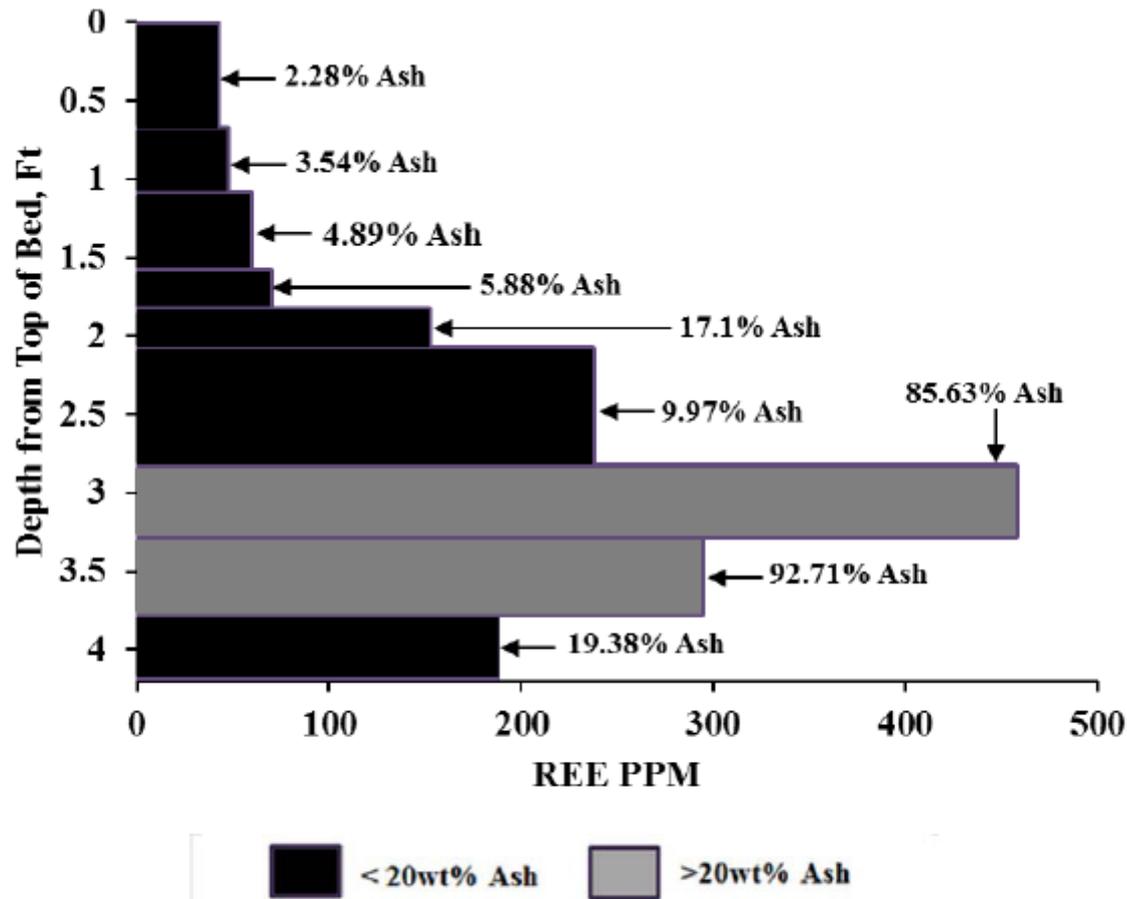
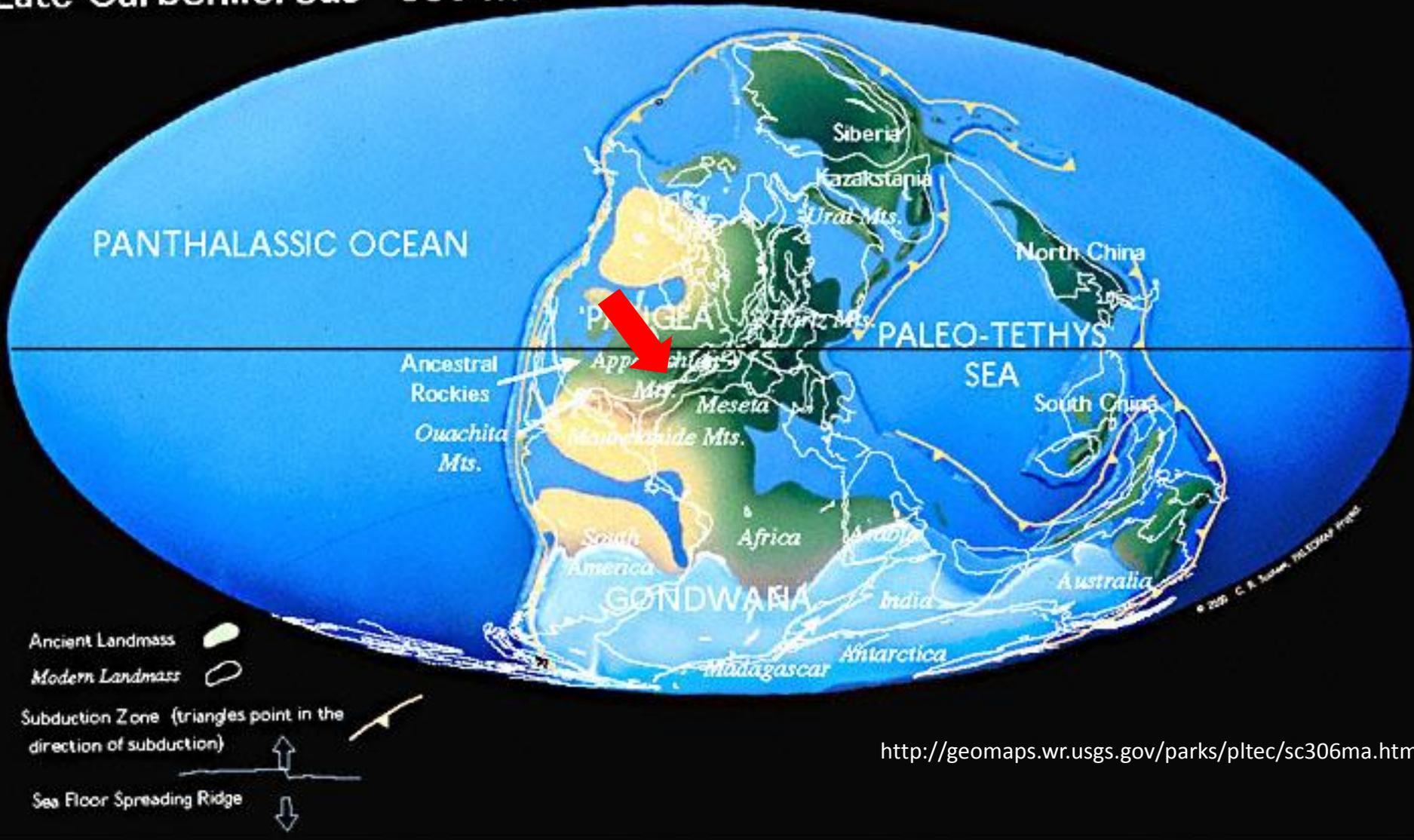


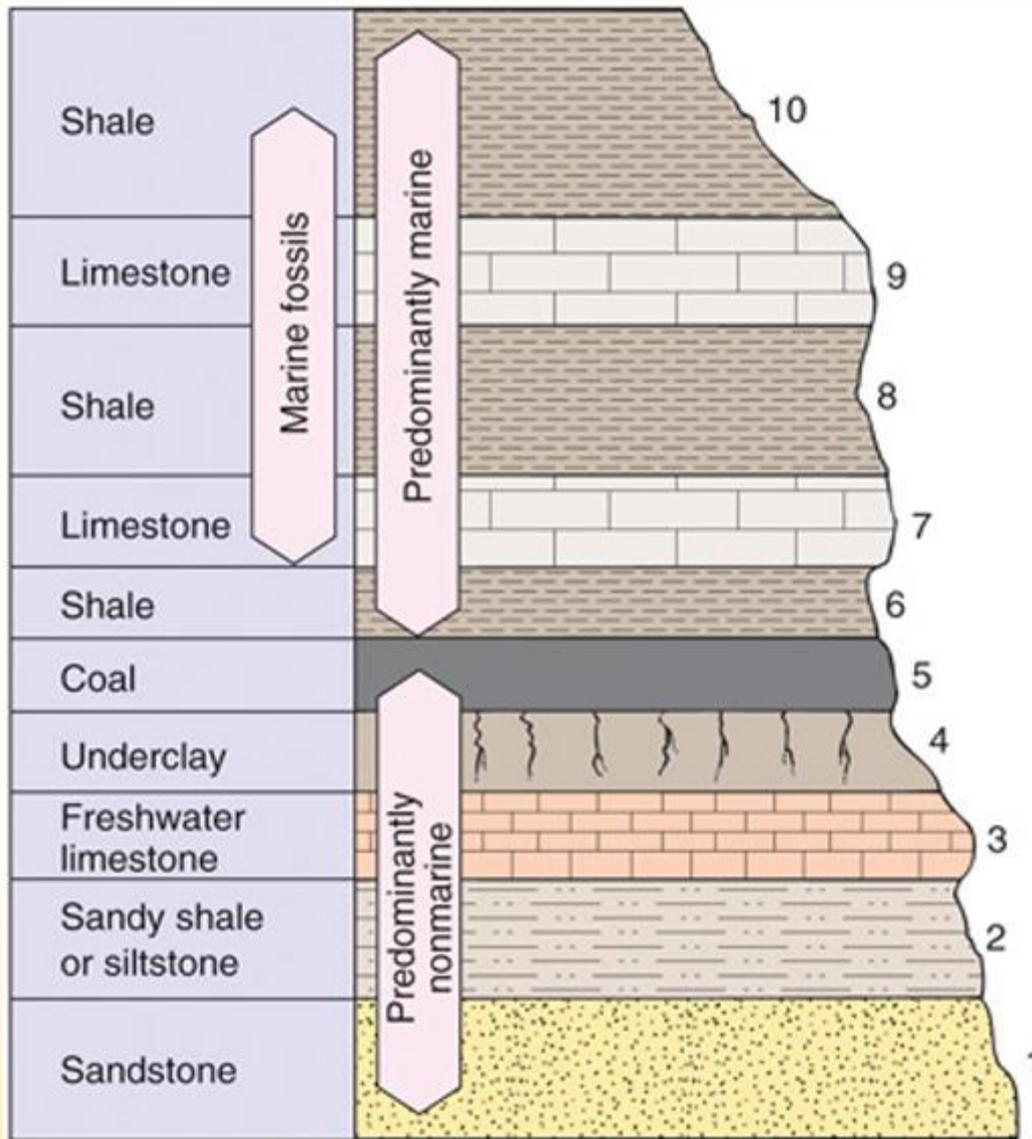
Figure 15: Stratigraphic Distribution of REE Content, Fire Clay Coal Bed, Letcher County, Kentucky, Data from Hower et al.⁵⁶

Bryan et al., 2015

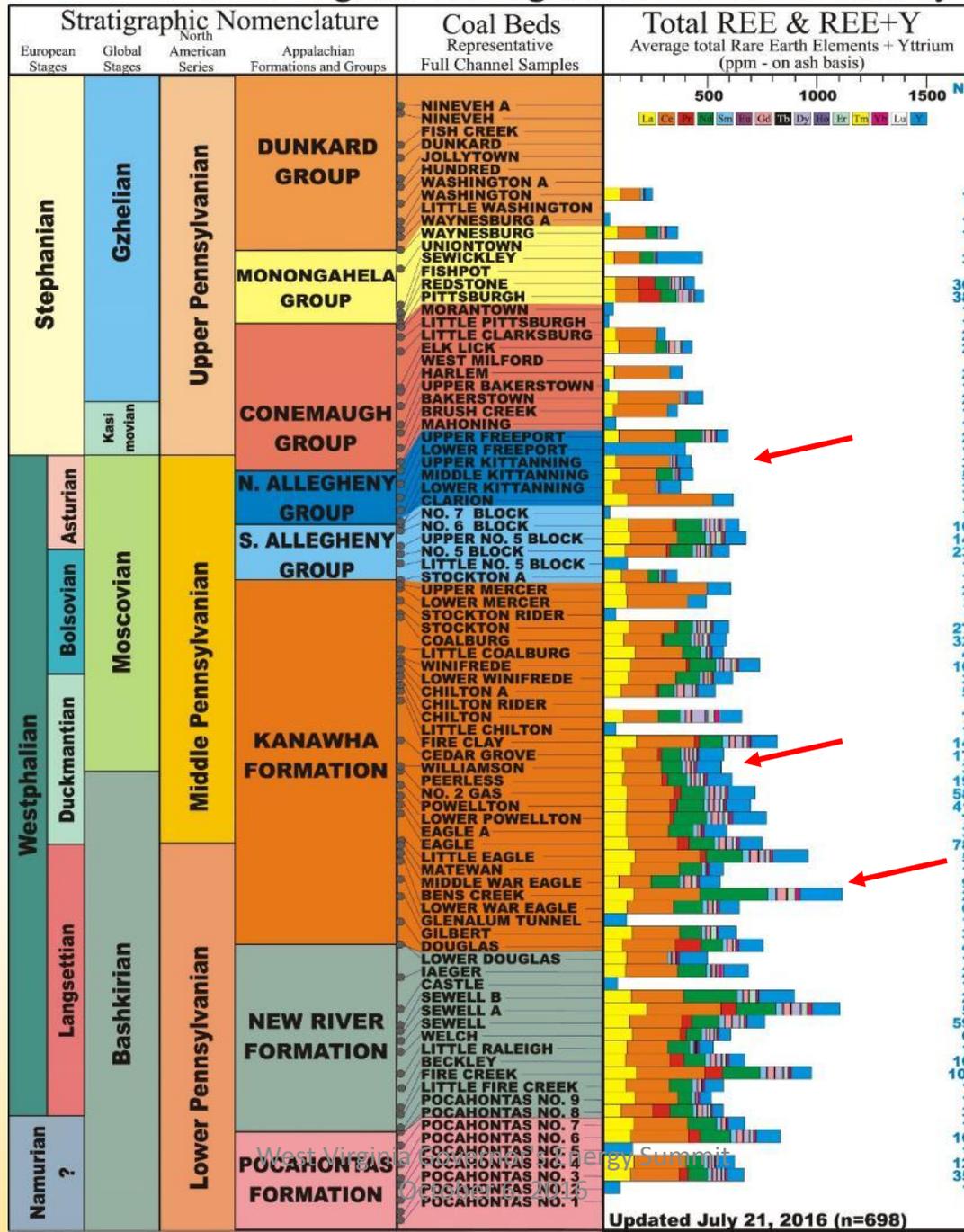
Late Carboniferous 306 Ma



<http://geomaps.wr.usgs.gov/parks/pltec/sc306ma.html>

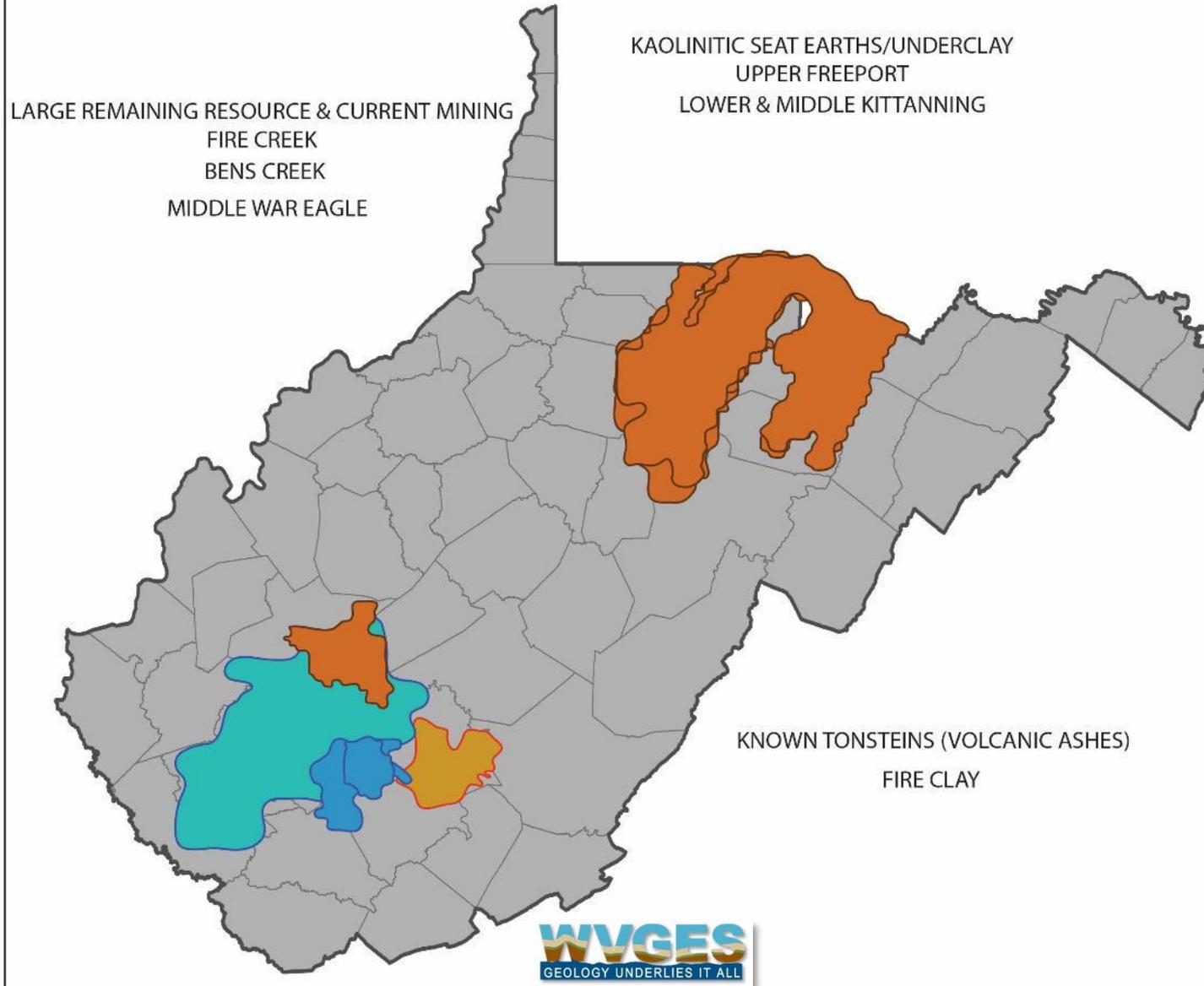


A <http://www.docsity.com/en/cyclothem-environmental-geology-lecture-slides/380561/>

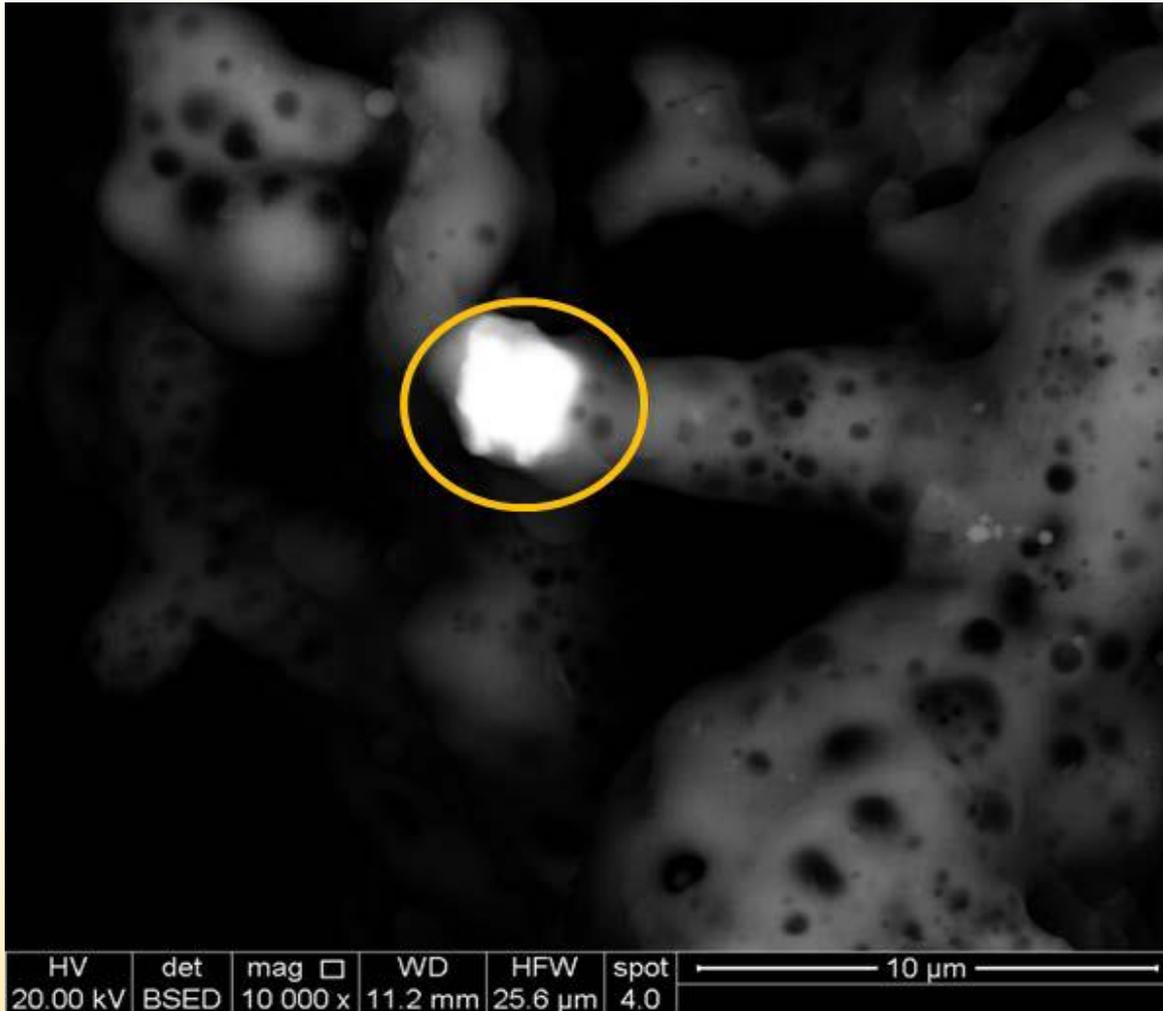


Updated July 21, 2016 (n=698)

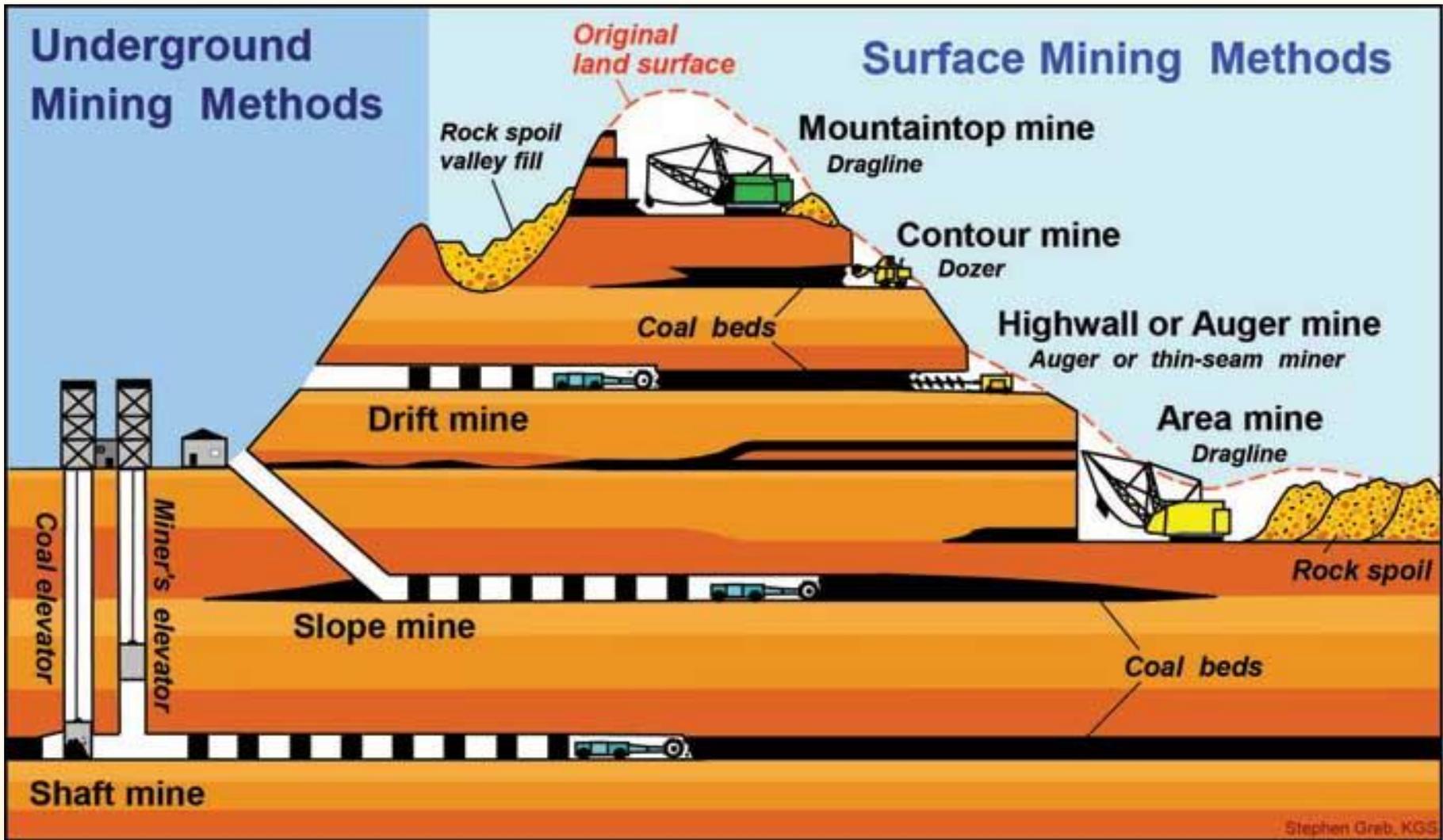
WVGES is conducting detailed sampling and research in conjunction with TetraTech in support of NETL award



Challenge 2: Extract REEs from Host Material



West Virginia Governor's Energy Summit
October 6, 2016

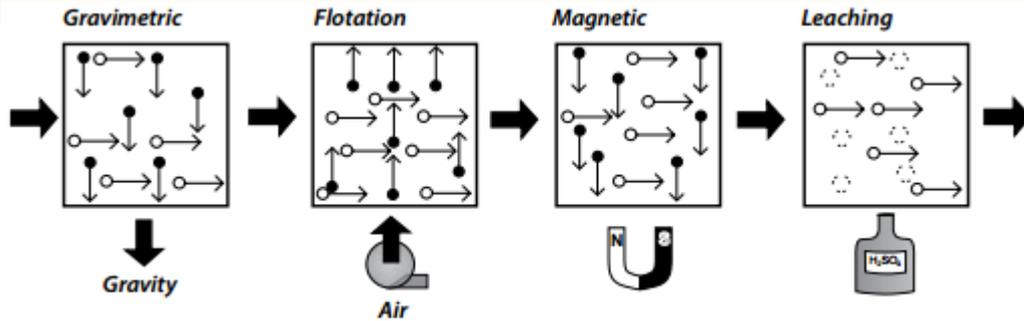


https://www.uky.edu/KGS/coal/images/Coal_mining_methods_med.jpg

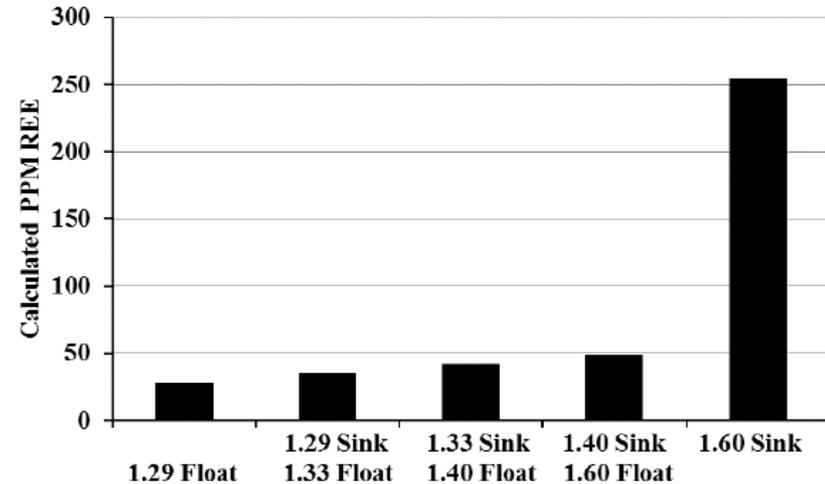
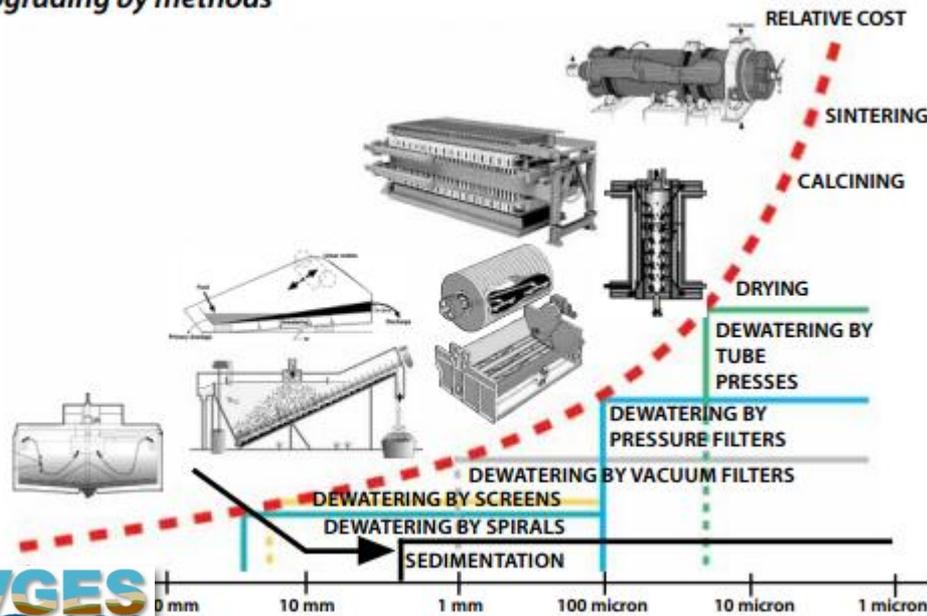
Large volumes of material must be processed to obtain REEs from host rock



Bryan et al., 2015

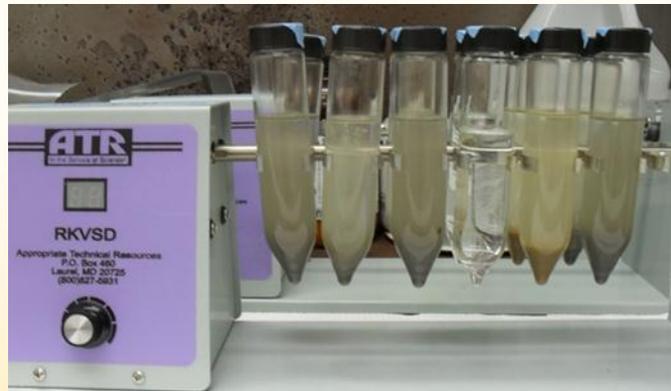


Upgrading by methods

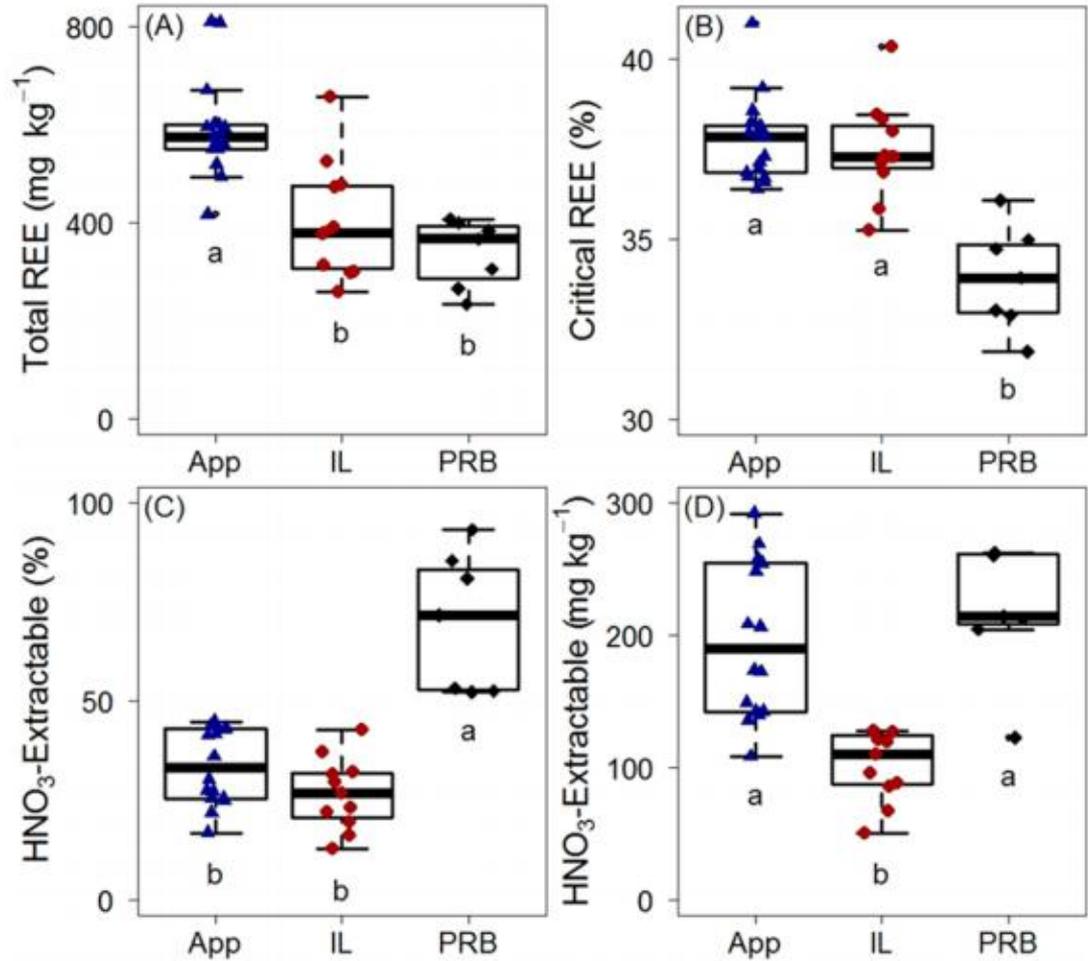


http://www.motioncontrolonline.org/content-detail.cfm/Motion-Control-Technical-Features/Market-Update-Rare-Earth-Magnet-Prices-and-Motion-Control/content_id/322

Post-combustion (fly) ash: Appalachian coals have highest REEs; more difficult to extract due to glassy encapsulation



<http://pubs.acs.org/doi/pdf/10.1021/acs.est.6b00085>



Goal: Water-Soluble Rare-Earth Concentrate

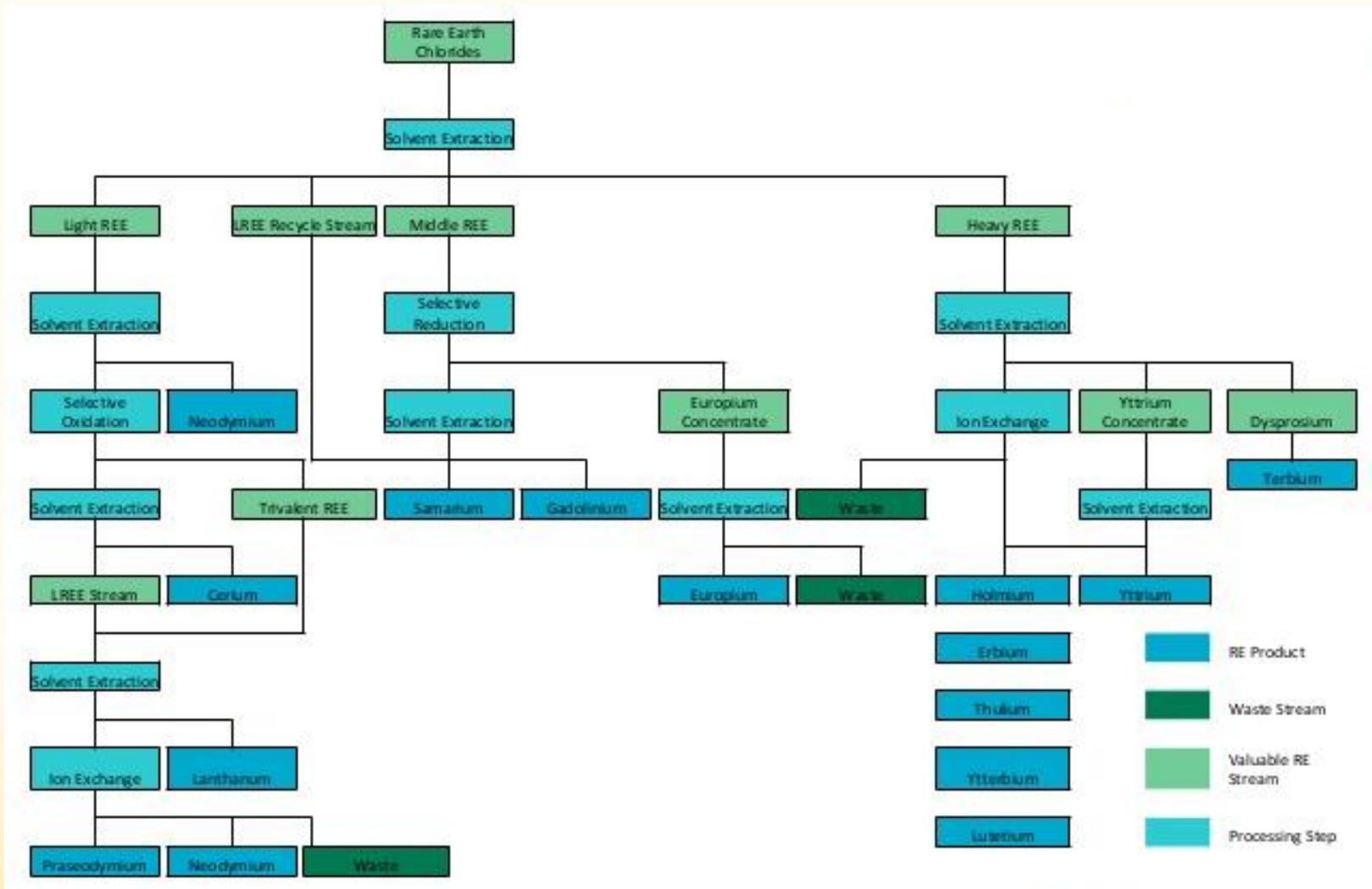


Challenge 3: Separate the Individual Rare Earth Elements



https://en.wikipedia.org/wiki/Rare_earth_element

Traditional Separation Methods: Multiple Steps, Multiple Solvents



<http://www.slideshare.net/CallumBrowning/lca-of-re-production-from-mz>

It's not easy being green...



...but technologies are advancing

White Paper on Separation of Rare Earth Elements, February 20, 2016

Molecular Recognition Technology:

A GREEN CHEMISTRY PROCESS FOR SEPARATION OF INDIVIDUAL RARE EARTH METALS

http://ucore.com/documents/WhitePaper_REE_Separations.pdf

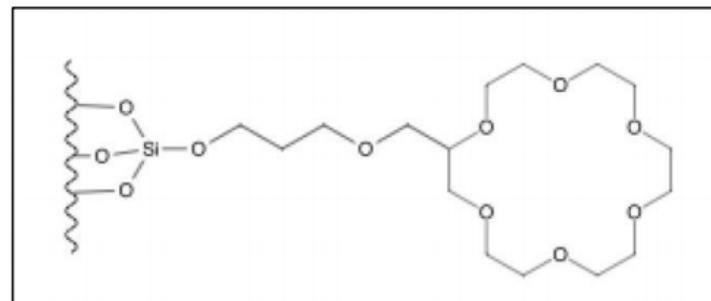


Figure 1

REEs During Fractional Crystallization

Magma is REE-enriched.

Lower REE concentration

Higher REE concentration

Most rare-earth elements remain in the melt due to incompatibility with precipitating minerals.

1

2

3

4

1200°C

600°C

Cooling

Rare-earth element sorting by "exclusion"; they literally won't fit in the crystal lattice of the forming minerals.

LIGANDS



SuperLig®
Ligands attached to solid particles

Solid Particle

- Ligands are customized molecules that attract specific elements
- SuperLig® particles use specialized ligands
- Ligands are covalently attached to SuperLig® particles
- SuperLig® particles fill the column to selectively extract REE



ucore
RARE METALS



Advanced Technologies



ucore[®]
RARE METALS

MRT Columns

pH Adjustment

Filtration

Precipitation

Treated PLS

Control Interface



MRT Pilot Plant Production

SUMMARY

- Coal measures in WV demonstrate significant resource potential with regard to rare earth elements
- REEs can occur in multiple rock types, and identification of optimal feedstock material is key
- Large volumes of material must be processed at the preparation-plant level; each feedstock stream will require customized processing
- Opportunities exist for recycling of waste products

SUMMARY

- West Virginia possesses the experience, knowledge, and trained workforce to develop and enhance these emerging technologies
- Cooperation and collaboration is essential to overcoming operational challenges





Thank You!

www.wvgs.wvnet.edu