Carbon Management and Critical Minerals: West Virginia’s Role in Energy Transitions

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Director and State Geologist
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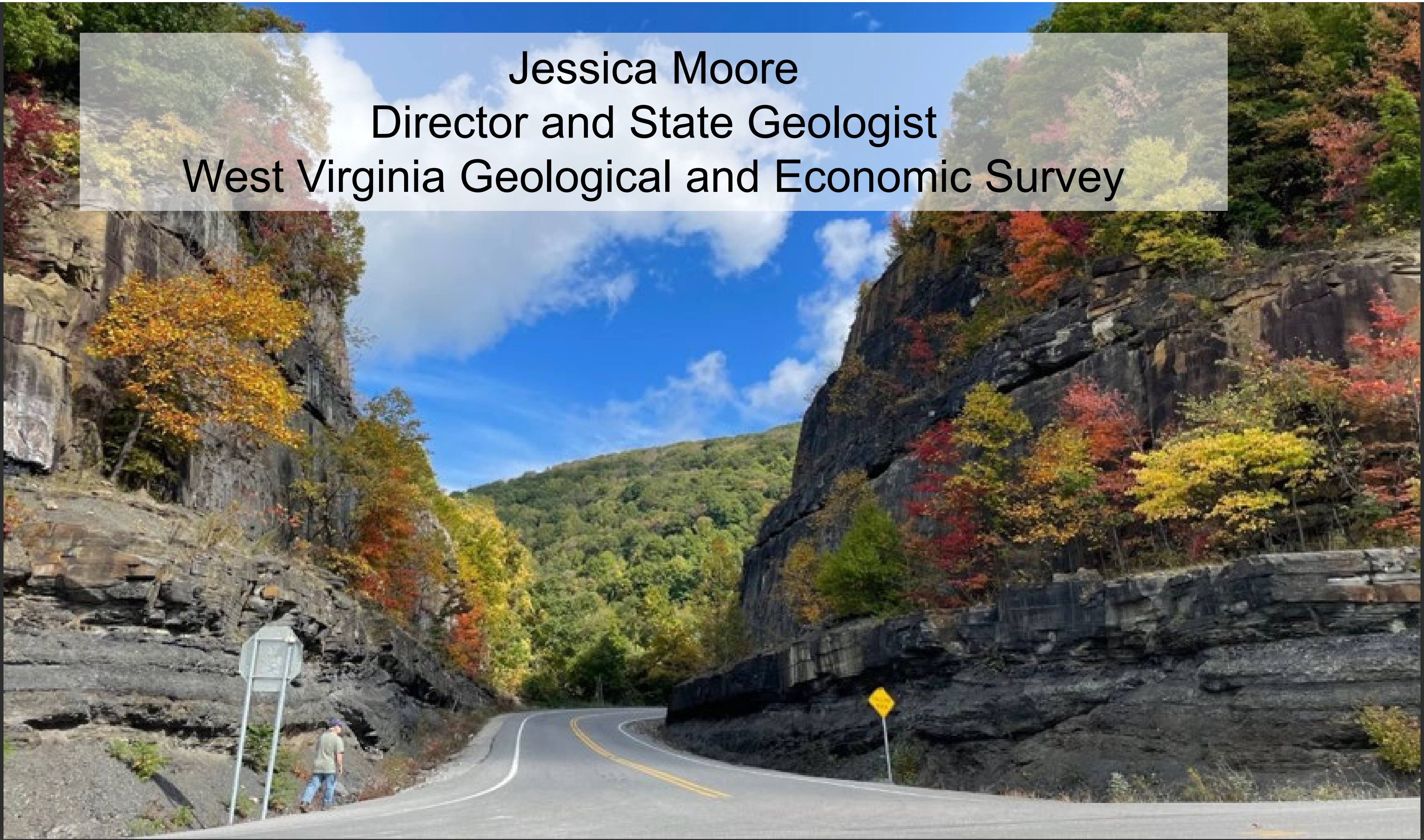

West Virginia Geological and Economic Survey

- State Agency since 1897
- Housed in the WV Department of Commerce
- Non-Regulatory, ~35 FTE; Coal/Oil and Gas/General Geosciences
- Applied geoscience research and "boots on the ground" mapping
- Maintains the State's geological sample collection
- Free Mini Museum on Cheat Lake in Morgantown

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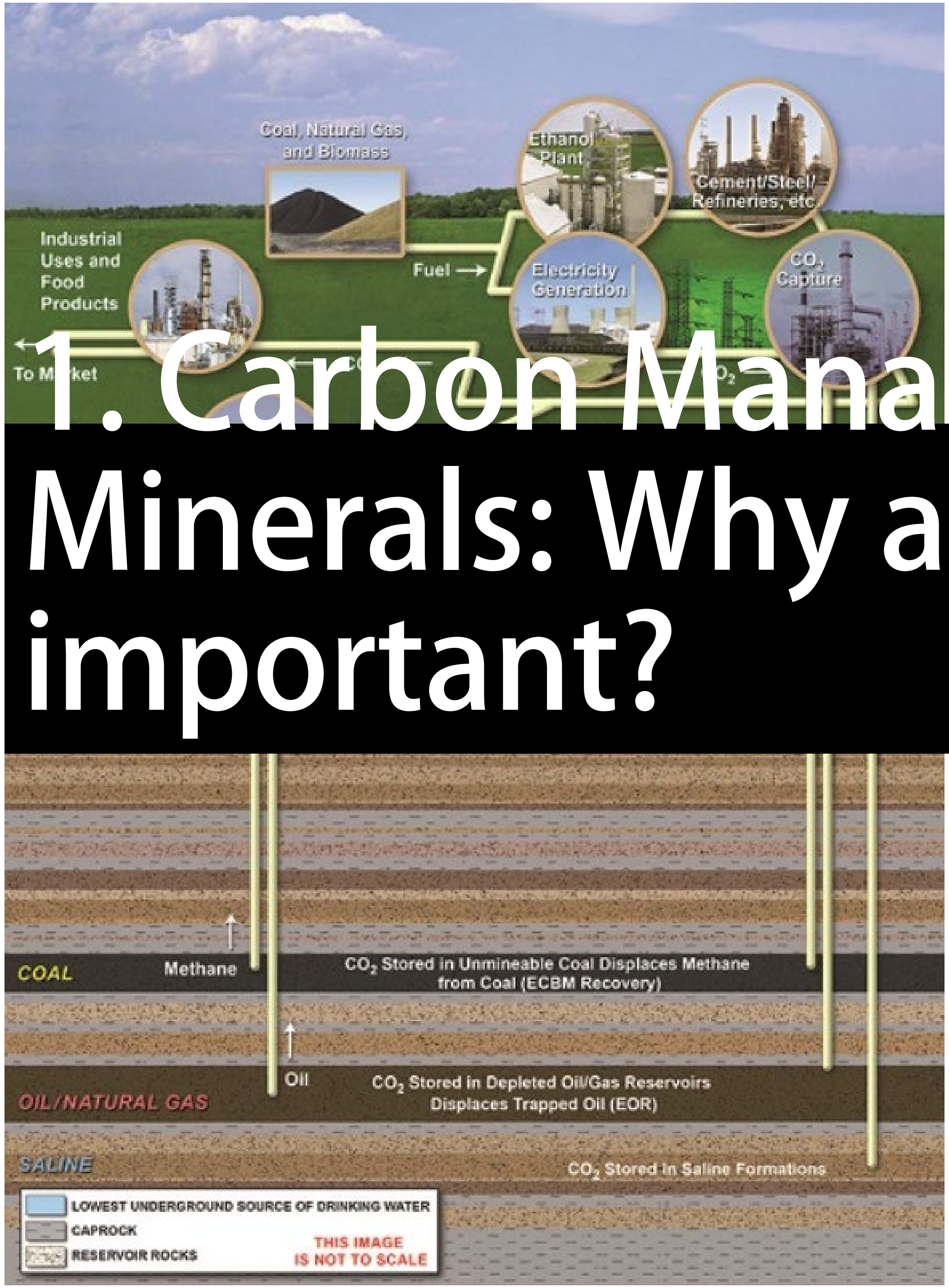
WEST VIRGINIA
DEPARTMENT of COMMERCE

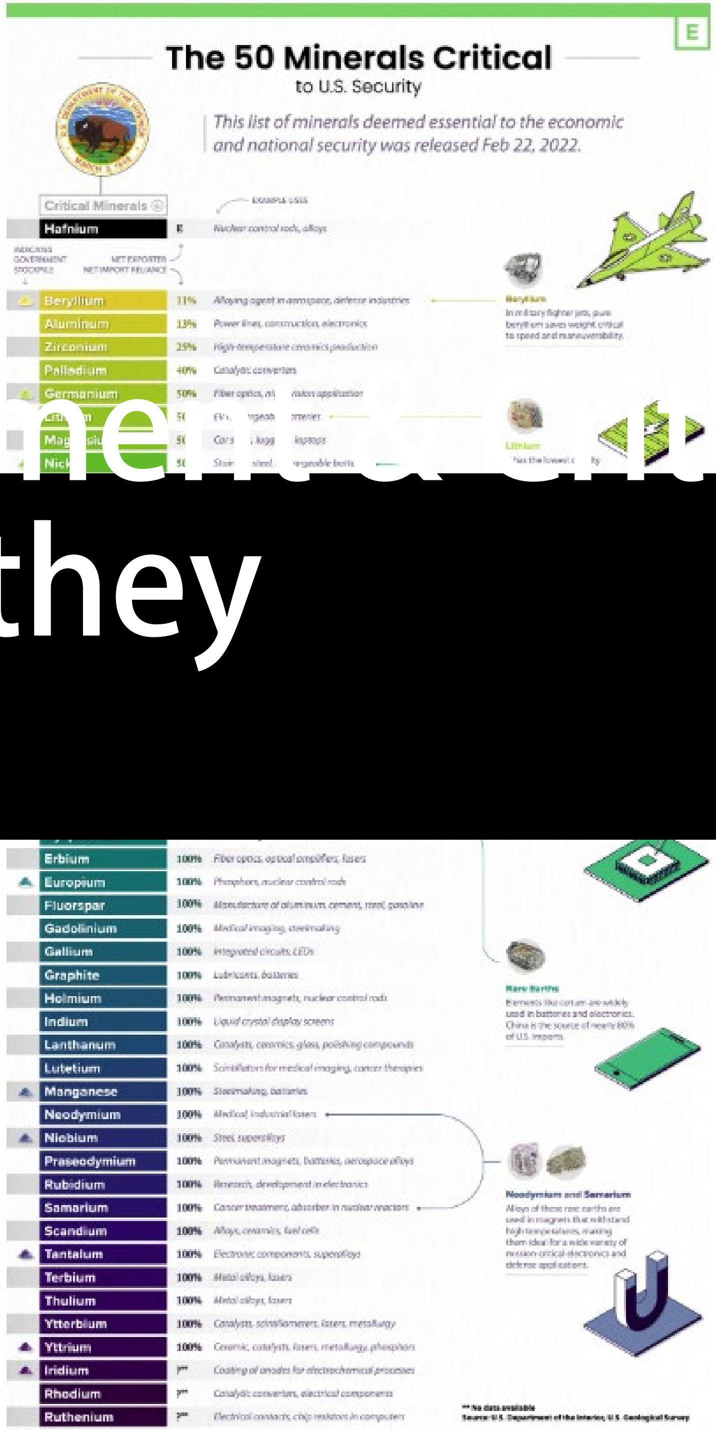
WVGES
West Virginia Geological and Economic Survey

Discussion Topics

1. Carbon Management and Critical Minerals: Why are they important?
2. The West Virginia Advantage
3. Geology Matters : Assessing the Framework Through (Deep) Time

1. Carbon Management & Critical Minerals: Why are they important?



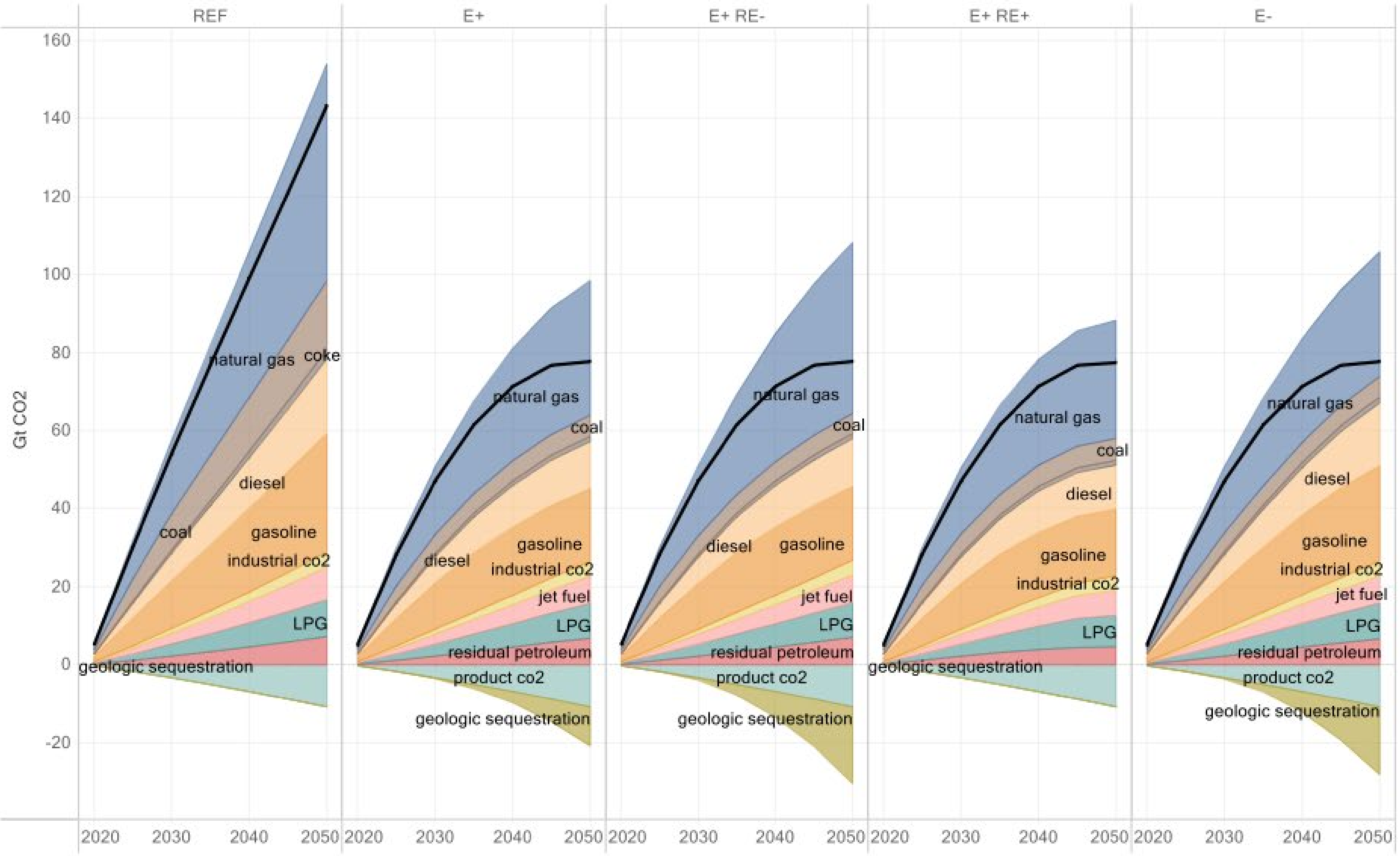


Cumulative energy and industrial CO_2 emissions (domestic consumption)

Cumulative emissions in the REF scenario were 143 Gt from 2020-2050 and 78 Gt in each of the decarbonization scenarios.

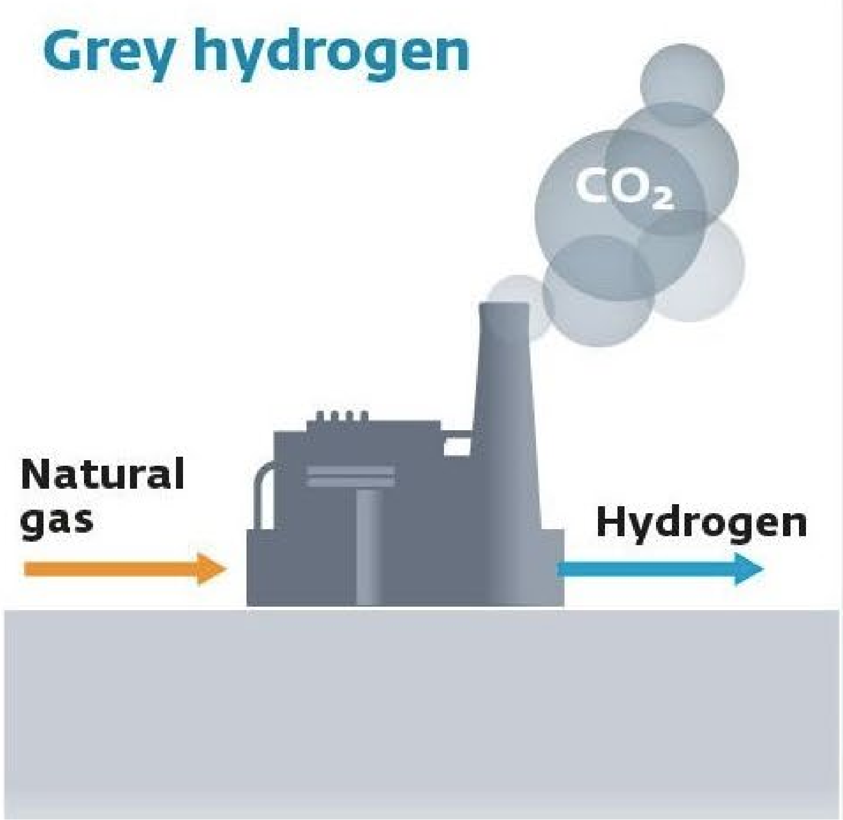
Oil products are responsible for most of the cumulative emissions, followed by natural gas, then coal. By 2050 11 Gt CO2 is sequestered in durable products that were produced using non-biogenic carbon [1]. Geologic sequestration is used to offset 10 Gt in the E+ scenario and 20 Gt in the E+ RE- scenario.

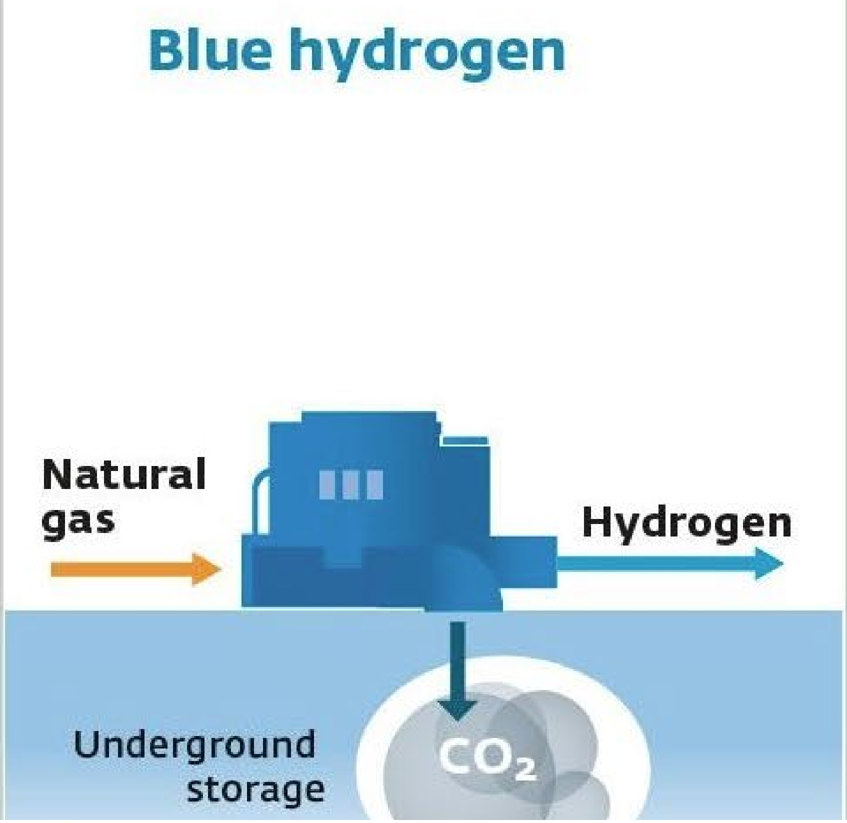
[1] Sequestration from lumber and wood products is not included in these estimates.

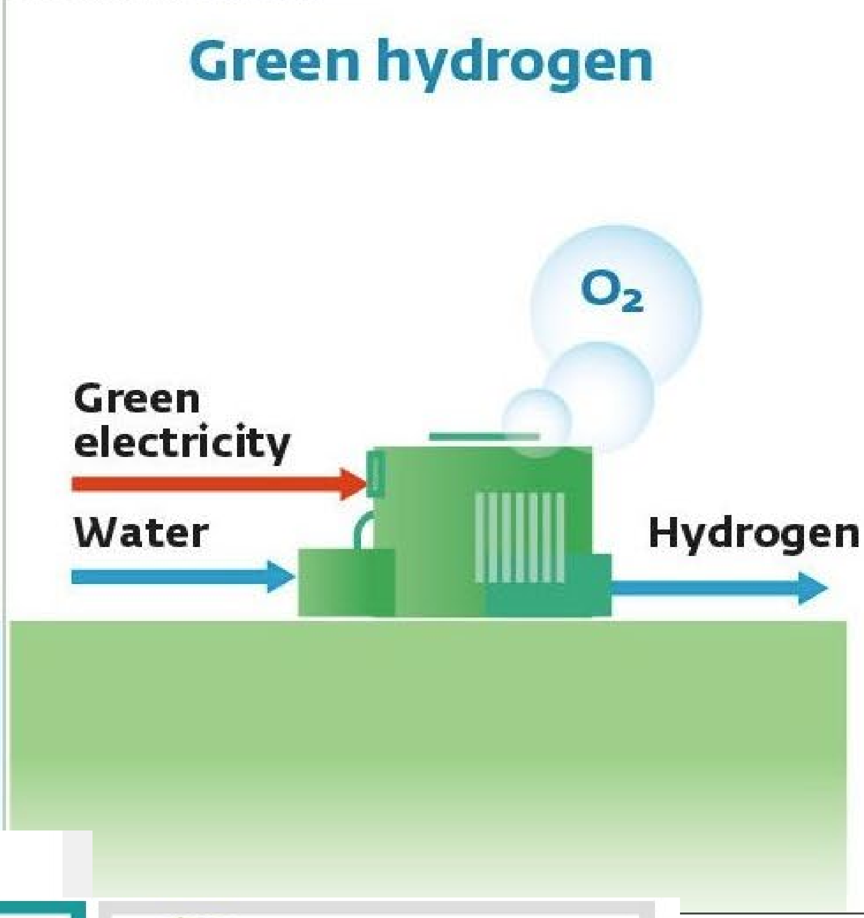


Note: excludes domestic emissions for fossil fuels produced for export.

Princeton Net-Zero America: [The Report | Net-Zero America Project (princeton.edu)]





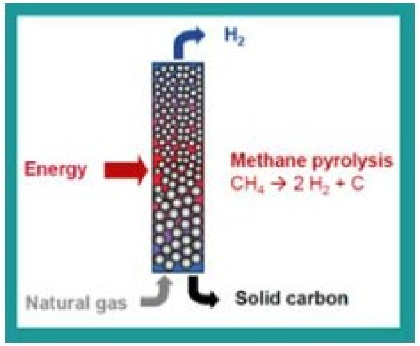


Other Colours of Hydrogen

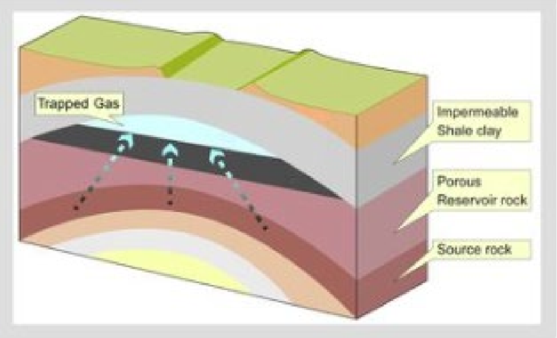
Bituminous coal is used to make black hydrogen[6]

Brown coal (lignite) is used to make brown hydrogen.[7]

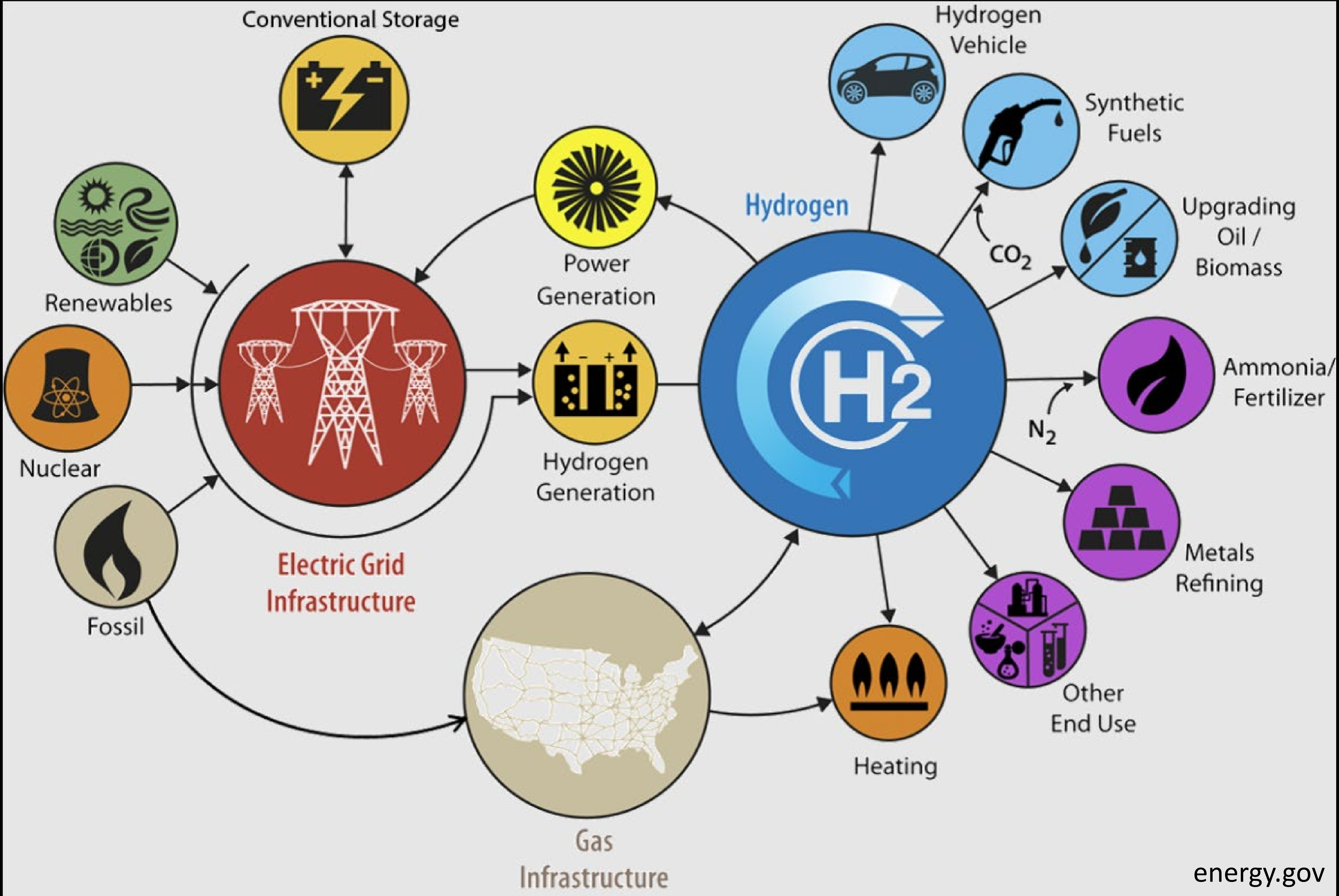
Solar power or a mix of energy sources from the electrical grid are used to make yellow hydrogen.[10]



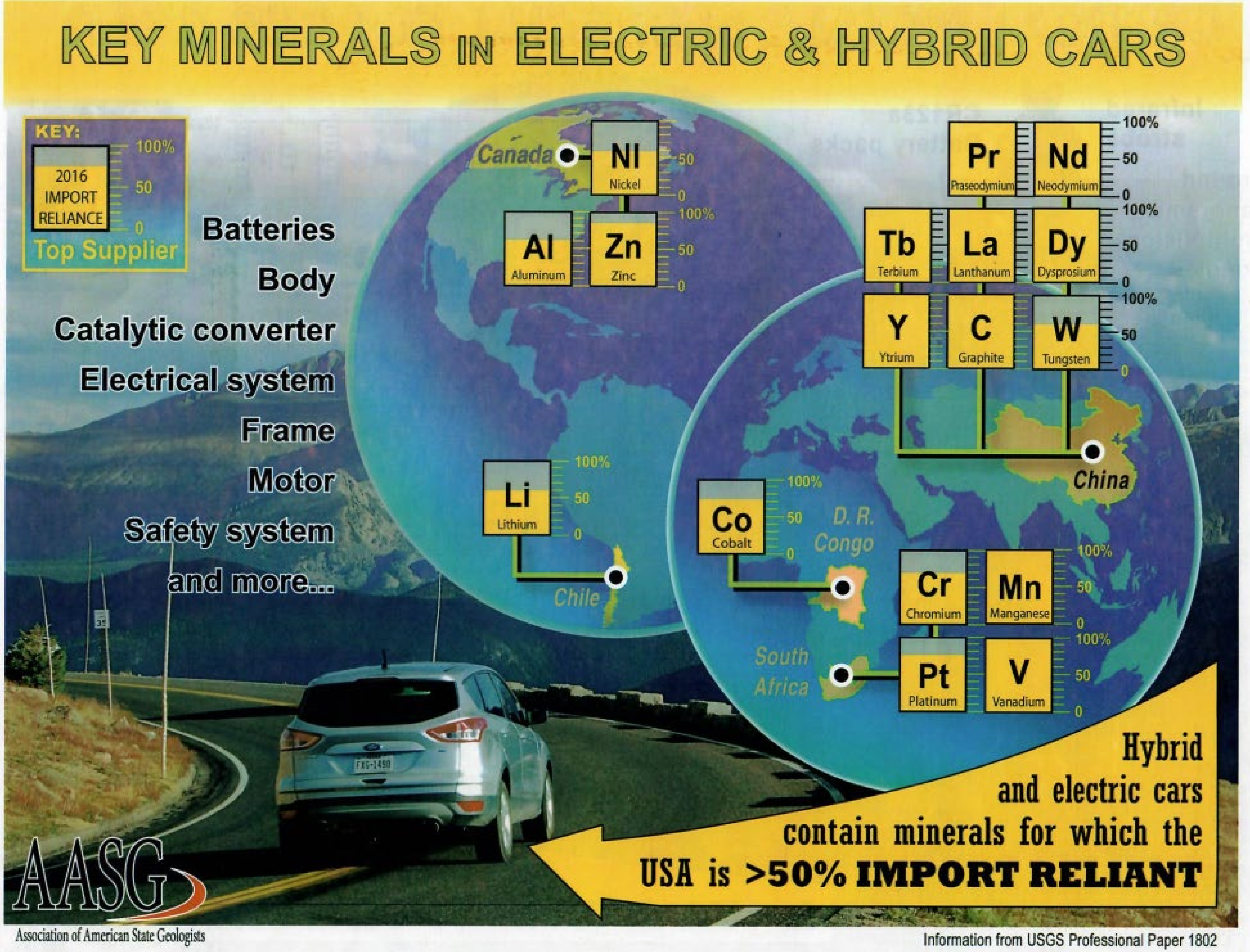
Methane pyrolysis is used to make turquoise hydrogen.[11]

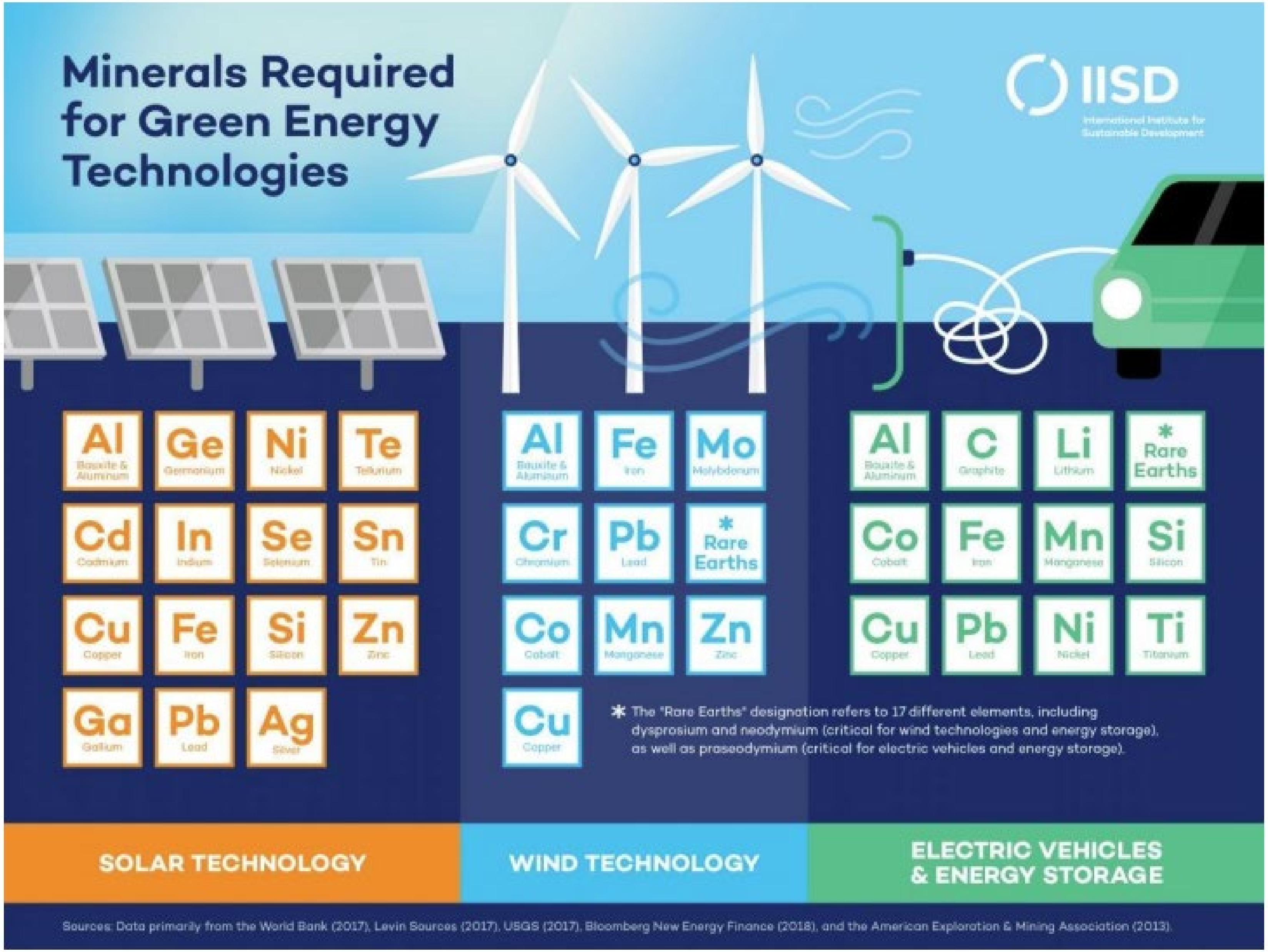


Naturally occurring geological hydrogen is called white hydrogen.[12]

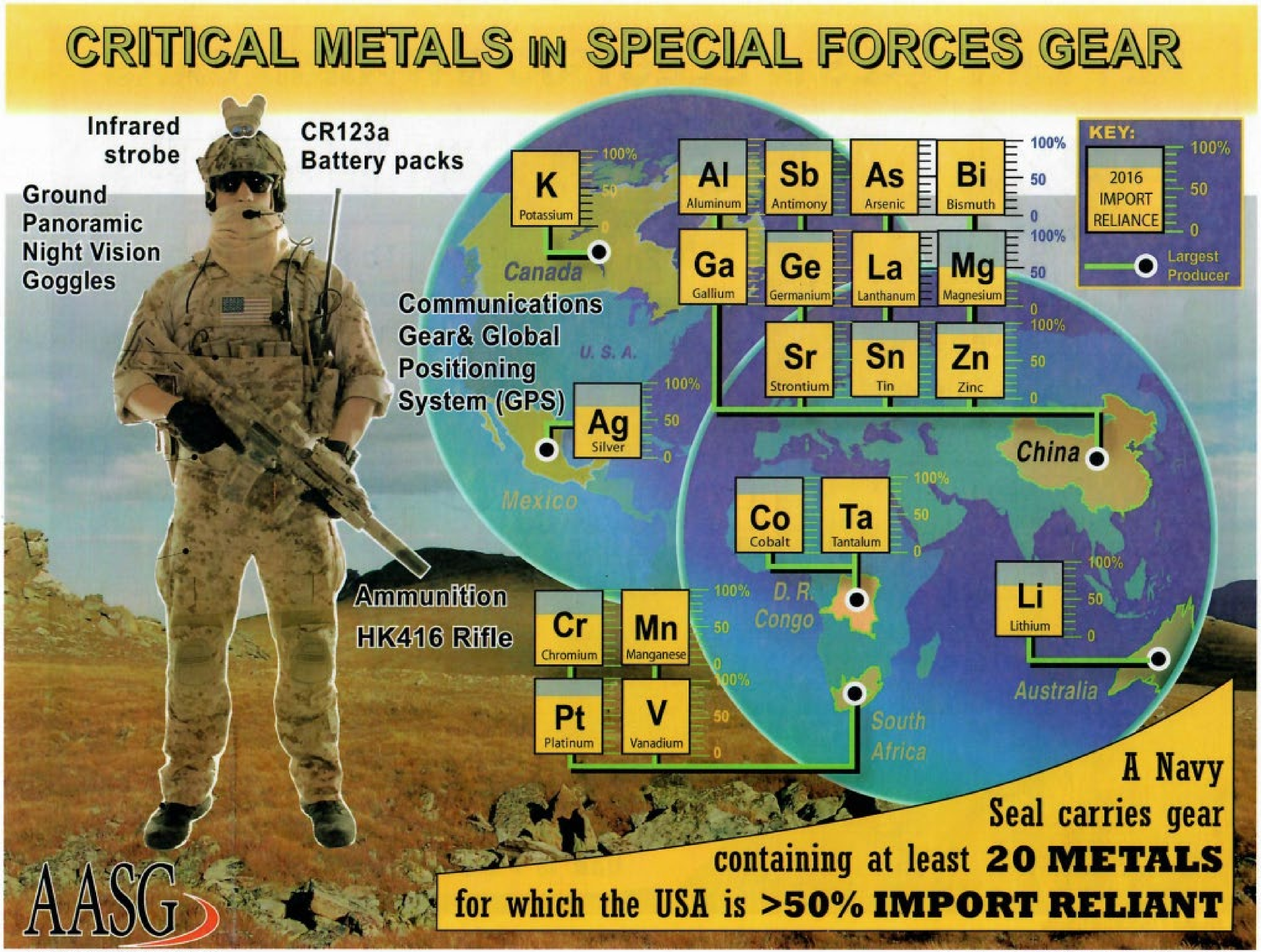

Conventional Storage
Renewables
Nuclear
Fossil
Electric Grid Infrastructure
Power Generation
Hydrogen Generation
Hydrogen
H_2
Gas Infrastructure
Hydrogen Vehicle
Synthetic Fuels
CO_2
Upgrading Oil / Biomass
Ammonia/ Fertilizer
N_2
Metals Refining
Other End Use
Heating

energy.gov


KEY MINERALS IN ELECTRIC & HYBRID CARS
KEY:
2016 IMPORT RELIANCE
100%
50
0
Top Supplier
Batteries
Body
Catalytic converter
Electrical system
Frame
Motor
Safety system
and more...
Canada
Ni Nickel
Al Aluminum
Zn Zinc
Li Lithium
Chile
Pr Praseodymium
Nd Neodymium
Tb Terbium
La Lanthanum
Dy Dysprosium
Y Ytrium
C Graphite
W Tungsten
China
Co Cobalt
D. R. Congo
Cr Chromium
Mn Manganese
Pt Platinum
V Vanadium
South Africa
Hybrid
and electric cars
contain minerals for which the
USA is >50% IMPORT RELIANT
AASG
Association of American State Geologists
Information from USGS Professional Paper 1802

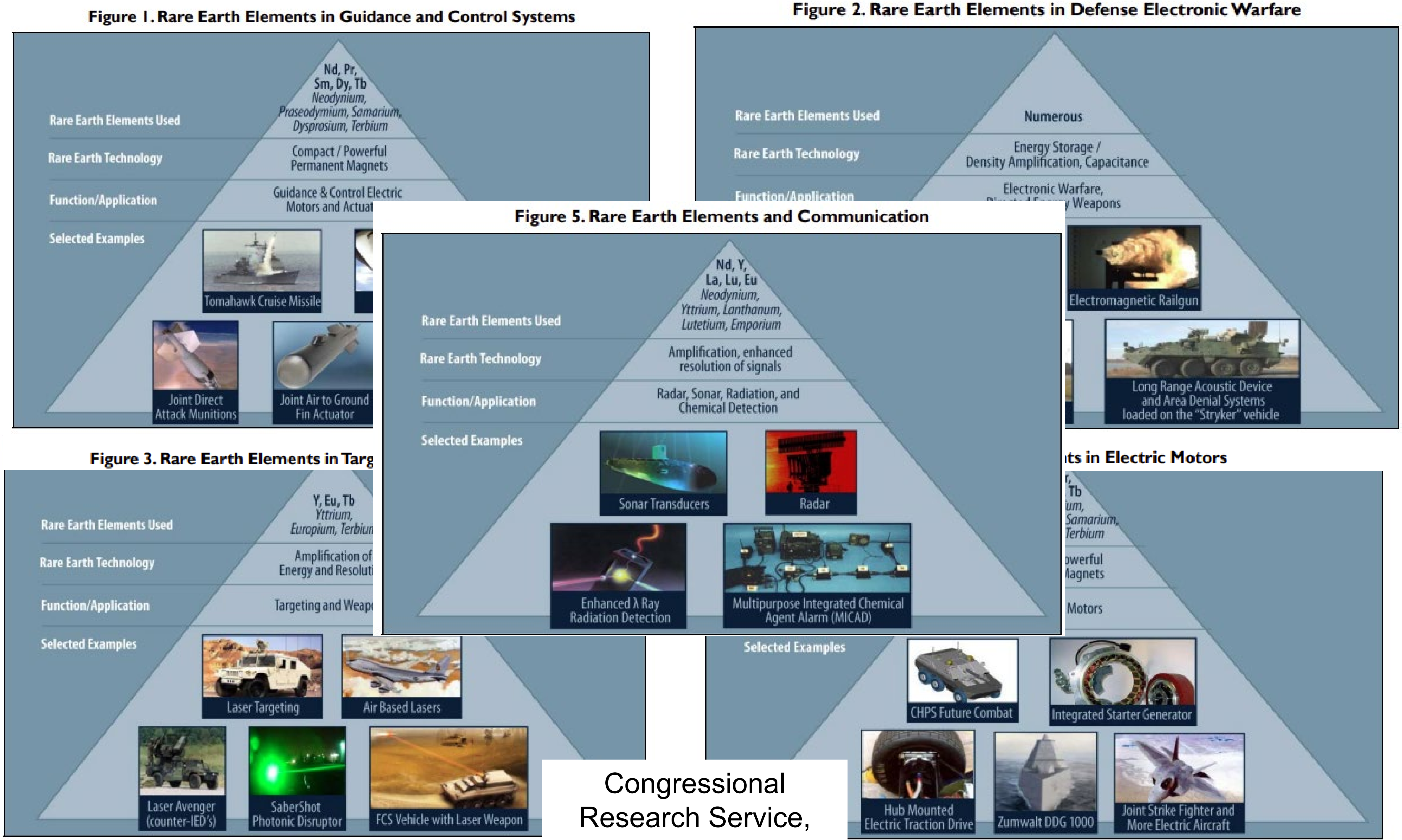


Source: International Institute for Sustainable Development, 2019



Association of American State Geologists

Information from USGS Professional Paper 1802



Congressional Research Service,

% Global Production (2017)
Select countries

	United States	Canada	Mexico	Argentina	Brazil	Chile	Poland	Spain	Algeria	DRC	Gabon	Guinea	Nigeria	Rwanda	S. Africa	Iran	Qatar	Burma	China	India	Indonesia	Japan	Kazakhstan	Russia	S. Korea	Australia	Other
Aluminum (Baux.)					12.5							15							22.6							28.5	21.4
Antimony																			72								28
Arsenic																			69								31
Barite																			37	18							45
Beryllium	71																										29
Bismuth																			73								27
Cesium	NA																										
Chromium															46.2								12.9				40.9
Cobalt										61																	39
Fluorspar			18																61								21
Gallium																			94								6
Germanium																			57								43
Graphite (Nat.)					10														75								15
Hafnium	NA																										
Helium	57								8.7								28										6.3
Indium																			40						31.5		27.5
Lithium				8.3		21													9.8							58	2.9
Magnesium Metal																			89								11
Manganese											12.7				31				9.8							16	30.5
Niobium					88																						12
PGMs															72									11			17
Potash		29																	13					17.6			40.4
Rare Earth Elements																			80							14	6
Rhenium	17						19												55								9
Rubidium	NA																										
Scandium	NA																										
Strontium			28					35.3								15.7			19.6								2
Tantalum										42			8.5	24													25.5
Tellurium																			68			12		12			9.2
Tin																		15	29.7		26.5						28.8
Titanium Conc.		16													18				15							13	38
Tungsten																			82								18
Uranium		22.5																					39			10	28.5
Vanadium															11.2				56					25			7.8
Zirconium															24.3				9							32.5	34.2

Based on USGS data.
NA = not available. Where there is no value, value may be 0 or be included in "Other".

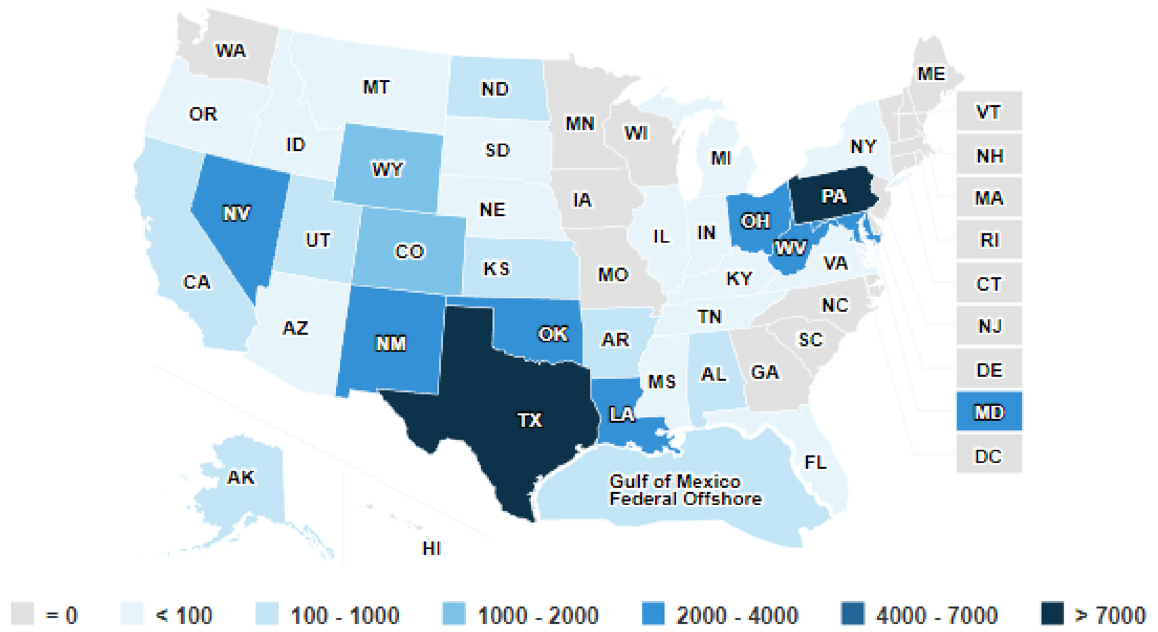
A laborer works at the site of a rare earth metals mine at Nancheng county, Jiangxi province in China.

2. The West Virginia Advantage

Resource and Policy Developments

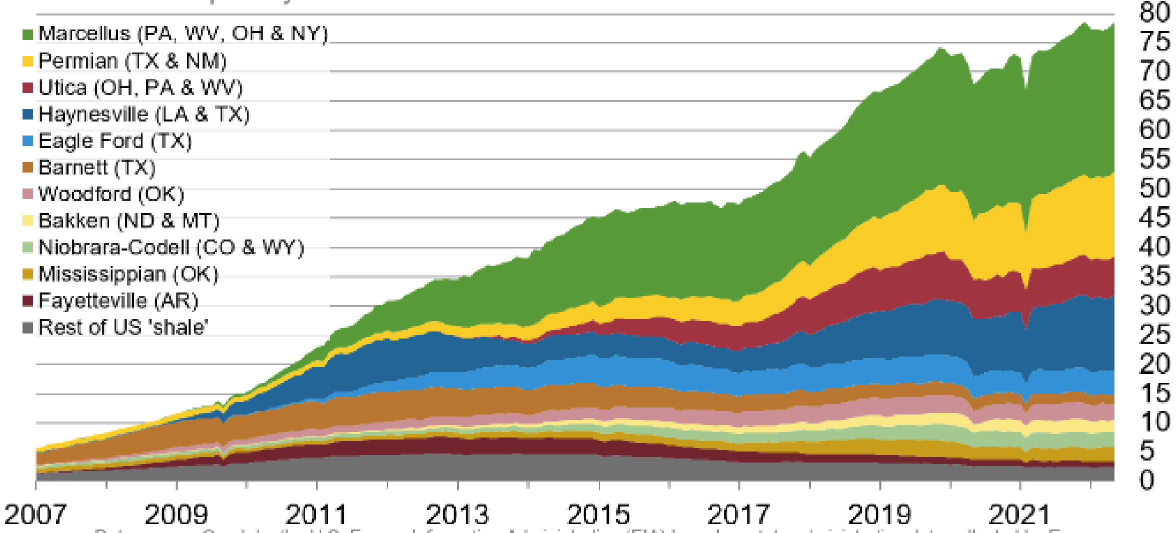
U.S. dry natural gas production by state in 2021

billion cubic feet



Monthly dry shale gas production

billion cubic feet per day



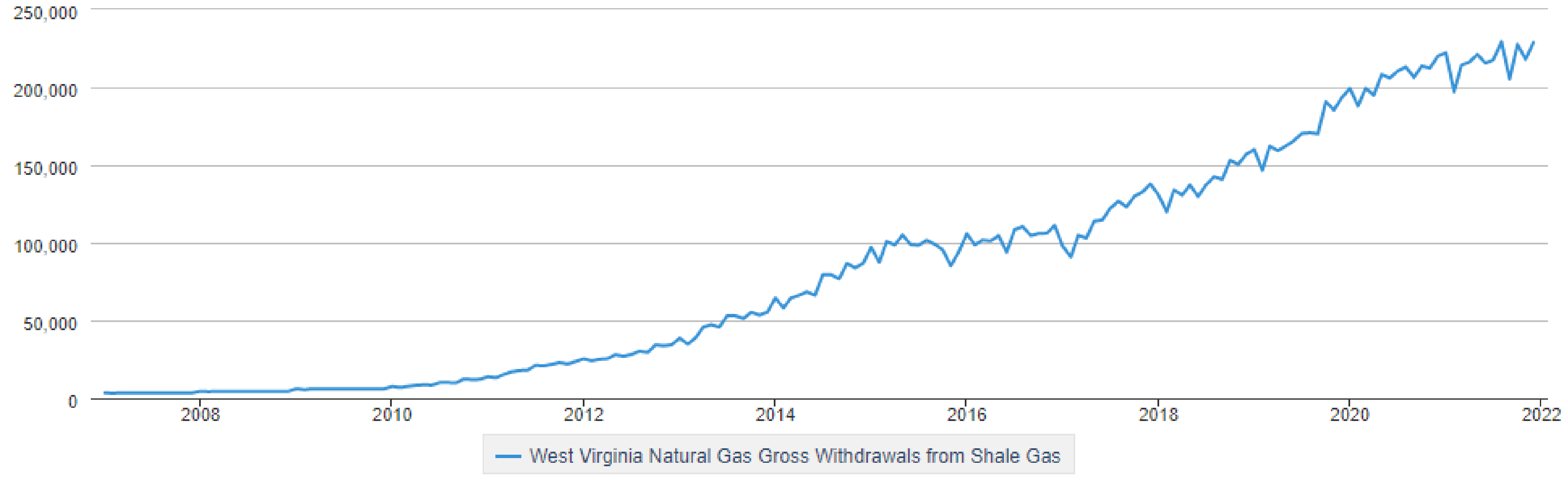
Data source: Graph by the U.S. Energy Information Administration (EIA) based on state administrative data collected by Enverus. Data are through August 2022 and represent EIA's official tight gas estimates, but are not survey data. State abbreviations indicate primary state(s).

Note: Improvements to play identification methods have altered production volumes of various plays.

West Virginia Natural Gas Gross Withdrawals from Shale Gas

DOWNLOAD

Million Cubic Feet



HB 4491: CO_2 Sequestration Pilot Program

- Passed WV Legislature 3/1/22 with wide bipartisan support (90-9-1 vote in House; unanimous vote in the Senate (33-0-0)); effective 5/30/22
- Pore space ownership vested with surface owner and cannot be severed
- Before a permit may be approved, must determine if proposed storage facility contains “commercially valuable minerals” . Must demonstrate that interests of mineral estate will not be adversely affected or have been addressed in written agreement. Mineral owners may drill through storage.
- Unitization: Owners of 75% of pore space acreage in the storage reservoir must consent

HB 4491: CO_2 Sequestration Pilot Program

- Access can be granted by the State for seismic surveys if operator is unable to reasonably negotiate with surface owners
- Can enter into cooperative agreements with other governments/gov't entities if project extends beyond state regulatory authority
- Certificate of Completion may be issued 10 years after cessation of injection
- Ownership of stored CO_2 transfers to surface owner once Certificate of Completion issued; State assumes responsibility and liability
- Carbon Dioxide Storage Facility Administrative Fund (Permit Fees)
- Carbon Dioxide Storage Facility Trust Fund (Injection Volume Fees)

WV Class 6 Primacy Rule

- 47CSR13: Represents a total revision of UIC regulations, including new section on Class 6. Last major update was in 1980s. Drafted with assistance from EPA
- June 23, 2021: Draft rule filed; 30-day public comment period begins
- July 23, 2021: Public Hearing (virtual meeting)
- July 30, 2021: Agency-approved rule filed; public comments addressed
- Spring 2022: Rules packaged approved by WV Legislature; primacy application submitted to EPA
- Still waiting on EPA determination

https://apps.sos.wv.gov/adlaw/csr/ruleview.aspx?document=17482&KeyWord

ECONOMY

Tech scientists see rare opportunity in Appalachia

Appalachian Coal Ash Richest in Rare Earth Elements

U.S. JOURNAL

COULD COAL WASTE BE USED TO MAKE SUSTAINABLE BATTERIES?

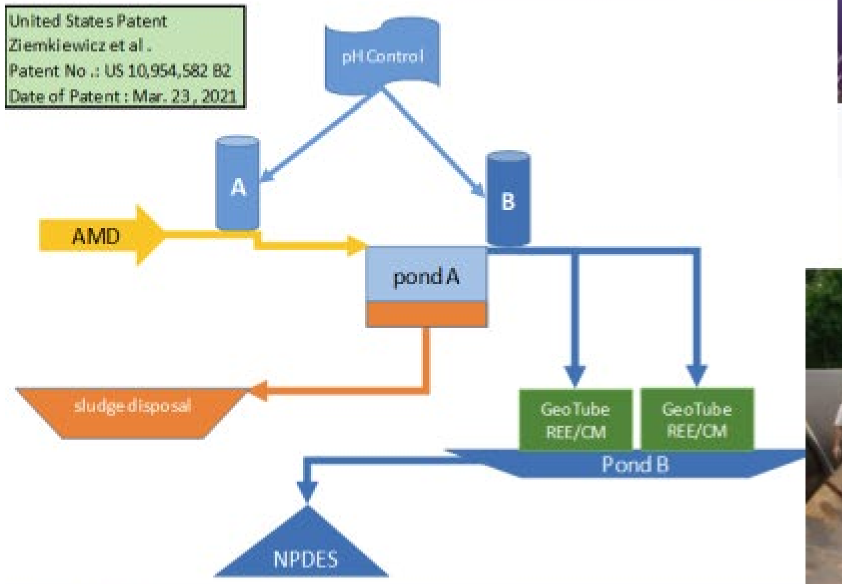
Researchers eye coal ash as a possible source of critical minerals — and Southwest Virginia jobs

BUSINESS

In coal country, a new chance to clean up a toxic legacy

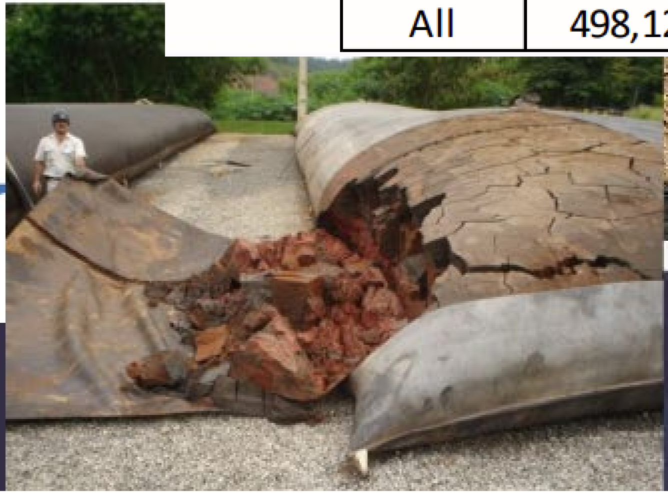
Waste from abandoned and bankrupt mines has contaminated more than 12,000 miles of waterways. Now states are looking at how to extract critical elements from those waters to try to offset the high cost of cleanup.

MID-APPALACHIAN CORE-CM PROJECT: ACID MINE DRAINAGE TREATMENT



Randomly collected AMD sludge vs. preconcentrate

	BP P1 SL		A34 HPC	
	mg/kg		mg/kg	
Al	98,549	19.8%	92,301	23.7%
Ca	38,906	7.8%	35,386	9.1%
Co	204	0.0%	7,221	1.9%
Fe	35,288	7.1%	1,746	0.4%
Mg	54,555	11.0%	8	0.0%
Mn	7,177	1.4%	67,072	17.2%
Ni	322	0.1%	7,182	1.8%
Si	261,920	52.6%	132,593	34.0%
Zn	549	0.1%	24,619	6.3%
TREE	659	0.1%	22,142	5.7%
All	498,129	100.0%	390,272	100.0%



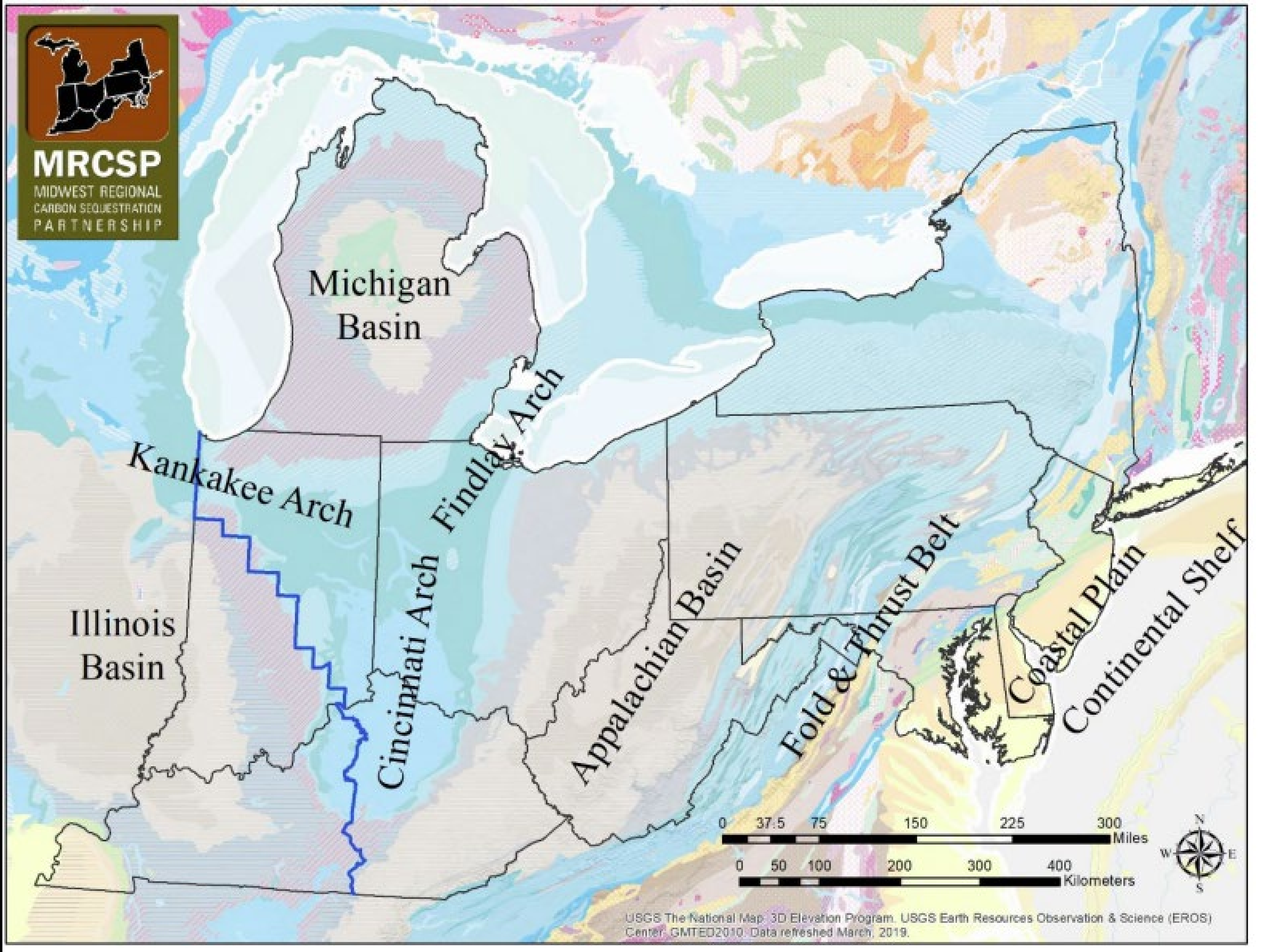
Critical Minerals Policy Developments--WV

HB 4003: any party that treats any mine drainage may derive “commercial benefit” from any elements or other byproducts of the treated material. Passed during 2022 Legislative Session by 91-7 vote.

- Meant to encourage treatment of acid mine drainage problems and clarify ownership of REEs/critical minerals

Did Not Pass: HB 4025: 5 yr. exemption from severance tax for all extraction of REEs by any mining process (normally 4% of gross value of natural resource production).

3. Why the Geology Matters



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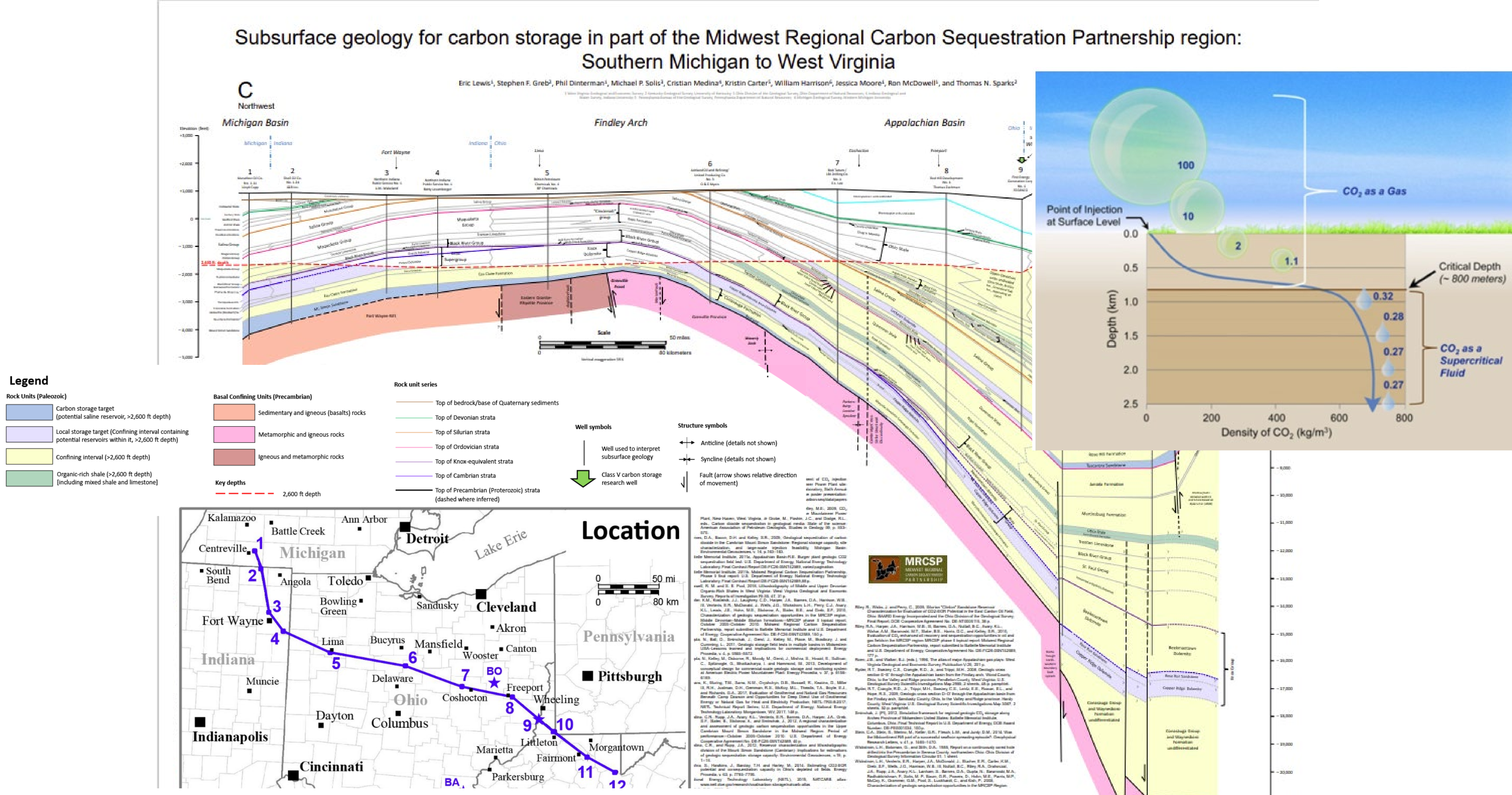
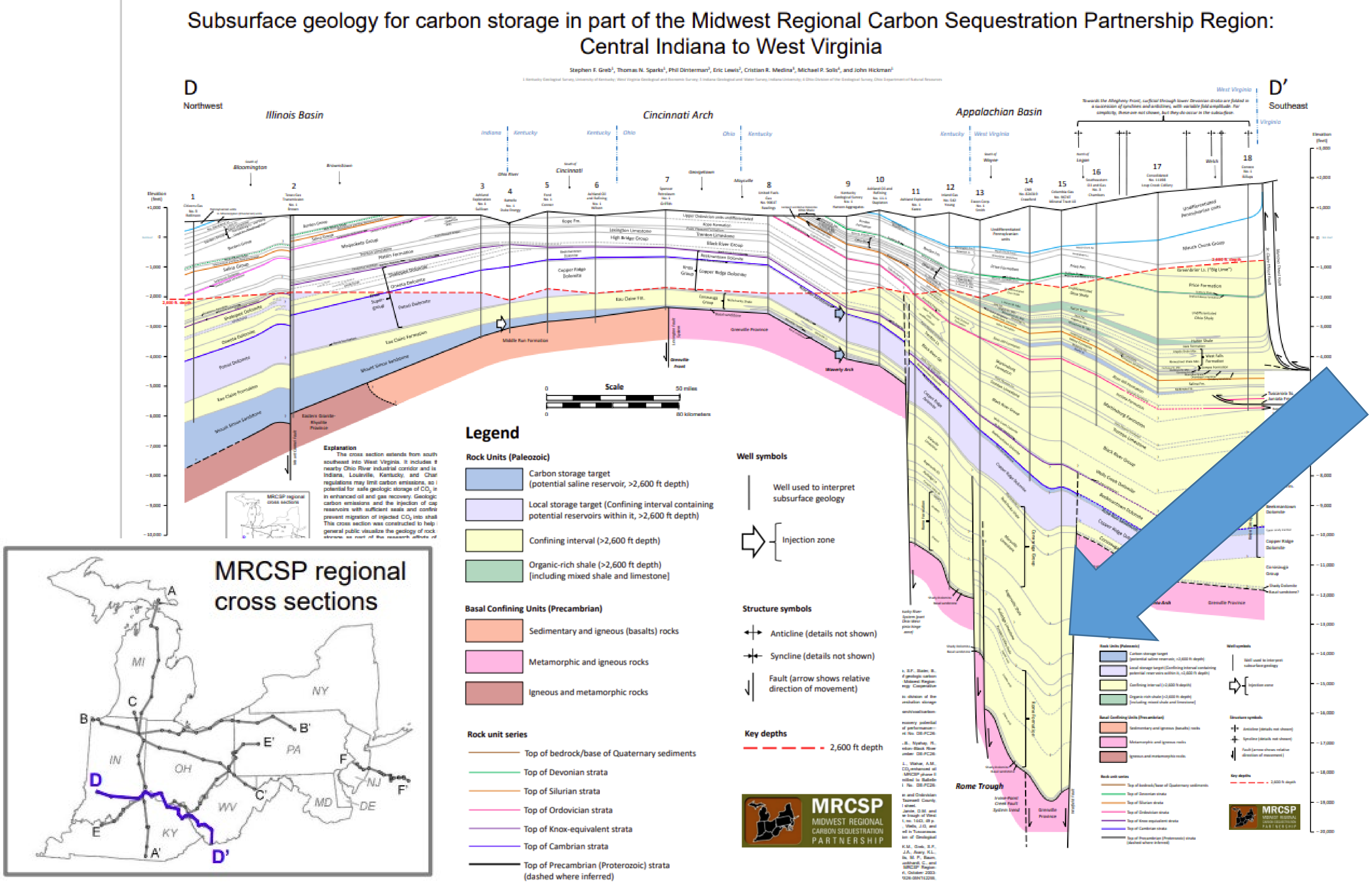


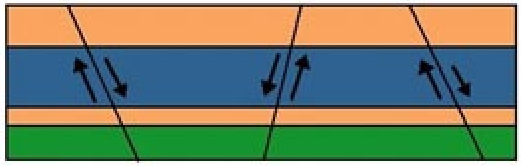
[Regional Geologic Cross Sections for Potential Storage and Containment Zones in the MRCSP Region - Submissions - EDX (doe.gov)]



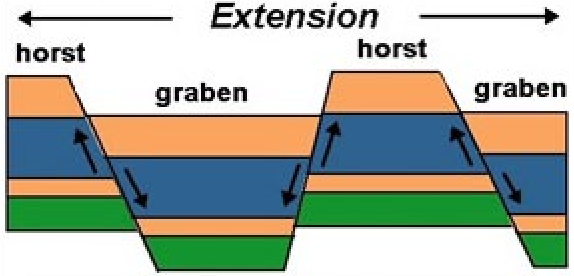
The Rome Trough

Textbook horst and graben formation

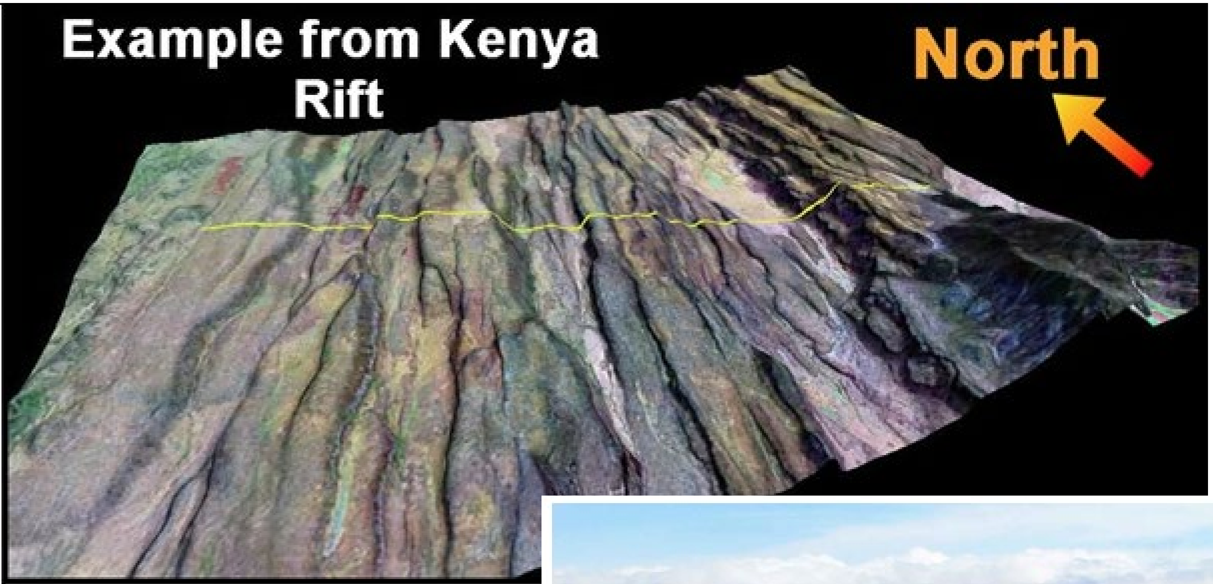
1. Layered rock units

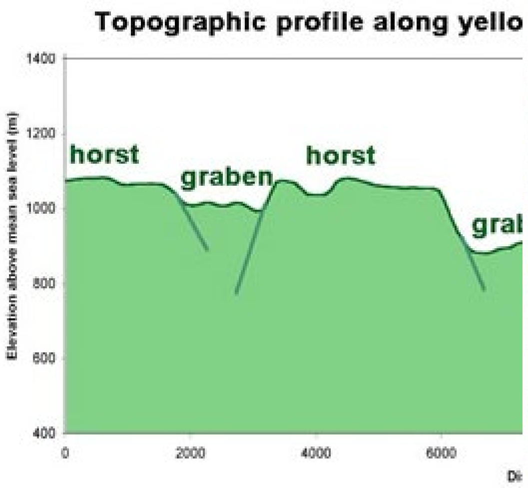


2. Layers are cut by normal faults



3. Down-dropped blocks are grabens, and upthrown blocks are horsts, note that the extension that occured.

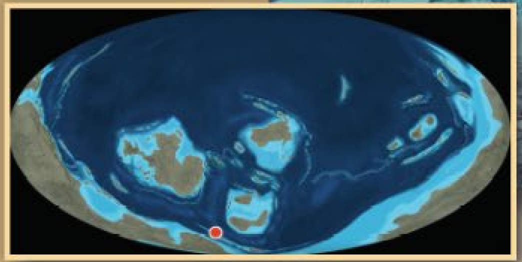




USGS
science for a changing world

Trek Through Time **Cambrian Period** *541-485* million years ago

Courtesy of Masato Hattori



Courtesy of Deep Time Maps produced by Colorado Plateau Geosystems, Inc.

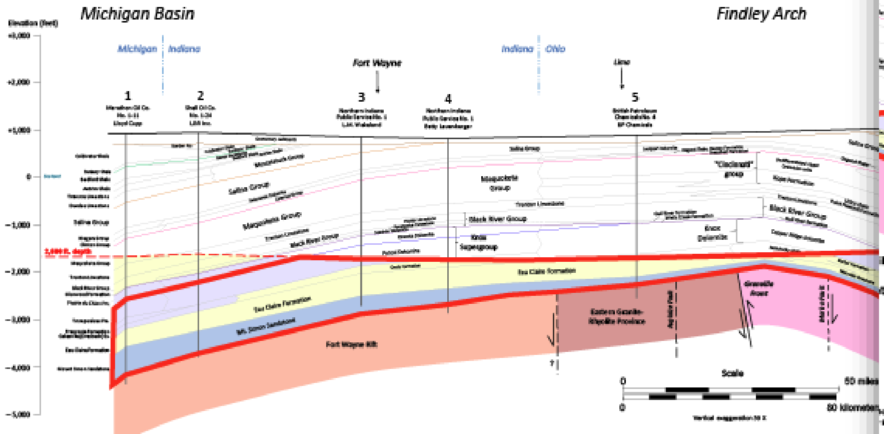
PALEOZOIC ERA *541-252 million years ago*

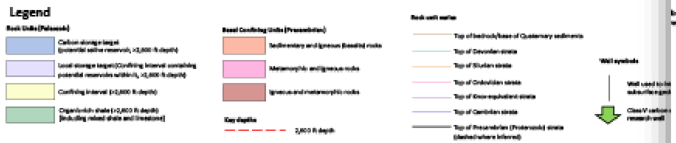

Eq
60° S
Early Cambrian -- 540 Ma (550-530)
0
600 Mi
0
1000 Km

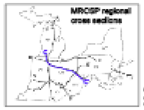

Eq
30° S
Late Cambrian -- 500 Ma (505-495)
0
600 Mi
0
1000 Km

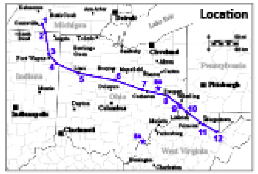
Subsurface geology for carbon storage in part of th
Southern Mi

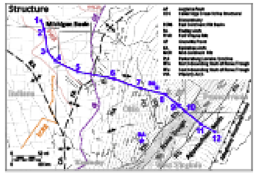
Eric Lewis[1], Stephen F. Greb[2], Phil Dinterman[1], Michael P. Solis[3], Cristian
1 West Virginia Geological and Economic Survey 2 Kentucky Geological Sur
Water Survey, Indiana University 3 Pennsylvania Bureau of the Geo

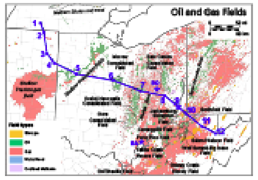












Explanation

This cross section extends from the southern margin of the Michigan Basin, across the arches province of eastern Ohio, and southeastward into the Appalachian Basin in West Virginia. The section crosses through, or near, several large cities, power plants, and industrial areas with significant CO_2 emissions. Future regulations may limit carbon emissions, so it is important to understand the potential for safe geologic storage of CO_2 in the subsurface and for CO_2 use in enhanced oil and gas recovery. Geologic storage involves the capture of carbon emissions and the injection of captured CO_2 under pressure into reservoirs with sufficient seals and confining zones deep underground to prevent migration of injected CO_2 into shallower strata (e.g., NETL, 2015).

This cross section was constructed to help industry, policy makers, and the general public visualize the geology of rock units relative to subsurface carbon storage as part of the research efforts of the Midwest Regional Carbon Sequestration Partnership (MRCSP). Subsurface units in the cross section are color-coded at depths greater than 2,600 ft based on a unit's potential as a (1) storage interval (regional saline reservoir), (2) confining interval with local potential reservoirs, (3) confining zone, or (4) organic-rich shale. Units are color-coded at depths greater than 2,600 ft, which is a conservative estimate of the depth needed for CO_2 to be in a dense super-critical phase (with variation). Below this depth, natural pressures beneath the surface should be great enough to cause CO_2 to dramatically decrease in volume allowing for maximum storage capacity. This depth should also allow CO_2 to be miscible in oil, for efficient use in enhanced oil recovery.

The cross section is based on 12 deep wells, one in Michigan, three in Indiana, five in Ohio, and three in West Virginia. Deep wells with the best down-hole geophysical logs available were chosen for correlations in order to illustrate the relationship between depth and potential future carbon storage units along the section. The eastern end of the section follows part of cross section D–D' of Ryder et al. (2009), which highlighted Cambrian and Ordovician rocks in the subsurface. The current cross section shows all strata from the surface to depth. Well data used in the section are from the Indiana, Kentucky, Ohio, and West Virginia geological surveys. The FEGENCO No. 1 well (no. 9 on the cross section) was drilled by the MRCSP for CO_2-storage research. Additional CO_2 research wells in the region near the cross section are shown on the location map.

Potential carbon storage reservoirs are examined below 2,600 ft depth and above the Precambrian surface. The depth to the Precambrian surface is influenced by geologic structures, including regional basins, arches, and faults (see structure map). Fault locations and vertical extent through the Paleozoic rocks are based on regional studies by Patchen et al. (2006). Rock units shallow to the south out of the Michigan Basin above the Findlay Arch and along the Grenville Front, before deepening southeastward into the Appalachian Basin. In West Virginia, the section traverses the Rome Trough, in which thick accumulations of Cambrian sediments were deposited (Harris et al., 2004; Ryder et al., 2006, 2009).

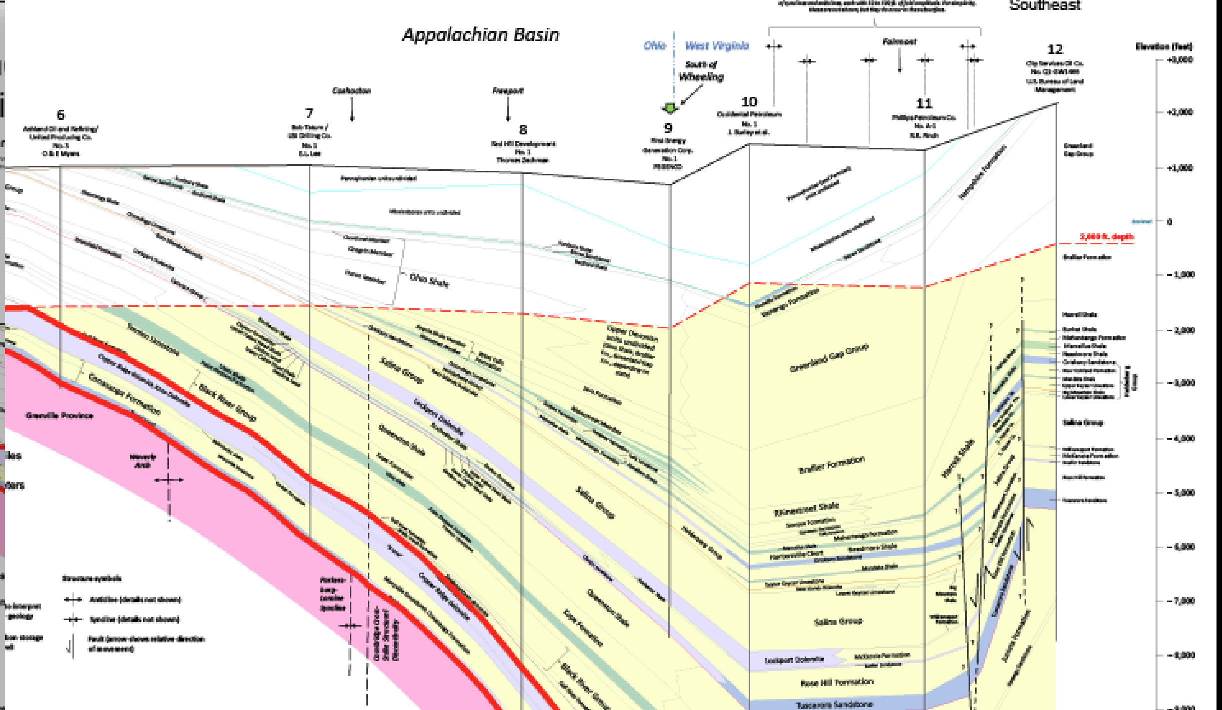
The Cambrian Mount Simon Sandstone is thick and permeable on the western end of the cross section. It is used for industrial waste disposal near Gary, Indiana (west of South Bend on location map), and is one of the primary potential carbon storage intervals in the region (Barnes et al., 2009; Medina and Rupp, 2012; Sminchak, 2012; NETL, 2015). The Mount Simon Sandstone thins as it shallows toward the Grenville Front in western Ohio, and is correlative to the thinner basal sand in Ohio east of the Grenville Front.

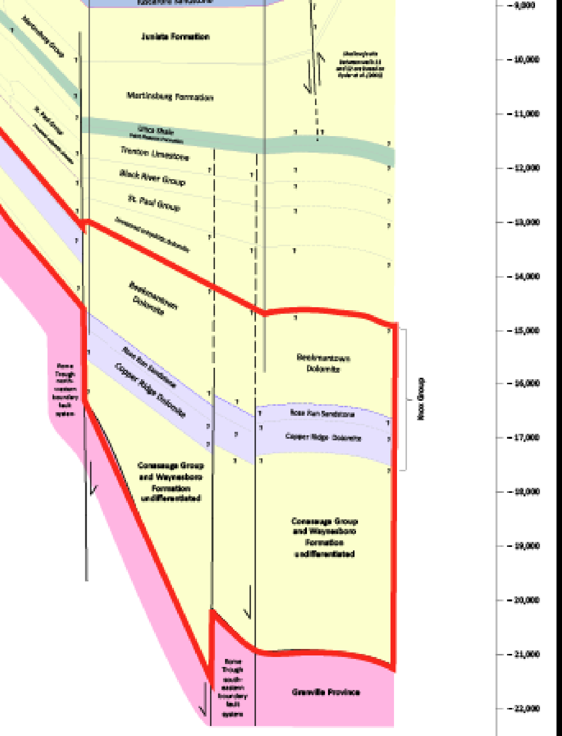
East of the Findlay Arch, the section approximately parallels the dip of strata into the Appalachian Basin (see structure map), with units gradually deepening and some thickening to the east. Potential saline reservoirs for CO_2 storage in the eastern part of the section include parts of the (1) Upper Cambrian Copper Ridge Dolomite, and Rose Run Sandstone, (2) Silurian Tuscarora Sandstone, (3) Keefer Sandstone, and (4) Cataract-Medina Group (including the "Clinton" and "Medina" sand of drillers), and (5) Devonian Oriskany and (6) Berea sandstones. Information about the reservoir characteristics and carbon storage potential of these units can be found in MRCSP and other reports (Roen and Walker, 1996; Wickstrom et al., 2005; Carter et al., 2010; 2012; Riley et al., 2010; Battelle Memorial Institute, 2011a, b; Greb et al., 2012; Medina et al., 2012).

A large amount of data was collected from the Cambrian basal sandstone, Rose Run Sandstone, and overlying strata in a well drilled by the Ohio Division of the Geological Survey between wells 7 and 8 on the cross section (BO on location map, Wickstrom et al., 2011). Carbon storage tests in the Copper Ridge B zone and Rose Run Sandstone were conducted at the Mountaineer power plant (BA on map), south of the section (Bacon et al., 2007; 2009; Gupta et al., 2013). Deeper downdip, the FEGENCO No 1 well (no. 9 on the section) was a Class V CO_2 injection test well and one of the first wells in the region to test the potential for CO_2 storage at a coal-fired power plant (Wickstrom et al., 2008). The well found insufficient permeability for injection at depth in the Silurian-aged Clinton Sandstone, Salina Group dolomites, and Devonian-aged Oriskany Sandstone, but collected significant data on these units and their caprocks (Battelle, 2011a; Gupta et al., 2011).

In the east, the cross section is near numerous oil and gas fields. CO_2 can be used for enhanced oil recovery (EOR) in conventional reservoirs, enhanced gas recovery (EGR) in unconventional reservoirs, as well as for repressurizing depleted reservoirs (e.g., NETL, 2015), especially in hydrocarbon accumulations encountered at depths greater than approximately 2,600 ft. Although many of the fields shown on the oil and gas map produce at depths shallower than 2,600 ft, some of these fields may exhibit unique pressure and temperature conditions that promote near-miscible conditions, and several deeper fields have potential for EOR or EGR via miscible CO_2 floods. Outlined and named fields on the oil and gas map are discussed in MRCSP Phase 3 reports. The East Canton, Gratiot-Newcastle, and Gore fields have significant EOR potential (e.g., Mishra et al., 2014) from reservoirs in the Silurian Clinton-Medina interval. Small-scale field tests of CO_2 injectivity and modeling of the Silurian Clinton sands in in the East Canton Field have had positive results (Riley et al., 2009) Eastward, Devonian "Gordon sands" of the Hampshire Formation in the Salem-Wallace and Wolf Summit-Big Isaac fields, and the Mississippian "Big Injun" sand in the Centerpoint and Granny Creek fields (in individual Mississippian units on the cross section and labeled on the inset oil and gas map) may have near-miscible CO_2 EOR potential. The Big Injun sand has safely been used for natural gas storage at relatively shallow depths in West Virginia.

Organic-rich shales (green on cross section) such as the Upper Ordovician Utica Shale, and the Devonian Marcellus, and Burket shales may have potential for enhanced gas recovery with CO_2 (Nuttall, 2010; Patchen and Carter, 2015), but more research is needed. More information regarding CO_2 storage and enhanced oil and gas recovery opportunities in the region are available at the MRCSP website (mrcsp.org), and in published reports summarizing research (Wickstrom et al., 2005; Riley et al., 2010; Battelle, 2011b; see Phase 3 results).





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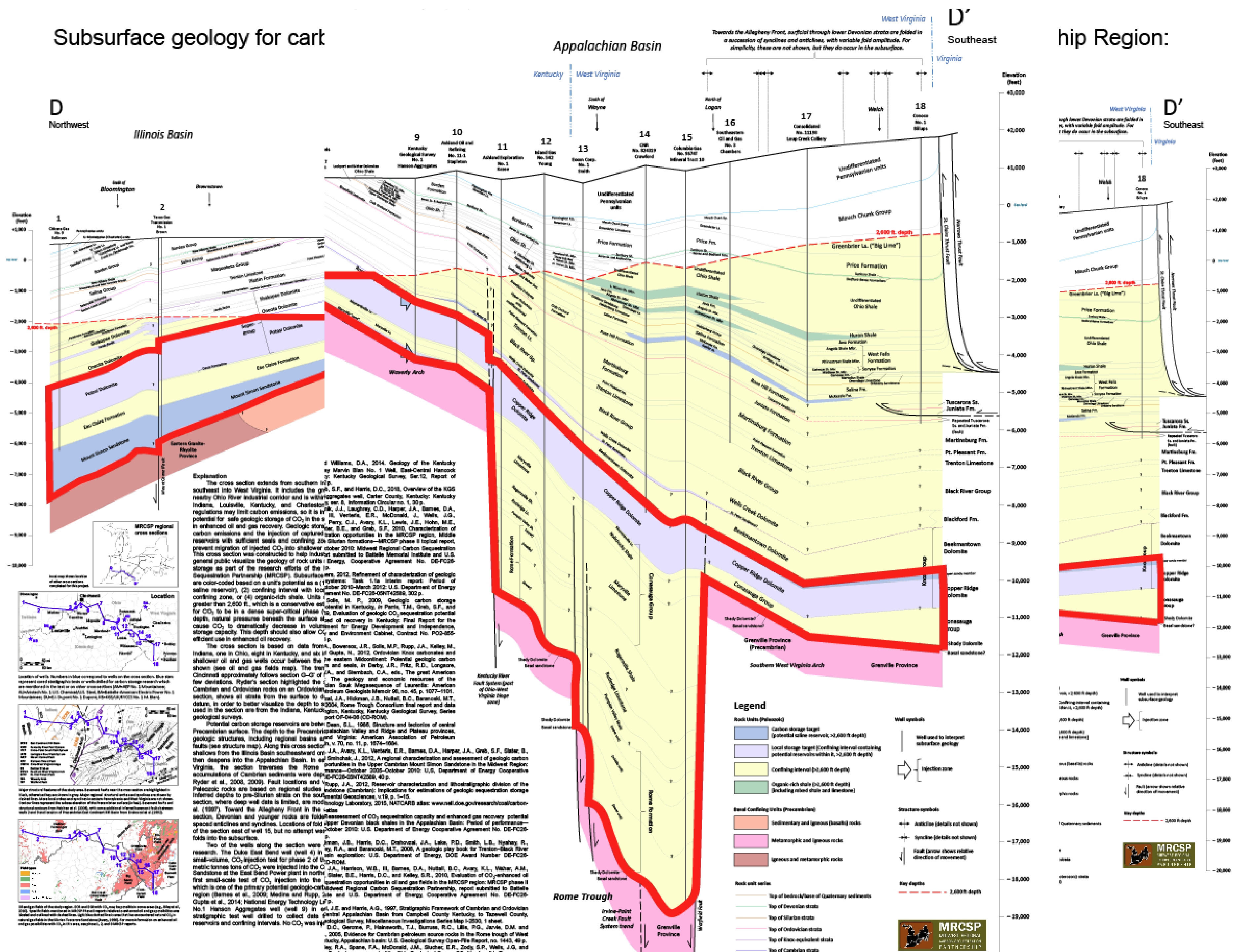
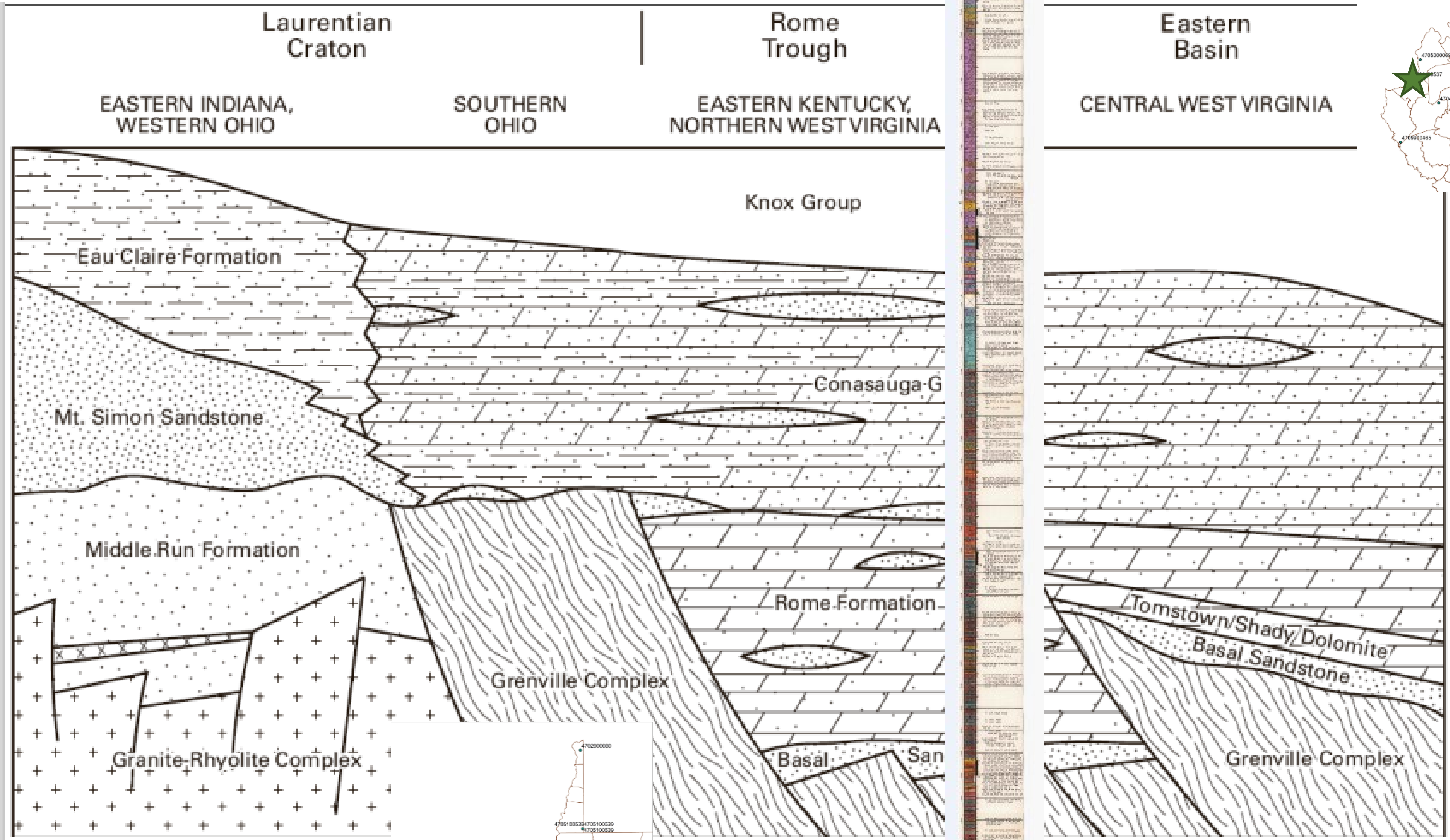
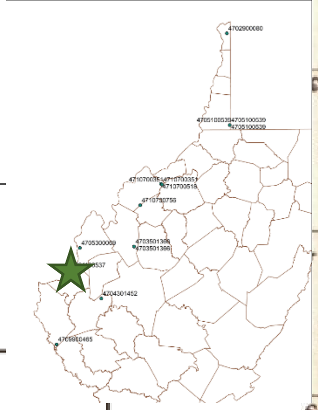
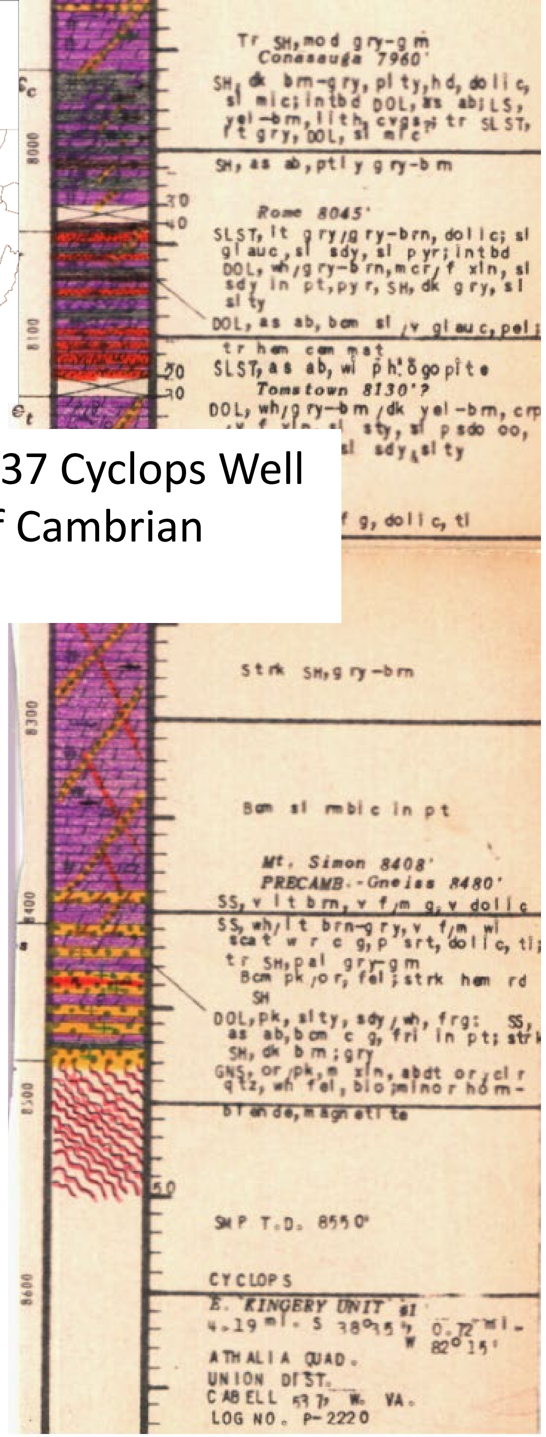
Subsurface geology for cart … hip Region:



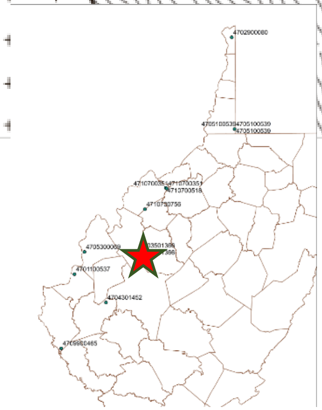




Cabell 537 Cyclops Well
~520' of Cambrian
Strata



Jackson 1366
McKoy#1 Well
~4969' of
Cambrian Strata



AEP Mountaineer
New Haven, WV
Injection Test

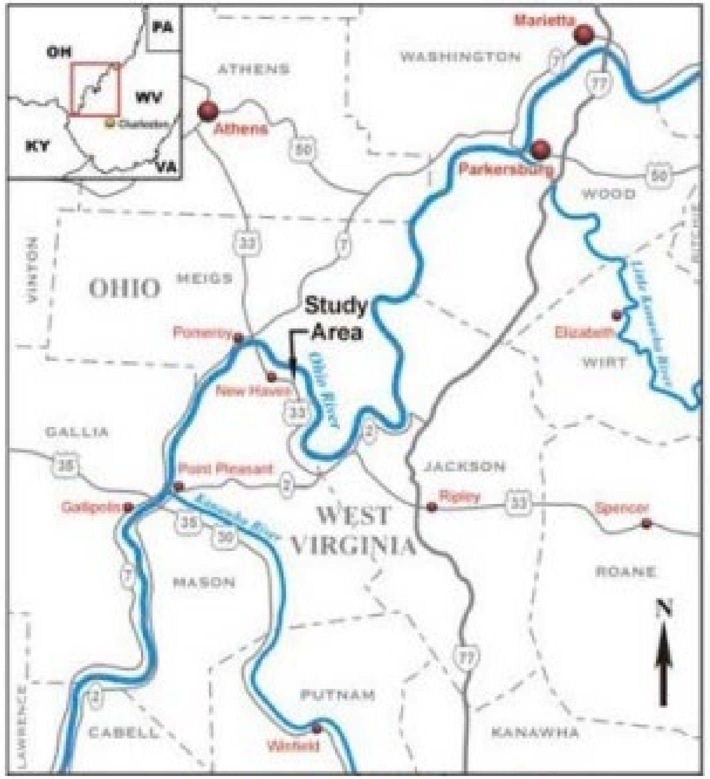
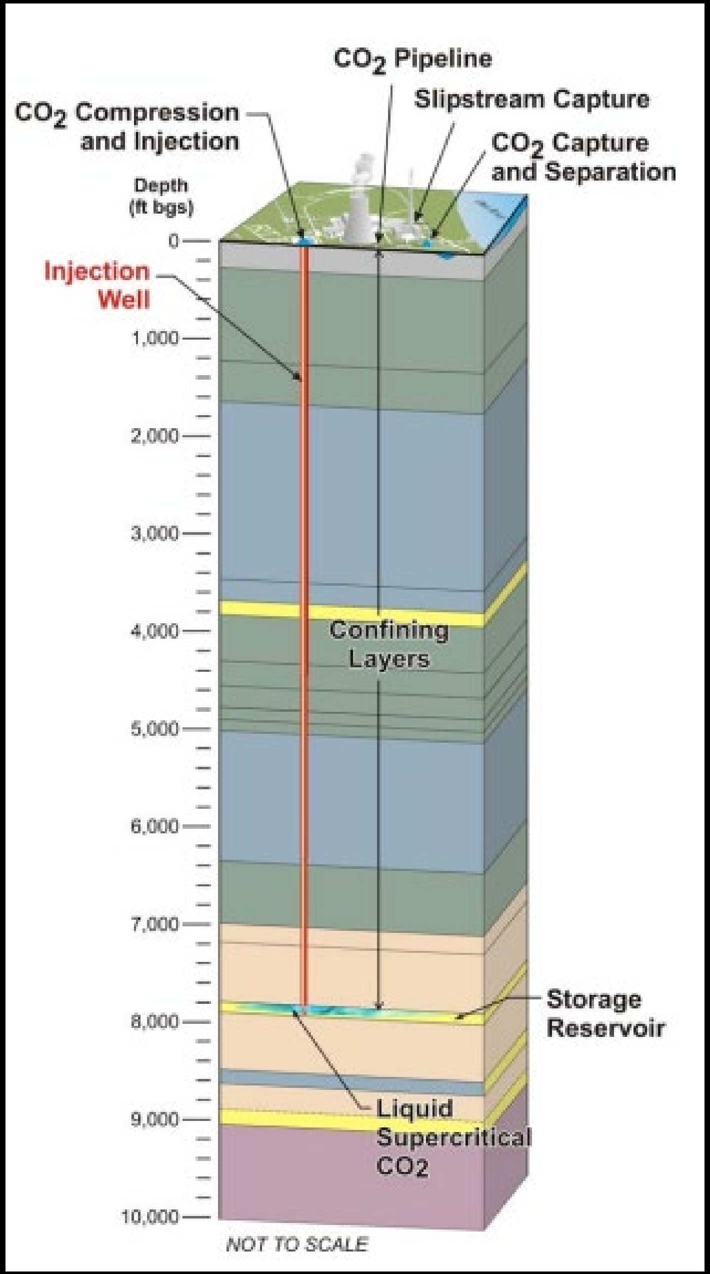
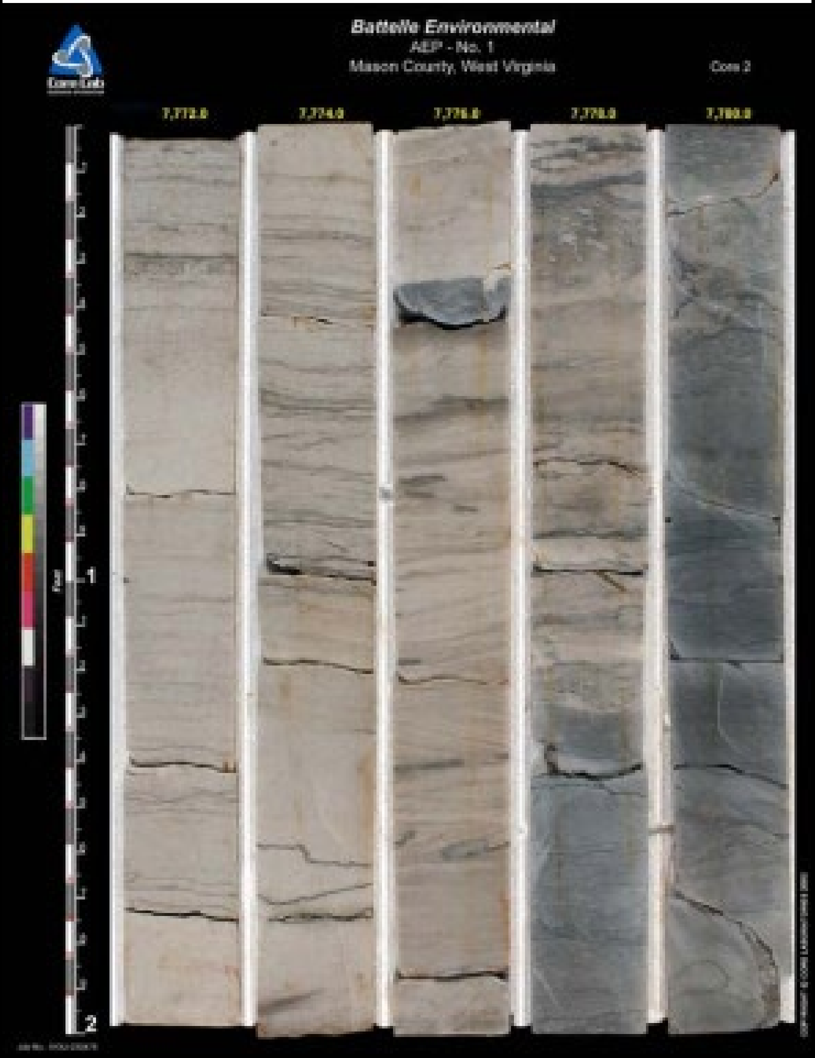


Figure 3-1. Study Area Location





Rose Run Sandstone 7,772 — 7,782 ft.

Upper Cambrian Section, Calhoun County, WV

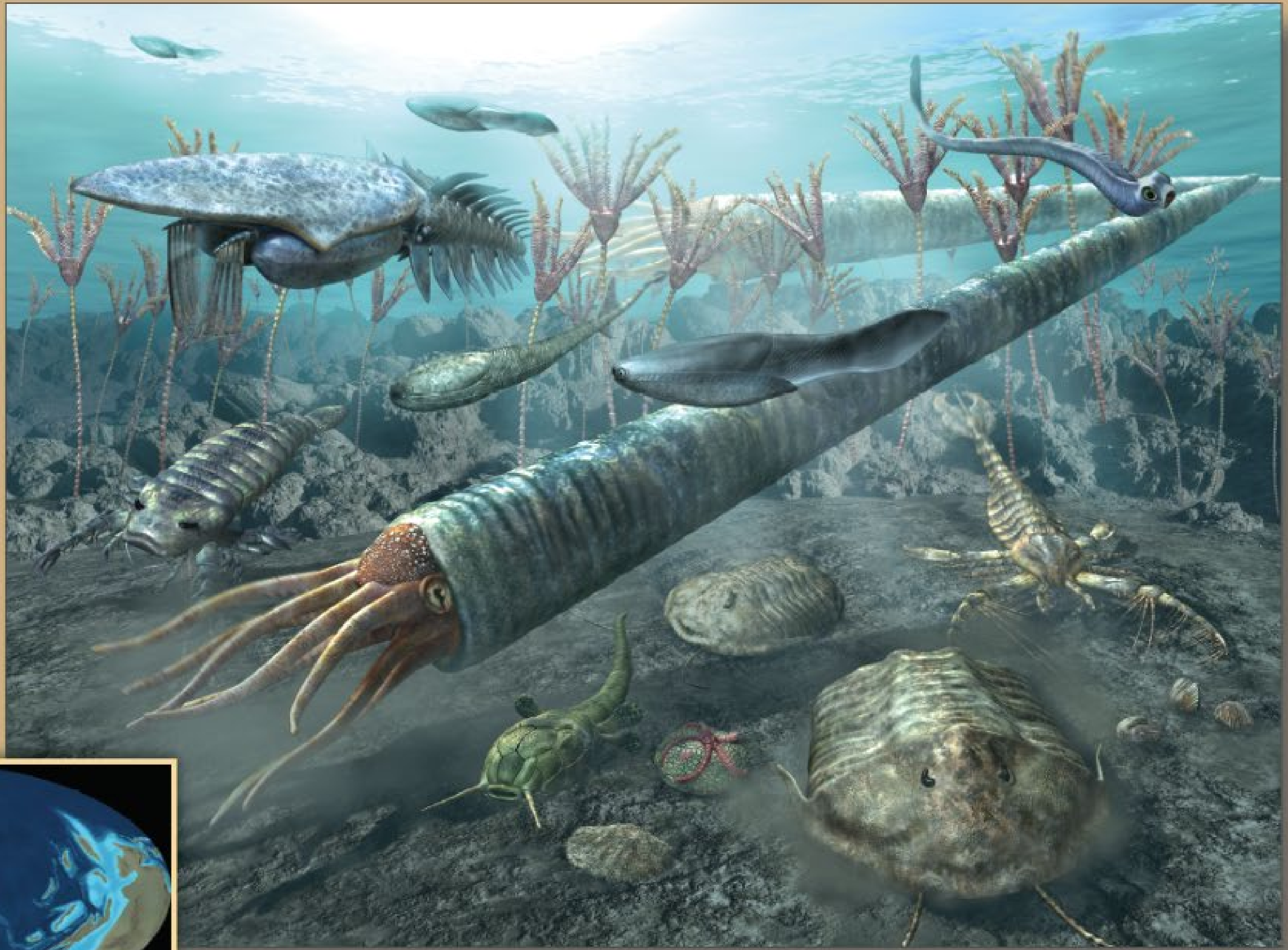
Deep Cambrian Section

- Abrupt thickening in Rome Trough; up to 20K ft. depth
- Thousands of feet of limestone, dolomite, and shale
- Coarser sands present (Basal Sand, Rose Run), and can be thick, but are poorly understood.
- Areas of hydrothermal mineralization in dolomites (Copper Ridge)

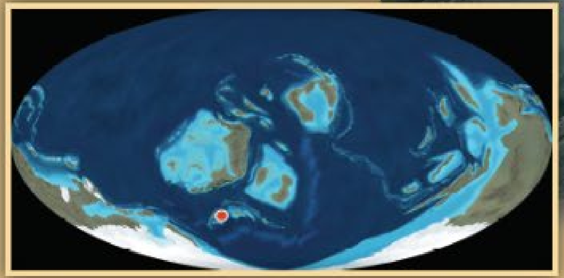
Exxon Gainer-Lee
Calhoun County, WV
15,250 ft.
200x magnification

USGS
science for a changing world

Trek Through Time **Ordovician Period** *485-444* million years ago

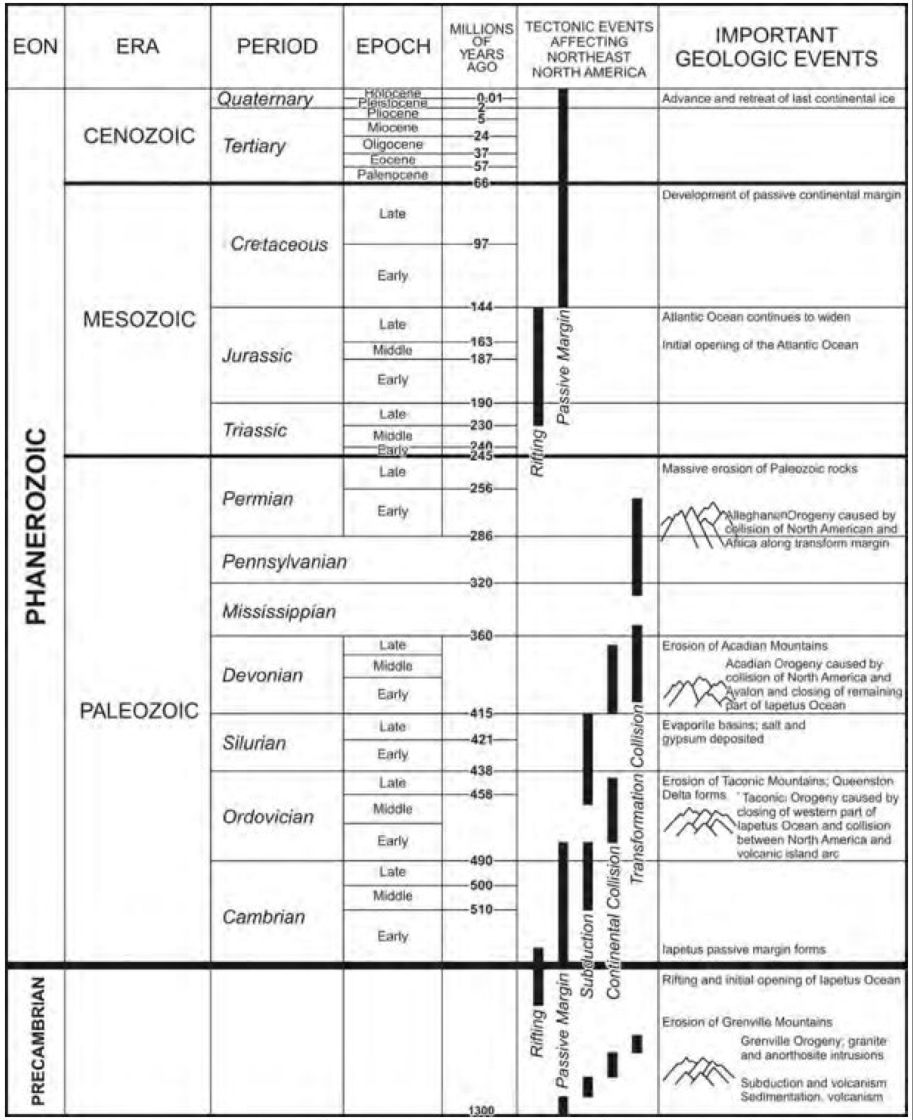


Courtesy of Masato Hattori

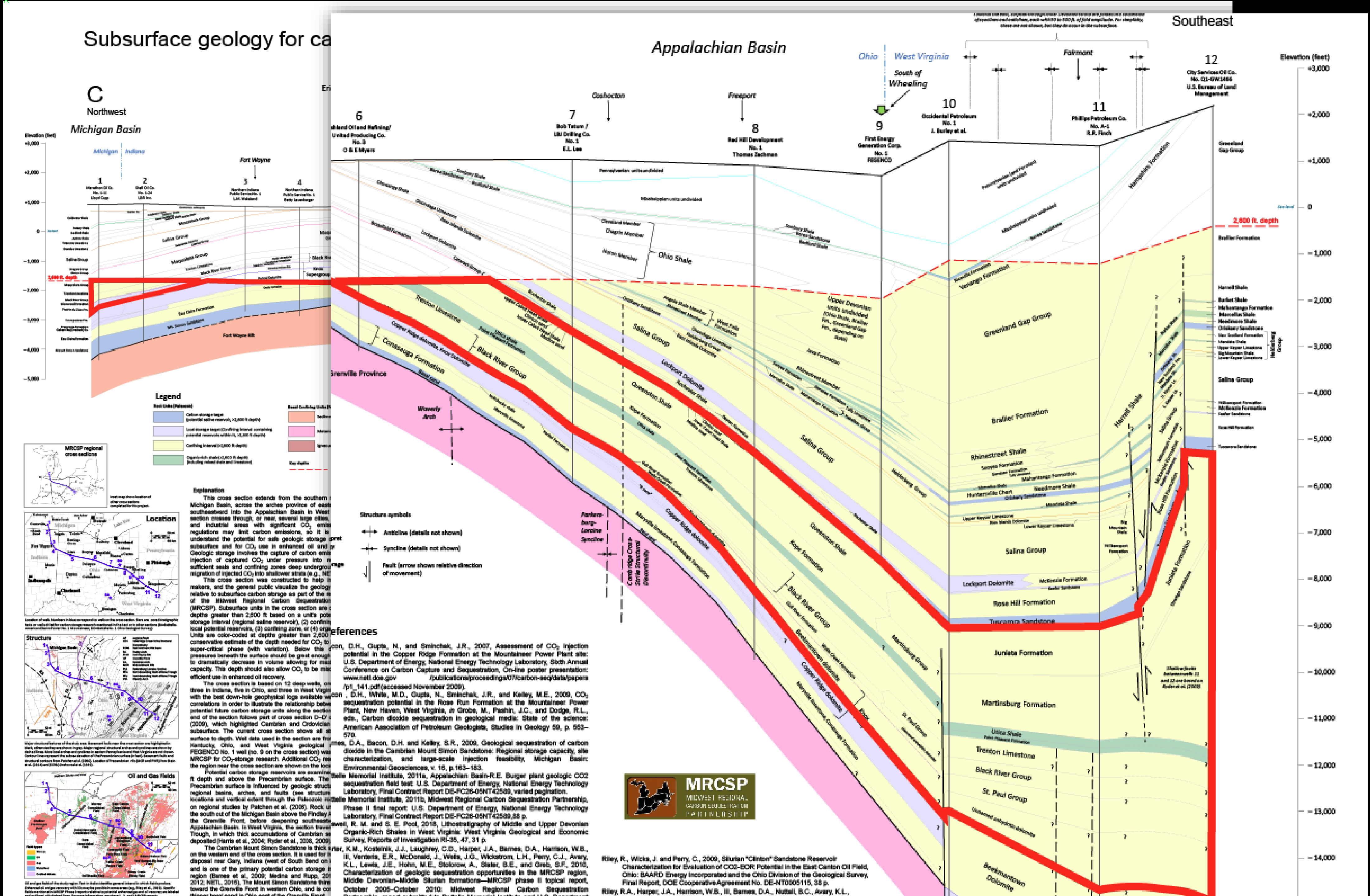


Courtesy of Deep Time Maps produced by Colorado Plateau Geosystems, Inc.

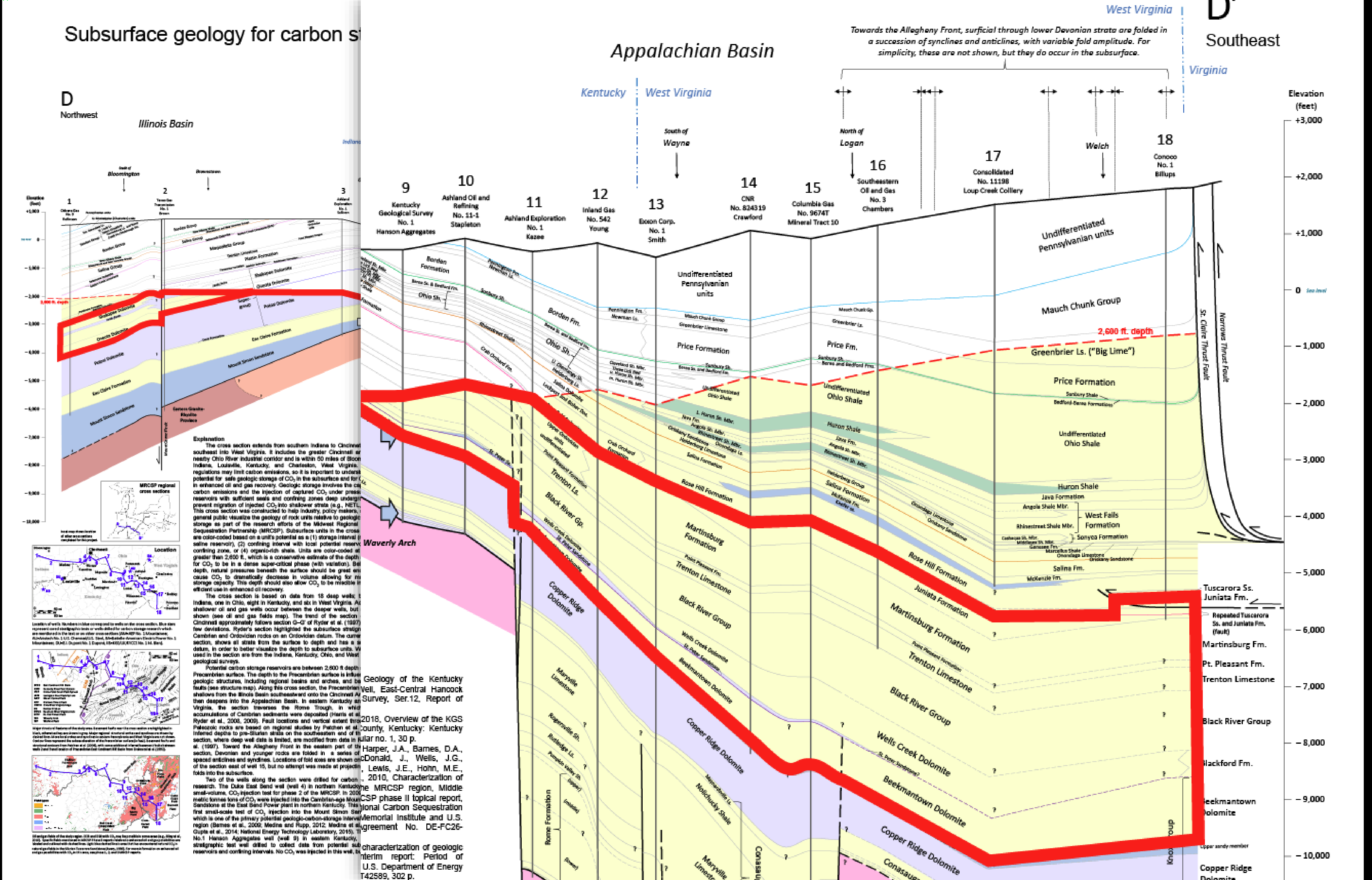
PALEOZOIC ERA *541-252 million years ago*



Note: Geologic time is presented on the left. Major tectonic events and their effect on depositional and post-depositional processes are presented on the right. (modified from *Geologic History of New York*)

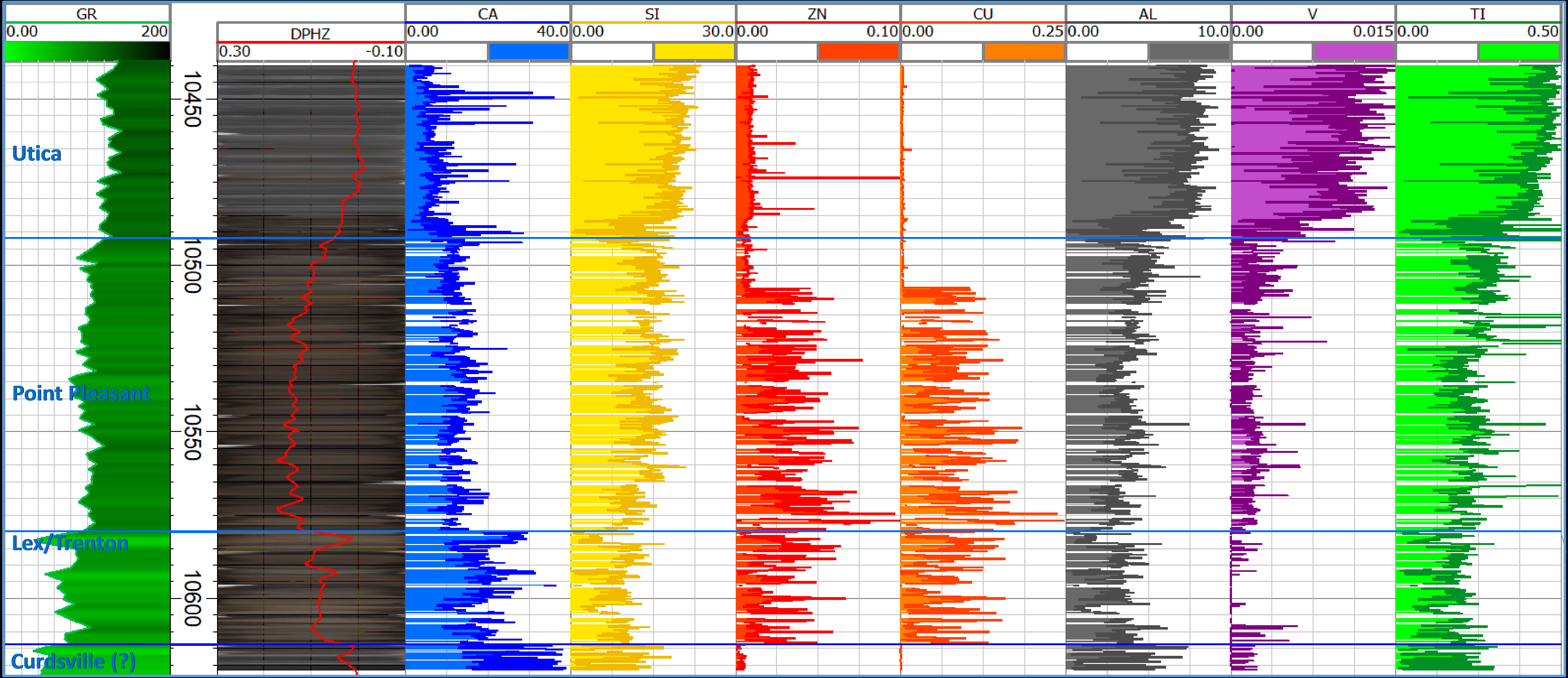


Subsurface geology for ca
C
Northwest
Michigan Basin
Michigan
Indiana
Fort Wayne
Legend
Explanation
Location
Structure
Oil and Gas Fields
Appalachian Basin
Southeast
Ohio
West Virginia
South of Wheeling
Coshocton
Freeport
Fairmont
Elevation (feet)
2,600 ft. depth
Ohio Shale
Salina Group
Trenton Limestone
Black River Group
Conasauga Formation
Grenville Province
Lockport Dolomite
Queenston Shale
Kope Formation
Greenland Gap Group
Brallier Formation
Rhinestreet Shale
Tuscarora Sandstone
Juniata Formation
Martinsburg Formation
Utica Shale
St. Paul Group
Beekmantown Dolomite
Rose Hill Formation
Waverly Arch
Structure symbols
Anticline (details not shown)
Syncline (details not shown)
Fault (arrow shows relative direction of movement)
References
MRCSP



Subsurface geology for carbon st
D
Northwest
Illinois Basin
Appalachian Basin
Kentucky
West Virginia
Virginia
D'
Southeast
Towards the Allegheny Front, surficial through lower Devonian strata are folded in a succession of synclines and anticlines, with variable fold amplitude. For simplicity, these are not shown, but they do occur in the subsurface.
South of Wayne
North of Logan
Welch
9 Kentucky Geological Survey No. 1 Hanson Aggregates
10 Ashland Oil and Refining No. 11-1 Stapleton
11 Ashland Exploration No. 1 Kazee
12 Inland Gas No. 542 Young
13 Exxon Corp. No. 1 Smith
14 CNR No. 824319 Crawford
15 Columbia Gas No. 9674T Mineral Tract 10
16 Southeastern Oil and Gas No. 3 Chambers
17 Consolidated No. 11198 Loup Creek Colliery
18 Conoco No. 1 Billups
Elevation (feet)
+3,000
+2,000
+1,000
0
– 1,000
– 2,000
– 3,000
– 4,000
– 5,000
– 6,000
– 7,000
– 8,000
– 9,000
– 10,000
Undifferentiated Pennsylvanian units
Mauch Chunk Group
2,600 ft. depth
Greenbrier Ls. ("Big Lime")
Price Formation
Undifferentiated Ohio Shale
Huron Shale
Java Formation
West Falls Formation
Sonyea Formation
Salina Fm.
Borden Formation
Ohio Sh.
Borden Fm.
Price Formation
Rose Hill Formation
Juniata Formation
Martinsburg Formation
Trenton Limestone
Black River Group
Wells Creek Dolomite
Beekmantown Dolomite
Copper Ridge Dolomite
Maryville Limestone
Rome Formation
Waverly Arch
St. Clair Thrust Fault
Narrows Thrust Fault
Tuscarora Ss.
Juniata Fm.
Repeated Tuscarora Ss. and Juniata Fm. (fault)
Martinsburg Fm.
Pt. Pleasant Fm.
Trenton Limestone
Black River Group
Blackford Fm.
Beekmantown Dolomite
Copper Ridge Dolomite
Explanation

Utica/Point Pleasant: Metalliferous Black Shale?



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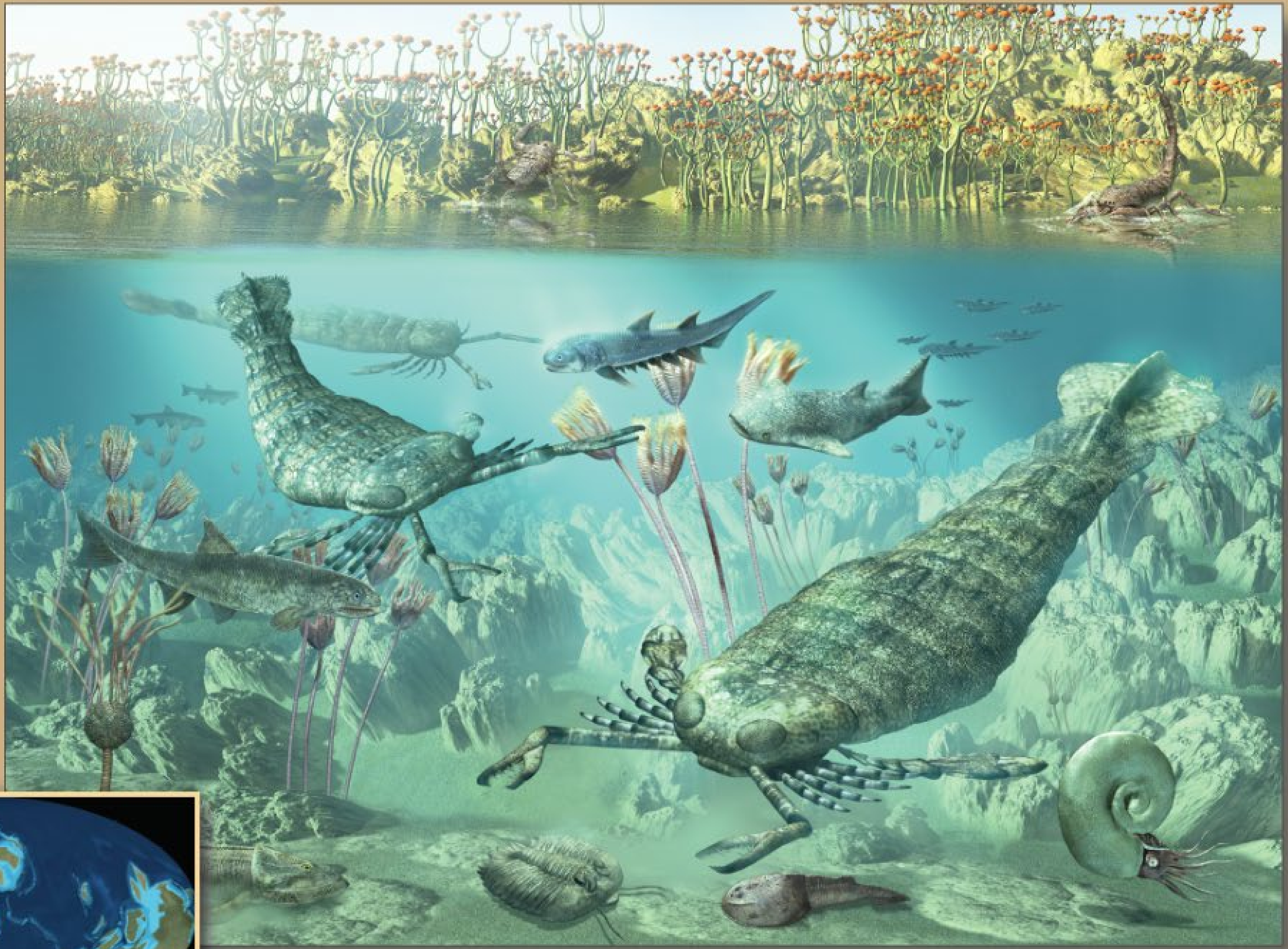
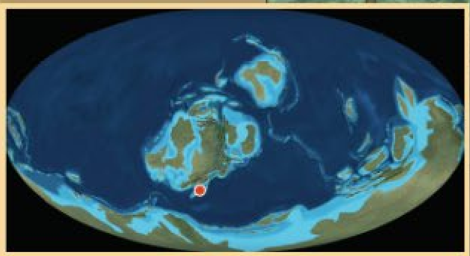
Trek Through Time **Silurian Period** *444-419* million years ago

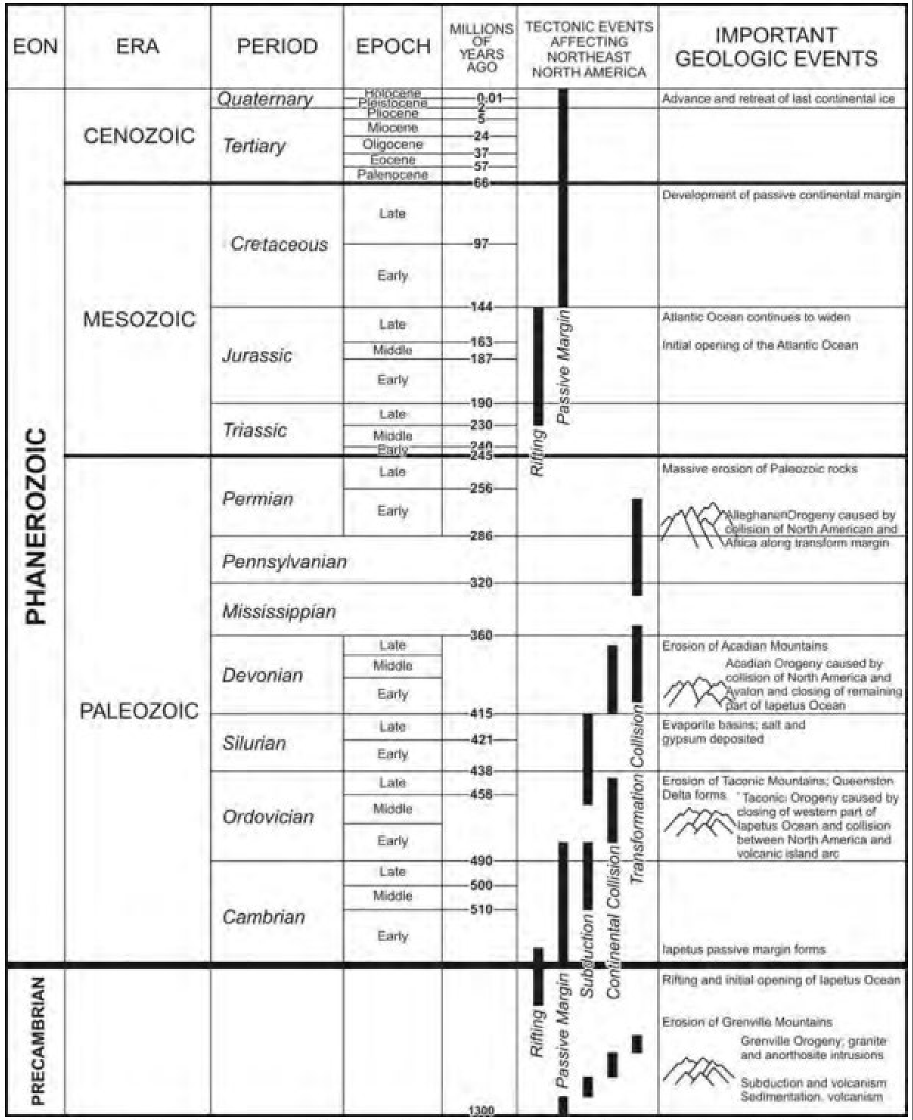


Courtesy of Masato Hattori

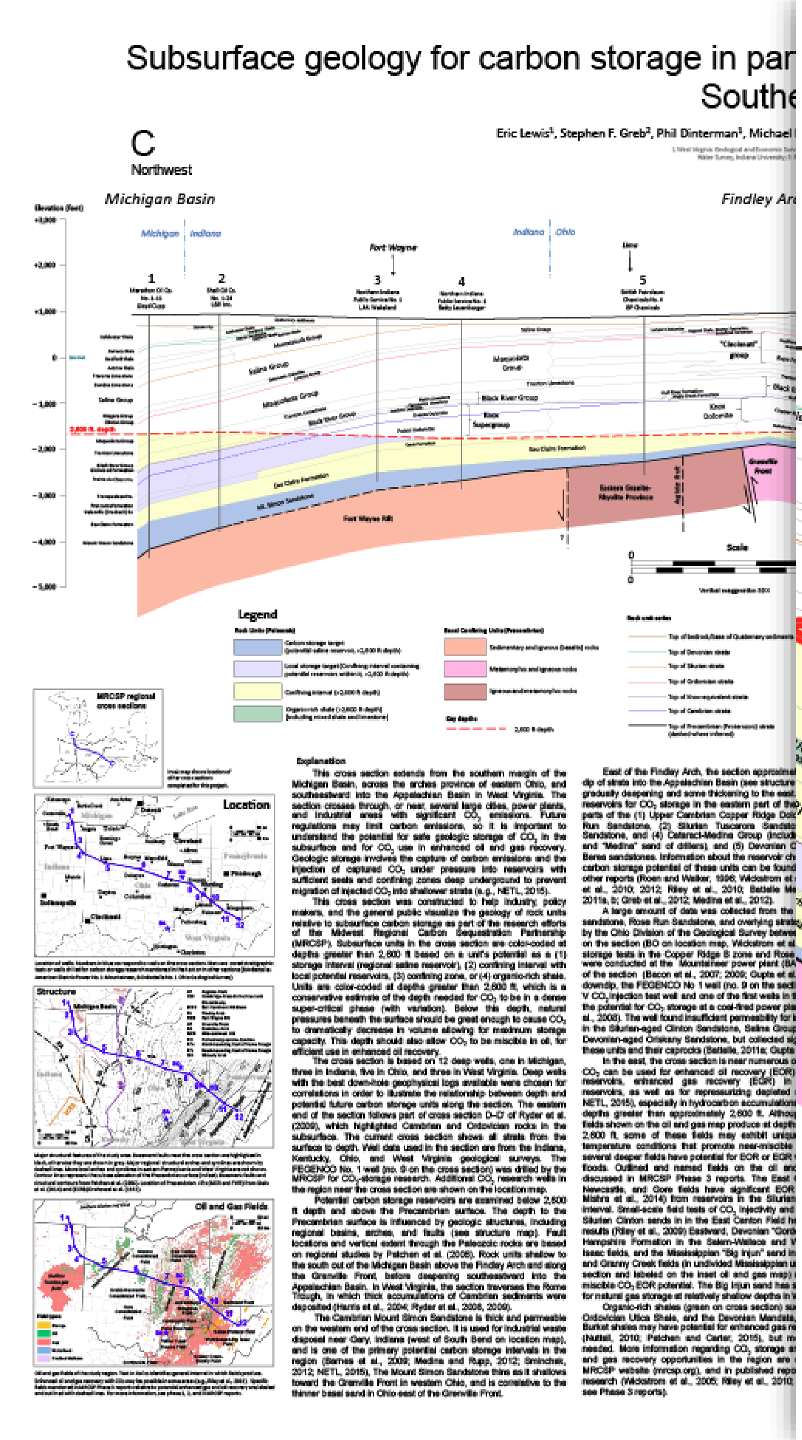


Courtesy of Deep Time Maps produced by Colorado Plateau Geosystems, Inc.

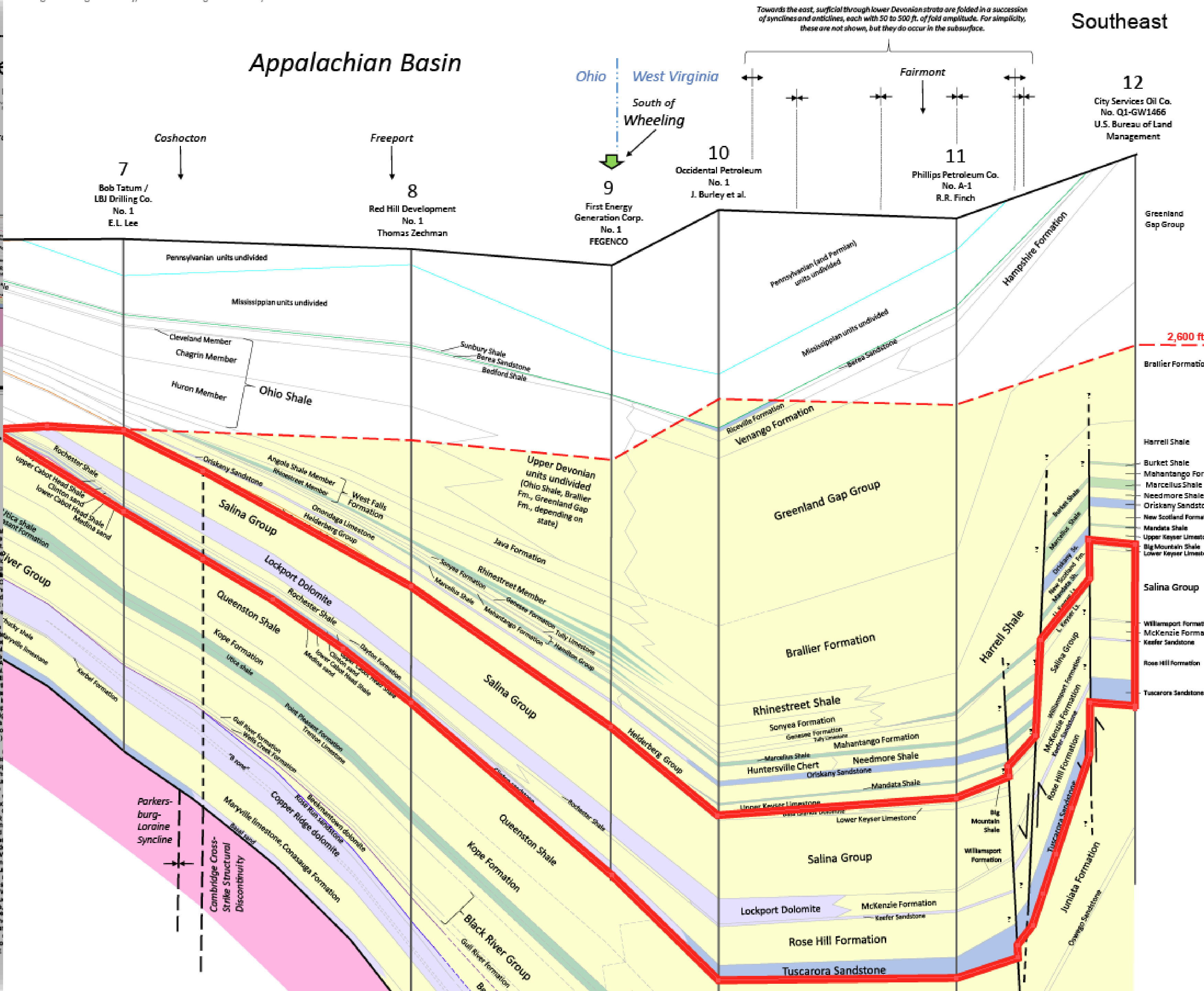
PALEOZOIC ERA *541-252 million years ago*



Note: Geologic time is presented on the left. Major tectonic events and their effect on depositional and post-depositional processes are presented on the right. (modified from *Geologic History of New York*)



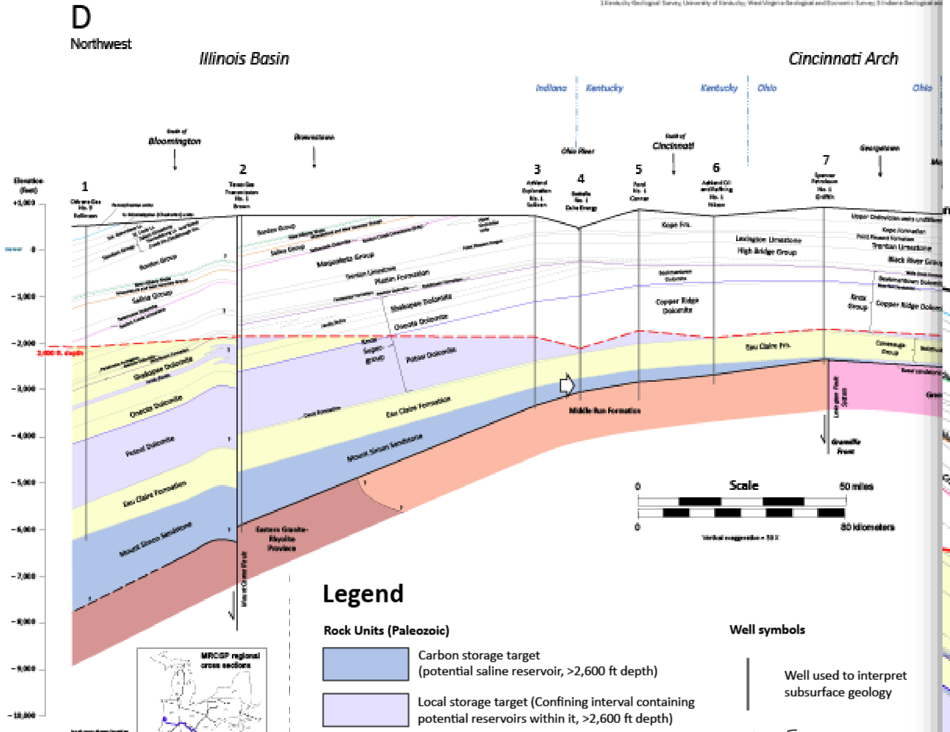
Subsurface geology for carbon storage in par
Southe
C
Northwest
Michigan Basin
Findley Ar
Eric Lewis[1], Stephen F. Greb[2], Phil Dinterman[1], Michael
Legend
Explanation
Location
Structure
Oil and Gas Fields
MRCSP regional cross sections

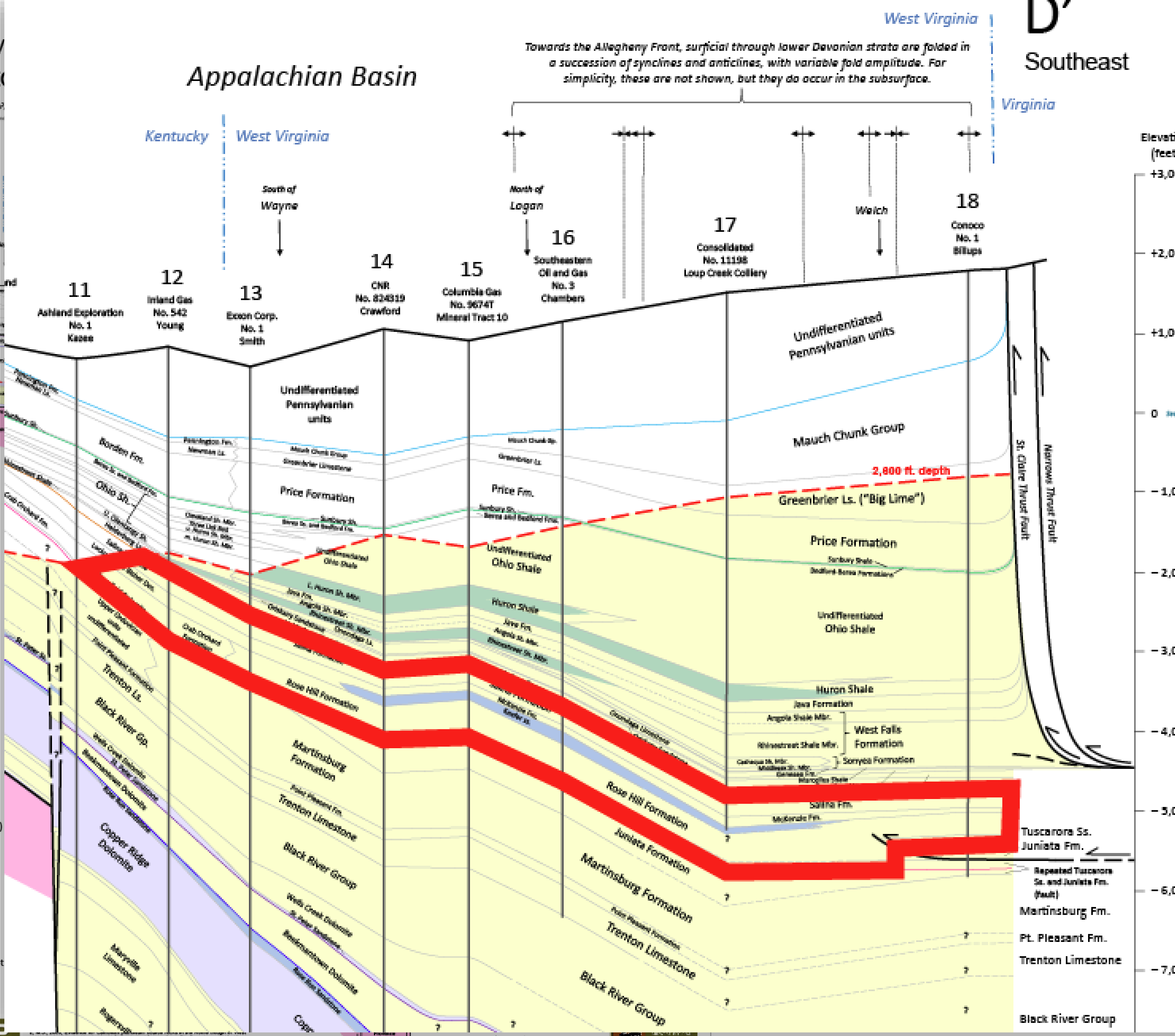


Appalachian Basin
Southeast
Towards the east, surficial through lower Devonian strata are folded in a succession of synclines and anticlines, each with 50 to 500 ft. of fold amplitude. For simplicity, these are not shown, but they do occur in the subsurface.
Ohio
West Virginia
South of Wheeling
Fairmont
Coshocton
Freeport
7
Bob Tatum / LBJ Drilling Co. No. 1 E.L. Lee
8
Red Hill Development No. 1 Thomas Zechman
9
First Energy Generation Corp. No. 1 FEGENCO
10
Occidental Petroleum No. 1 J. Burley et al.
11
Phillips Petroleum Co. No. A-1 R.R. Finch
12
City Services Oil Co. No. Q1-GW1466 U.S. Bureau of Land Management
Pennsylvanian units undivided
Mississippian units undivided
Cleveland Member
Chagrin Member
Huron Member
Ohio Shale
Sunbury Shale
Berea Sandstone
Bedford Shale
Upper Devonian units undivided (Ohio Shale, Brallier Fm., Greenland Gap Fm., depending on state)
Pennsylvanian (and Permian) units undivided
Mississippian units undivided
Berea Sandstone
Hampshire Formation
Riceville Formation
Venango Formation
Greenland Gap Group
Brallier Formation
Rhinestreet Shale
Sonyea Formation
Genesee Formation
Tully Limestone
Mahantango Formation
Marcellus Shale
Needmore Shale
Huntersville Chert
Oriskany Sandstone
Mandata Shale
Upper Keyser Limestone
Lower Keyser Limestone
Salina Group
Lockport Dolomite
McKenzie Formation
Keefer Sandstone
Rose Hill Formation
Tuscarora Sandstone
Juniata Formation
Oswego Sandstone
Harrell Shale
Big Mountain Shale
Williamsport Formation
Rochester Shale
Upper Cabot Head Shale
Clinton sand
Lower Cabot Head Shale
Medina sand
Oriskany Sandstone
Angola Shale Member
Rhinestreet Member
West Falls Formation
Onondaga Limestone
Helderberg Group
Java Formation
Rhinestreet Member
Sonyea Formation
Marcellus Shale
Genesee Formation
Mahantango Formation
Tully Limestone
Hamilton Group
Salina Group
Lockport Dolomite
Rochester Shale
Queenston Shale
Kope Formation
Utica shale
Point Pleasant Formation
Trenton Limestone
Helderberg Group
Black River Group
Gull River Formation
Wells Creek Formation
"B zone"
Beekmantown dolomite
Rose Run sandstone
Copper Ridge dolomite
Maryville limestone, Conasauga Formation
Basal sand
Kerbel Formation
Parkersburg-Loraine Syncline
Cambridge Cross-Strike Structural Discontinuity
2,600 ft
Brallier Formation
Greenland Gap Group
Harrell Shale
Burket Shale
Mahantango For
Marcellus Shale
Needmore Shale
Oriskany Sandsto
New Scotland Forma
Mandata Shale
Upper Keyser Limesto
Big Mountain Shale
Lower Keyser Limesto
Salina Group
Williamsport Format
McKenzie Forma
Keefer Sandstone
Rose Hill Formation
Tuscarora Sandstone

Subsurface geology for carbon storage in part of the Midw[est] Central Indiana t[o]

Stephen F. Greb[1], Thomas N. Sparks[1], Phil Dinterman[2], Eric Lewis[2]





Legend

Rock Units (Paleozoic)

- Carbon storage target (potential saline reservoir, >2,600 ft depth)
- Local storage target (Confining interval containing potential reservoirs within it, >2,600 ft depth)
- Confining interval (>2,600 ft depth)
- Organic-rich shale (>2,600 ft depth) [including mixed shale and limestone]

Basal Confining Units (Precambrian)

- Sedimentary and igneous (basalts) rocks
- Metamorphic and igneous rocks
- Igneous and metamorphic rocks

Rock unit series

- Top of bedrock/base of Quaternary sediments
- Top of Devonian strata
- Top of Silurian strata
- Top of Ordovician strata
- Top of Knox-equivalent strata
- Top of Cambrian strata
- Top of Precambrian (Proterozoic) strata (dashed where inferred)

Well symbols

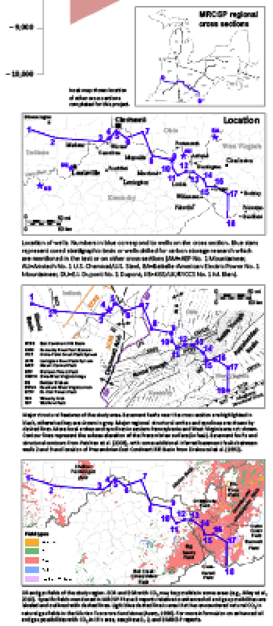
- Well used to interpret subsurface geology
- Injection zone

Structure symbols

- Anticline (details not shown)
- Syncline (details not shown)
- Fault (arrow shows relative direction of movement)

Key depths

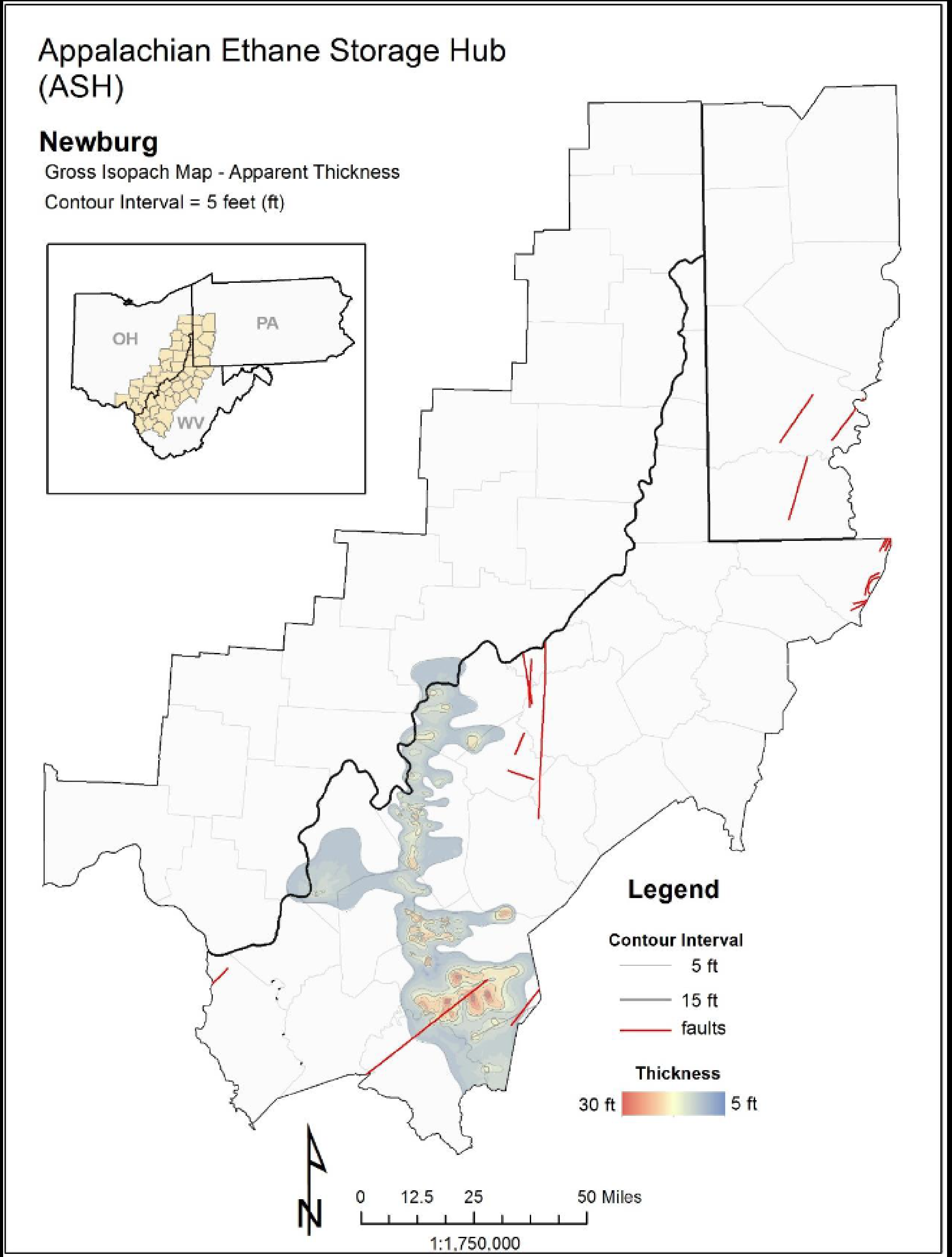
- 2,600 ft dept[h]

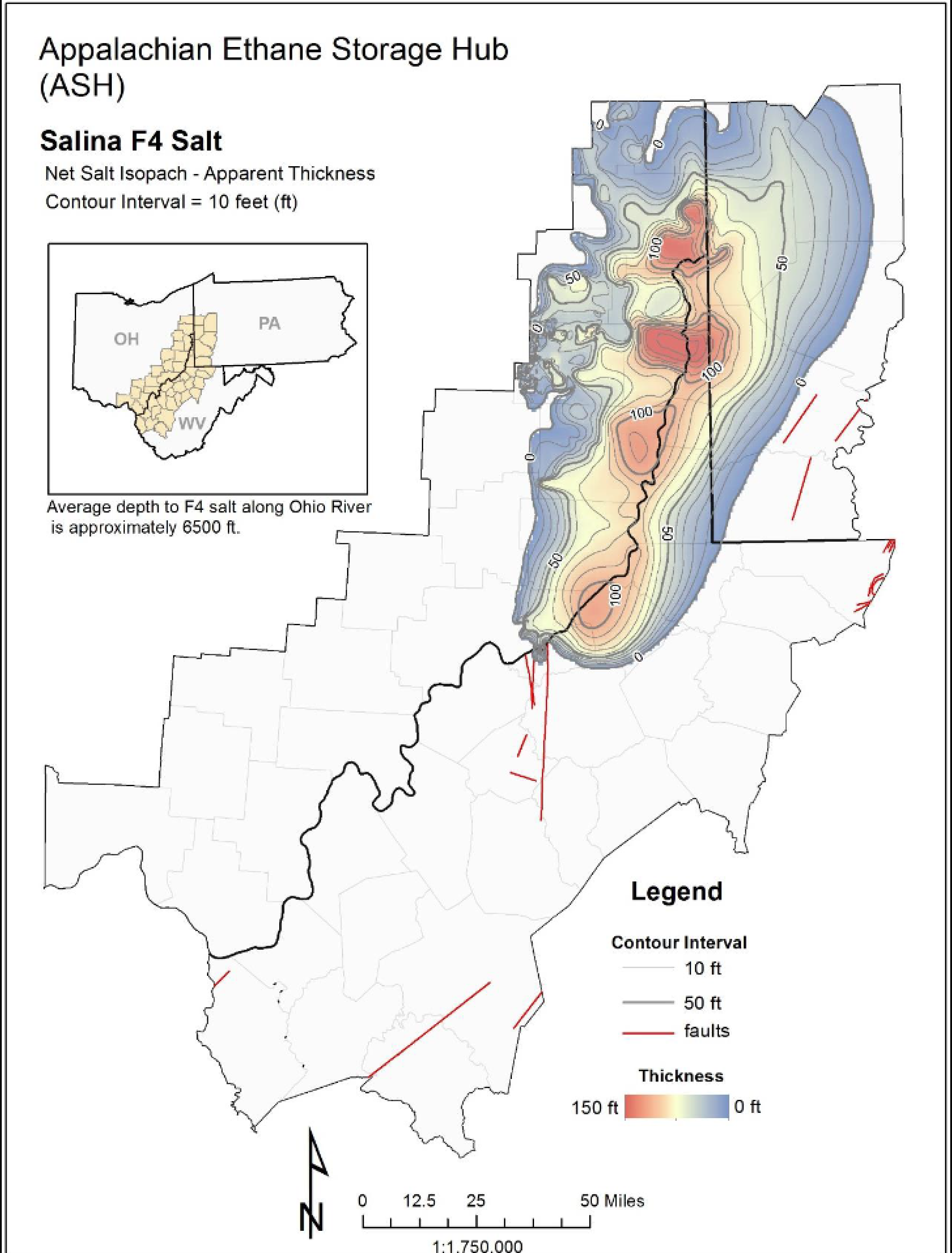


MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Tuscarora Sandstone
Clay County, WV

Silurian Storage Targets: Tuscarora & Newburg Sandstones





Salina F4 Salt
Marshall County, WV

Salina F4 Salt

- Salts are interbedded with other rocks, but can attain thicknesses over 100’
- Forms impermeable seal
- Salt dissolution caverns offer storage options for purity products
- Some Critical Minerals in salt, most embedded in rock material

USGS
science for a changing world

Trek Through Time **Devonian Period** *419-359* million years ago

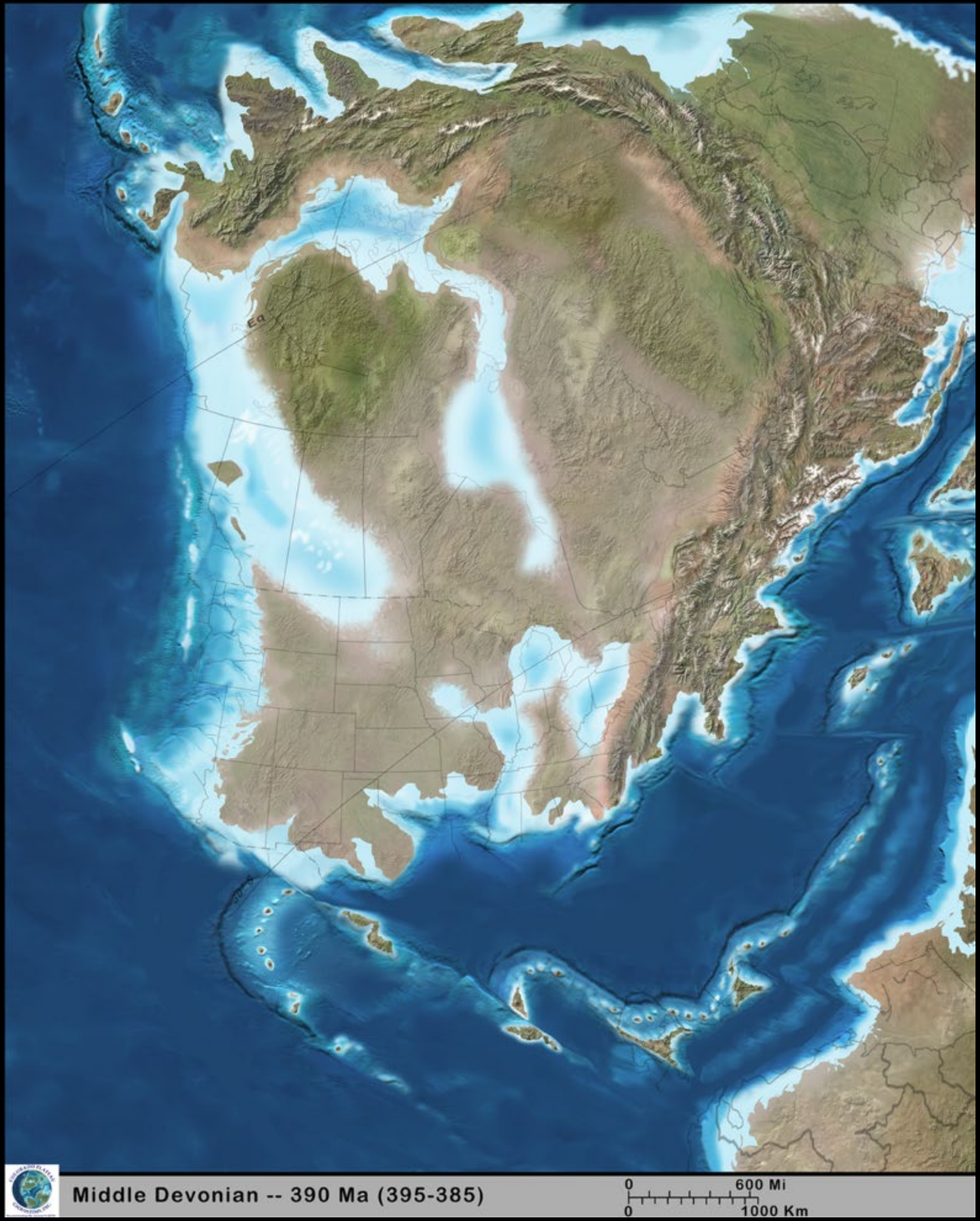
Courtesy of Masato Hattori

Courtesy of Deep Time Maps produced by Colorado Plateau Geosystems, Inc.

PALEOZOIC ERA *541-252 million years ago*

EON	ERA	PERIOD	EPOCH	MILLIONS OF YEARS AGO	TECTONIC EVENTS AFFECTING NORTHEAST NORTH AMERICA	IMPORTANT GEOLOGIC EVENTS
PHANEROZOIC	CENOZOIC	Quaternary	Holocene	0.01		Advance and retreat of last continental ice
			Pleistocene	2		
		Tertiary	Pliocene	5		
			Miocene	24		
			Oligocene	37		
			Eocene	57		
			Paleocene	66		
	MESOZOIC	Cretaceous	Late	97		Development of passive continental margin
			Early	144		
		Jurassic	Late	163	Passive Margin	Atlantic Ocean continues to widen
			Middle	187		Initial opening of the Atlantic Ocean
			Early	190		
		Triassic	Late	230	Rifting	
			Middle	240		
			Early	245		
	PALEOZOIC	Permian	Late	256		Massive erosion of Paleozoic rocks
			Early	286		Alleghanian Orogeny caused by collision of North American and Africa along transform margin
		Pennsylvanian		320		
		Mississippian		360		
		Devonian	Late		Transformation	Erosion of Acadian Mountains
			Middle			Acadian Orogeny caused by collision of North America and Avalon and closing of remaining part of Iapetus Ocean
			Early	415	Collision	
		Silurian	Late	421		Evaporite basins; salt and gypsum deposited
			Early	438		
		Ordovician	Late	458	Continental Collision	Erosion of Taconic Mountains; Queenston Delta forms
			Middle			Taconic Orogeny caused by closing of western part of Iapetus Ocean and collision between North America and volcanic island arc
			Early	490		
		Cambrian	Late	500	Subduction	
			Middle	510		
			Early		Passive Margin	Iapetus passive margin forms
PRECAMBRIAN				1300	Rifting	Rifting and initial opening of Iapetus Ocean; Erosion of Grenville Mountains; Grenville Orogeny; granite and anorthosite intrusions; Subduction and volcanism Sedimentation, volcanism

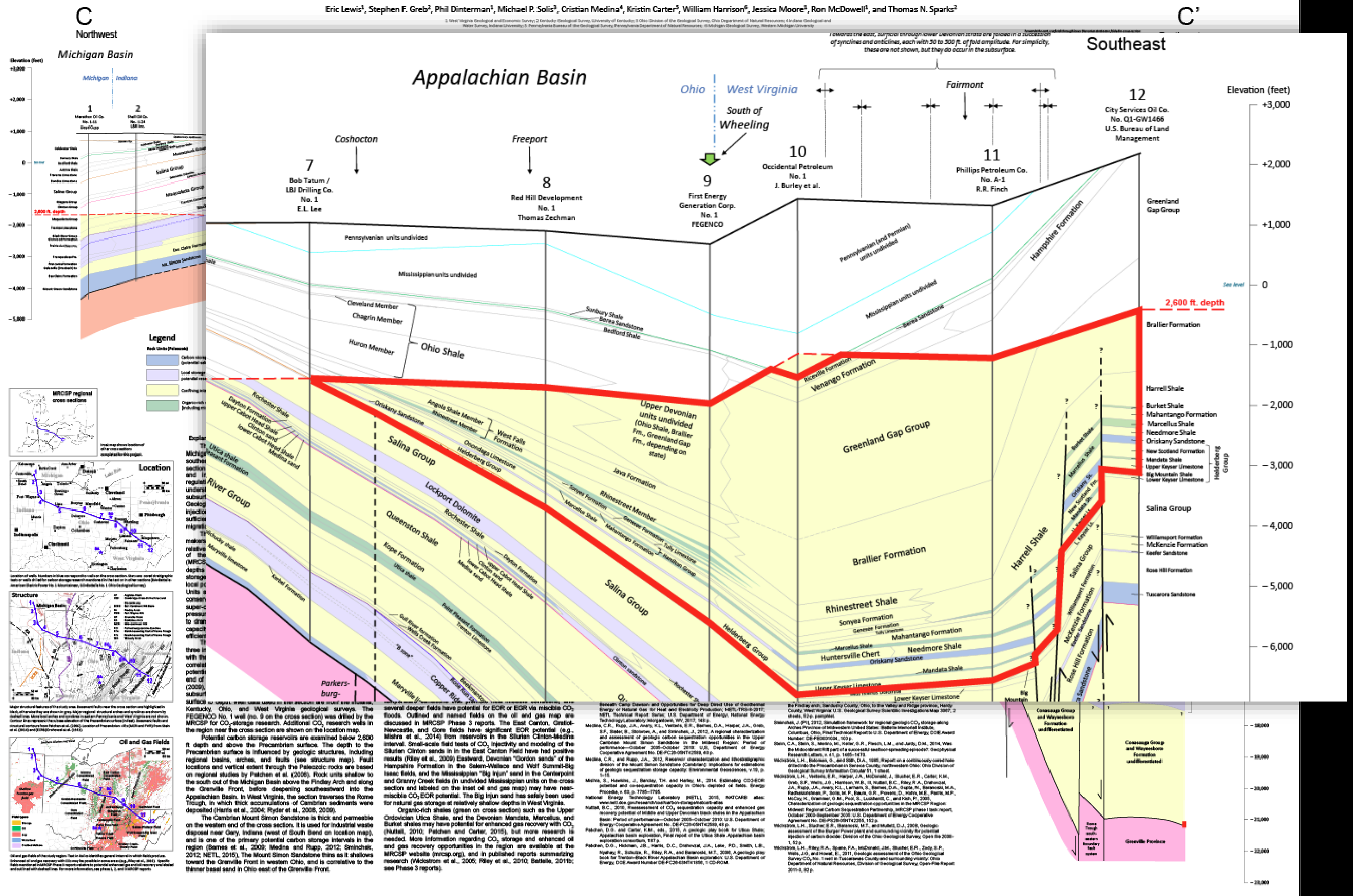
Note: Geologic time is presented on the left. Major tectonic events and their effect on depositional and post-depositional processes are presented on the right. (modified from *Geologic History of New York*)

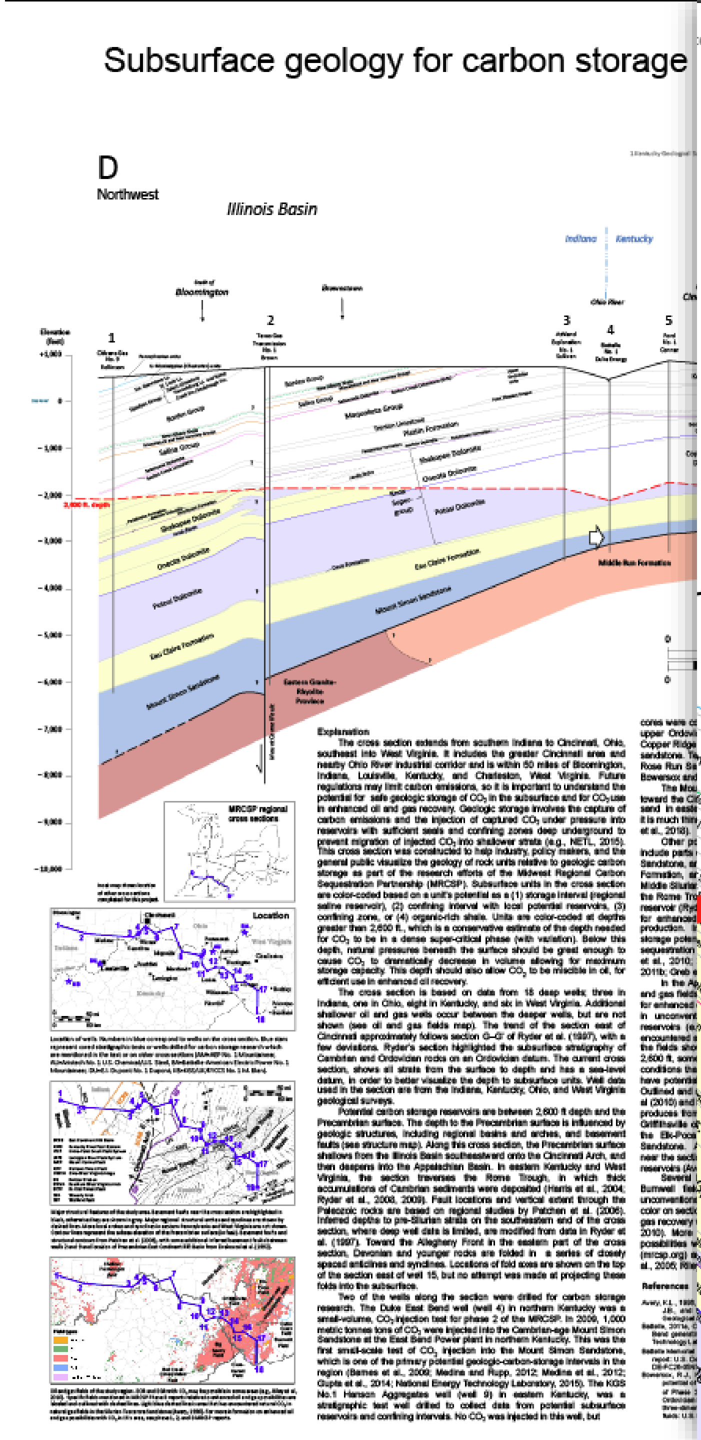


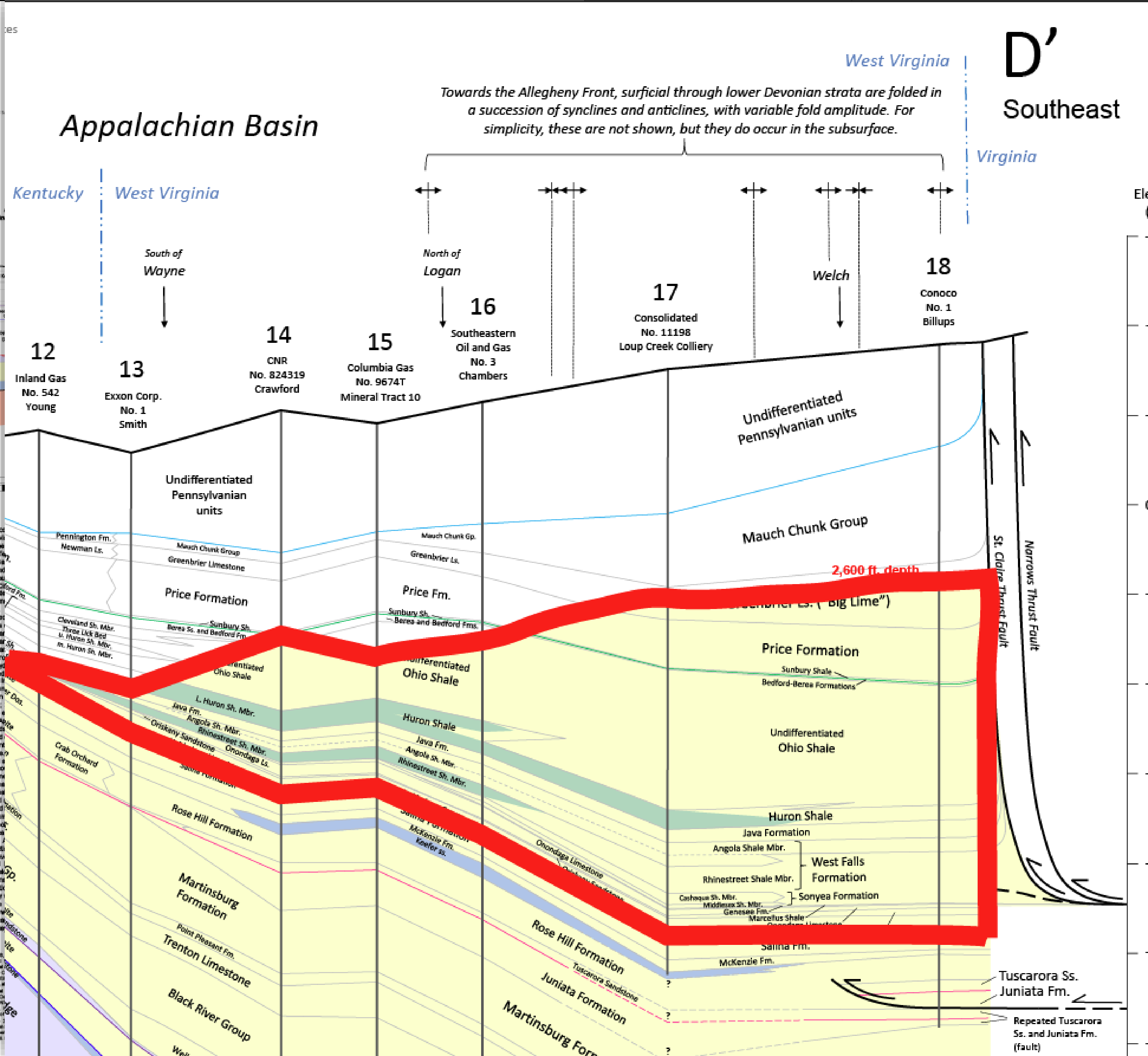
X: 0 in
Y: 0 in

Subsurface geology for carbon storage in part of the Midwest Regional Carbon Sequestration Partnership region: Southern Michigan to West Virginia

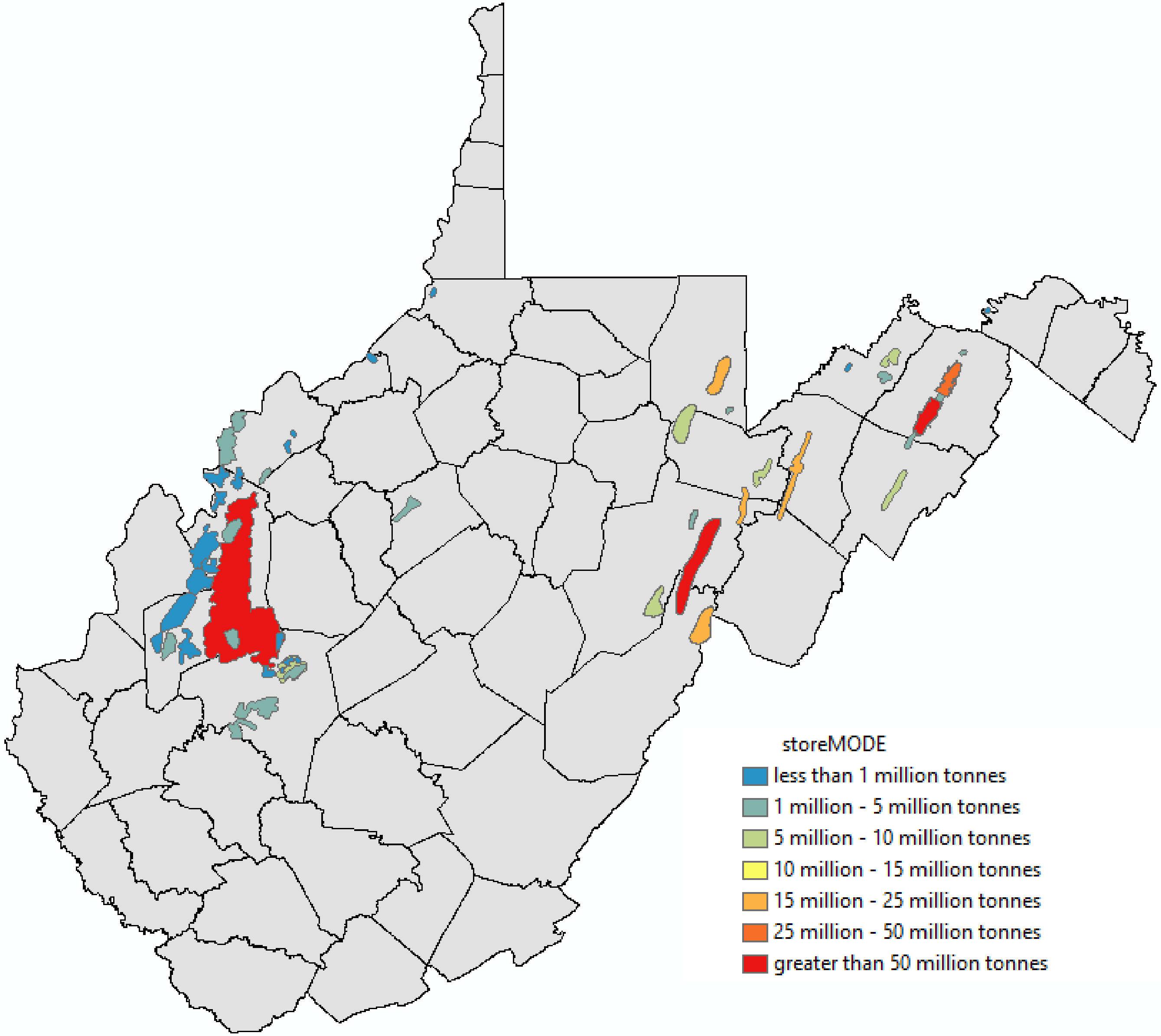
Eric Lewis[1], Stephen F. Greb[2], Phil Dinterman[1], Michael P. Solis[3], Cristian Medina[4], Kristin Carter[5], William Harrison[6], Jessica Moore[1], Ron McDowell[1], and Thomas N. Sparks[2]

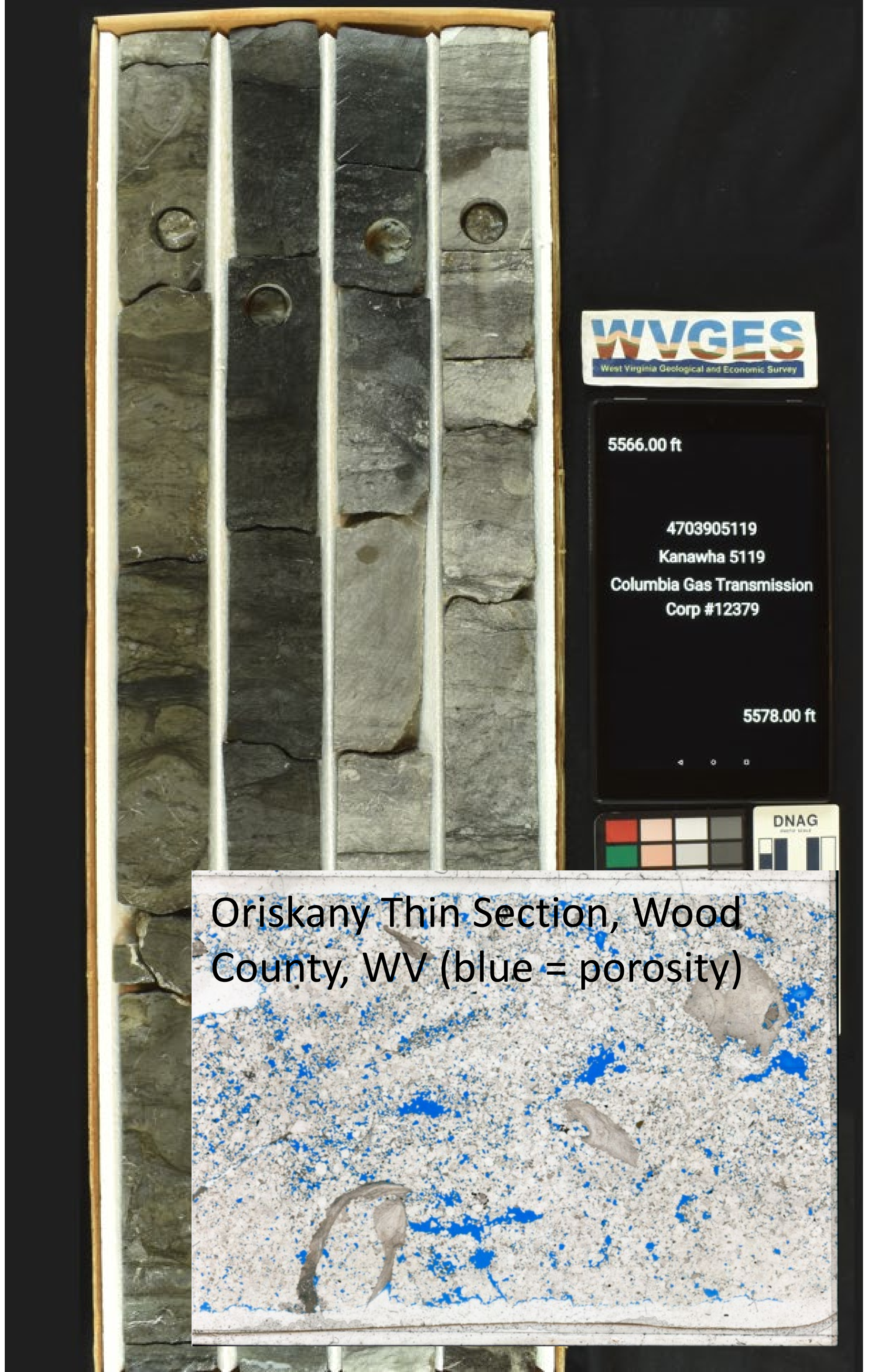



Subsurface geology for carbon storage
D
Northwest
Illinois Basin
Indiana
Kentucky
Explanation
References


Appalachian Basin
D'
Southeast
West Virginia
Virginia
Kentucky
West Virginia
Towards the Allegheny Front, surficial through lower Devonian strata are folded in a succession of synclines and anticlines, with variable fold amplitude. For simplicity, these are not shown, but they do occur in the subsurface.
South of Wayne
North of Logan
Welch
12
Inland Gas No. 542 Young
13
Exxon Corp. No. 1 Smith
14
CNR No. 824319 Crawford
15
Columbia Gas No. 9674T Mineral Tract 10
16
Southeastern Oil and Gas No. 3 Chambers
17
Consolidated No. 11198 Loup Creek Colliery
18
Conoco No. 1 Billups
Undifferentiated Pennsylvanian units
Undifferentiated Pennsylvanian units
Mauch Chunk Group
2,600 ft. depth
Pennington Fm.
Newman Ls.
Mauch Chunk Group
Greenbrier Limestone
Price Formation
Mauch Chunk Gp.
Greenbrier Ls.
Price Fm.
Sunbury Sh.
Berea and Bedford Fms.
Greenbrier Ls. ("Big Lime")
Price Formation
Sunbury Shale
Bedford-Berea Formations
Cleveland Sh. Mbr.
Three Lick Bed
u. Huron Sh. Mbr.
m. Huron Sh. Mbr.
Sunbury Sh.
Berea Ss. and Bedford Fm.
Undifferentiated Ohio Shale
Undifferentiated Ohio Shale
Undifferentiated Ohio Shale
L. Huron Sh. Mbr.
Java Fm.
Angola Sh. Mbr.
Rhinestreet Sh. Mbr.
Oriskany Sandstone
Onondaga Ls.
Huron Shale
Java Fm.
Angola Sh. Mbr.
Rhinestreet Sh. Mbr.
Huron Shale
Java Formation
Angola Shale Mbr.
West Falls Formation
Rhinestreet Shale Mbr.
Cashaqua Sh. Mbr.
Middlesex Sh. Mbr.
Genesee Fm.
Sonyea Formation
Marcellus Shale
Onondaga Limestone
Salina Fm.
McKenzie Fm.
Salina Formation
McKenzie Fm.
Keefer Ss.
Crab Orchard Formation
Rose Hill Formation
Rose Hill Formation
Tuscarora Sandstone
Juniata Formation
Martinsburg Formation
Martinsburg Formation
Point Pleasant Fm.
Trenton Limestone
Black River Group
St. Clair Thrust Fault
Narrows Thrust Fault
Tuscarora Ss.
Juniata Fm.
Repeated Tuscarora Ss. and Juniata Fm. (fault)

Oriskany CO_2 Storage Capacity





Marcellus Shale: The Role of Organics

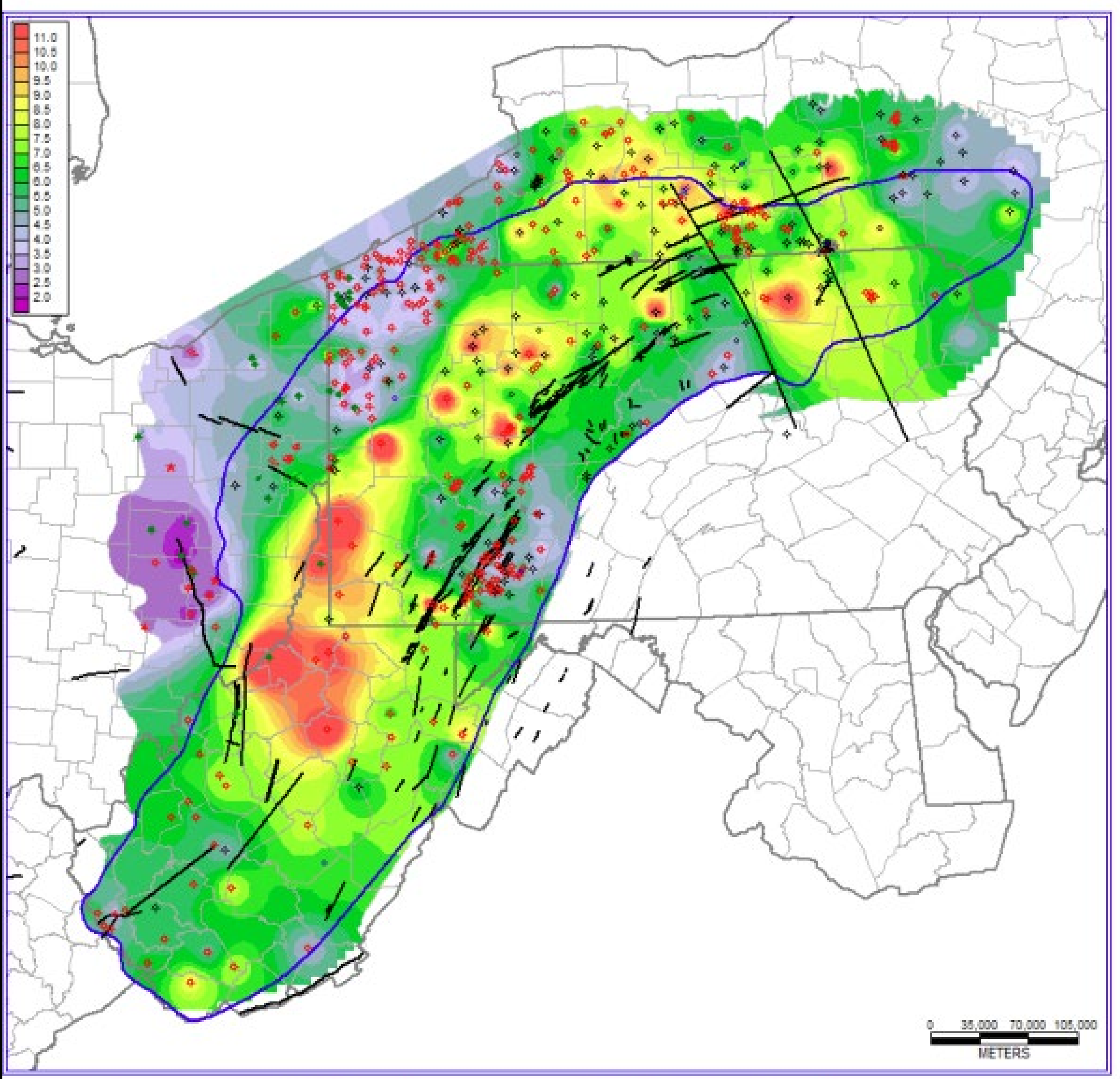
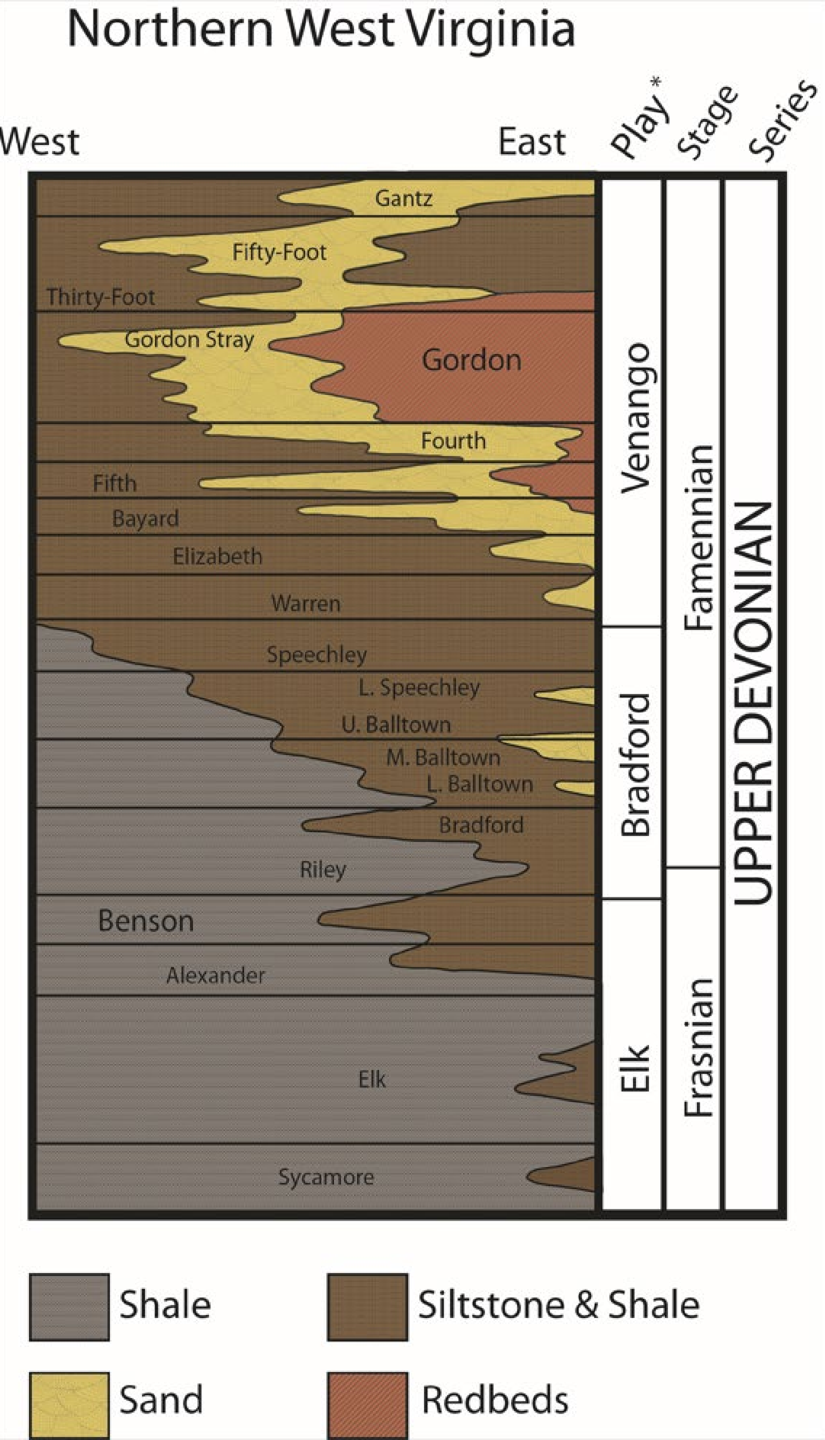
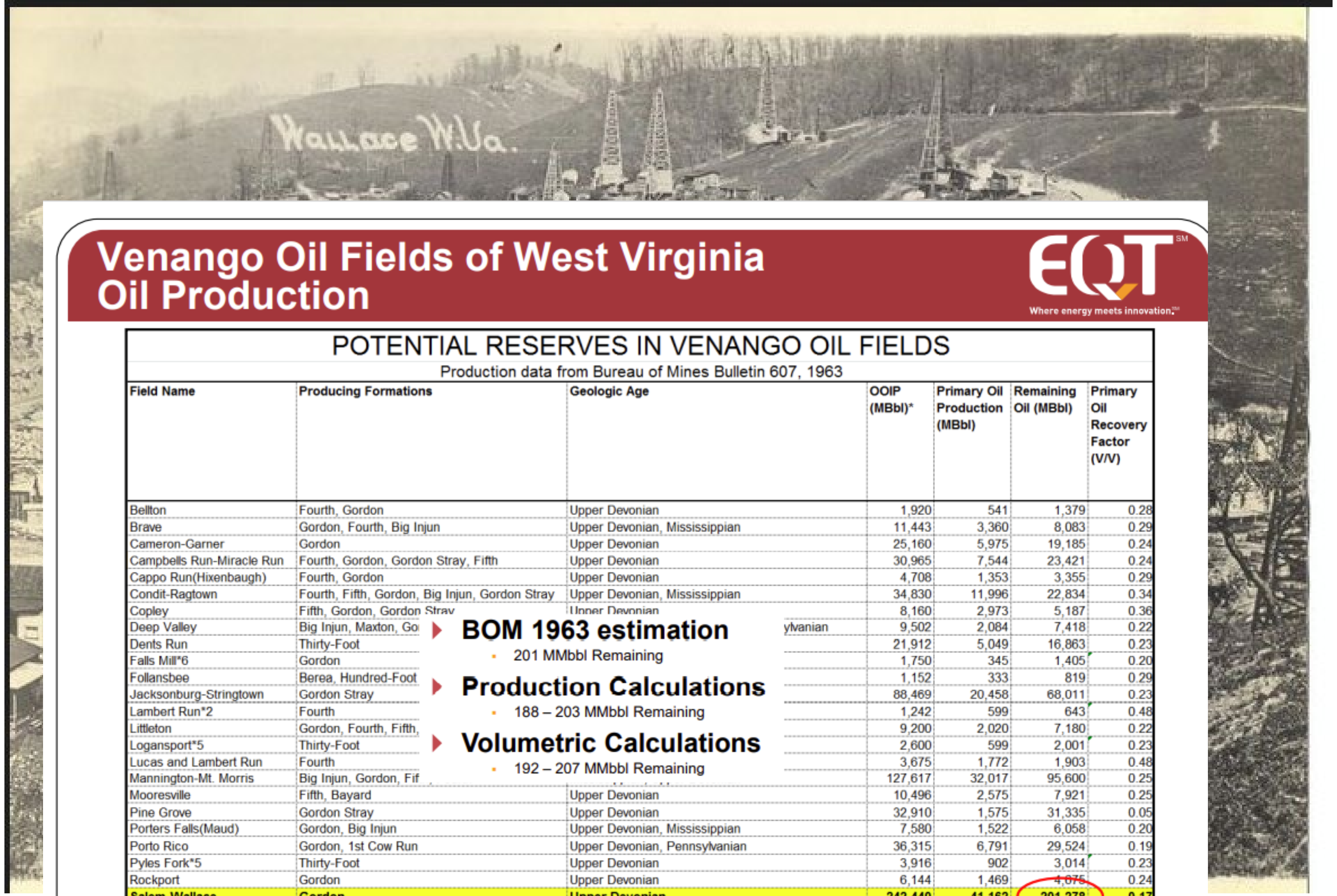


Figure 5-14. Spatial distribution of average TOC in the Marcellus Shale interval from calculated P50 well log curve data. The blue outline is the Marcellus assessment area.

- Organic-Rich shales are found throughout the Devonian section
- Prolific gas reservoir in the Appalachian Basin
- CO_2 attracted to organic particles, thereby releasing methane
- Potential for storage in depleted/underpressured shale
- Potential for CO2 enhanced gas/NGL recovery
- Potential for Critical Minerals (e.g. Vanadium) in well cuttings

Devonian Sandstones: CO_2 EOR





Venango Oil Fields of West Virginia
Oil Production

EQT Where energy meets innovation.

POTENTIAL RESERVES IN VENANGO OIL FIELDS

Production data from Bureau of Mines Bulletin 607, 1963

Field Name	Producing Formations	Geologic Age	OOIP (MBbl)*	Primary Oil Production (MBbl)	Remaining Oil (MBbl)	Primary Oil Recovery Factor (V/V)
Bellton	Fourth, Gordon	Upper Devonian	1,920	541	1,379	0.28
Brave	Gordon, Fourth, Big Injun	Upper Devonian, Mississippian	11,443	3,360	8,083	0.29
Cameron-Garner	Gordon	Upper Devonian	25,160	5,975	19,185	0.24
Campbells Run-Miracle Run	Fourth, Gordon, Gordon Stray, Fifth	Upper Devonian	30,965	7,544	23,421	0.24
Cappo Run(Hixenbaugh)	Fourth, Gordon	Upper Devonian	4,708	1,353	3,355	0.29
Condit-Ragtown	Fourth, Fifth, Gordon, Big Injun, Gordon Stray	Upper Devonian, Mississippian	34,830	11,996	22,834	0.34
Copley	Fifth, Gordon, Gordon Stray	Upper Devonian	8,160	2,973	5,187	0.36
Deep Valley	Big Injun, Maxton, Go	ylvanian	9,502	2,084	7,418	0.22
Dents Run	Thirty-Foot		21,912	5,049	16,863	0.23
Falls Mill*6	Gordon		1,750	345	1,405	0.20
Follansbee	Berea, Hundred-Foot		1,152	333	819	0.29
Jacksonburg-Stringtown	Gordon Stray		88,469	20,458	68,011	0.23
Lambert Run*2	Fourth		1,242	599	643	0.48
Littleton	Gordon, Fourth, Fifth,		9,200	2,020	7,180	0.22
Logansport*5	Thirty-Foot		2,600	599	2,001	0.23
Lucas and Lambert Run	Fourth		3,675	1,772	1,903	0.48
Mannington-Mt. Morris	Big Injun, Gordon, Fif		127,617	32,017	95,600	0.25
Mooresville	Fifth, Bayard	Upper Devonian	10,496	2,575	7,921	0.25
Pine Grove	Gordon Stray	Upper Devonian	32,910	1,575	31,335	0.05
Porters Falls(Maud)	Gordon, Big Injun	Upper Devonian, Mississippian	7,580	1,522	6,058	0.20
Porto Rico	Gordon, 1st Cow Run	Upper Devonian, Pennsylvanian	36,315	6,791	29,524	0.19
Pyles Fork*5	Thirty-Foot	Upper Devonian	3,916	902	3,014	0.23
Rockport	Gordon	Upper Devonian	6,144	1,469	4,675	0.24
Salem-Wallace	**Gordon**	**Upper Devonian**	**242,440**	**41,162**	**201,278**	**0.17**
Sand Fork	Fifth Sand	Upper Devonian	3,808	1,072	2,736	0.28
Shinnston	Fifty-Foot	Upper Devonian	10,000	5,144	5,656	0.40
Smithfield	Big Injun, Gordon, Maxton	Mississippian, Upper Devonian	83,392	11,646	71,746	0.14
Steele Run	Gordon Stray, Gordon	Upper Devonian	26,629	3,969	22,660	0.15
West Milford	Gordon	Upper Devonian	6,475	1,276	5,199	0.20
Wolf Summit-Big Isaac	Fifth, Gordon, Gordon Stray	Upper Devonian	68,919	12,629	56,290	0.18
Total			924,129	190,750	733,379	0.21

- BOM 1963 estimation
  - 201 MMbbl Remaining
- Production Calculations
  - 188 – 203 MMbbl Remaining
- Volumetric Calculations
  - 192 – 207 MMbbl Remaining

From Whieldon & Eckard, 1963

USGS
science for a changing world

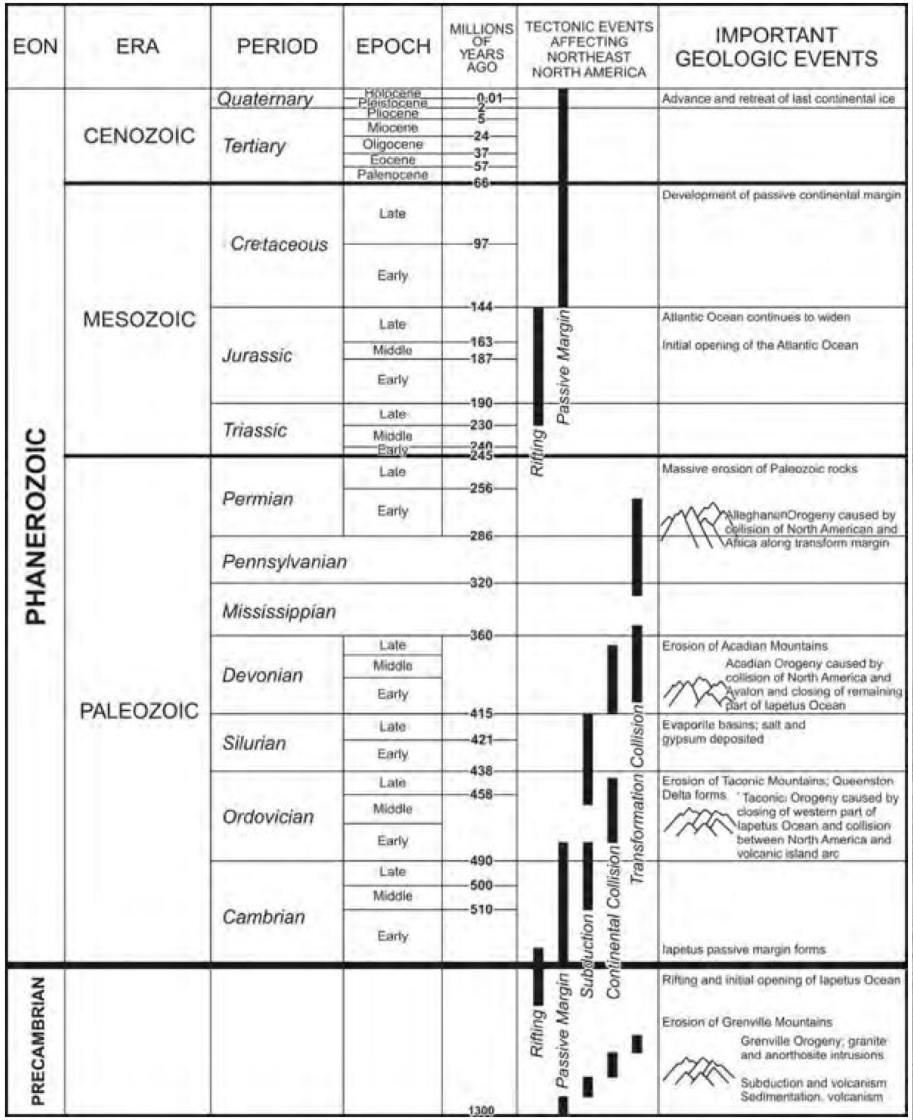
Trek Through Time **Carboniferous Period** *359-299* million years ago

Courtesy of Masato Hattori

Courtesy of Deep Time Maps produced by Colorado Plateau Geosystems, Inc.

PALEOZOIC ERA *541-252 million years ago*

PENNSYLVANIAN GEOLOGIC SETTING



EON	ERA	PERIOD	EPOCH	MILLIONS OF YEARS AGO	TECTONIC EVENTS AFFECTING NORTHEAST NORTH AMERICA	IMPORTANT GEOLOGIC EVENTS
PHANEROZOIC	CENOZOIC	Quaternary	Holocene	0.01	Passive Margin	Advance and retreat of last continental ice
			Pleistocene	2		
		Tertiary	Pliocene	5		
			Miocene	24		
			Oligocene	37		
			Eocene	57		
			Palenocene	66		
	MESOZOIC	Cretaceous	Late	97		Development of passive continental margin
			Early	144		
		Jurassic	Late	163	Rifting	Atlantic Ocean continues to widen
			Middle	187		Initial opening of the Atlantic Ocean
			Early	190		
		Triassic	Late	230		
			Middle	240		
			Early	245		
	PALEOZOIC	Permian	Late	256		Massive erosion of Paleozoic rocks
			Early	286		AlleghanianOrogeny caused by collision of North American and Africa along transform margin
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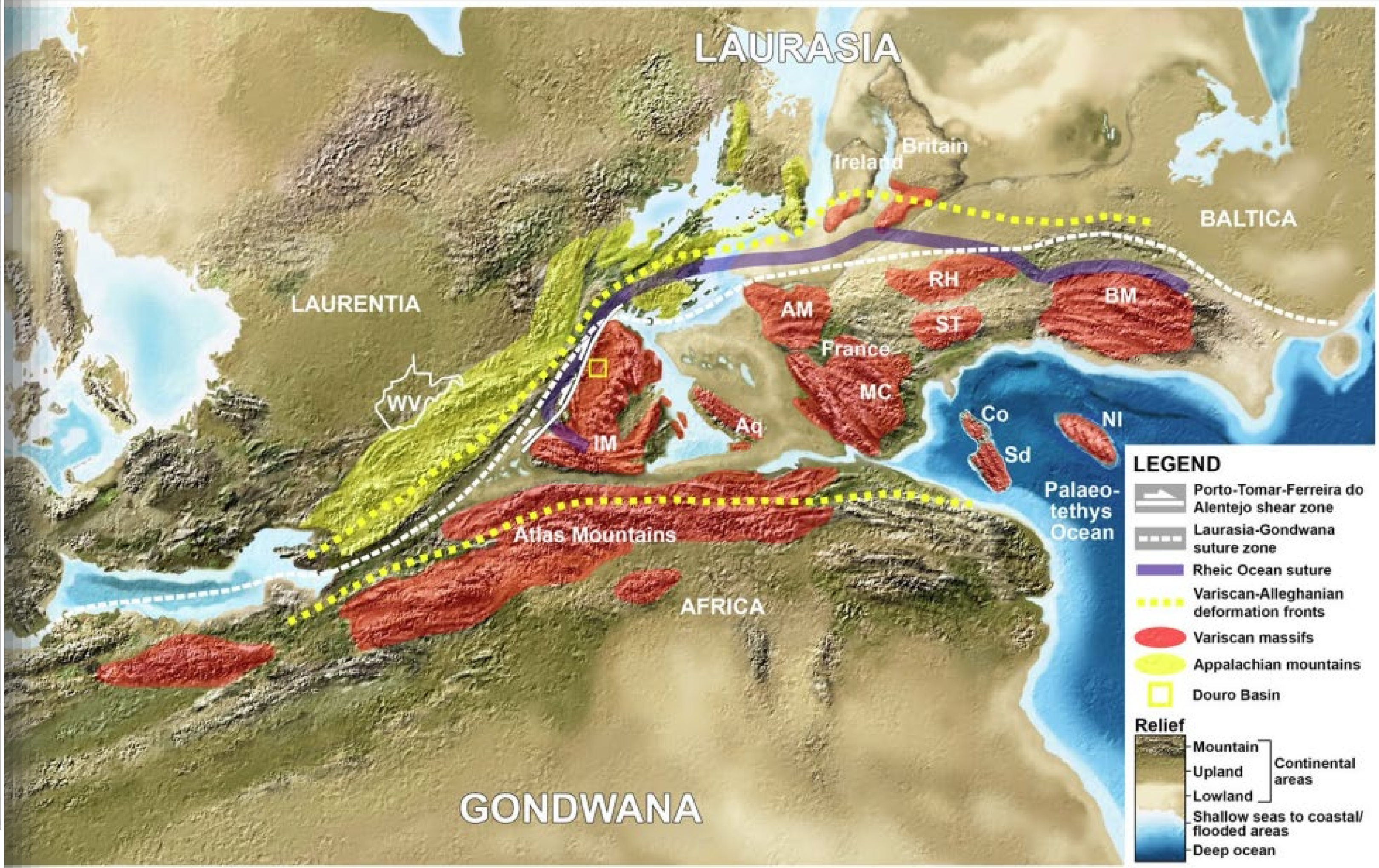
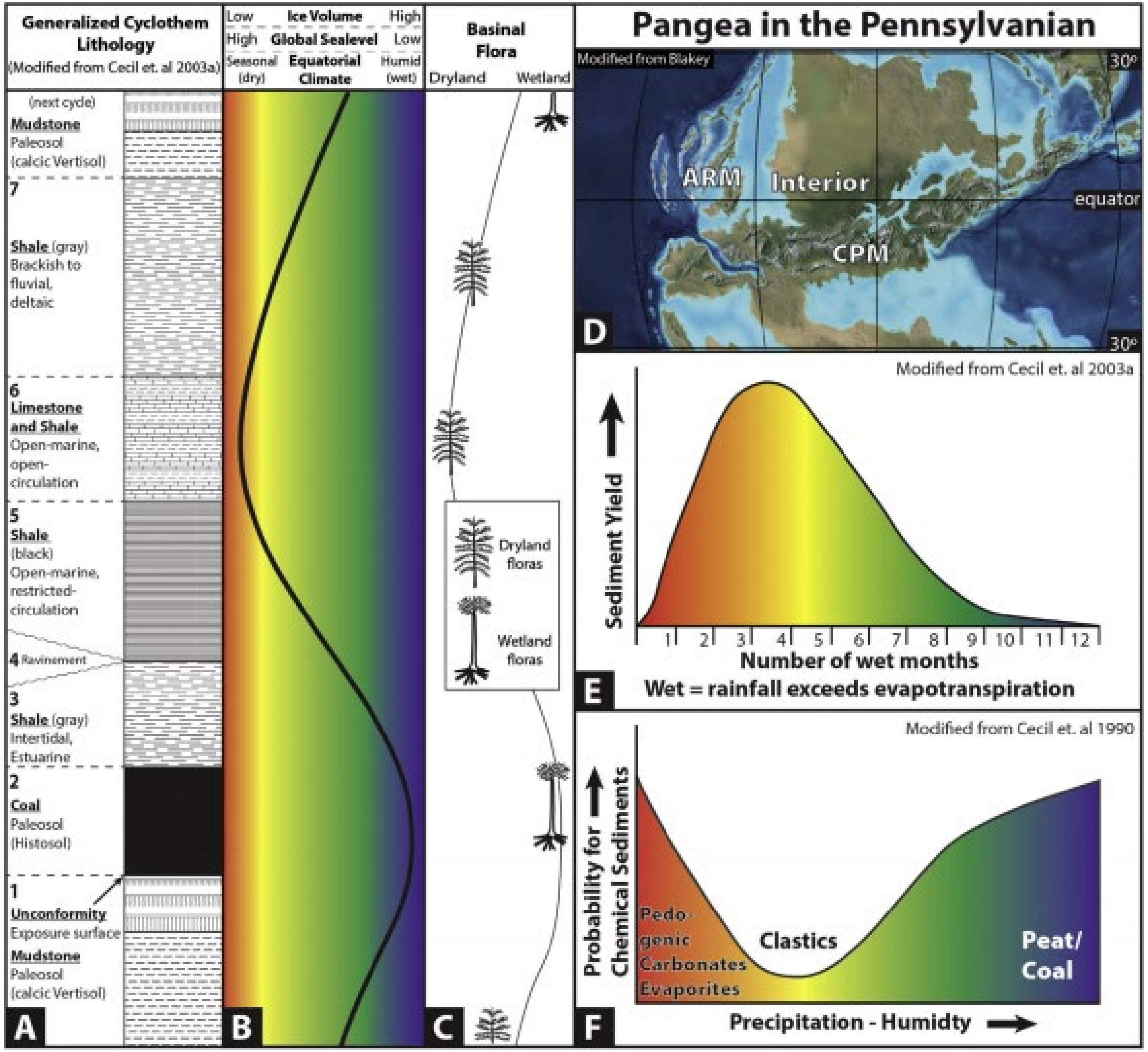
		Mississippian		360		
		Devonian	Late			Erosion of Acadian Mountains
			Middle			
			Early	415		Acadian Orogeny caused by collision of North America and Avalon and closing of remaining part of Iapetus Ocean
		Silurian	Late	421		Evaporite basins; salt and gypsum deposited
			Early	438		
		Ordovician	Late	458		Erosion of Taconic Mountains; Queenston Delta forms
			Middle			
			Early	490		Taconic Orogeny caused by closing of western part of Iapetus Ocean and collision between North America and volcanic island arc
		Cambrian	Late	500	Transformation Collision	
			Middle	510	Continental Collision	
			Early		Subduction	Iapetus passive margin forms
PRECAMBRIAN					Rifting	Rifting and initial opening of Iapetus Ocean
					Passive Margin	Erosion of Grenville Mountains
						Grenville Orogeny; granite and anorthosite intrusions
						Subduction and volcanism
				1300		Sedimentation, volcanism

Note: Geologic time is presented on the left. Major tectonic events and their effect on depositional and post-depositional processes are presented on the right. (modified from *Geologic History of New York*)

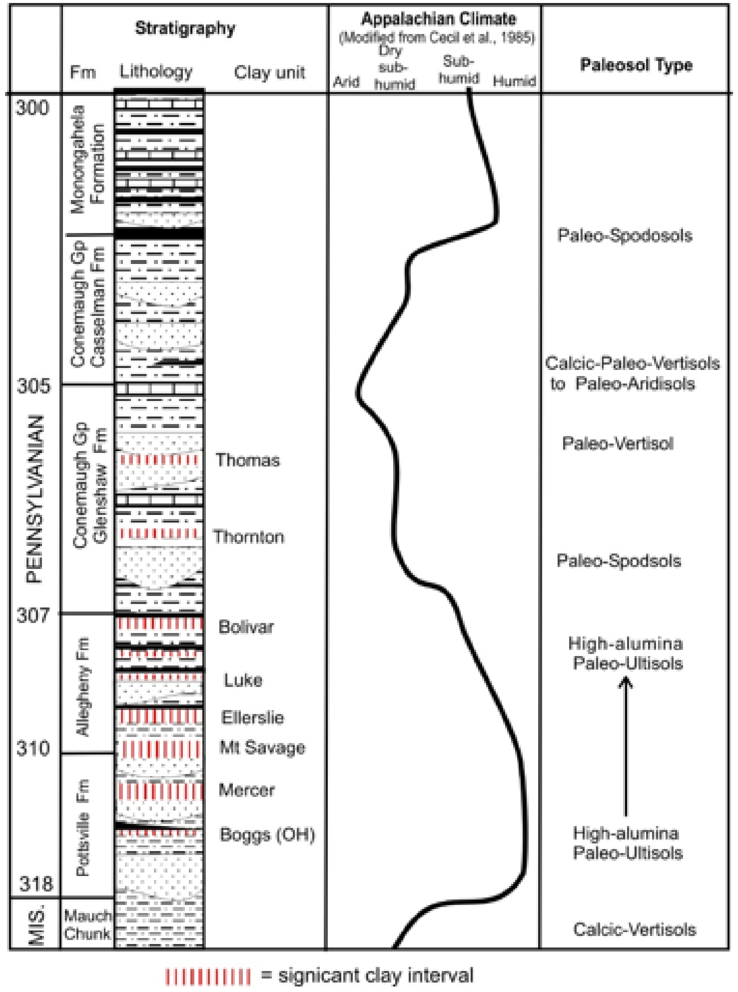


Correia and Murphy, 2020

PALEOCLIMATE & DEPOSITIONAL CONTROLS



Cecil et al., 2014



Brezinski and Kollar, 2011

REE ENRICHMENT & MOBILITY

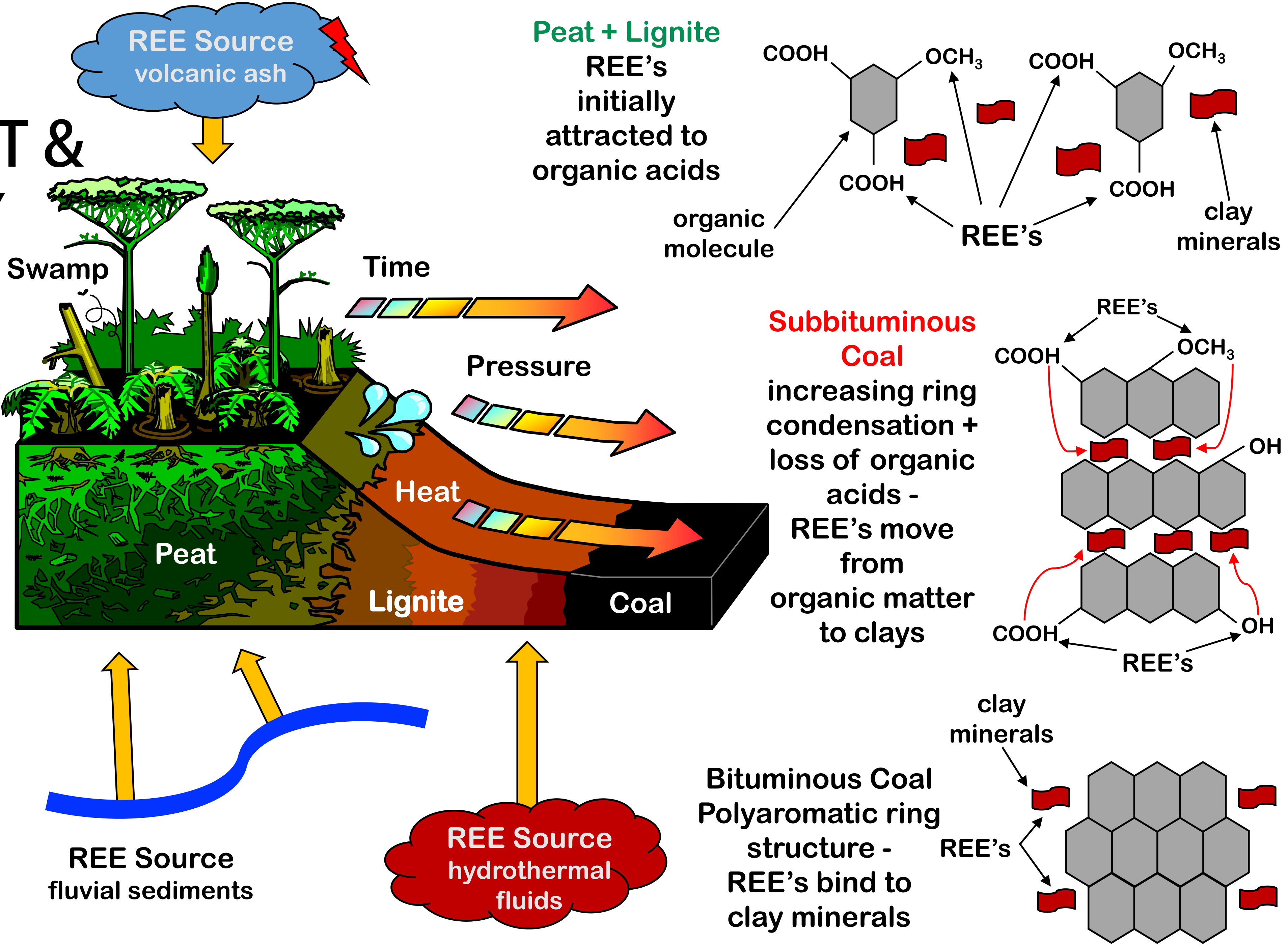
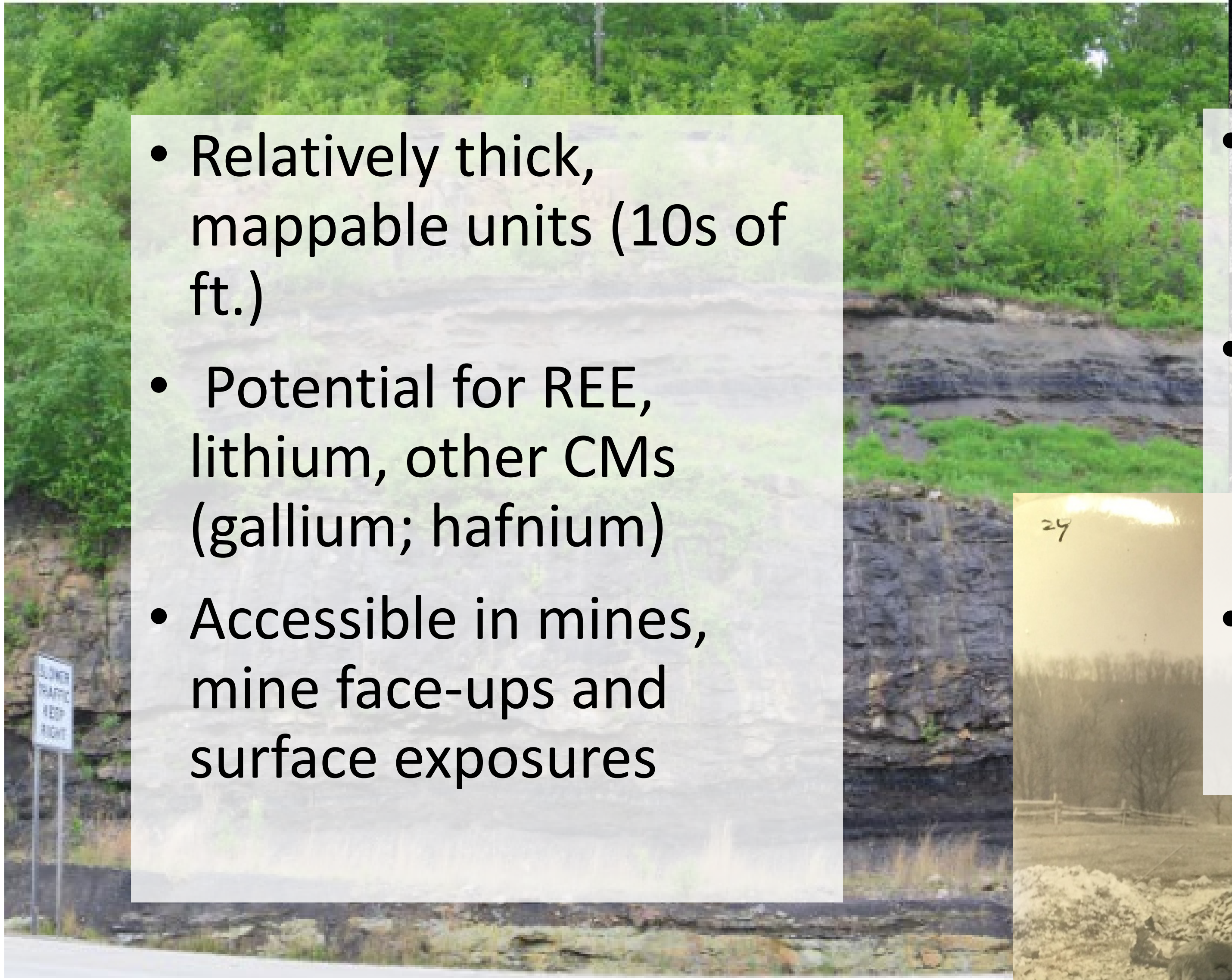
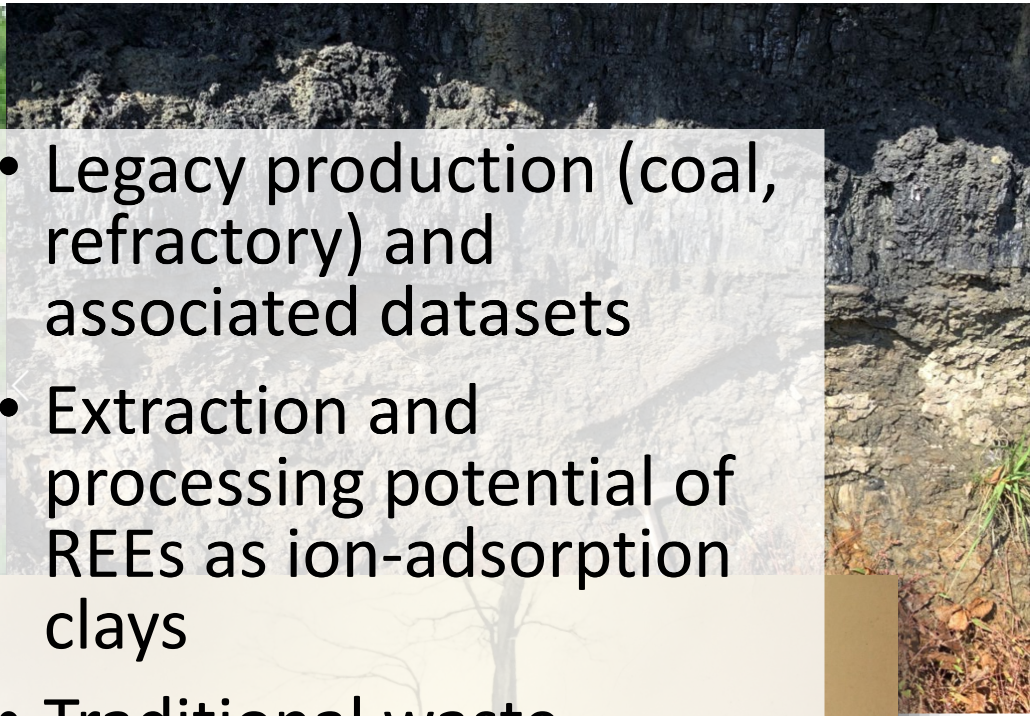


Image Courtesy of
Cortland Eble, KGS

WHY UNDERCLAYS?



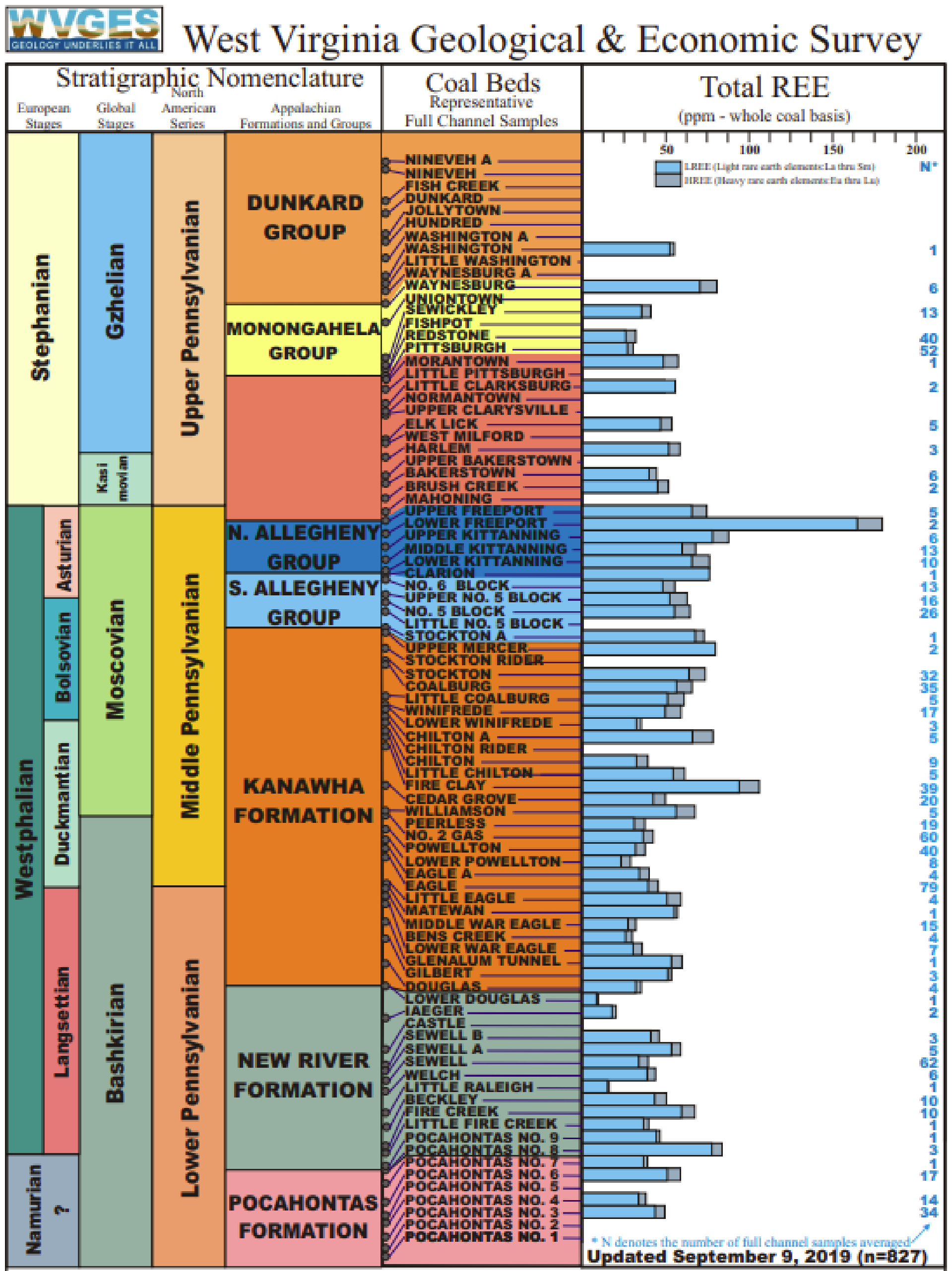
- Relatively thick, mappable units (10s of ft.)
- Potential for REE, lithium, other CMs (gallium; hafnium)
- Accessible in mines, mine face-ups and surface exposures



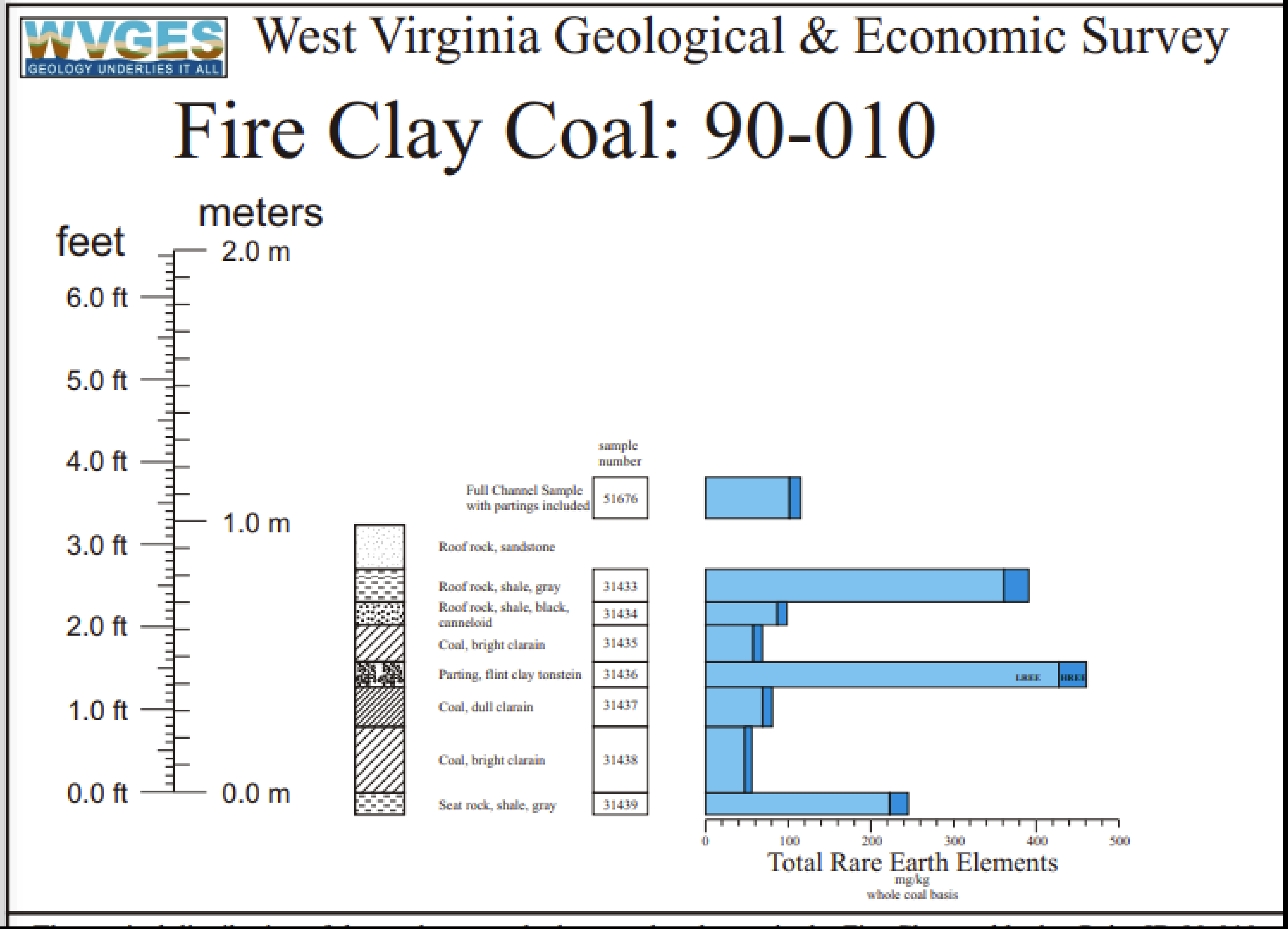
- Legacy production (coal, refractory) and associated datasets
- Extraction and processing potential of REEs as ion-adsorption clays
- Traditional waste stream; potential for beneficial reuse

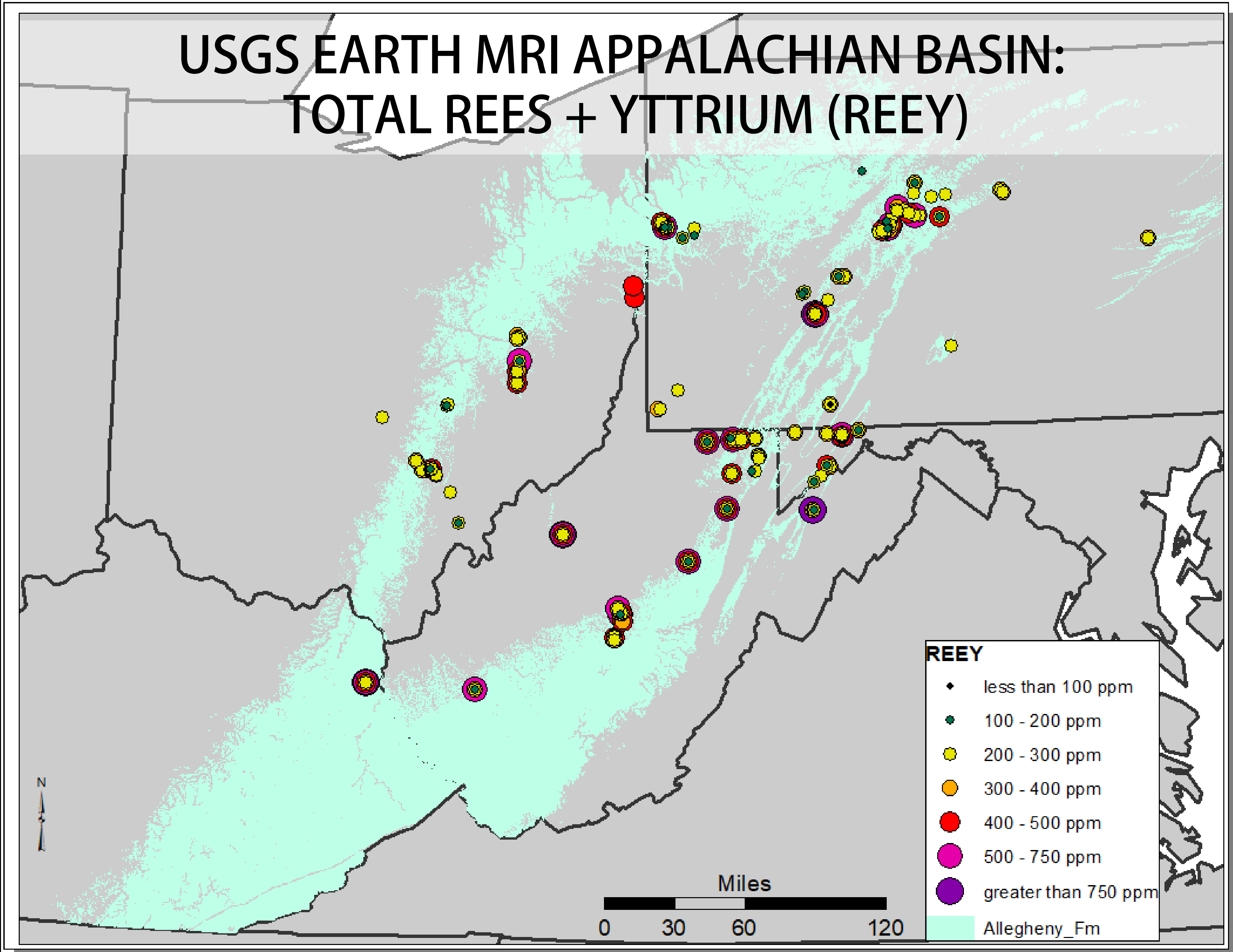
WVGES
West Virginia Geological and Economic Survey

WV Coal Legacy Data

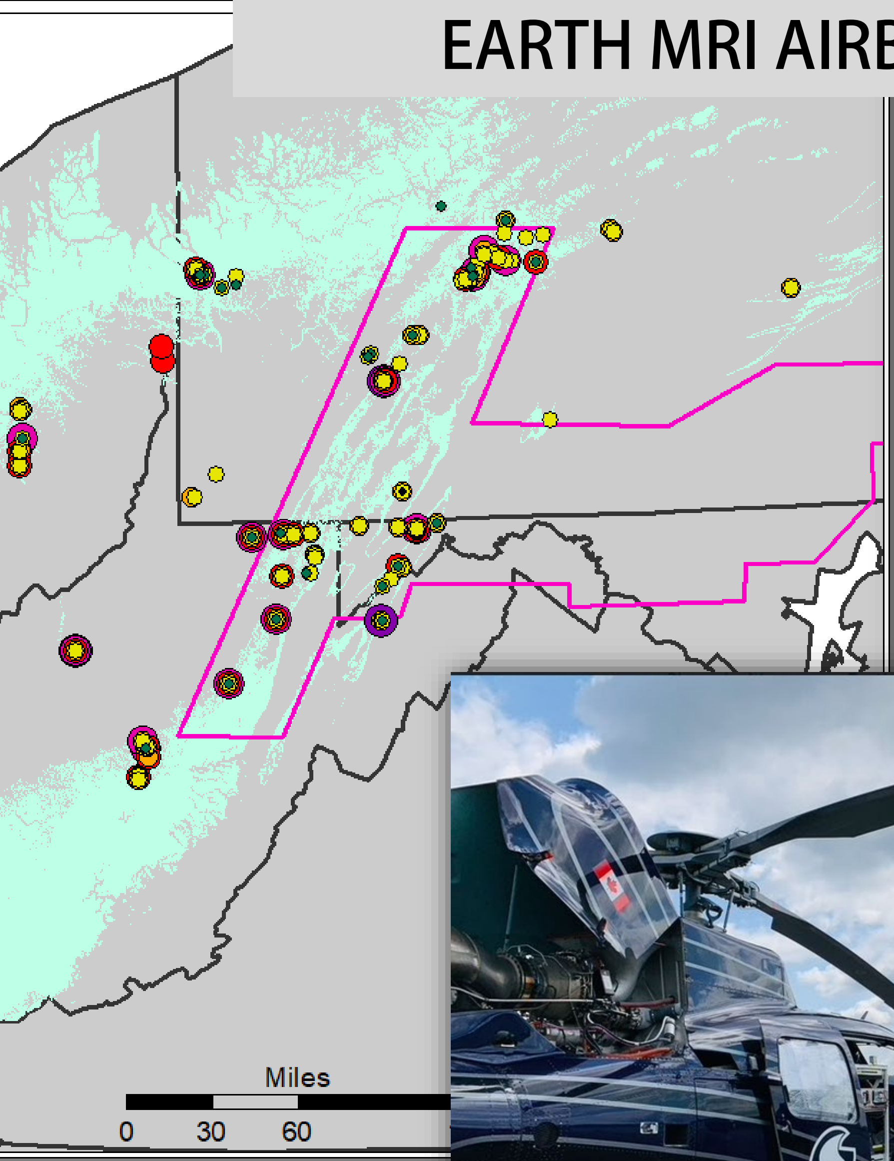


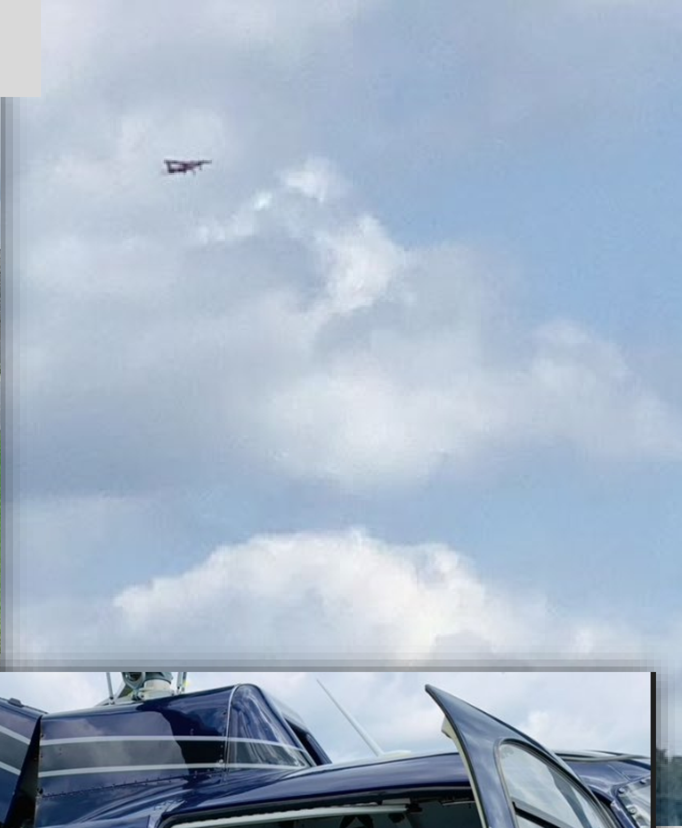
The average Total Rare Earth Element (REE) contents of 63 West Virginia coal beds on a parts-per-million (mg/kg) whole-coal basis. The coal beds are plotted on in stratigraphic order against the various stratigraphic nomenclatures. The REE totals are binned into Light REEs (La thru Sm) and Heavy REEs (Eu thru Lu).




USGS EARTH MRI APPALACHIAN BASIN:
TOTAL REES + YTTRIUM (REEY)
REEY
less than 100 ppm
100 - 200 ppm
200 - 300 ppm
300 - 400 ppm
400 - 500 ppm
500 - 750 ppm
greater than 750 ppm
Allegheny_Fm
Miles
0
30
60
120
N

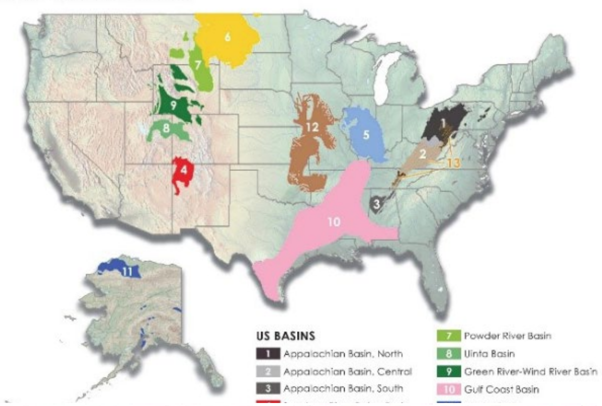
EARTH MRI AIRBORNE GEOPHYSICAL STUDY





Photos Courtesy of
Alex Demas, USGS

USDOE CORE-CM: Identifying Critical Mineral Resources in Unconventional Sources



Holz Dam, South Charleston, Kanawha County, ID # 03902

Height:	225 feet
Max Storage:	1,280 acre-feet
Dam Safety Act Certificate of Approval:	Issued 01/22/1996
DEP Inspection Date:	03/05/2009
Hazard Potential Classification:	1 - High
Condition (NID Criteria):	Satisfactory
Owner:	Dow Chemical Company

The Holz Dam is composed of two embankments to create an impoundment between two natural hillsides. The larger embankment is southwest of the reservoir and the smaller is northeast of the reservoir.

West Virginia
Geological & Economic Survey

Critical Minerals | *Point ID Search* | *Coal Sample # Search* | *Search by Coal Seam* | *Downloads*

Downloads - Click link to download data type

WVGES Coal Samples

- Coal Sample Header Data
- Trace Element Data
- Major Element Data

WVGES Clay Samples

- High Alumina Clays Data

WVGES_Trace_Element_Data - Excel

	SAMPLE NUMBE	POINT ID	COAL SEAM NAME	STATE	COUNTY	QUAD	UTMN	UTME	SURFACE ELEVATION (	USGS ID NUMBER	DATE SUBMITTED
2	440	16-078	EAGLE	West Virginia	Kanawha	Dorothy	4205441.08	465202.78	1432	170189	6/28/1974
3	440	16-078	EAGLE	West Virginia	Kanawha	Dorothy	4205441.08	465202.78	1432	D170189	6/28/1974
4	441	16-078	EAGLE	West Virginia	Kanawha	Dorothy	4205441.08	465202.78	1432	170188	6/28/1974
5	441	16-078	EAGLE	West Virginia	Kanawha	Dorothy	4205441.08	465202.78	1432	D170188	6/28/1974
6	442	16-082	FIRE CLAY	West Virginia	Kanawha	Eskdale	4210035.76	461250.97	1524.17	170190	7/10/1974
7	442	16-082	FIRE CLAY	West Virginia	Kanawha	Eskdale	4210035.76	461250.97	1524.17	D170190	7/10/1974
8	444	16-076	EAGLE	West Virginia	Kanawha	Belle	4223110.67	450043.86	549	170187	6/27/1974
9	444	16-076	EAGLE	West Virginia	Kanawha	Belle	4223110.67	450043.86	549	D170187	6/27/1974
10	445	16-076	EAGLE	West Virginia	Kanawha	Belle	4223110.67	450043.86	549	170186	6/27/1974
11	445	16-076	EAGLE	West Virginia	Kanawha	Belle	4223110.67	450043.86	549	D170186	6/27/1974
12	498	17-080	POWELLTON	West Virginia	Kanawha	Montgomery	4233029.4	471799.38	614	190630	9/5/1974
13	498	17-080	POWELLTON	West Virginia	Kanawha	Montgomery	4233029.4	471799.38	614	190630	9/5/1974
14	499	17-044	WINIFREDE	West Virginia	Kanawha	Quick	4235085.92	458560.25	943.98	170194	8/20/1974
15	499	17-044	WINIFREDE	West Virginia	Kanawha	Quick	4235085.92	458560.25	943.98	D170194	8/20/1974
16	500	17-084	NO.2 GAS	West Virginia	Kanawha	Montgomery	4229768.97	469788.6	618	190687	9/5/1974
17	500	17-084	NO.2 GAS	West Virginia	Kanawha	Montgomery	4229768.97	469788.6	618	190687	9/5/1974
18	501	17-070	NO.2 GAS	West Virginia	Fayette	Gauley Bridge	4233547.28	481138.57	808	190623	9/4/1974
19	501	17-070	NO.2 GAS	West Virginia	Fayette	Gauley Bridge	4233547.28	481138.57	808	190623	9/4/1974
20	502	17-006	POWELLTON	West Virginia	Fayette	Pax	4201233.24	471785.32	2109	170193	7/25/1974
21	502	17-006	POWELLTON	West Virginia	Fayette	Pax	4201233.24	471785.32	2109	D170193	7/25/1974
22	503	17-006	POWELLTON	West Virginia	Fayette	Pax	4201233.24	471785.32	2109	170192	7/25/1974
23	503	17-006	POWELLTON	West Virginia	Fayette	Pax	4201233.24	471785.32	2109	D170192	7/25/1974
24	504	17-006	POWELLTON	West Virginia	Fayette	Pax	4201233.24	471785.32	2109	170191	7/25/1974
25	504	17-006	POWELLTON	West Virginia	Fayette	Pax	4201233.24	471785.32	2109	D170191	7/25/1974
26	505	17-066	STOCKTON	West Virginia	Kanawha	Montgomery	4220140.48	467427.63	1564	170196	8/29/1974
27	505	17-066	STOCKTON	West Virginia	Kanawha	Montgomery	4220140.48	467427.63	1564	D170196	8/29/1974
28	506	17-062	COALBURG	West Virginia	Kanawha	Cedar Grove	4223888.07	466680.86	1229.46	170195	8/28/1974
29	506	17-062	COALBURG	West Virginia	Kanawha	Cedar Grove	4223888.07	466680.86	1229.46	D170195	8/28/1974
30	507	17-064	COALBURG	West Virginia	Kanawha	Montgomery	4223065.2	467442.8	1282	190621	8/28/1974
31	507	17-064	COALBURG	West Virginia	Kanawha	Montgomery	4223065.2	467442.8	1282	190621	8/28/1974
32	508	17-068	COALBURG	West Virginia	Kanawha	Eskdale	4219744.01	465005.09	1369.38	190622	8/29/1974

	REPORTING BASIS	ASH USGS WEIGHT	ASH WVGS WEIGHT	ANTIMONY	ARSENIC	BARIUM	BERYLLIUM	BISMUTH	BORON	BROMINE	CADMIUM	CERIUM	CESIUM
2	Element in High Temperature Ash	7.9	3.35	68.72	89.6	3540.64	165.23		236			472	
3	Element in Whole Coal			2.3	3	118.5	5.53		7.9			16	
4	Element in High Temperature Ash	5.6	5.09	11.78	19.6	1649.76	54.99		110		1.1	220	
5	Element in Whole Coal			0.6	1	84	2.8		5.6		0.056	11	
6	Element in High Temperature Ash	12.2	10.89	15.62	45.9	1120.8	11.21		78.5				
7	Element in Whole Coal			1.7	5	122	1.22		8.5				
8	Element in High Temperature Ash	6.9	16.48	1.82	12.1	293.08	2.93		125.6			84	
9	Element in Whole Coal			0.3	2	48.3	0.48		20.7			14	
10	Element in High Temperature Ash	8.9	9.13	4.38	219.1	975	29.25		292.5				
11	Element in Whole Coal			0.4	20	89	2.67		26.7				
12	Element in High Temperature Ash	7.2	8.1	8.89	181.4	675.34	49.76		239.9	333	0.675	136	2.5
13	Element in Whole Coal			0.72	14.7	54.72	4.03		19.4	27	0.055	11	0.2
14	Element in High Temperature Ash	9.3	10.79	5.56	18.5	431.02	17.24		129.3				
15	Element in Whole Coal			0.6	2	46.5	1.86		14				
16	Element in High Temperature Ash	9.1	10.13	5.82	78.9	880.09	8.8		269.4	286	0.431	227	3
17	Element in Whole Coal			0.59	8	89.18	0.89		27.3	29	0.044	23	0.3
18	Element in High Temperature Ash	5.6	8.1	11.35	44.4	829.37	32.48		269.5	321	0.76	123	7.4
19	Element in Whole Coal			0.92	3.6	67.2	2.63		21.8	26	0.062	10	0.6
20	Element in High Temperature Ash	4.8	3.8	31.56	26.3	1893.41	37.87		126.2		1.893	252	
21	Element in Whole Coal			1.2	1	72	1.44		4.8		0.072	10	
22	Element in High Temperature Ash	8.1	5.52	16.3	90.6	1467	10.27		146.7				
23	Element in Whole Coal			0.9	5	81	0.57		8.1				
24	Element in High Temperature Ash	4.8	6.56	6.1	228.7	1464	7.32		73.2			146	
25	Element in Whole Coal			0.4	15	96	0.48		4.8			10	
26	Element in High Temperature Ash	17.5	18.04	2.77	66.5	484.96	9.7		48.5				
27	Element in Whole Coal			0.5	12	87.5	1.75		8.8				
28	Element in High Temperature Ash	13.6	15.6	3.85	12.8	261.6	8.72		61			174	
29	Element in Whole Coal			0.6	2	40.8	1.36		9.5			27	
30	Element in High Temperature Ash	7.2	10.35	3.96	8.7	326.89	21.56		132.1	222	0.473	193	3.9
31	Element in Whole Coal			0.41	0.9	33.84	2.23		13.7	23	0.049	20	0.4
32	Element in High Temperature Ash	7.3	4.03	17.13	22.3	1685.06	74.29		561.7	645	0.544	323	7.4

In Summary: Carbon Management

- Recent policy developments in WV provide a strong foundation for carbon storage
- As CCS gains traction in the Appalachian Basin, industry can leverage knowledge gained from CCUS operations in the Illinois/Michigan basins plus in-basin drilling expertise and high-resolution subsurface information gained from unconventional shale exploration and production
- Many data gaps remain, especially with the deep Cambrian and Ordovician section in the Rome Trough. Multiple deep stratigraphic test wells and analyses are necessary
- IIJA and IRA both offer significant research funding opportunities

In Summary: Critical Minerals

- West Virginia holds significant and unique potential for critical minerals
- Many are hosted in the coal measures and are observed in elevated volumes in clay-rich beds above, below, or between the coal beds
- Enrichment observed over broad areas, but vertical variation can be significant, even within a given unit
- Potential also exists in organic shales and units exposed to hydrothermal mineralization
- Waste products, including AMD, gob, coal ash may have potential for beneficial reuse.

THANK YOU!

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