Central Appalachian Partnership for Carbon Storage Deployment

SUBSURFACE GEOLOGY AND CARBON STORAGE

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AGENDA

- Appalachian basin geologic history
- Geologic storage
- Perspectives on geologic carbon storage and resource development

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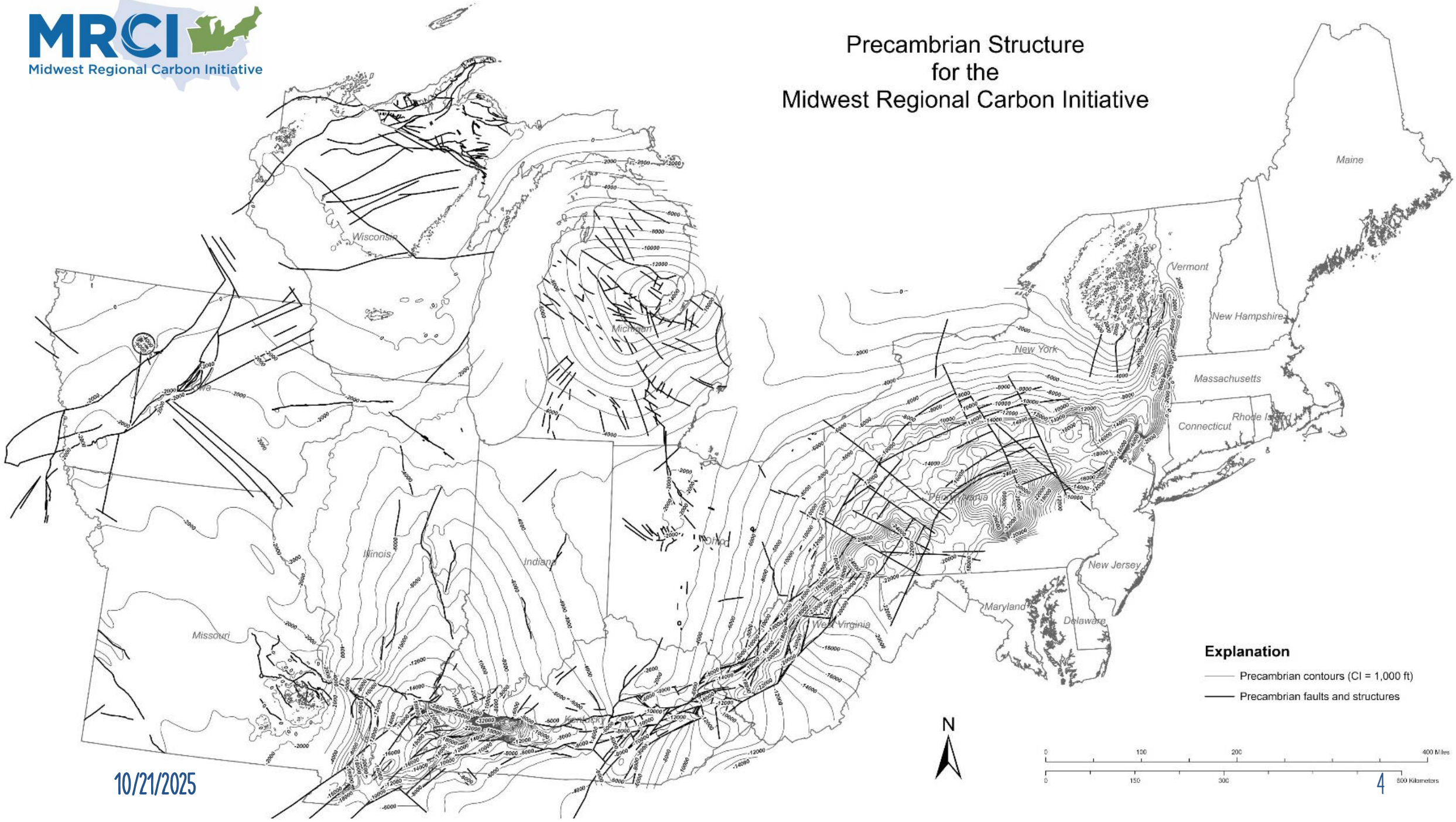
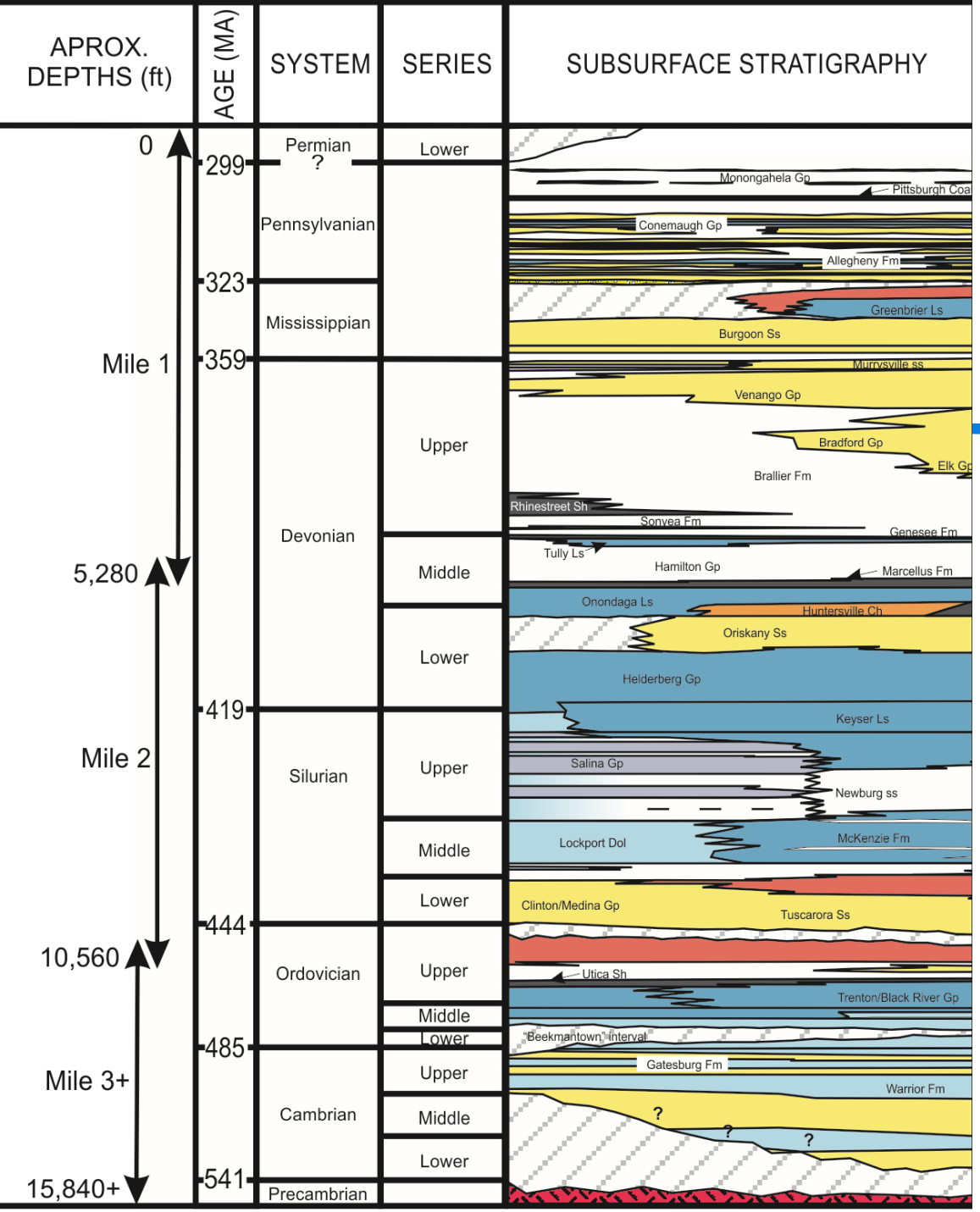
APPALACHIAN BASIN GEOLOGIC HISTORY

"Nature Vs. Nurture Aspects of the Rock Record"

MRCI
Midwest Regional Carbon Initiative

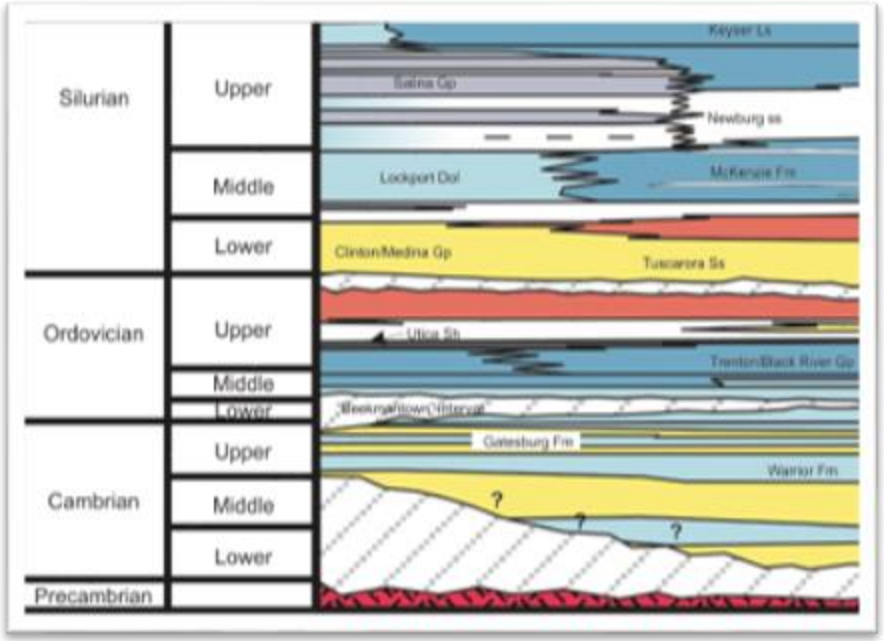
Precambrian Structure for the Midwest Regional Carbon Initiative





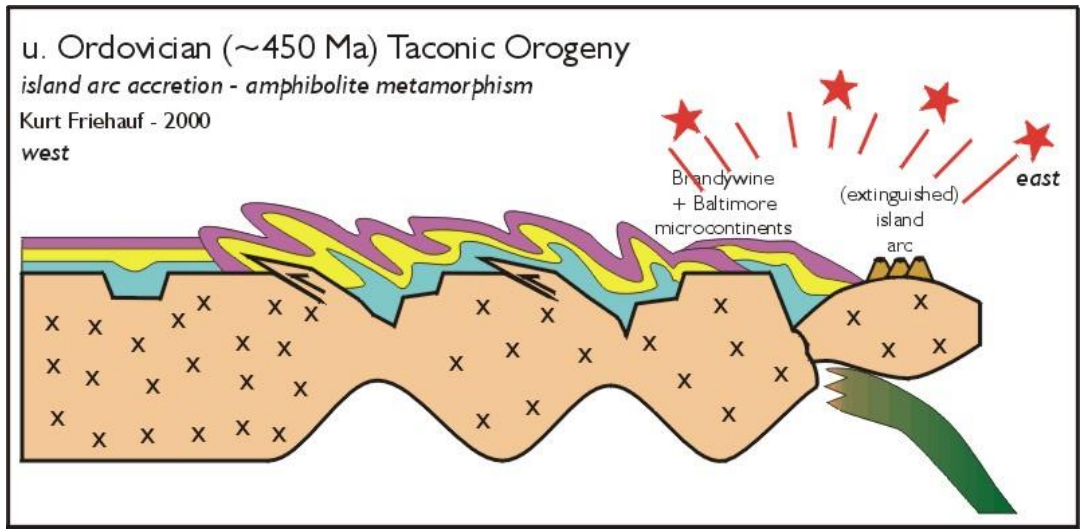
SUBSURFACE LITHOLOGY AND STRATIGRAPHY

- Permian (~252-299 MA) through Precambrian (>~541 MA) age rocks
- Rock record comprised of multiple lithologies
- Depth, thickness, extent and nomenclature for rock units vary
- Rock record punctuated by unconformities
- Rock character impacted by mountain building events over geologic time
- Coal and coalbed methane in Pennsylvanian rocks, oil and gas in Devonian - Cambrian rocks

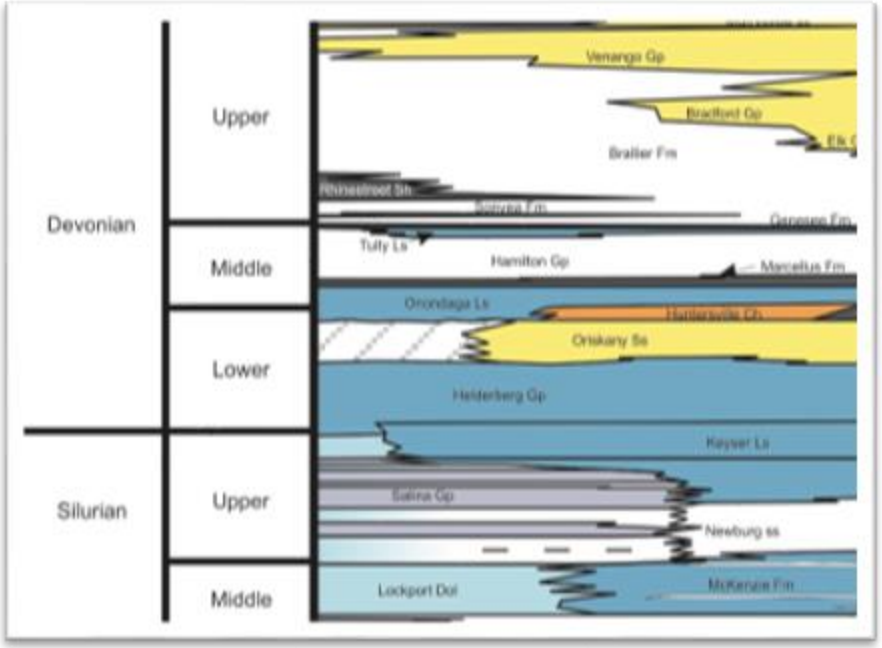


TACONIC OROGENY (~450 MA)

- Cambrian rifting creating a passive margin along the North American continent, which facilitated carbonate deposition into the Early to Middle Ordovician
- Subduction, ocean closure and collision of volcanic arcs with North America occurred in Late Ordovician time

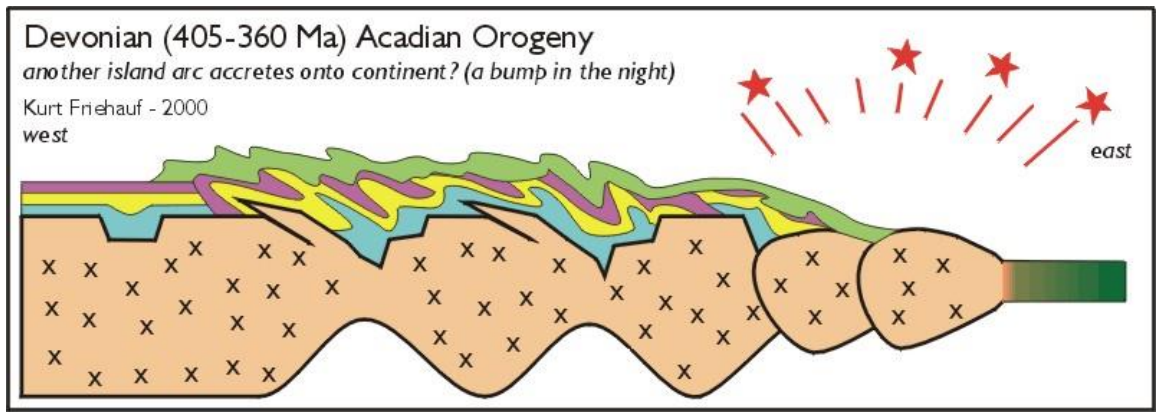


From Friehauf (2000)



ACADIAN OROGENY (~405-360 MA)

- Taconic mountains erode, and Silurian carbonate reefs and salt basins form in the central Appalachian basin
- Avalonia (a microcontinent) and volcanic arc hit North America again in Late Devonian time, and subduction ensues



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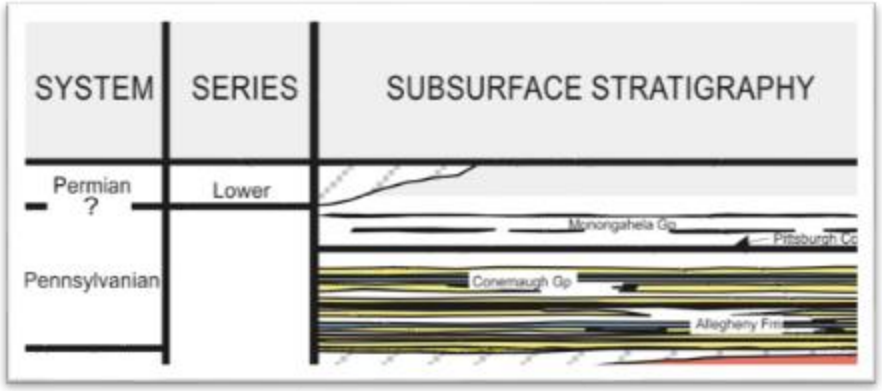
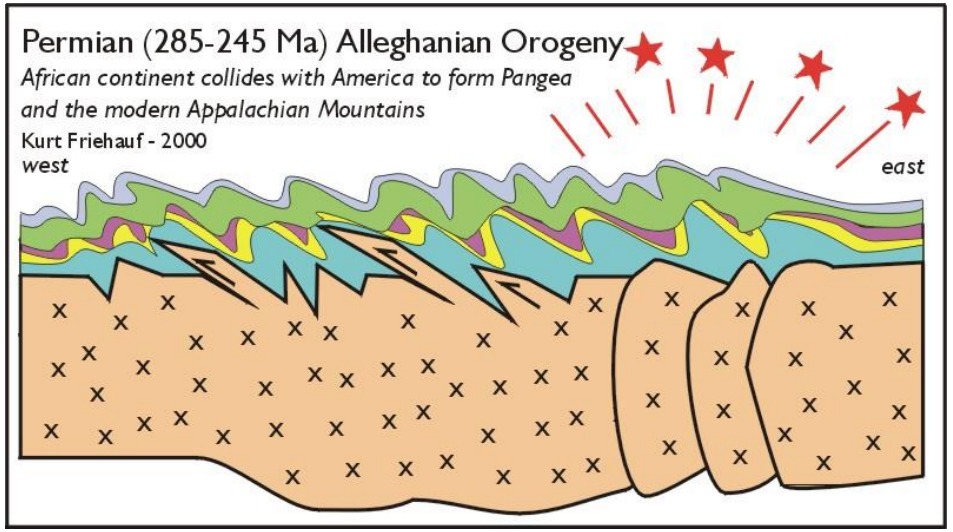


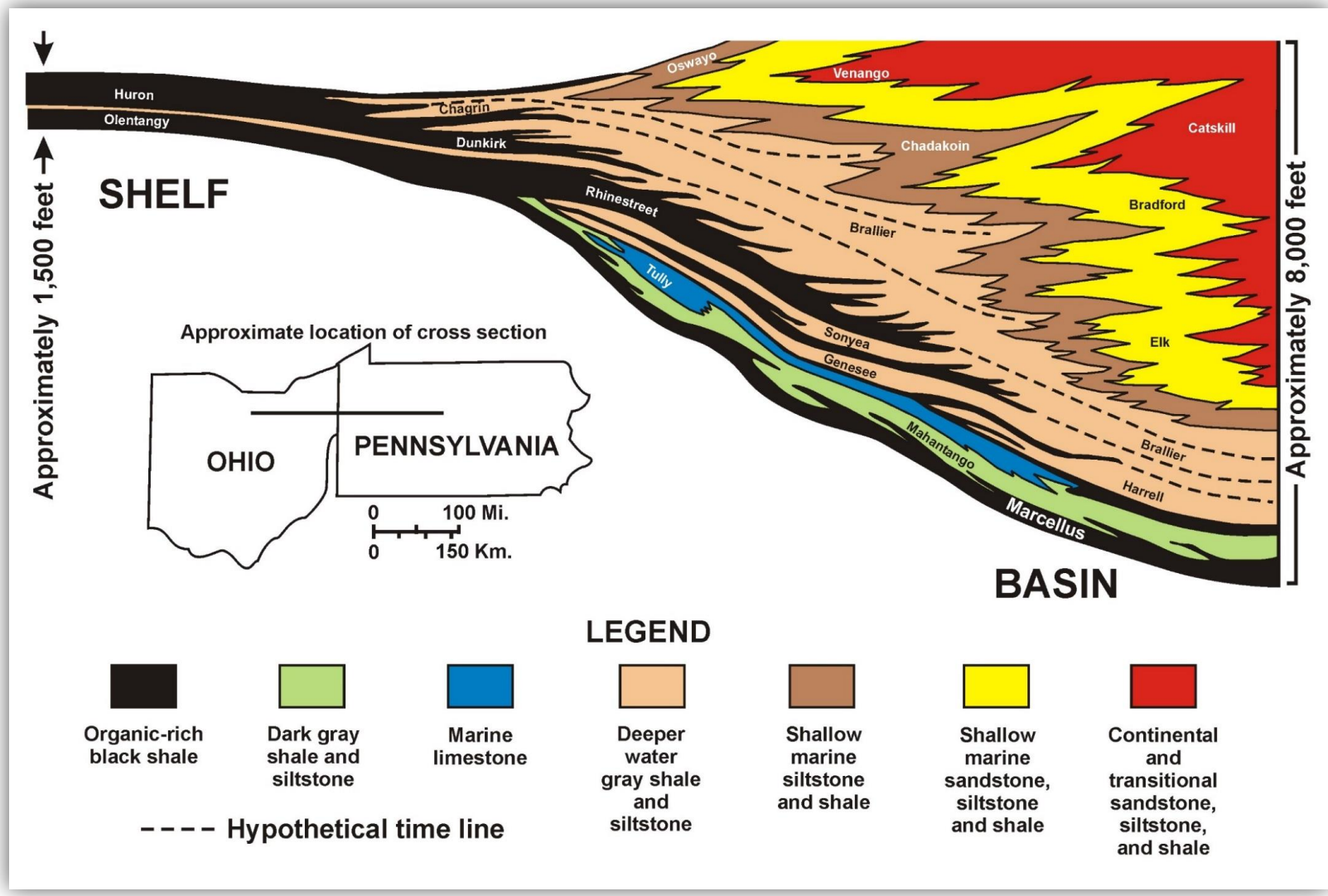
ALLEGHANIAN OROGENY (~285-245 MA)



From Friehauf (2000)

- West Africa collides with North America in Permian time, and subduction ensues
- The Protoatlantic Ocean is closed
- The Supercontinent Pangaea is formed
- We've got a mountain range much like the modern Himalayas...

SO, WE HAVE A SEDIMENTARY BASIN...



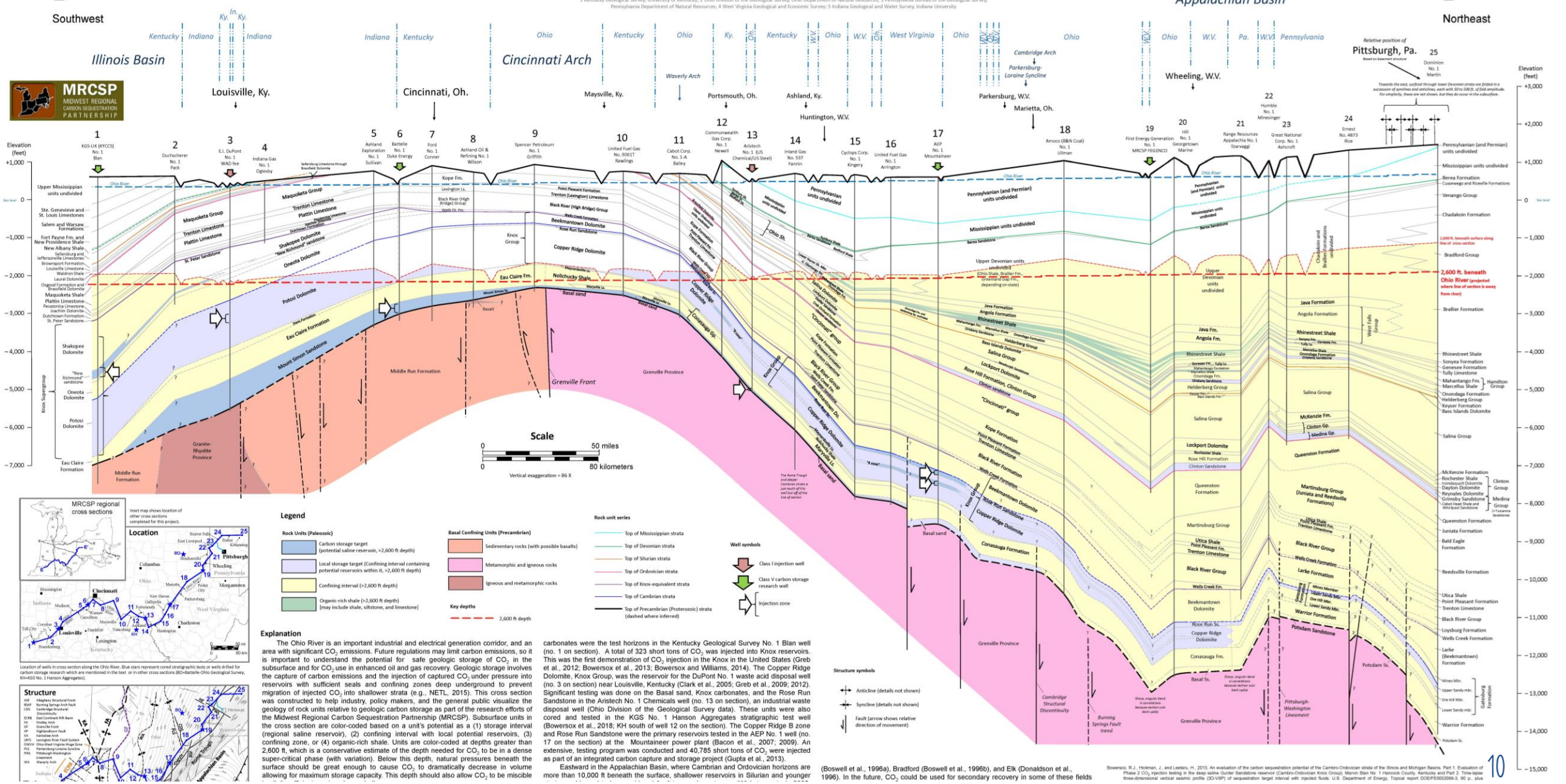
Courtesy John A. Harper

Subsurface geology for carbon storage along the Ohio River in part of the Midwest Regional Carbon Sequestration Partnership region

From Dinterman et al. (2020)

Stephen F. Greb[1], Thomas Sparks[1], Michael P. Solis[2], John A. Harper[3], Kristin M. Carter[3], Phil Dinterman[4], Eric Lewis[4], and Cristian Medina[5]

1 Kentucky Geological Survey, University of Kentucky; 2 Ohio Division of the Geological Survey, Ohio Department of Natural Resources; 3 Pennsylvania Bureau of the Geological Survey, Pennsylvania Department of Natural Resources; 4 West Virginia Geological and Economic Survey; 5 Indiana Geological and Water Survey, Indiana University



Explanation

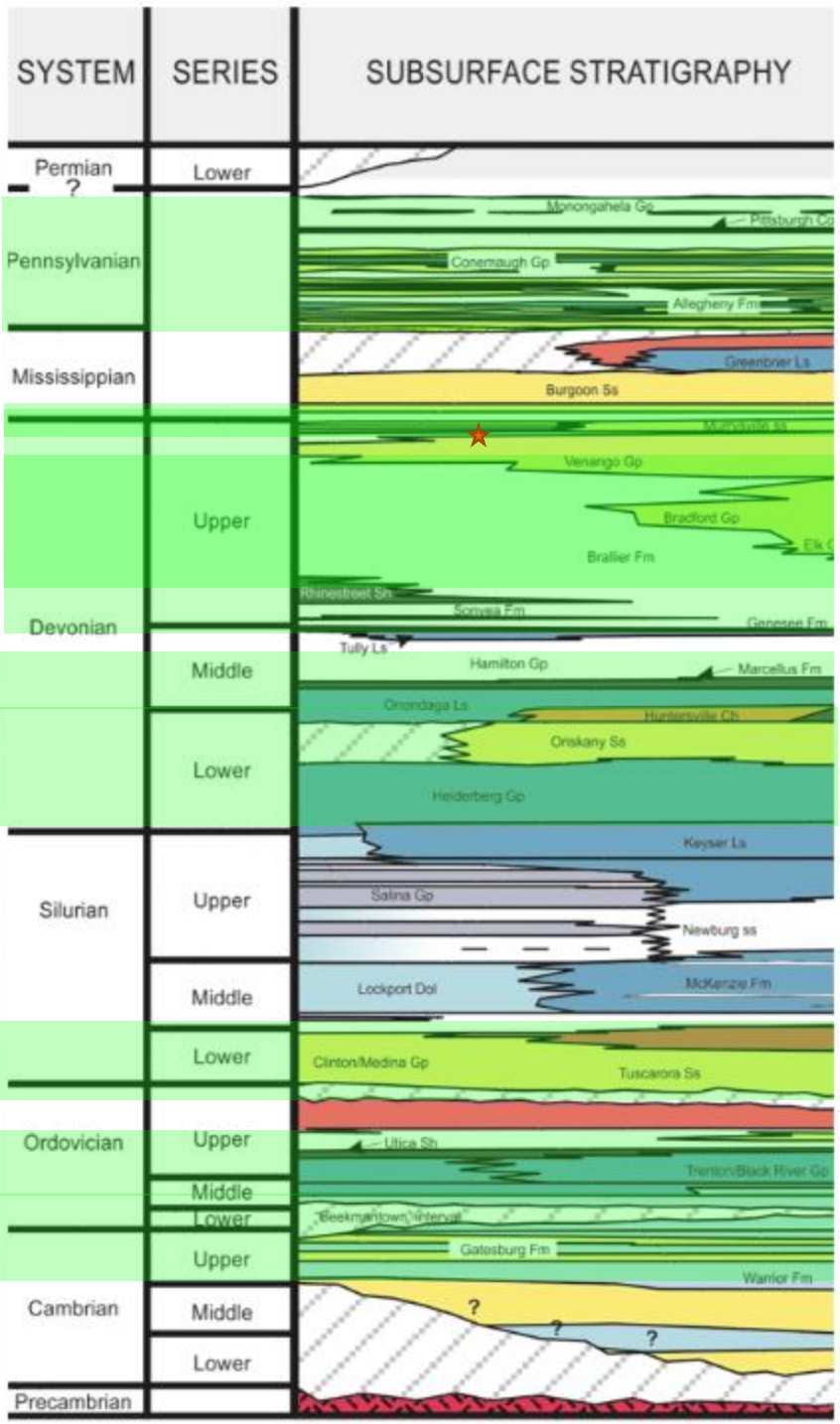
The Ohio River is an important industrial and electrical generation corridor, and an area with significant CO_2 emissions. Future regulations may limit carbon emissions, so it is important to understand the potential for safe geologic storage of CO_2 in the subsurface and for CO_2 use in enhanced oil 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 geologic 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 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 with oil (Boswell et al., 1996a), Bradford (Boswell et al., 1996b), and Elk (Donaldson et al., 1996). In the future, CO_2 could be used for secondary recovery in some of these fields carbonates were the test horizons in the Kentucky Geological Survey No. 1 Blan well (no. 1 on section). A total of 323 short tons of CO_2 was injected into Knox reservoirs. This was the first demonstration of CO_2 injection in the Knox in the United States (Greb et al., 2012; Bowersox et al., 2013; Bowersox and Williams, 2014). The Copper Ridge Dolomite, Knox Group, was the reservoir for the DuPont No. 1 waste acid disposal well (no. 3 on section) near Louisville, Kentucky (Clark et al., 2005; Greb et al., 2009; 2012). Significant testing was done on the Basal sand, Knox carbonates, and the Rose Run Sandstone in the Aristech No. 1 Chemicals well (no. 13 on section), an industrial waste disposal well (Ohio Division of the Geological Survey data). These units were also cored and tested in the KGS No. 1 Hanson Aggregates stratigraphic test well (Bowersox et al., 2018; KH south of well 12 on the section). The Copper Ridge B zone and Rose Run Sandstone were the primary reservoirs tested in the AEP No. 1 well (no. 17 on the section) at the Mountaineer power plant (Bacon et al., 2007; 2009). An extensive, testing program was conducted and 40,785 short tons of CO_2 were injected as part of an integrated carbon capture and storage project (Gupta et al., 2013).

Eastward in the Appalachian Basin, where Cambrian and Ordovician horizons are more than 10,000 ft beneath the surface, shallower reservoirs in Silurian and younger

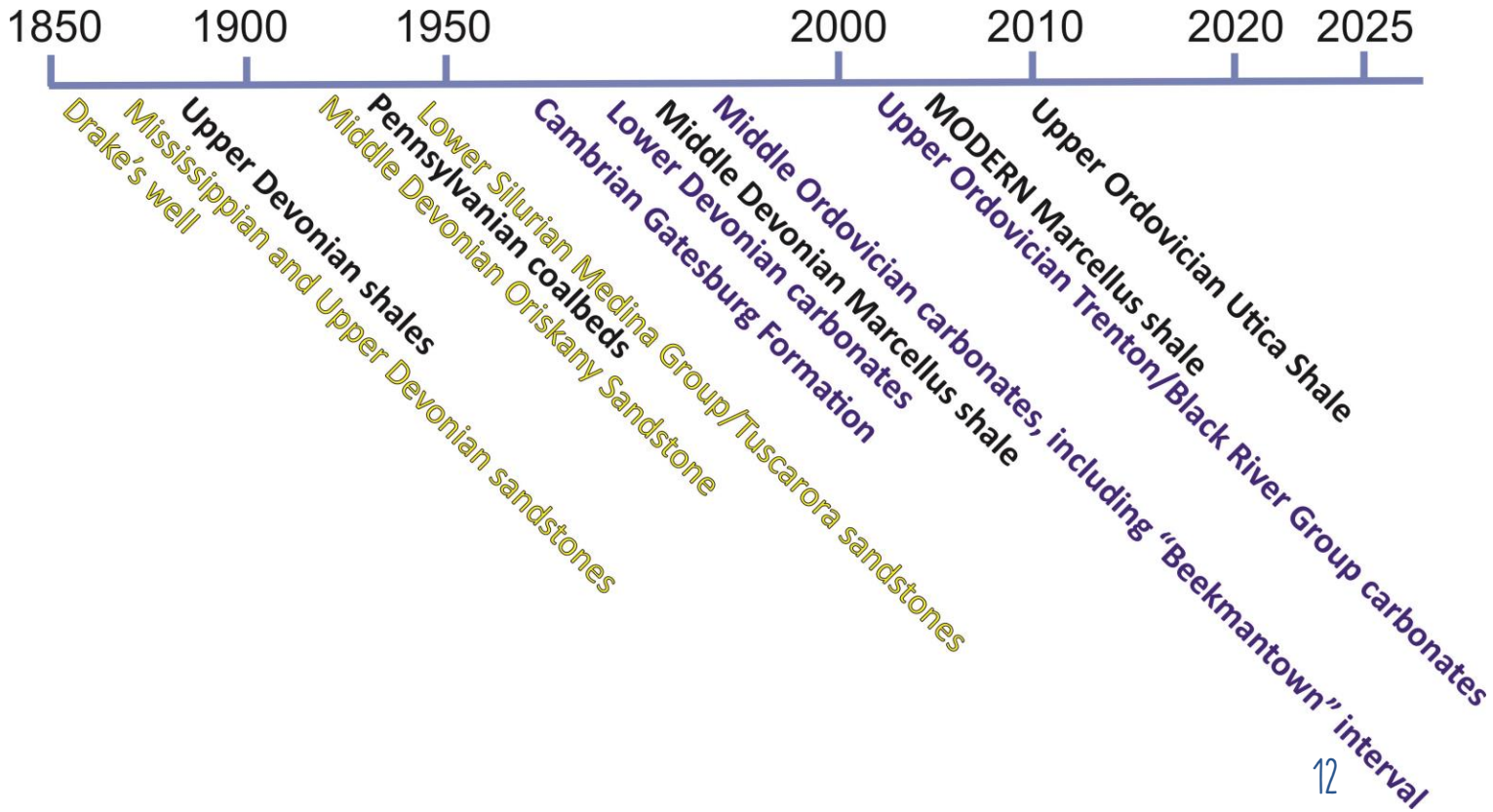
Bowersox, R.J., Hickman, J., and Leetaru, H., 2013, An evaluation of the carbon sequestration potential of the Cambro-Ordovician strata of the Illinois and Michigan Basins: Part 1. Evaluation of Phase 2 CO_2 injection testing in the deep saline Dunter Sandstone reservoir (Cambro-Ordovician Knox Group), Marvin Blan No. 1 Hancock County, Kentucky and Part 2. Time-lapse three-dimensional vertical seismic profile (3D-VSP) of sequestration target interval with injected fluids: U.S. Department of Energy, Topical report DOE/FE0002068-3, 90 p., plus

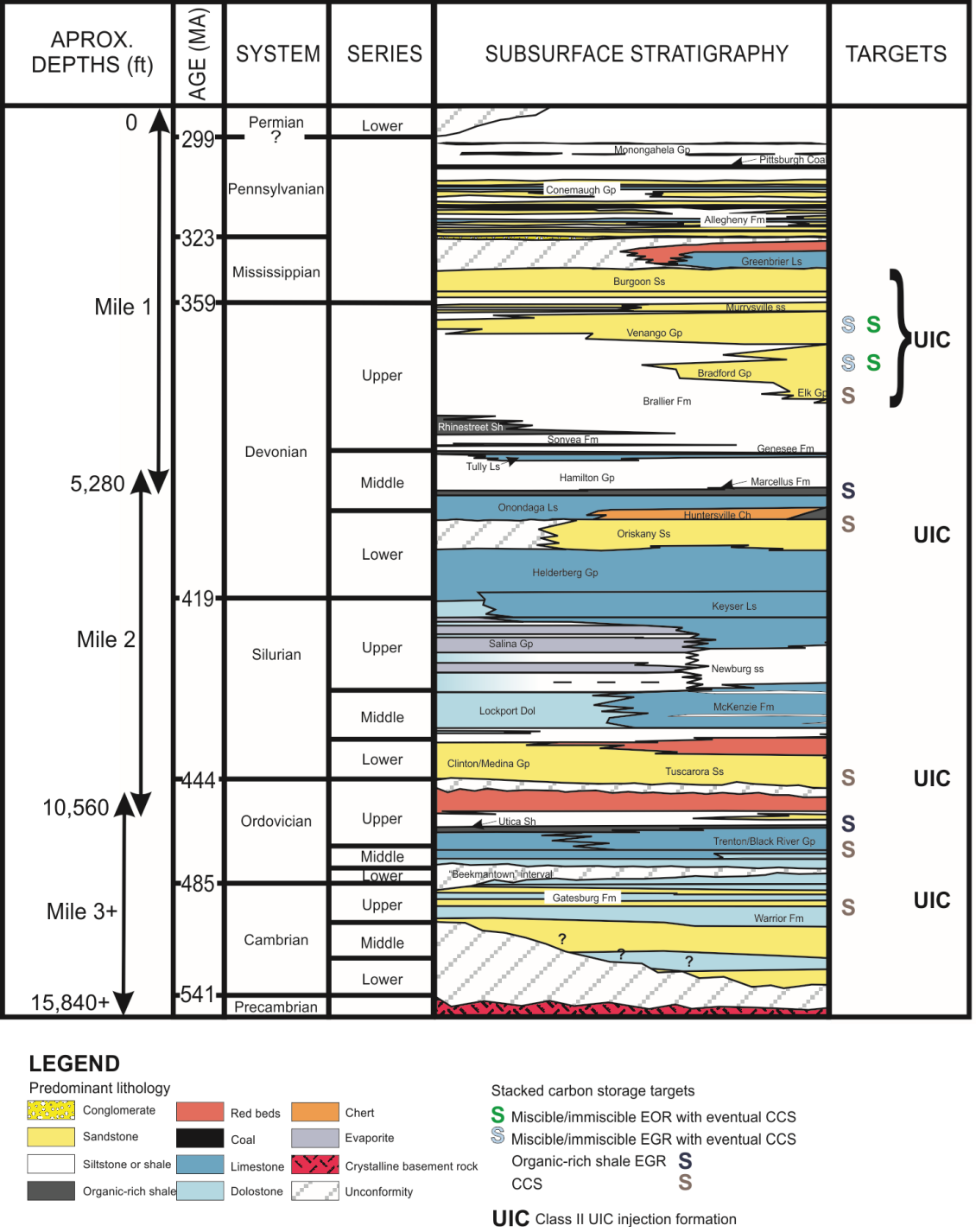
GEOLOGIC STORAGE

"If it can make it, it can take it..."



OIL AND GAS DEVELOPMENT





CAP PROJECT FOCUS

PA's EDWIN: >276,000 wells of record

WV's PIPELINE: >155,000 wells of record

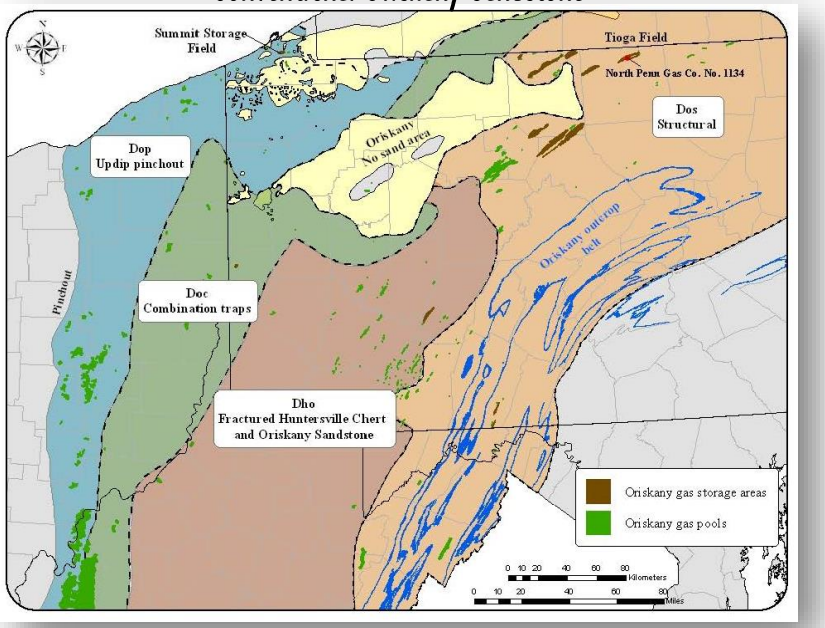
First mile - existing oil and gas production, natural gas storage, UIC wells, opportunities for CO_2-EOR and CO_2-EGR with associated storage

Second mile - some knowledge, based on conventional and unconventional gas production

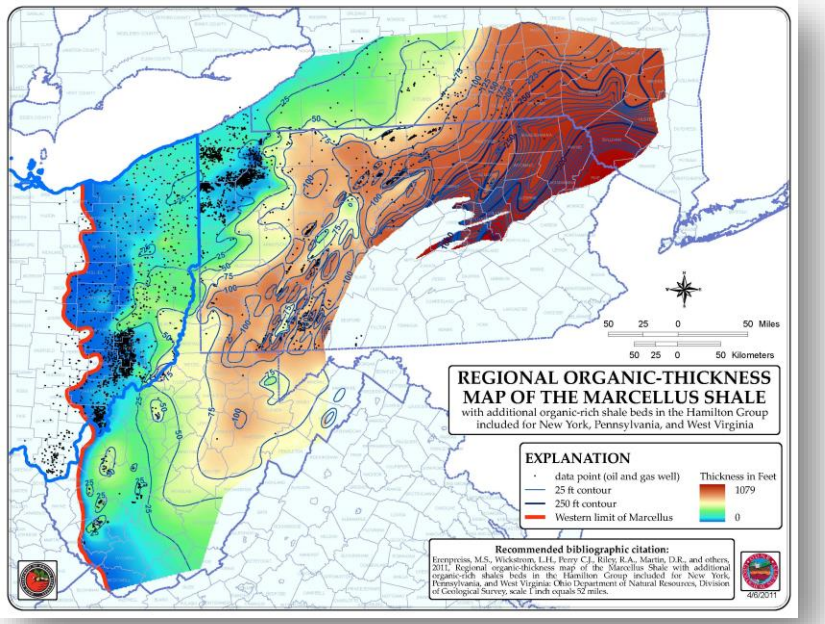
Third mile - least knowledge, with only a small number of basement test wells

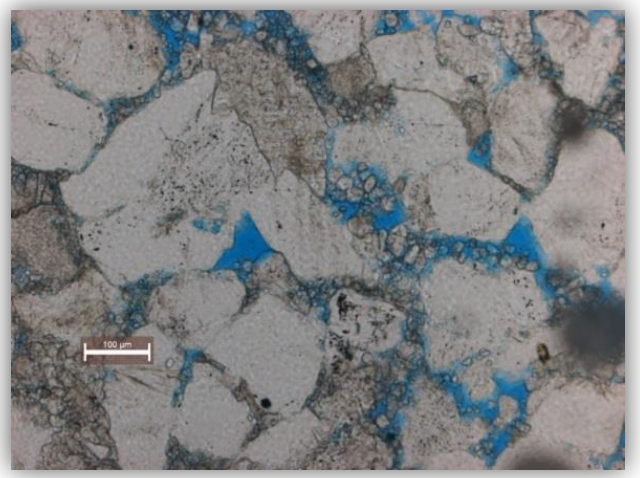
RESERVOIRS AND TRAPS

Conventional Oriskany Sandstone



Unconventional Marcellus Shale





Oriskany Sandstone (WVGES)

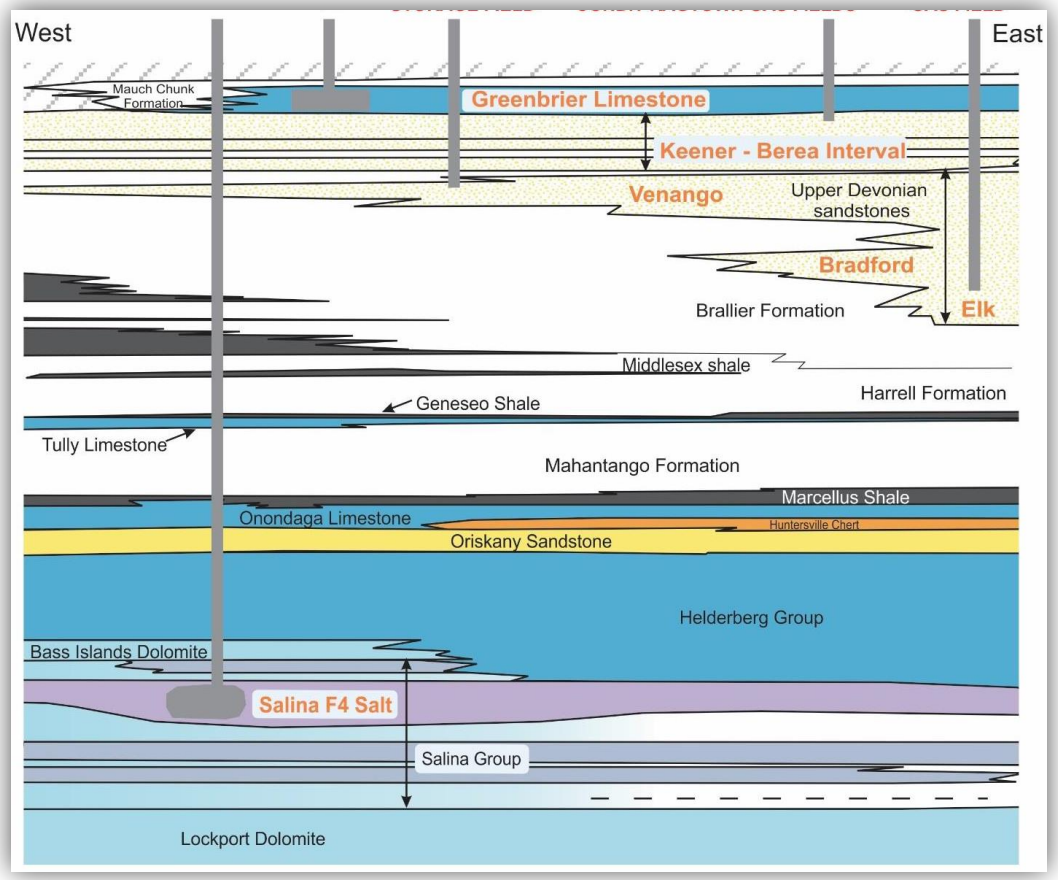
[Reservoir] - porous rock that contain fluids/gases ("product") and has permeability to allow product flow through the formation's pore space

[Caprock (Seal)] - low-porosity/low-permeability rock adjacent to a reservoir

[Trap] - means by which impervious caprock helps keep a reservoir's product in place - stratigraphic, structural, combination

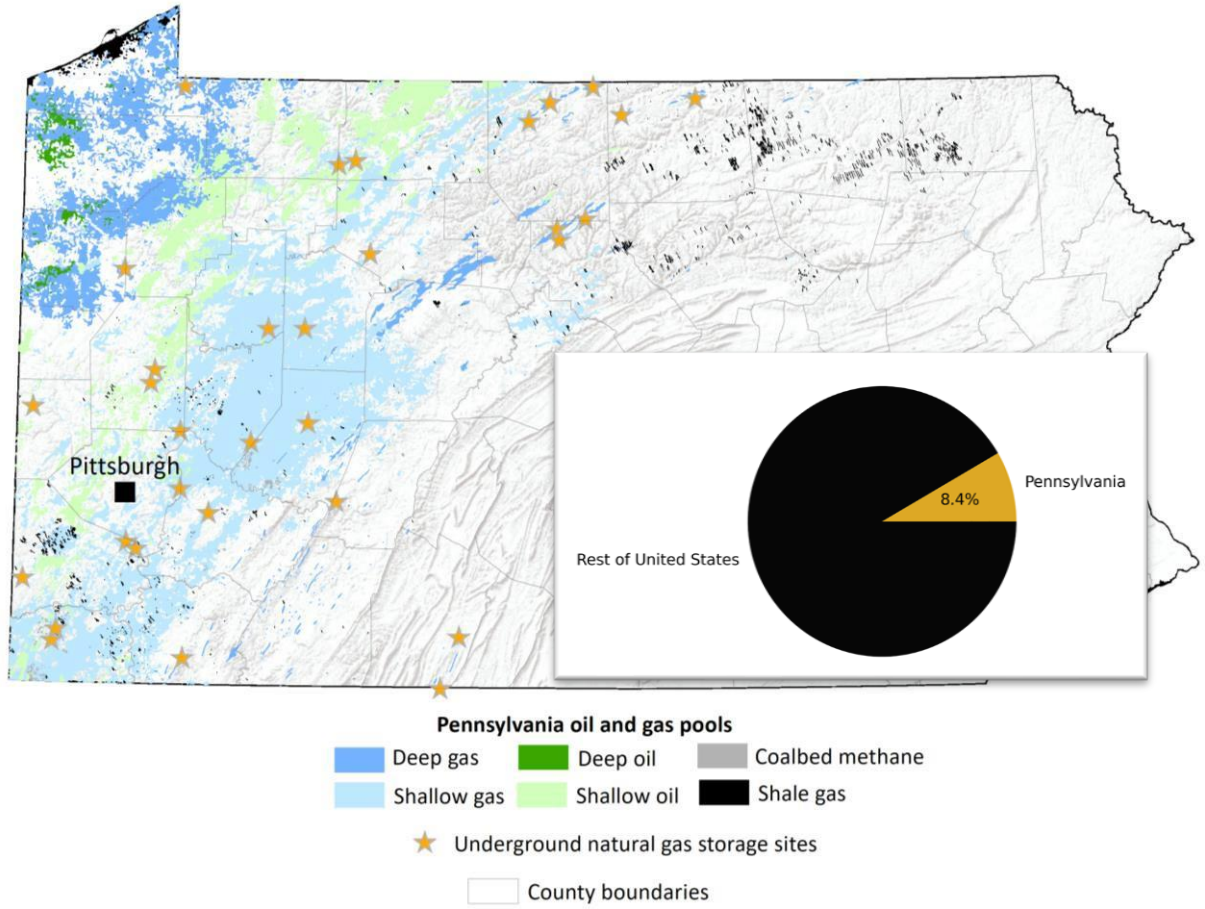
GEOLOGIC STORAGE

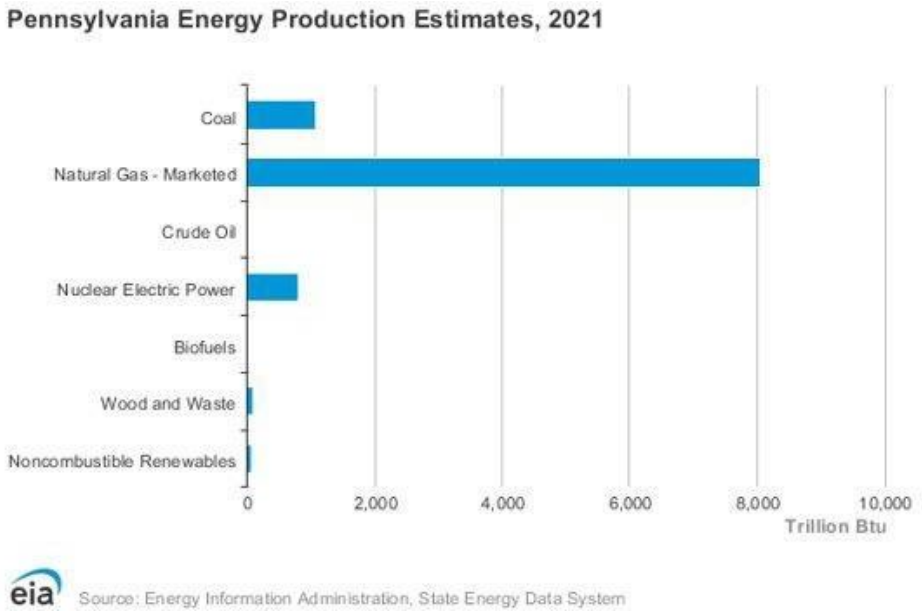
- Many liquids and gases are temporarily and/or permanently stored underground
- Methane (CH_4) has been stored underground in the tri-state region by utility operators since the late 1930s
- Like CH_4, carbon dioxide (CO_2), natural gas liquids, hydrogen (H_2), and wastewater can be stored underground in geologic reservoirs
- Three classes - porous rocks, salt caverns and mined/engineered caverns



From Carter and Patchen (2017)

UNDERGROUND NATURAL GAS STORAGE





There are 56 UNGS facilities in PA, which contribute ~8.4% of U.S. UNGS.

PERSPECTIVES ON GEOLOGIC CARBON STORAGE AND RESOURCE DEVELOPMENT

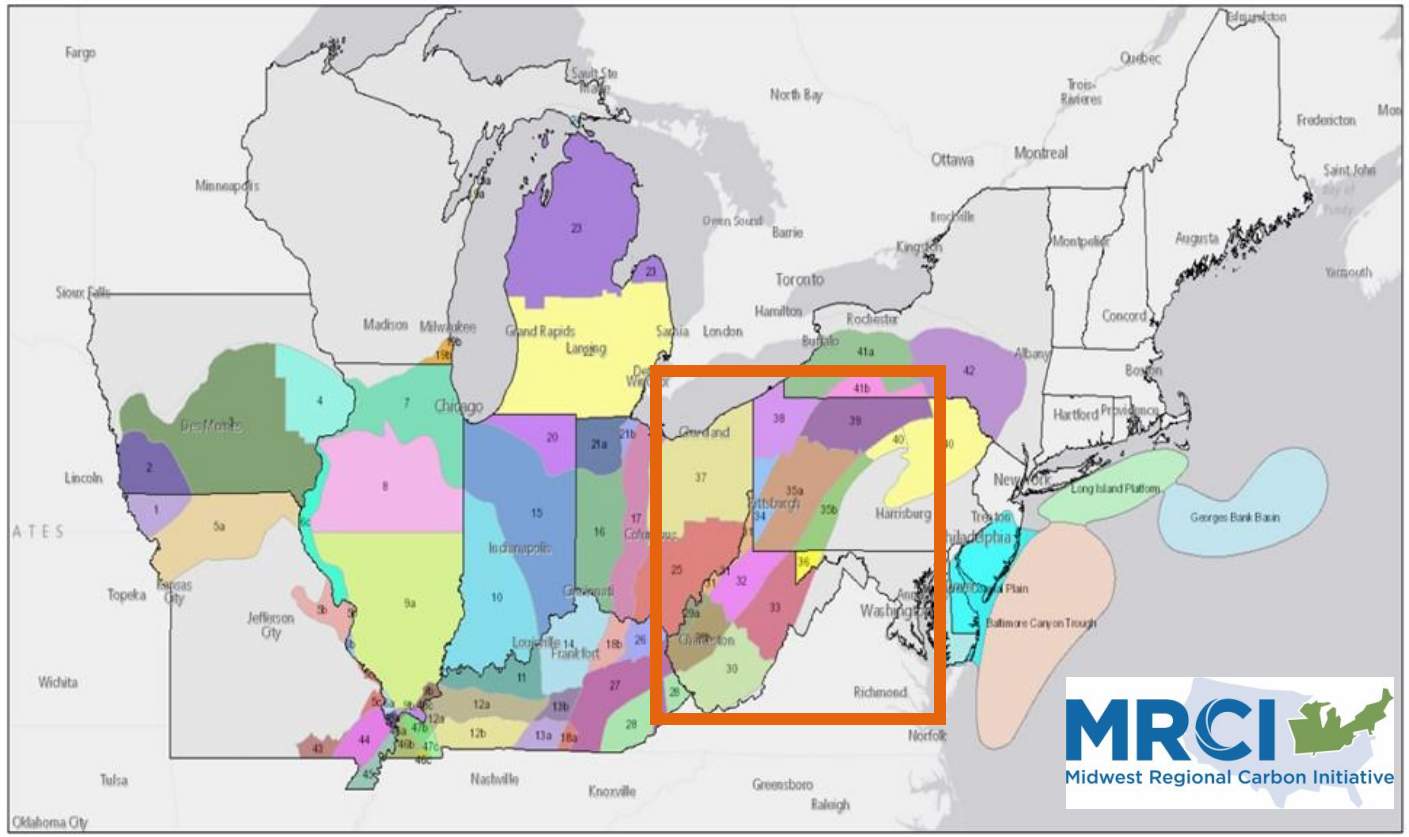
"Can't we all just get along?"

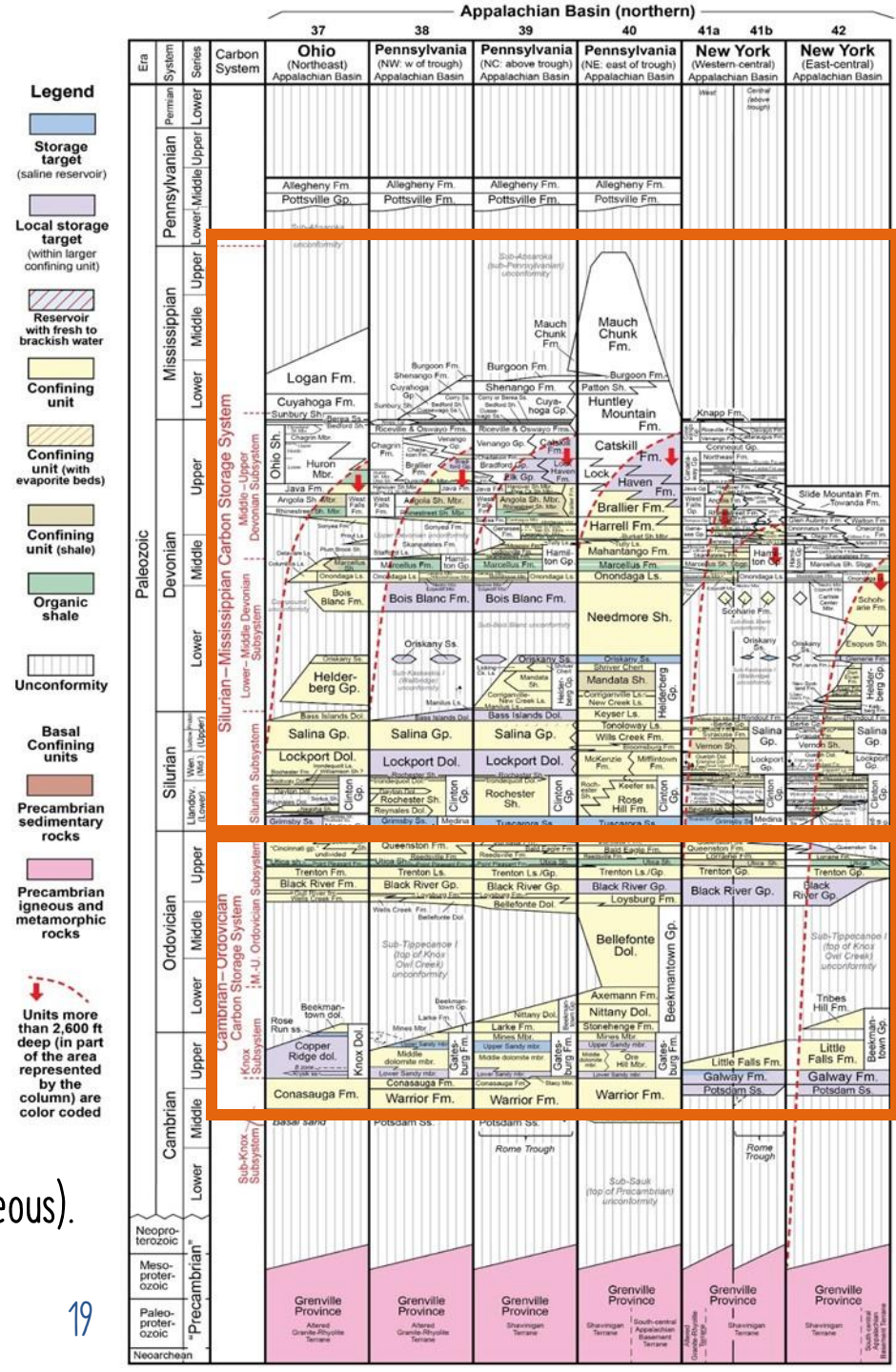
GEOLOGIC CARBON STORAGE SYSTEMS

Geologic carbon storage specifically refers to the injection of captured CO_2 into subsurface storage reservoirs by way of specially constructed (Class VI) injection wells.

- Thick, regional saline reservoir - clastic rocks with significant thickness (50+ ft) and porosity, more than 2,600 ft deep, with a good seal
- Local large saline reservoir - some type of secondary saline reservoir with a regional seal, and other conditions as above
- Stacked reservoir - cumulative porosity-ft comprised of multiple formations. There could be different groupings of "stacked" reservoirs based on the units and seals envisioned; major regional seals would be a good first-order divisions
- Depleted reservoirs with Enhanced Oil Recovery (EOR) potential - could be a standalone system, superimposed on saline reservoir system, or part of the stacked reservoir potential

DEFINING CARBON STORAGE SYSTEMS

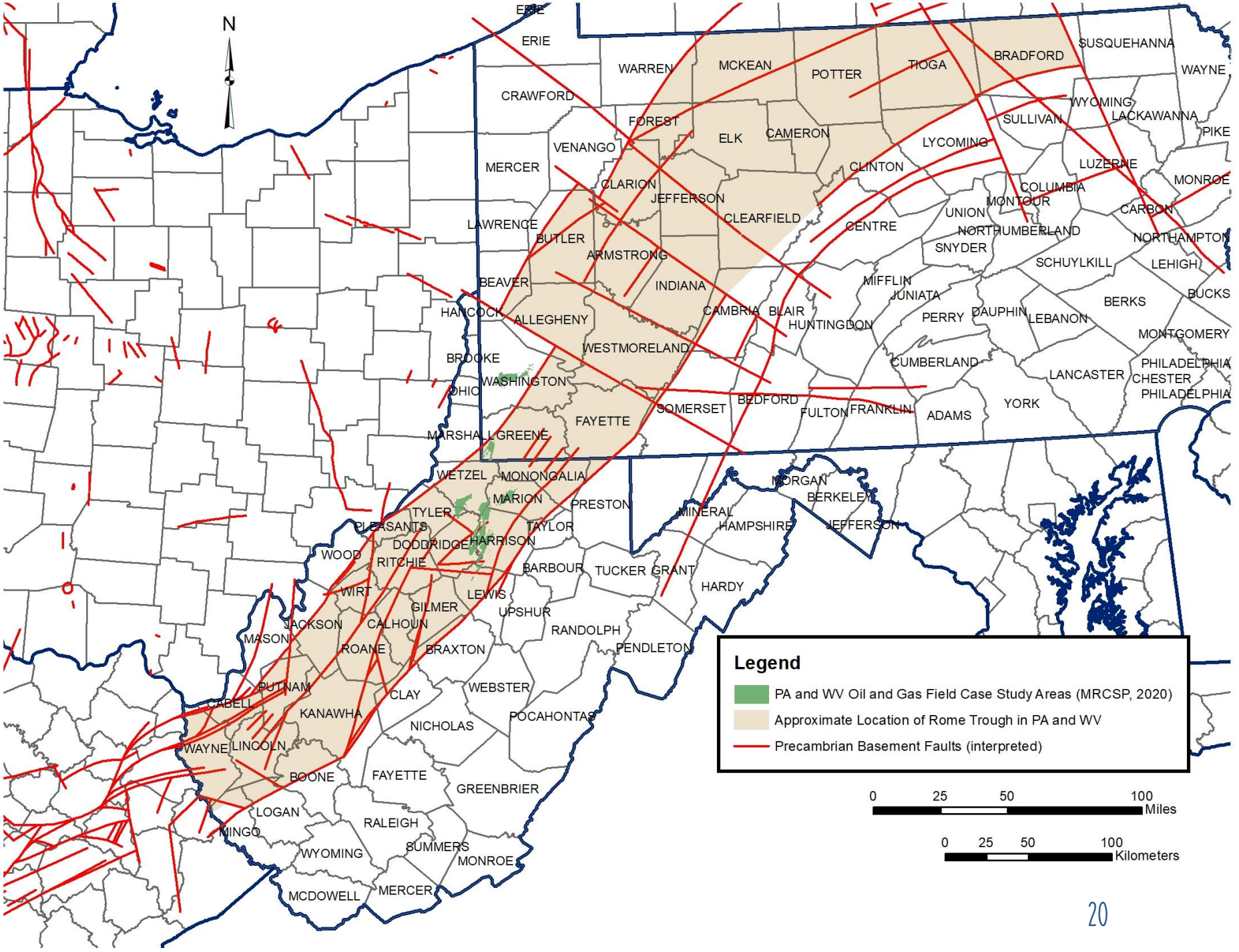




Potential reservoirs and seals were grouped into multiple carbon storage systems (Cambrian; Cambrian–Ordovician; Silurian–Mississippian; Late Triassic–Early Jurassic; and Late Jurassic–Cretaceous).

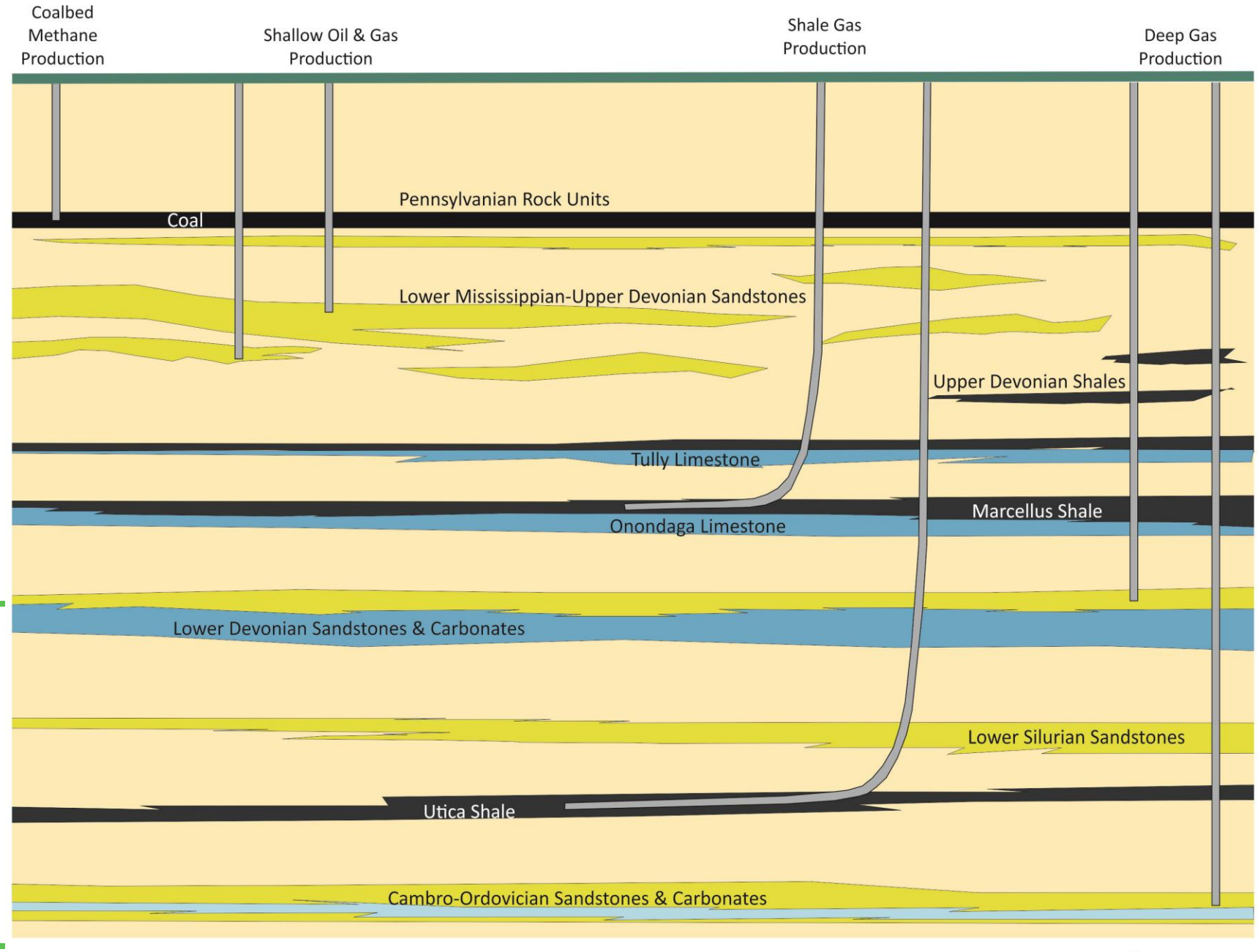
CAP PROJECT STUDY AREA

- Rich history of hydrocarbon extraction activities
- Regional reservoir characterization work is well-established
- Rome Trough (deepest part of the basin, thick sequences of sedimentary rocks)
- Home to a workforce poised to pivot to CCUS activities



APPALACHIAN PLATEAUS

- ✓ OUT:
  Active mining, petroleum hydrocarbon production
- ✓ IN:
  Energy storage (CH_4, H_2), Carbon sequestration, Wastewater disposal



Cartoon not to scale

TAKE HOME POINTS…

- By virtue of its relatively complex geologic history, the Appalachian basin is home to world-class oil and gas resources. What's more, our subsurface geologic formations have been used for seasonal natural gas storage and may also be used for other storage applications.
- Advances in regional geologic characterization over the past 20+ years offer mapping products and digital datasets that industry can apply to carbon storage project development efforts.
- Delineation of carbon storage systems, consideration of stacked reservoir potential, and preparation of site-specific characterization efforts are key to building CO_2 storage projects in the Appalachian region.
- U.S. DOE-funded technical assistance partnerships, such as the CAP Project, have been established to compile, distill, further analyze and communicate information regarding our region's subsurface geologic resources for the purpose of Class VI UIC permitting efforts and carbon sequestration projects.

THANK YOU

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