CLASS VI PERMIT APPLICATION NARRATIVE
40 CFR 146.82(a)

Project Name: Tri-State CCS Redbud 1

Facility Information

Facility Contact: Tri-State CCS, LLC
14302 FNB Parkway
Omaha, Nebraska 68154
402-691-9500

Well Locations: Fairhaven, Hancock County, West Virginia

Well Name	Latitude	Longitude
TR1-1	40.59722582	-80.5716718
TR1-2	40.55529898	-80.6001

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Acronym List

amsl	Above mean sea level
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
AOI	Area of Interest
AoR	Area of Review
AP	Artificial Penetrations
bgs	Below ground surface
BH	Bottom Hole
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
CI	Casing Inspection
CBL	Cement Bond Log
COCORP	Consortium for Continental Reflection Profiling
DAS	Distributed Acoustic Sensing
DTS	Distributed Temperature Sensing
DH	Downhole
ERRP	Emergency and Remedial Response
EPA	Environmental Protection Agency
ft	Feet
GS	Geologic Sequestration
gm	Gram
H_2S	Hydrogen Sulfide
KY	Kentucky
LIC	Lockport Injection Complex
MIT	Mechanical Integrity Test
MIC	Medina Injection Complex
MMt	Million Metric Tonnes
MMt/y	Millions of Metric Tonnes per year
Mt/y	Thousand Metric Tonnes per year
NACE	National Association of Corrosion Engineers
NY	New York
OH	Ohio
OSU	Ohio State University
ppmv	Parts per million volume
PA	Pennsylvania
mol%	Percentage of Total Moles in a Mixture made up by One Constituent
PISC	Post-Injection Site Care
psi	Pounds per Square Inch
psia	Pounds per Square Inch, Absolute

P/T	Pressure-Temperature
PNC	Pulsed Neutron Capture
QASP	Quality Assurance and Surveillance Plan
SAPT	Standard Annulus Pressure Test
SIC	Standard Industrial Classification
SEM	Static Earth Model
SSTVD	Sub-Sea True Vertical Depth
TN	Tennessee
TD	Total Depth
TDS	Total Dissolved Solids
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
VSP	Vertical Seismic Profile
VA	Virginia
WV	West Virginia
WVDEP	West Virginia Department of Environmental Protection

1. Project Background and Contact Information

Tri-State CCS, LLC is proposing the development of an industrial scale carbon capture and storage (CCS) hub in the tri-state region of Ohio (OH), Pennsylvania (PA), and West Virginia (WV) (Figure 1). The Tri-State CCS Hub envisions the development of several CO_2 injection wells with the capability of storing over 50-million metric tonnes (MMt) with injection taking place over 30 years. The hub was selected by the U.S. Department of Energy to receive Phase III funding under the CarbonSAFE Initiative. Partners include the Southern States Energy Board (the Prime Recipient), Tenaska Sequestration Services, LLC, Projeo Corporation, Ohio State University, West Virginia Geological and Economic Survey, and West Virginia University.

Tenaska is in the process of developing a series of injection fields that will be utilized to provide the region's emitters with a safe and secure subsurface storage solution. Nine separate emitters reporting more than 20 million metric tonnes per year (MMt/y) of aggregate CO_2 emissions have indicated their support for this project. These sources include AEP Dresden (1.9 MMt/y), AEP Mountaineer (9.2 MMt/y), Carroll County Energy (2.0 MMt/y), Ergon West Virginia (0.2 MMt/y), Hill Top Energy Center (1.5 MMt/y), Lakeview Energy (0.16 MMt/y), LS Power – Springdale (2.0 MMt/y), Southfield Energy (3.0 MMt/y), and Westmoreland Energy (2.8 MMt/y).

This narrative in support of a Class VI Underground Injection Control (UIC) permit application covers the Tri-State CCS Redbud 1 project in Hancock County, West Virginia (the "project"), which is a subset of the Tri-State CCS Hub. The project proposes development and operation of two injection wells (TR1-1 and TR1-2), two in-zone observation wells (TR1-IOB-1 and TR1-IOB-2), two above zone monitoring wells (TR1-AOB-1 and TR1-AOB-2), two lowermost underground source of drinking water (USDW) observation wells (TR1-UOB-1 and TR1-UOB-2), and up to two groundwater observation wells that will be drilled on the existing injection and monitoring well pads (Figure 2). This Application Narrative is for proposed TR1-1 and TR1-2.

Tri-State CCS, LLC is an affiliate of Tenaska, Inc. (Tenaska) who has made major, corporate-level commitments toward the development of the hub. Tenaska is a privately held, independent power company based in Omaha, Nebraska. Established in 1987, Tenaska has a generating fleet over 7,500 MW, is one of the largest gas marketing companies in North America and has balance sheet equity of $2.9 billion. Tri-State CCS, LLC will serve as the hub owner and will assume liability for development, finance, and operation of the hub.

The key project contacts are:

Claimed as PBI
Tri-State CCS, LLC
14302 FNB Parkway
Omaha, Nebraska 68154
Claimed as PBI

Claimed as PBI
Projeo Corporation
1700 S Mount Prospect Rd.
Des Plaines, Illinois 60018

Claimed as PBI [redacted]

The supporting documentation was prepared in accordance with 40 CFR 146.81 et seq.

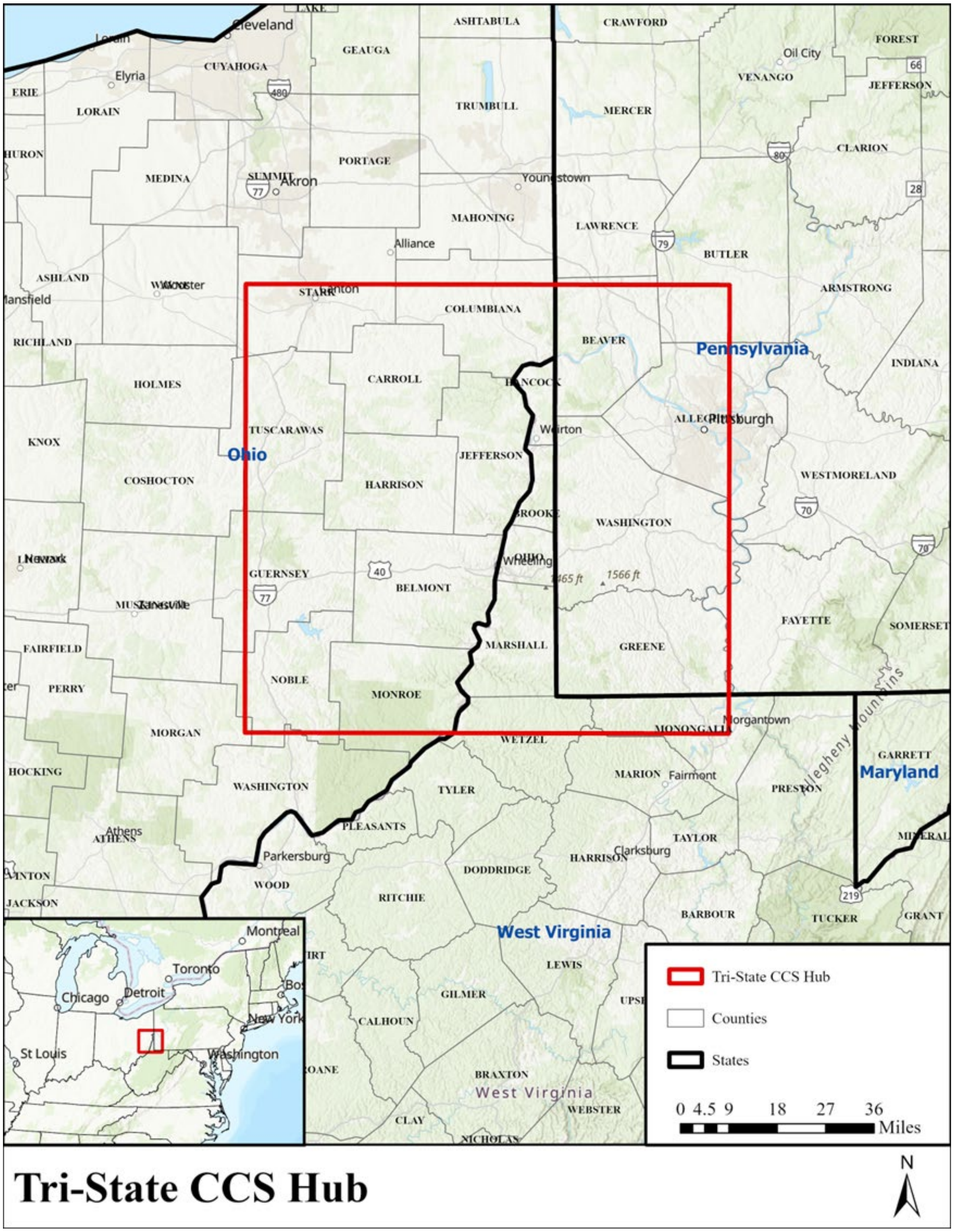

Figure 1: Location of Tri-State CCS Hub.

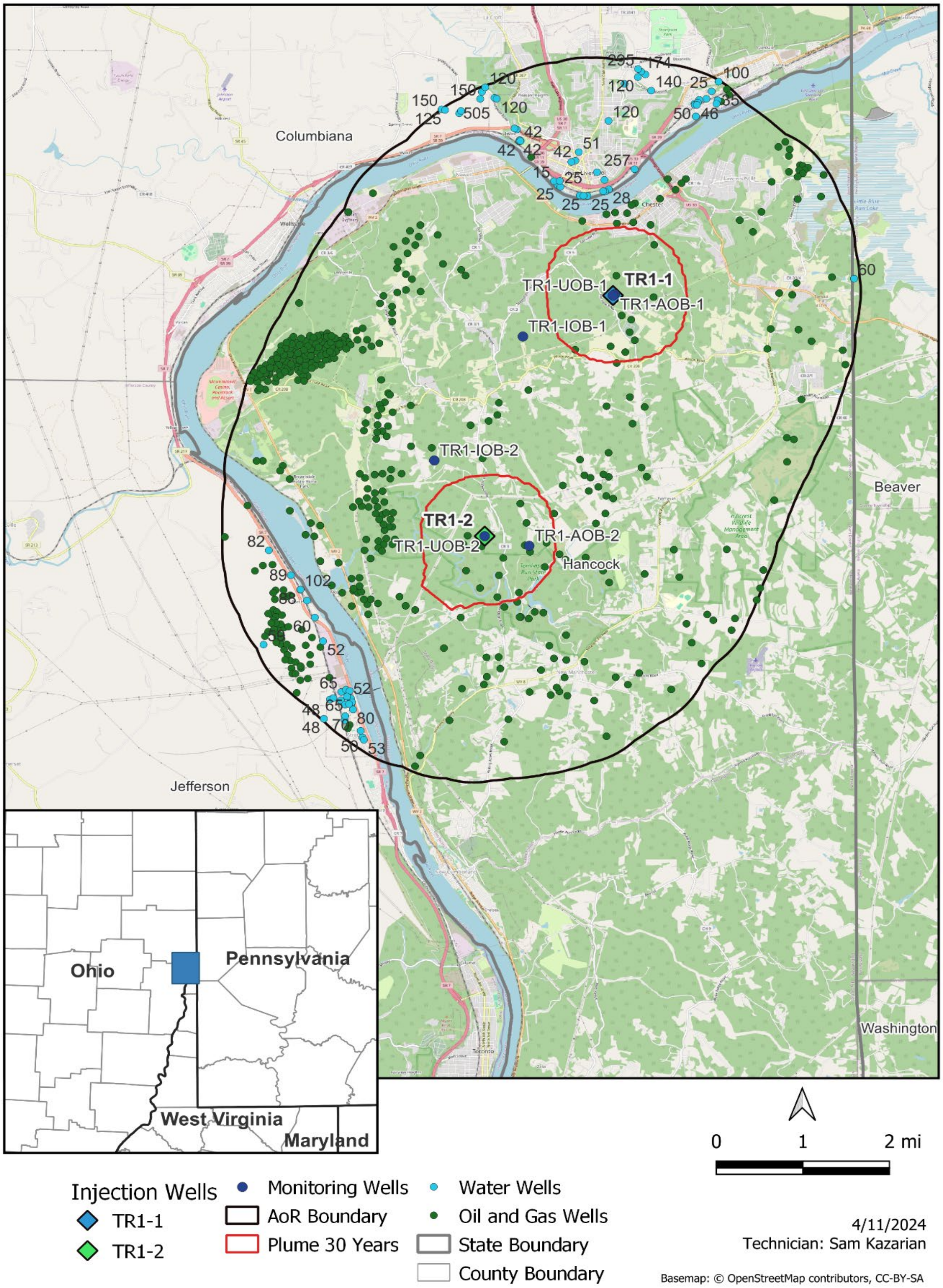

Figure 2: Locations of proposed injection and observation wells, oil and gas wells, water wells, and the 30-year plume boundary.

With this application, Tri-State CCS, LLC is requesting permits to construct for TR1-1 and TR1-2. After issuance of the permits by the UIC Program Director, Tri-State CCS, LLC plans to start construction of the injection wells within 2 years but additionally requests two options to extend the permit term by 2 years. The reason for this request is that the project relies on the installation of capture equipment at the emitter and construction of pipeline infrastructure to the emitter, both of which may be delayed for reasons outside the control of Tri-State CCS, LLC. After submittal of required documentation to the UIC Program Director and receiving authorization to inject and once the emitter is ready to operate their CO_2 capture equipment, Tri-State CCS, LLC will initiate injection. This application assumes that the 30-year injection period will start in approximately 2027, end in 2057, and be followed by a 50-year post-injection site care period, taking the project to 2107. Start of injections could vary by 1 to 5 years.

The project is not requesting an injection depth waiver or an expansion of aquifer exemptions with this application.

There are no federally recognized Native American tribal lands or territories within the proposed Area of Review (AoR) (40 CFR 146.82(a)(20)).

The SIC codes applicable to the project are identified below (40 CFR 144.31(e)(3)):

- 49530300 Nonhazardous waste disposal sites – primarily engaged in collection and disposal of refuse by processing or destruction or in operation of incinerators/waste treatment plants/landfills/other sites for disposal of such materials;
- 51690203 Carbon Dioxide – primarily engaged in wholesale distribution of CO_2; and
- 4619 Pipelines, not elsewhere classified – primarily engaged in pipeline transportation of commodities except petroleum and natural gas.

State contacts with jurisdictions within the proposed AoR include the following (40 CFR 146.82(a)(20)):

West Virginia Department of Environmental Protection
Division of Water and Waste Management, Groundwater/UIC Program
601 57th St. SE, Charleston, WV 25304
Todd Cooper: 304-926-0499, todd.cooper@wv.gov

Ohio Department of Natural Resources (Class II UIC wells)
Division of Oil & Gas Resources
2045 Morse Road, Columbus, OH 43229
Kenny Brown: 614-265-6933, michael.brown@dnr.state.ohio.us

Ohio Environmental Protection Agency (Class 1, IV, and V UIC wells)
Division of Drinking and Ground Waters, Underground Injection Control Program
P.O. Box 1049, Columbus, OH 43216-1049
Lindsay Taliaferro: 614-644-2771, l.taliaferro@epa.ohio.gov

Pennsylvania Department of Environmental Protection

Southwest Regional Office
400 Waterfront Drive, Pittsburgh, PA 15222
Jim Miller: jamesmill@pa.gov, 412-442-4181 or 412-442-4000

The permits and authorizations that will likely be required for the project, the permit/authorization jurisdictions, and the associated project development activities are provided in Table 1 (40 CFR 144.31(e)(6)).

Table 1: Permits and Authorizations necessary for the development of Tri-State CCS Redbud 1.

Required Permits and Authorizations for Hancock County, West Virginia		
Permit/Authorization	**Activity**	**Jurisdiction**
UIC Class VI Permit to Construct	Drilling of Injection Wells	Federal
UIC Class VI Authorization to Inject	Injecting CO_2	Federal
Greenhouse Gas Rule Subpart RR Monitoring, Reporting, and Verification Plan Approval	Injecting CO_2	Federal
Section 404 Nationwide Permit	Temporary impacts to jurisdictional waters	Federal
Construction Stormwater General Permit	Management of stormwater during construction	WVDEP Division of Water and Waste Management
Monitoring Well Completion Report	Monitoring well construction	WVDEP Division of Water and Waste Management

The project is currently proposing an AoR that includes a 1-mile buffer on the modeled maximum extent of the pressure front to mitigate the current unknowns in subsurface data that will be resolved with the planned CarbonSAFE stratigraphic test well and pre-injection testing, as further described in this Application Narrative and in the Area of Review and Corrective Action Plan. Due to the extent of the AoR, four figures were created (Figures 2, 3, 4, and 5) to address federal requirements at 40 CFR 146.82(a)(2) for a map of the area, with features shown or absent as noted below:

- Injection wells: There are no records of currently active injection wells in the AoR other than proposed TR1-1 and TR1-2.
- Producing wells: There are seven known (7) producing wells (Berea Sandstone, the Pennsylvanian system, and unknown) in the AoR, shown as part of the oil and gas wells in Figure 2. The Area of Review and Corrective Action Plan further discusses oil and gas wells, including available well data.
- Abandoned wells: There are 357 well with the status "completed," "inactive," or "unknown" in the AoR, shown as part of the oil and gas wells in Figure 2. The Area of

Review and Corrective Action Plan further discusses oil and gas wells, including available well data.

- Plugged wells or dry holes: There are 105 known plugged and abandoned wells in the AoR, shown as part of the oil and gas wells in Figure 2. The Area of Review and Corrective Action Plan further discusses oil and gas wells, including available well data.
- Deep stratigraphic boreholes: There are no records of deep stratigraphic boreholes in the AoR.
- State or U.S. EPA-approved subsurface cleanup sites: There are no records of state subsurface cleanup sites and one record of an EPA subsurface cleanup site in the AoR (Figure 5).
- Surface bodies of water: The following named surface bodies of water are in the mapped area, as shown in Figure 3: Ohio River, North Fork Tomlinson Run, South Fork Tomlinson Run, Tomlinson Run, Dry Run, Mercer Run, Middle Run, Muchmore Run, Deep Gut Run, Langfitt Run, Little Blue Run Lake (currently drained), and Goose Run. There are various unnamed tributaries and ponds in the AoR as well.
- Springs: There are no records of springs in the mapped area.
- Surface and subsurface mines: There are no records of surface or subsurface mines in the AoR. Mining operations in the mapped area are shown in Figure 4.
- Quarries: There are no records of quarries in the AoR.
- Water wells: There are eighty-eight (88) known water wells in the AoR, as shown in Figure 2.
- State, tribal, and territory boundaries: The AoR includes parts of West Virginia, Ohio, and Pennsylvania, as shown in Figure 2. There are no tribal or territory boundaries in the AoR.
- Roads: U.S. Highway 30, State Highways 2 and 8, and various county and town roads are in the AoR, as shown in Figure 3.

  Other pertinent surface features: the towns of Chester, Newell, Lawrenceville, Fairhaven, and New Manchester, West Virginia, and Stratton and East Liverpool, Ohio are in the AoR, as shown in Figure 3. Additionally, Tomlinson Run State Park and Hillcrest Wildlife Management Area are in the AoR, as shown in Figure 3.

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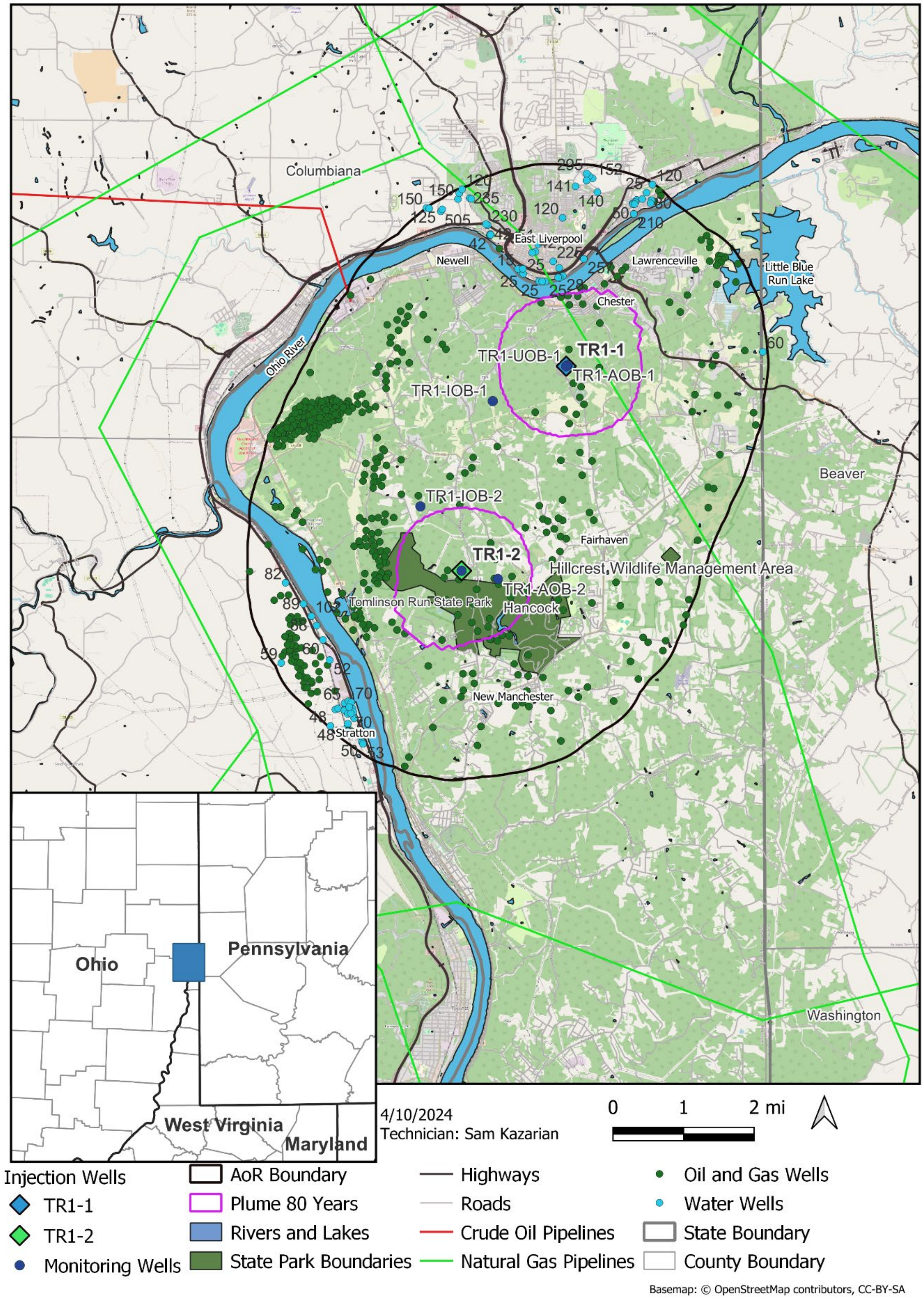

Figure 3: Infrastructure near proposed injection and observation wells.

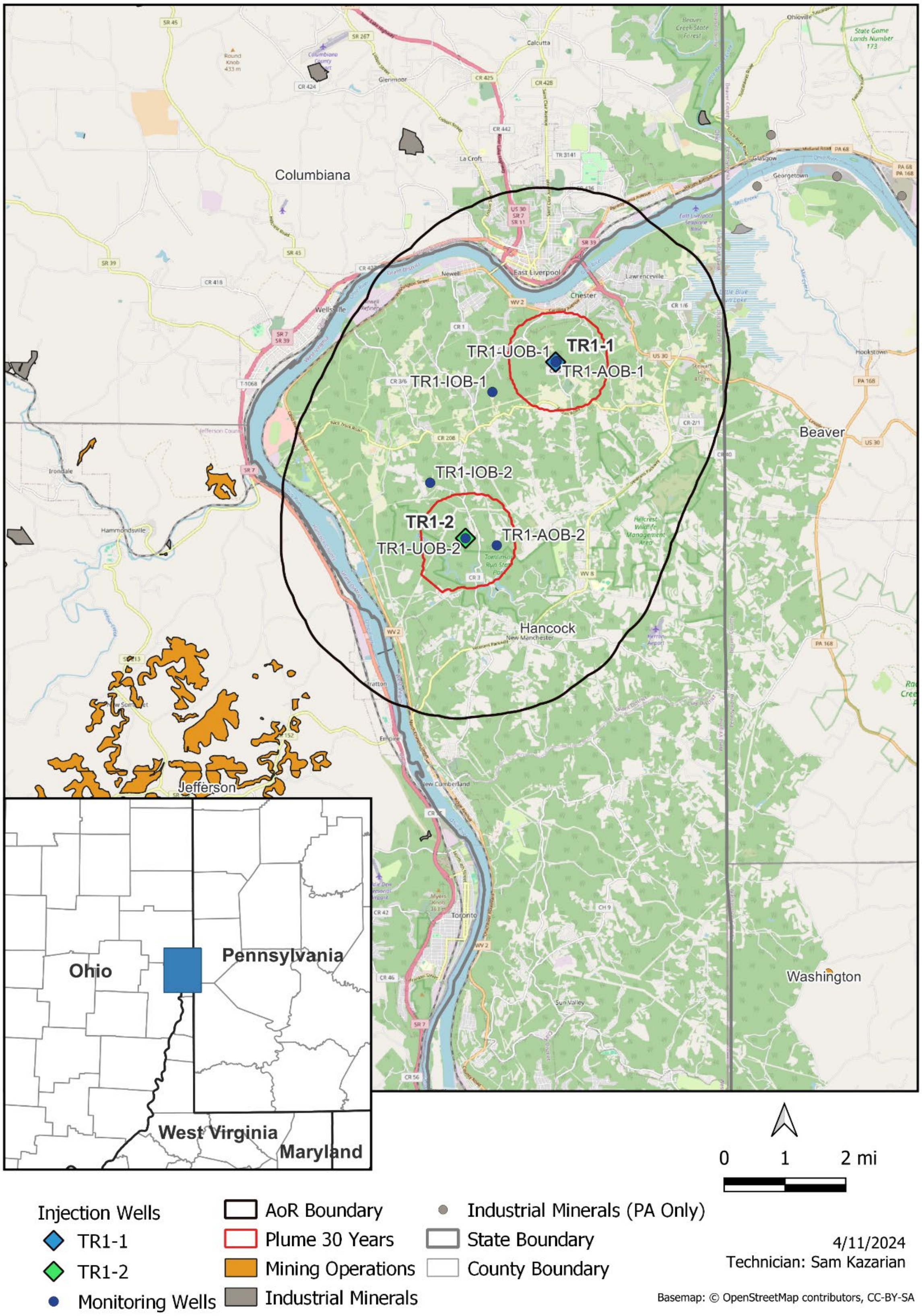

Figure 4: Mining and industrial minerals near proposed injection and observation wells.

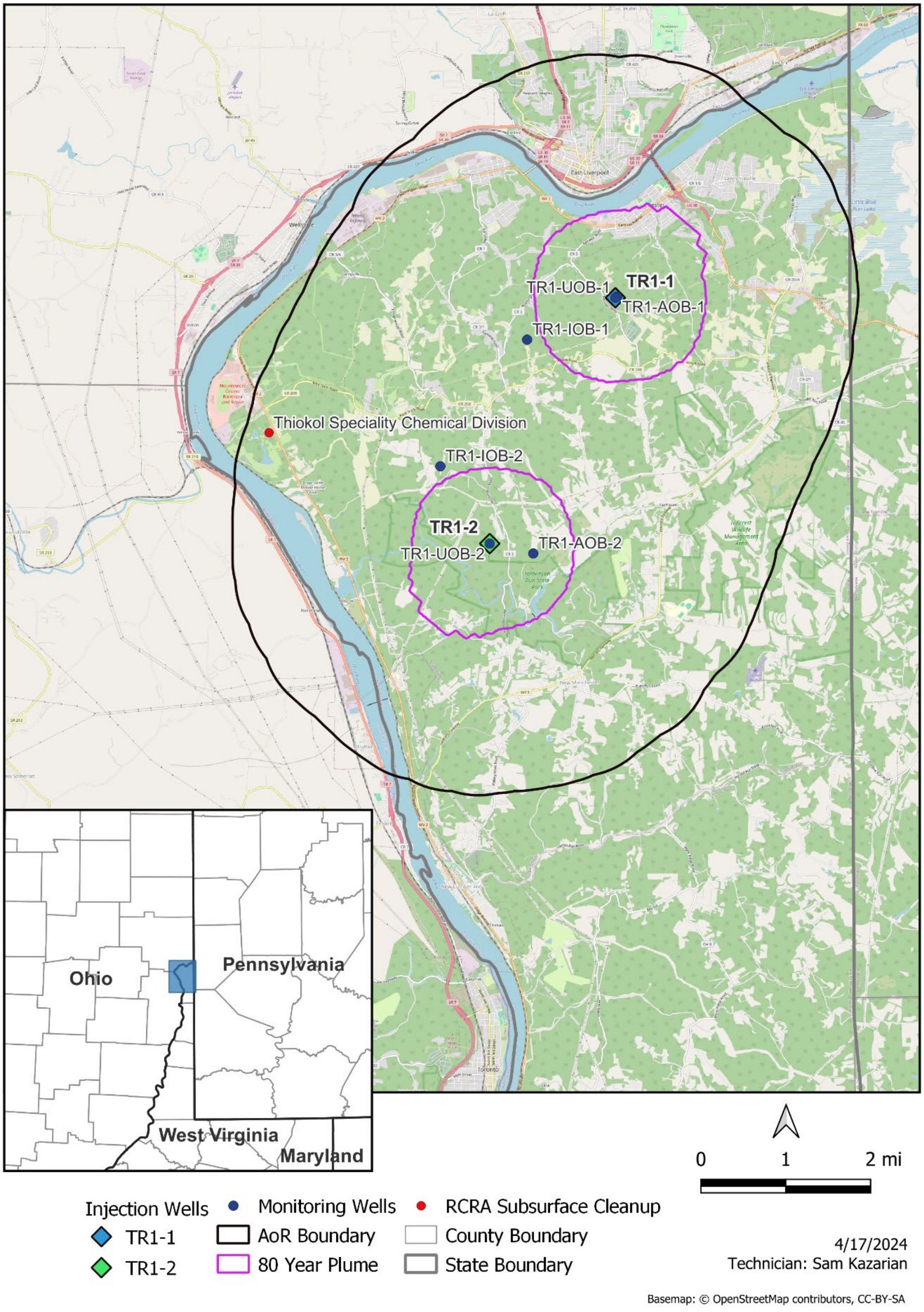

Figure 5: State and EPA subsurface cleanup sites.

2. Site Characterization

2.1. Regional Geology, Hydrogeology, and Local Structural Geology [40 CFR 146.82(a)(3)(vi)]

2.1.1. Geographic Overview

The Tri-State CCS Hub, which includes the project, is located within the tri-state region of eastern Ohio, northern West Virginia, and western Pennsylvania. This region lies within the Appalachian Basin, an elongate, retroarc foreland basin that sits within the physiographic province of the Appalachian Plateau (Figure 6). The Appalachian Basin extends approximately 1270 miles from Canada to Alabama and is flanked by the Cincinnati, Findlay, and Algonquin arches to the west, and the New England Uplands, Blueridge Uplands, and the Adirondack Dome to the east (Colton, 1970). The northern boundary of the basin is demarcated by the Laurentian and Frontenac arches of the Canadian Shield (Ettensohn, 2008), while to the south, the basin transitions into the Black Warrior Basin of northwestern Alabama and northeastern Mississippi (Figure 6).

2.1.2. Tectonic History

The Appalachian Basin developed as a result of flexurally driven subsidence caused by tectonic loading from four nearly continous orogenic events throughout the Paleozoic. Orogenic development related to the Applachian Basin began in the Early-Middle Ordovician (~472 Ma) and continued for almost 200 Ma until the Late Permian (Ettensohn, 2008). The orogenies include the Taconic or Taconian, the Salinic, the Acadian, and the Alleghanian tectophase orogenic cycles (Figure 7). These orogenies can be grouped into two higher-order supercycle phases related to continetal collision and plate convergence with the Taconic and Salinic orogenies included in the Caledonian orogenic phase and the Acadian and Alleghanian orogenies included in the Variscan-Hercynian orogenic phase (Figure 7).

The Caledonian orogeny is a result of the Ordovician to Early Devonian closure of the Iapetus Ocean that formed the continent of Laurussia through the collision of the continents of Laurentia, Baltica, and the Avalonian microcontinent (Kearey et al., 2009; Torsvik and Cocks, 2016).

The Variscan-Hercynian orogenic event occured during the Middle Devonian – Permian, as the Theic Ocean closed, and continetal collision between Laurussia and Gondwana formed the supercontinent of Pangaea (Kearey et al., 2009; Ziegler, 2012; Torsvik and Cocks, 2016).

2.1.3. Influence of Precambrian – Cambrian Tectonic Events

Paleozoic development of the Appalachian Foreland Basin was heavily influenced by Precambrian-Cambrian age tectonic events. The basement rocks that underlay the basin mainly comprise Grenvillian age crust (1.35 – 0.95 Ga, Figure 8) that were deformed and metamorphosed during the Grenville orogeny as the supercontinent Rodinia was formed (Ettensohn, 2008). Portions of the Grenville crust have been uplifted and deformed through Paleozoic orogenic events and are exposed at the surface in both the Blue Ridge physiographic province and the Adirondack dome (Figure 6).

Late Precambrian-Cambrian rifting and volcanism occurred during the separation of Laurentia from Gondwana and the formation of the Iapetus, Theic, and Rheic Oceans (Kearey et al., 2009; Torsvik and Cocks, 2016). Inboard rifting resulted in the deposition and emplacement of time-equivalent sedimentary and volcanic rocks (Figure 8) along what is currently the physiographic provinces of the Blue Ridge and Valley and Ridge (Figure 6; Ettensohn, 2008).

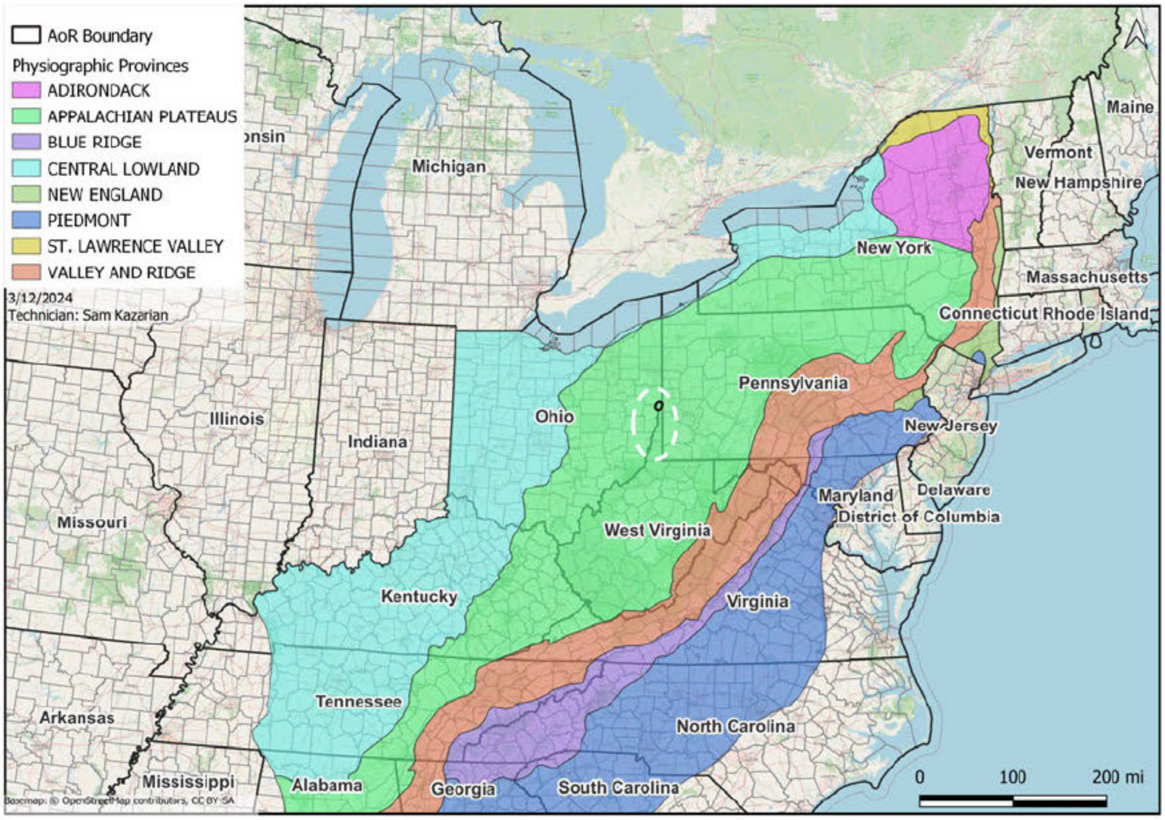

Figure 6: Physiographic provinces of the Appalachian Mountains. The Tri-State CCS Hub location is indicated with a white dashed circle, with the project's AoR boundary in black within it.

Rifting was followed by a period of stabilization across the margin, relative sea level rise, and thermally driven subsidence of the basin that resulted in the widespread deposition of Precambrian-Early Cambrian synrift siliciclastic sediments (Colton, 1970). During the Late Cambrian, continued submergence of the platform established the "Great American Carbonate Bank", depositing up to 3,000 ft of mixed limestone, dolostone, and minor siliciclastic sediment (Figure 8; Demicco and Mitchell, 1982).

2.1.4. Early Ordovician

The Late Cambrian post-rift passive margin phase continued into the Early Ordovician as sedimentation and carbonate development continued across the passive margin (Figure 7 and Figure 8). The near equatorial paleogeographic setting and aridification of the climate, during the Early Ordovician, resulted in the uninterrupted deposition of carbonates, dolomites, and sedimentary strata of the Knox Group (Figure 8; Read, 1989; Scotese, 2003; Ettensohn, 2008).

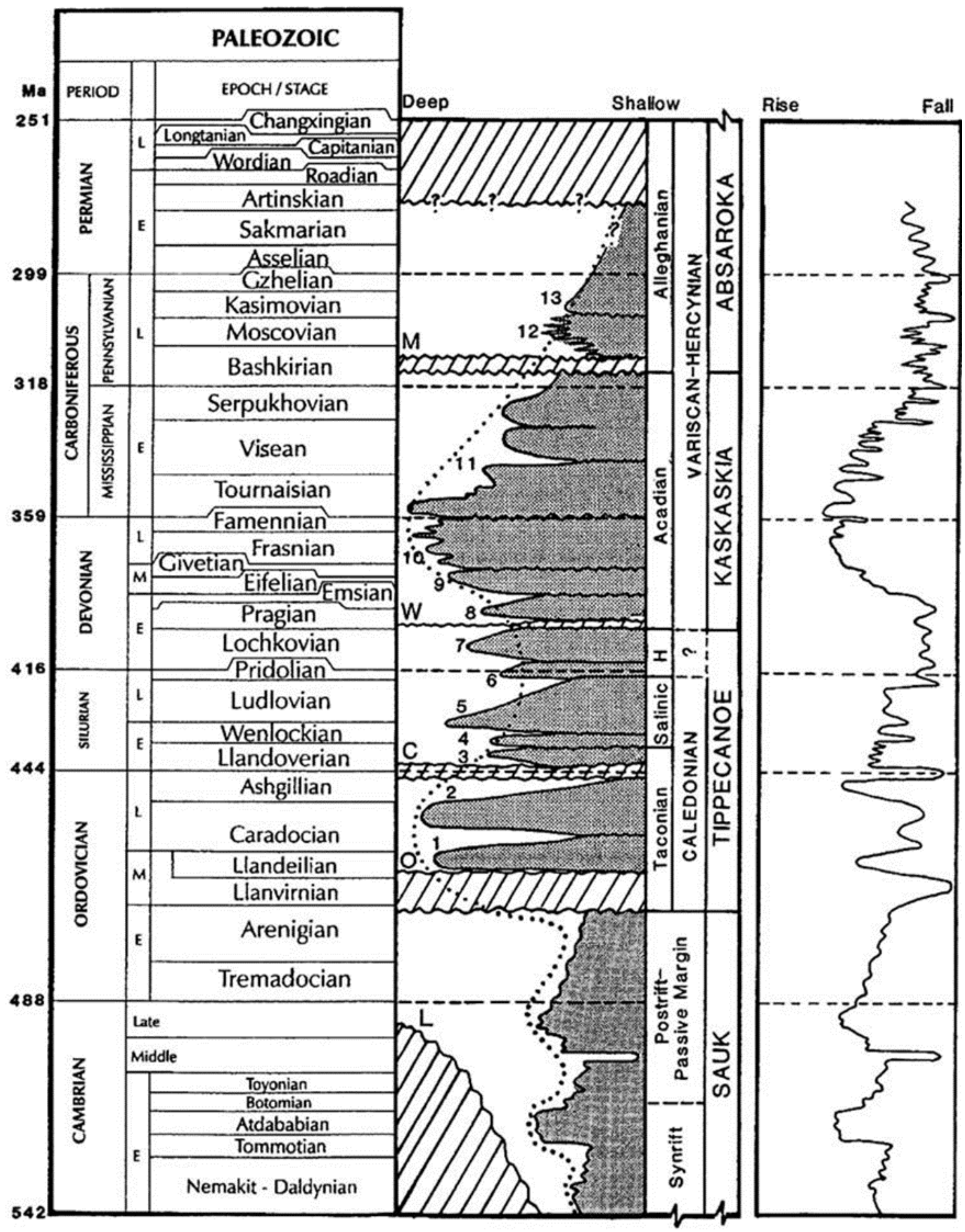

Figure 7: Paleozoic geologic time scale, showing the occurrence and relative duration of synrift, postrift passive margin, and 13 third-order, tectophase cycles (numbered) in the Appalachian Basin as a relative sea-level curve, compared with generalized sea-level curve (modified from Ross and Ross, 1988; Read, 1989; and Dennison, 1989). Unconformities are labeled on the sea-level curve: L, Lipalian; O, Owl Creek (Knox); C, Cherokee; W, Wallbridge; and M, Monday Creek. (Figure from Ettensohn, 2008)

2.1.5. Ordovician-Silurian Caledonian Orogeny

During the transition from the Early to Middle Ordovician period, the Knox (Owl Creek) unconformity formed as a result of tectonic loading and subsidence related to the onset of Caledonian (Taconian/Taconic orogenic phase) orogenesis (Figure 7 and Figure 8; Ettensohn, 2008; Ziegler, 1989). This shift to a protracted period of mountain building and subsequent foreland basin development is reflected in the deposition of a thick and diverse assemblage of basinal sediments (Figure 8).

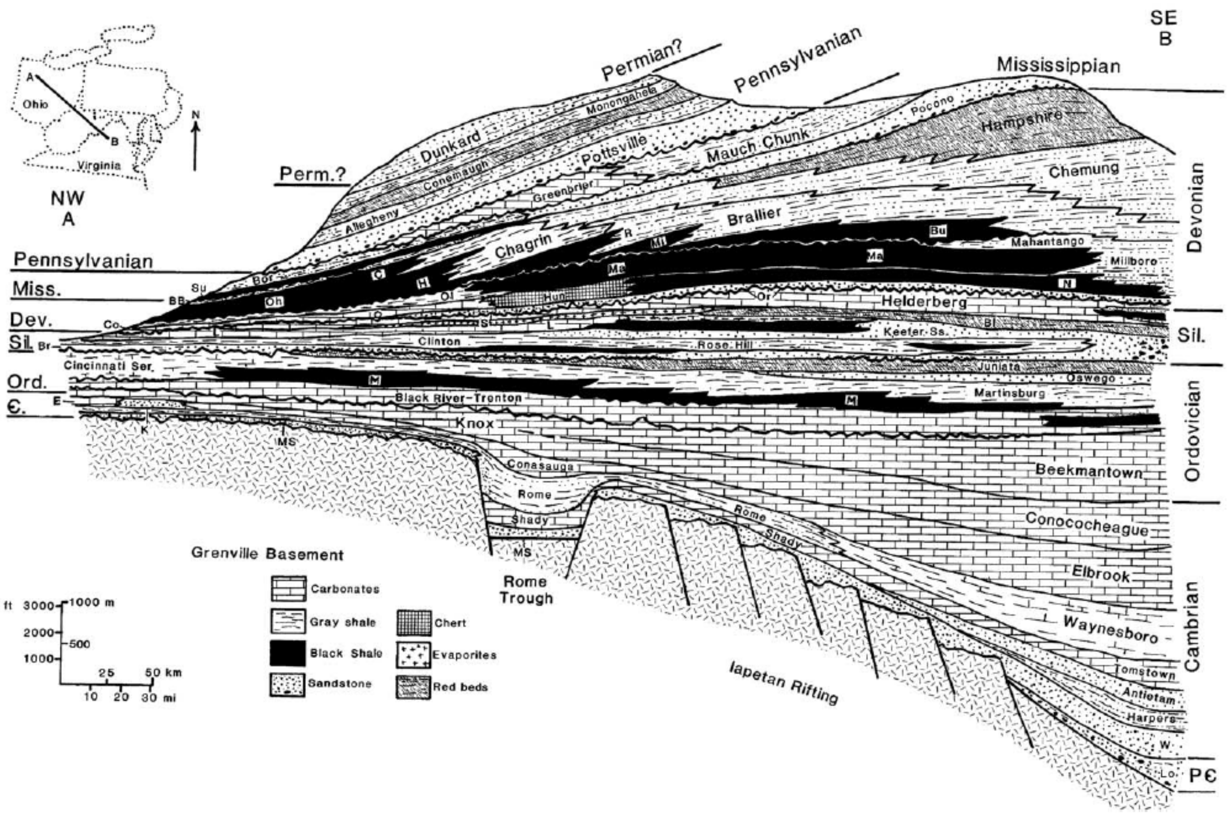

Figure 8: Schematic cross section of the Appalachian Basin from Virginia to Ohio showing the major relationships of stratigraphic units from the Precambrian to the Permian. The section is flattened on the base of the Silurian. Precambrian Grenville age basement rocks and the influence of Iapetan rifting and the development of the Rome Trough is visible at the base of the section. Syn- and post-rift sedimentation is observed from the Late Precambrian through the Ordovician. Ordovician transition to foreland basin development as a result of the Caledonian orogeny is represented by the Knox unconformity (dark black squiggly line) between the Knox Group and the Black River-Trenton limestone stratigraphic units. Subsequent flexurally and thermally driven subsidence of the foreland basin is represented by expansion of sedimentary units across the basin as the foredeep of the basin progressively translates from the present-day southeast to the northwest. (Figure from Ettensohn, 2008)

The Early-Middle Ordovician Taconian Orogeny commenced with the Owl Creek (Knox) unconformity (Figure 7) and followed with a shift from broad deposition of carbonate facies to more structural variability, and with it, variability in sedimentation. Deposition began with the St. Peter Sandstone in the west and progressed with widening of the foreland basin and deposition of a thick (up to 7500 ft) succession of dark shales: the Martinsburg, Reedsville, and Utica (Figure 8; Ettensohn, 2008). Dark shale deposition was followed by extensive infill of the fluvial-delta, transitional/marginal marine redbeds of the Queenston Delta (Figure 8 and Figure 9; Colton, 1970; Dennison, 1976; Blue, 2011), and development of the Cherokee discontinuity (Figure 7; Dennison and Head, 1975).

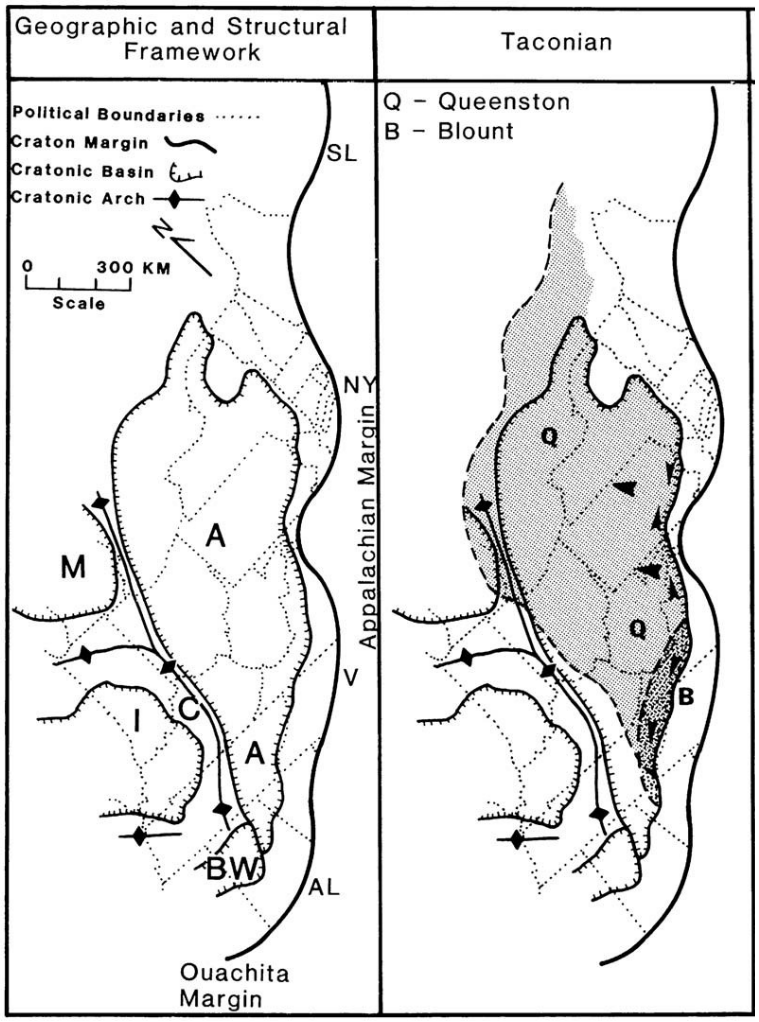

Figure 9: Distribution of Taconian Queenston Delta clastic wedge on southeastern Laurussia. Paleo currents noted by arrows. (Figure from Ettensohn, 2008)

Boucot's (1962) Salinic orogenic event was initially identified as an angular unconformity in the northeastern U.S. but marks the multi-phase north to south migration of tectonism and the accretion of Baltica to form Laurussia. A series of dark shales were deposited in the foreland basin that include the Williamson and time-equivalent Rose Hill formations (Figure 8 and Figure 14;

Ettensohn and Brett, 1998). In the project area, Early Salinic tectonism saw the deposition of a series of iron-rich siliciclastics, shed from the Taconic highlands (Folk, 1960; Colton, 1970; Cecil et al, 2004; Ettensohn, 2008). These clastic sequences are what make up the Medina Group: Grimsby, Whirlpool, Medina, the “Clinton” sands in Ohio, and the Tuscarora of Pennsylvania (see subsection 2.4 of this Application Narrative for more information on the formations that make up the project’s injection zones; Figure 8 and Figure 10; Folk, 1960; Colton, 1970).

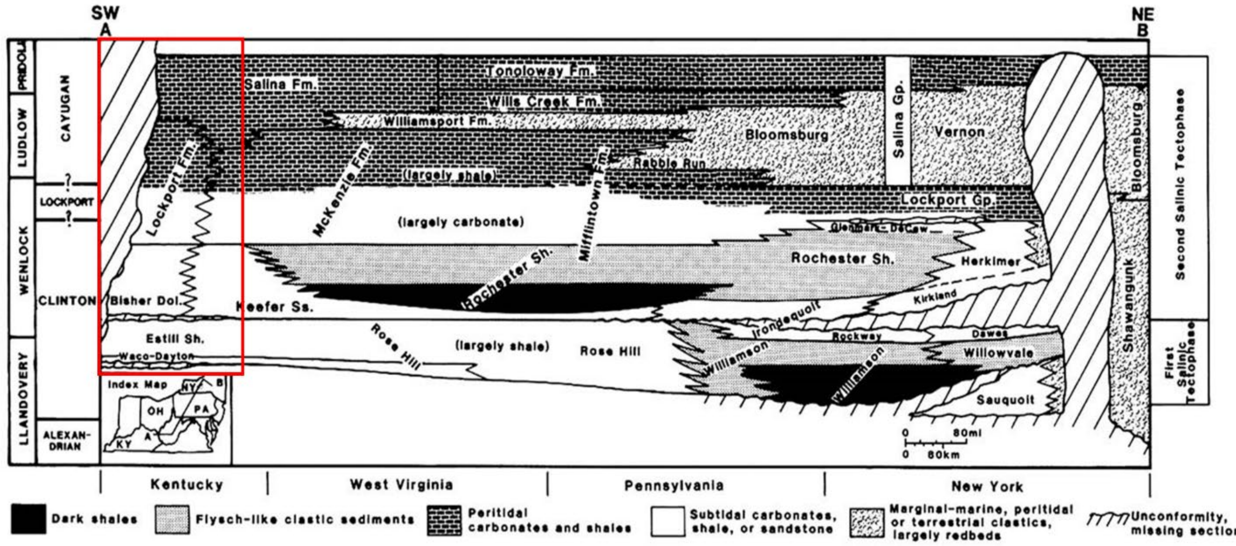

Figure 10: Southwest-northeast section partially parallel to basin strike highlighting the two Salinic phases of tectonism in the Appalachian Basin and the associated formations deposited. The red square is the approximate location of the project. (Figure from Ettensohn, 2008).

Continued Salinic tectonism is evidenced by the Bloomsburg redbeds deposited in the foreland basin and the Salina evaporites covering the central Appalachians and Michigan Basin in response to restriction of the basin and eustatic sea-level fall (Ultieg, 1964; Ricker 1969; Ziegler, 1989, Ettensohn, 2008). During the Middle Silurian, carbonate platform deposits formed on uplifted terranes, including the Cincinnati-Kankakee-Algonquin arch system, which isolated specific basin areas and led to widespread evaporite deposition in the Upper Silurian (Figure 11; Colton, 1970, Ettensohn, 2008; Coyle, 2022). The evaporite beds of the Salina group were followed by a period of tectonic quiescence and development of a thick succession of carbonates (Figure 8 and Figure 11; Ettensohn, 2008).

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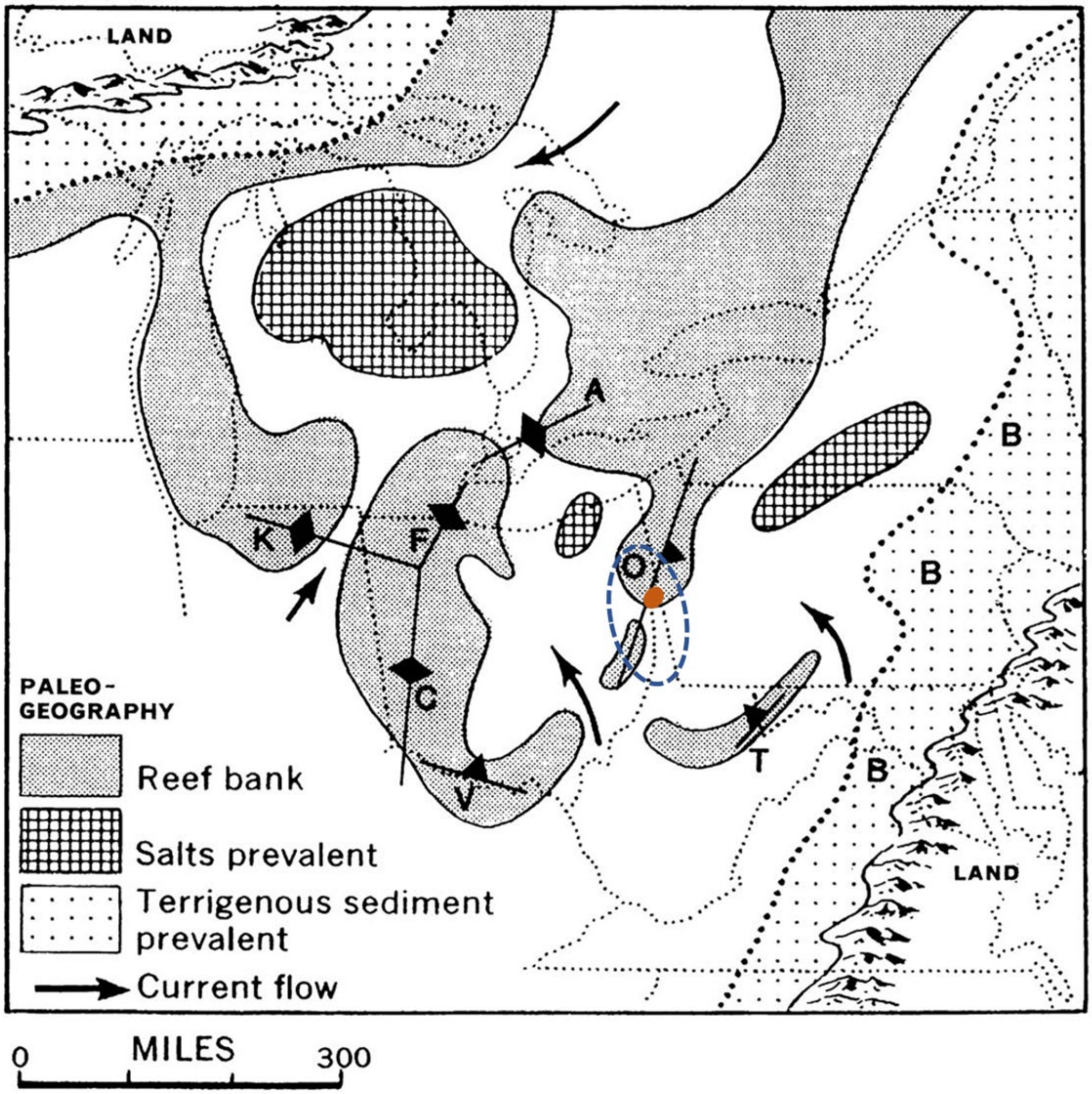

Figure 11: Schematized Late Silurian paleogeographic map of Salinic depositional systems. Deposition and lithologies were driven by bulge migration that reactivated regional basement structures, as well as by foreland subsidence. Depositional systems are labeled as Algonquin arch (A), Findlay arch (F), Kankakee arch (K), Cincinnati arch (C), Iapetan Ohio-West Virginia hinge zone (O), Tristate block (T), and Grenvillian Vanceburg-Ironton fault zone (V). Arrows point to downthrown or down-dipping sides. Bloomsburg-Vernon redbeds (B). Adapted from Kay and Colbert (1965). Approximate Tri-State CCS Hub location in dashed blue oval and approximate AoR in orange oval.

2.1.6. Devonian-Permian Variscan-Hercynian Orogeny

The Variscan–Hercynian (Acadian phase) orogenic cycle is characterized by the closure of the Rheic Ocean during collision with Gondwana to form Pangaea (Kearey et al., 2009; Torsvik and Cocks, 2016). The Early Devonian Acadian orogenic phase of the Variscan-Herynian orogeny is characterized by dextral transgressional accretion of the Avalon and Laurussian terranes moving from northeast to southwest; this contrasts with the sinistral accretion of the Salinic orogenic cycle (van Staal et al., 1998; Ettensohn, 2008). Onset of the Acadian orogeny is marked by the Wallbridge discontinuity (Figure 7) and deposition of the Lower Devonian Oriskany Sandstone (Figure 8; Colton, 1970; Etensohn, 2008). Continued cyclic orogenesis is characterized by the deposition of the Onondaga Formation and is later characterized by transgressive black shales (Marcellus Shale) alternating with clastic wedge deposits (Mahantango Formation) (Figure 8; Ettensohn, 2008). The transgressive shales were deposited in the proximal foreland basin, while coarser clastics were deposited craton-ward in toward the peripheral bulge of the foreland basin (Figure 8; Colton, 1970; Ettensohn, 2008). Paleogeographically, the amalgamating supercontinent of Pangaea was moving progressively northward during this time and passing from an arid sub-tropical climatic belt to a more humid tropical equatorial region (Scotese, 2003).

The Alleghenian orogeny is the final tectonic phase of the Appalachian Foreland Basin, signifying the ultimate closure of the Rheic Ocean and the gradual amalgamation of Gondwana and Laurussia, sealing the two landmasses together from South to North and forming Pangaea (Kearey et al., 2009; Torsvik and Cocks, 2016). Alleghenian related foreland basin subsidence is recorded in the sediments deposited from the Monday Creek Unconformity in the Pennsylvanian through the Early Permian (Figure 7 and Figure 8; Sloss, 1963). Hatcher (2005) described the Central Appalachian Basin as a broad fold and thrust belt with megathrusts carrying Paleozoic crust 218 mi across the Laurentian Platform and foreland basin. The thickest accumulations of these siliciclastic sediments, reaching up to 9,500 ft in thickness, are concentrated in the foredeep of the foreland basin (Figure 8; Meckel, 1967; Colton, 1970; Patchen et al., 1985a, b). In contrast to the distribution of clastic wedges in the previous orogenic events, a blanket of siliciclastic sediment advanced westward for over 620 mi, indicative of an overfilled foreland basin (Jordan, 1995). Notably, the sedimentary profile of this orogeny deviates from previous tectophase cycles, primarily comprising terrestrial (abundant coal) and marginal-marine, molasse-like sediments (Ettensohn, 2008). Sediments associated with the Alleghenian orogeny were deposited in a humid climate in a tropical equatorial belt with various paralic, estuarine, fluvial, and alluvial-plain environments being prevalent during this time (Scotese, 2003; Cecil et al., 2004; Ettensohn, 2008).

2.1.7. Paleogeographic Influences on Sedimentation

Though the regional tectonism is the primary control on sedimentation in the basin, the cyclic nature of the sedimentary fill in the basin is also influenced by the paleogeography and glacial-interglacial eustatic cycles (Cecil et al., 2004; Ettensohn, 2008). Through early Cambrian time, the Appalachian Basin area of the Laurentian continent shifted latitudinally from 60° to 40°S, and further north to 15°S through the Late Mississippian. By Late Permian, the Appalachian Basin area was located 5°N of the Equator (Kearey et al., 2009; Torsvik and Cocks, 2016). This shift to the north is recorded in the siliciclastic-carbonate-siliciclastic pattern of basinal sedimentation as the landmass passed through varying climatic zones (Scotese, 2003; Cecil et al., 2004).

2.1.8. Summary

Sediments deposited from the late Ordovician to the end of the Silurian are the intended injection complexes for the project. They include from oldest to youngest: the Queenston Shale (lower confining zone), the Medina Group (lower injection zone), the Rochester Shale (upper confining and lower confining zone), the Lockport Dolomite Group (upper injection zone), and the Salina

Group (Primary Confining Zone). Characterization, lateral continuity, and remaining uncertainties are discussed in subsection 2.4 of this Application Narrative.

2.1.9. Hydrogeology

Aquifers in the central region of the Appalachian Basin remain in the shallow subsurface and are represented by aquifers through the Lower Mississippian (Figure 8; see subsection 2.1 of the Application Narrative). They are the Conemaugh Group, the Allegheny Formation, the Pottsville Group, and the Mauch Chunk Formation, and in the project area, they are less than 1000 ft below mean sea level (bmsl). Each of these units has various layers of aquifer and aquitard materials, described further in subsection 2.7 of this Application Narrative. The hydrology of the region is largely influenced by seasonal precipitation, snowmelt, and groundwater recharge.

2.1.10. Local Structural Geology

Structural geology local to the project area is composed of the following major geologic features that are further discussed below:

- Rome Trough Fault System;
- Highlandtown Fault Zone;
- Burning Springs – Cambridge Fault Zone; and
- Unnamed Compressional Faults.

Additional discussion of faults in relation to the AoR and a determination that they would not interfere with containment in the injection zones is included in subsection 2.3 of the Application Narrative.

2.1.10.1. Rome Trough Fault System

The Rome Trough Fault System is a major structural feature of the region (Figure 12) and extends from central Kentucky to the northeast, crossing West Virginia, and into western Pennsylvania. The Rome Trough Fault System represents a broad zone of deformation related to failed Eastern Interior rifting during the Early and Middle Cambrian that is associated with the opening of the Iapetus-Theic Ocean (Woodward, 1961; McGuire and Howell, 1963; Shumaker, 1986; Thomas, 1991).

In northern West Virginia the failed rift graben of the Rome Trough is characterized by a broad, tilted horst block that is bound on its western margin by the Interior Fault and to the east by the East-Margin Fault (Figure 13; Gao et al, 2000). Seismic interpretation across the Rome Trough Fault System (Figure 13) suggests that the East-Margin Fault influenced both the basin geometry and depositional systems during the Early to Middle Cambrian rifting stage; however, during the Late Cambrian to Ordovician passive-margin and Middle to Late Paleozoic foreland basin stages, the structure is interpreted to be inactive (Gao et al., 2000).

The Rome Trough Fault System and related structures transect Marshall County, West Virginia and Washington County, Pennsylvania; they are located approximately 30 miles to the south and east of Hancock County, West Virginia (Figure 12).

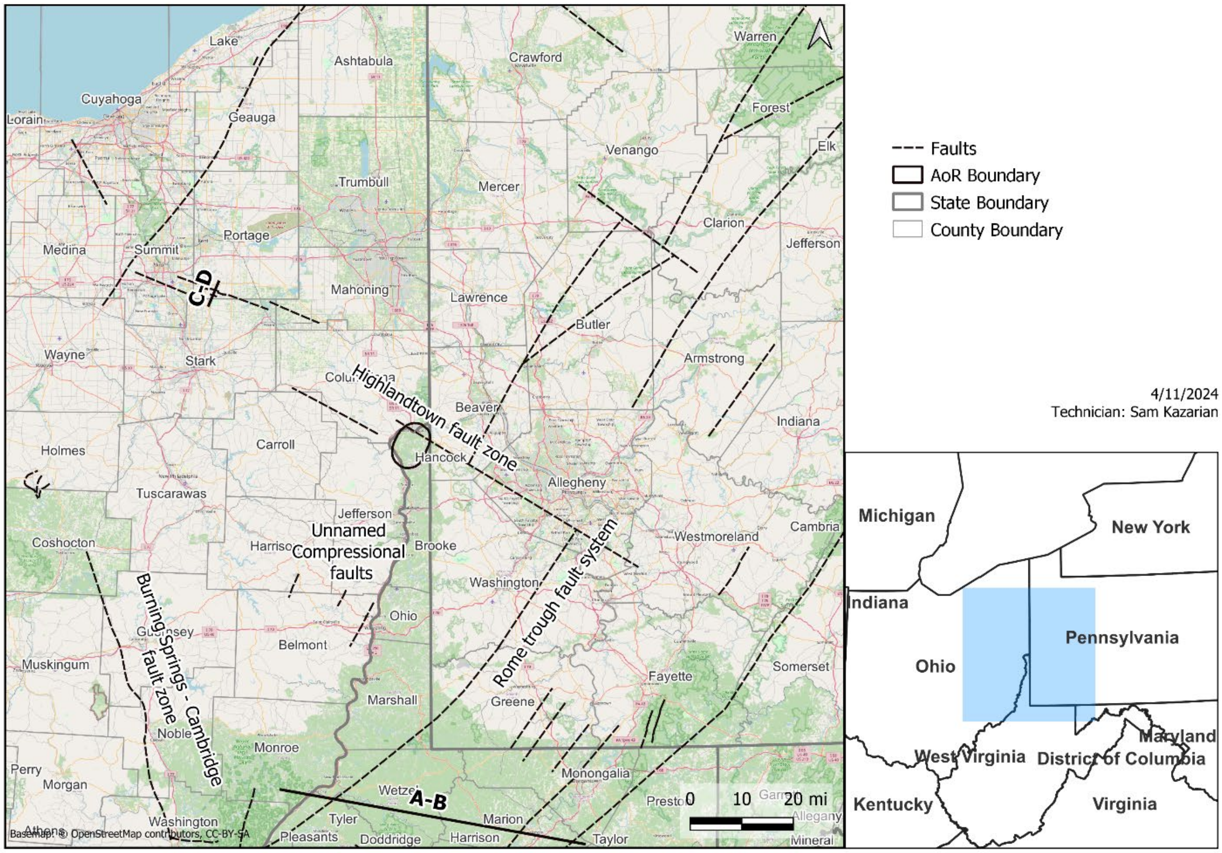

Figure 12: Regional fault map of the study area. Major structures discussed include the Rome Trough Fault System, Highlandtown Fault System, Burning Springs – Cambridge Fault Zone, and unnamed compressional faults. Location of cross-section A-B (Figure 13) and C-D (Figure 14) shown. Fault locations adapted from Baranoski, 2013; Root and Onasch, 1999. The AoR boundary is shown as a black oval.

2.1.10.2. Highlandtown Fault Zone

The Highlandtown Fault Zone (Figure 12) extends from southwestern Pennsylvania through northernmost West Virginia, continuing across northeastern Ohio (Root and Onasch, 1999). The Highlandtown Fault Zone is composed of multiple en-echelon fault segments. In the region of the AoR in northern West Virginia, this segment of the fault is referred to as the Pittsburgh-Washington lineament (Gray, 1982) or the Pittsburgh-Washington cross-strike structural discontinuity (Baranoski, 2013).

The Highlandtown Fault Zone is characterized by a series of steeply dipping basement faults that transect the structural grain of the region at a high angle (Root and Onasch, 1999). The fault system generally dips to the south and exhibits normal displacement that occurred intermittently throughout the Paleozoic affecting both the distribution and thickness of Cambrian to Permian age sediments (Root and Onasch, 1999). Figure 14 shows an example seismic line and interpretation across the Highlandtown Fault Zone in Ohio showing normal fault displacement and development of a flexural monocline in Paleozoic strata (Root and Onasch, 1999).

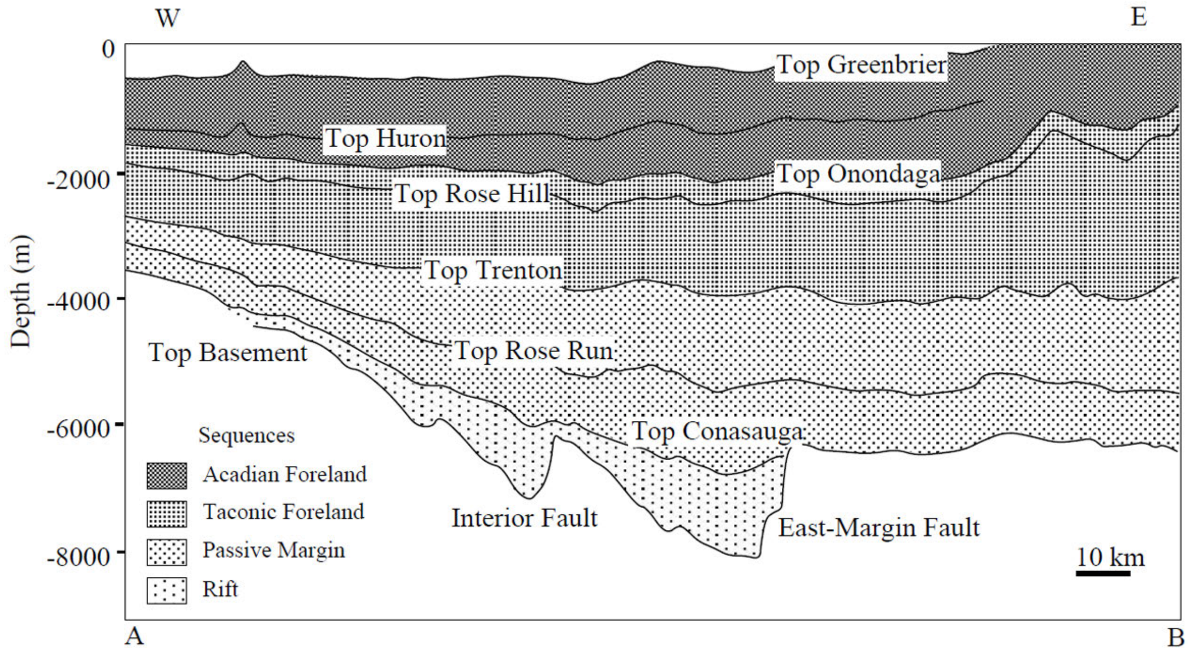

Figure 13: Regional cross-section across the Rome Trough Fault System. See Figure 12 for location of cross-section A-B. Interior Fault and the East-Margin Fault are part of the Rome Trough Fault System. From Gao et al., 2000.

2.1.10.3. Burning Springs – Cambridge Fault Zone

The Burning Springs – Cambridge Fault Zone, also known as the Cambridge cross-strike structural discontinuity (Baranoski, 2013), trends north-northwest and extends from north-central West Virginia across Ohio toward Lake Erie (Root, 1996; Figure 12). The Burning Springs segment of the fault is located in West Virginia and transects the Rome Trough ault System at a high angle.

The Burning Springs segment of the fault zone is characterized by a broad zone of deformation that includes both basement-involved high-angle normal faulting and northwestward directed thrust faulting (Root and Onasch, 1999). Basement involved normal faulting, similar to the timing of other structures in the area, occurred on the Burning Springs fault segment from the Cambrian to the Pennsylvanian-Permian (Root, 1996). Later episodes of detached thrust faulting along the Burning Springs – Cambridge Fault Zone is attributed to the Pennsylvanian-Permian age Alleghanian orogeny (Root and Onasch, 1999). Compressional deformation associated with the Alleghanian orogeny forms several well developed anticlines, which includes the Burning Springs anticline, as a result of fault-related thrust faulting (Figure 14).

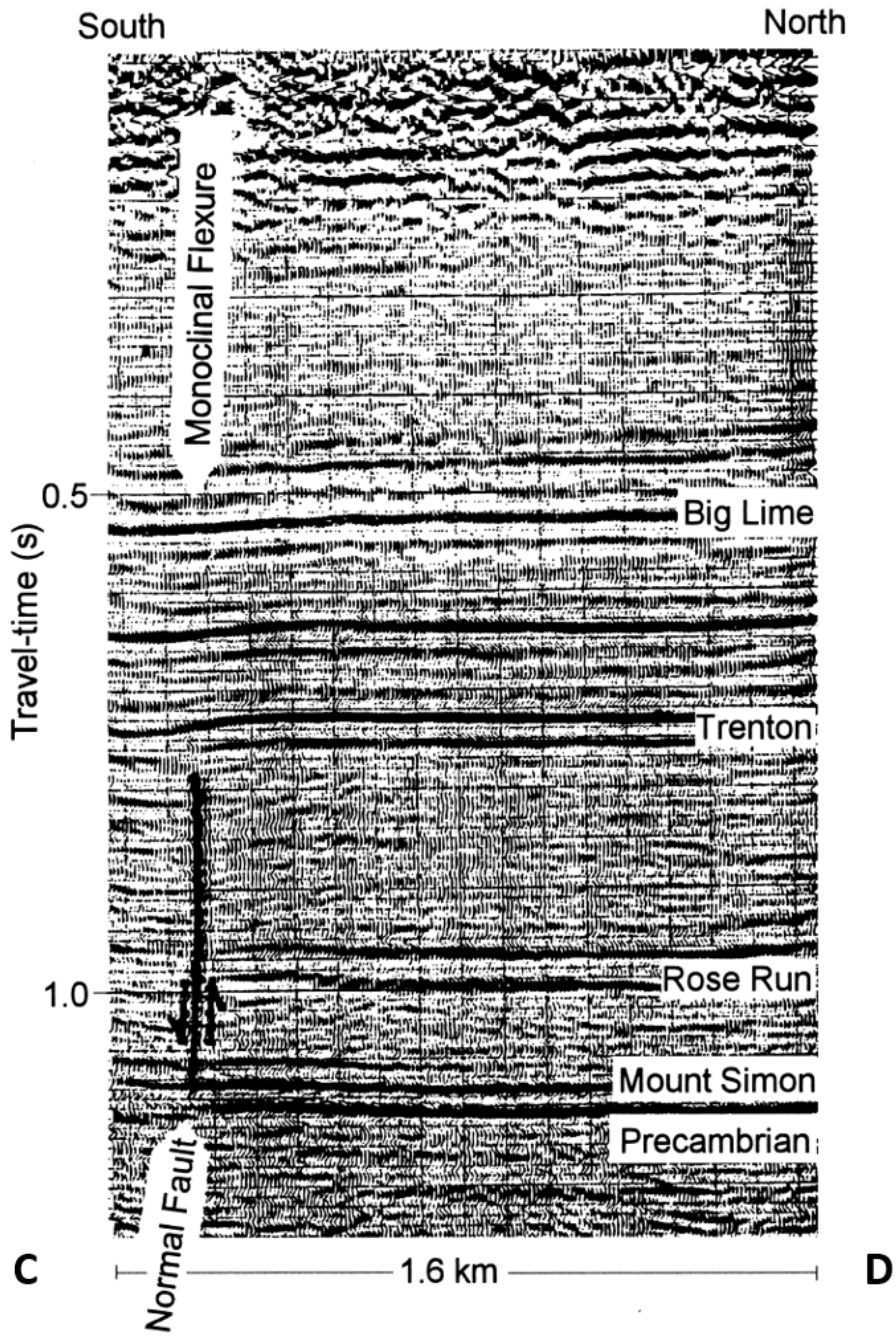

Figure 14: Example seismic cross-section across the Highlandtown Fault System in Ohio, see Figure 12 for location of cross-section C-D. From Root and Onasch, 1999.

2.1.10.4. Unnamed Compressional Faults

Several examples of unnamed compressional faults are observed from seismic reflection data in northernmost West Virginia and eastern Ohio (Figure 12). These faults were originally observed on reprocessed seismic reflection data collected as part of the Consortium for Continental

Reflection Profiling (COCORP) in Ohio (Dean et al., 1998; Baranoski, 2013). Similar structures are also observed on seismic reflection data interpreted in West Virginia and Ohio as part of this project (see subsection 2.3 of this Application Narrative for a discussion of these structures).

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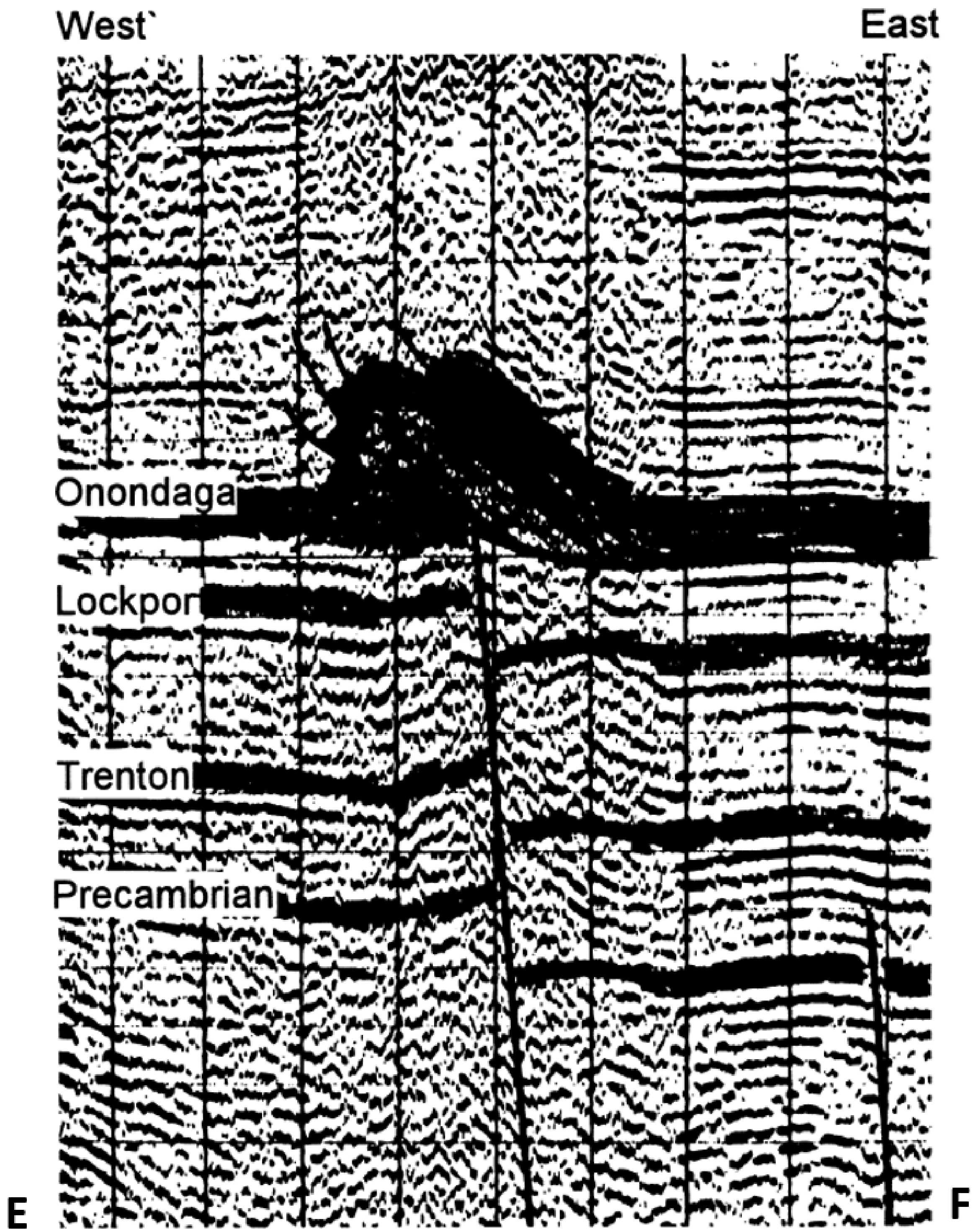

Figure 15: Seismic reflection profile across the Burning Springs anticline in West Virginia. Located along the Burning Springs – Cambridge Fault Zone. From Root and Onasch, 1999.

2.1.10.5. Data Used for Geologic Characterization

The data used to develop the geologic model for the project includes drilled well information and two-dimensional (2D) seismic data. Drilled well information includes location, deviation surveys, well logs, hydrocarbon production, and wastewater injection rates. The well logs include Measured Depth, Gamma Ray (GR), Neutron Porosity Sandstone, Density Porosity Sandstone, Bulk Density, Spontaneous Potential (SP), Caliper, Shallow, Medium and Deep Resistivity, and Sonic. In addition, historic core analyses from 9 wells along with literature analyses from other core were used to characterize the injection complexes (Table 2).

Digital well logs from 31 legacy wells were licensed and loaded into Petrel geologic interpretation software (Petrel is trademarked by and licensed from Schlumberger (SLB) Corporation) and used for picking tops for the two CCS Systems' reservoirs and confining units. Well log cross sections, shown later in this Application Narrative, were created using a subset of these logs. Subsets of these data sets were used to build the petrophysical model and calculate the porosity and permeabilities for the injection complexes (further discussed in subsection 2.4 and 2.5 of this Application Narrative). Locations of wells, cores, and type logs used to build the geologic model are outlined in Table 2, and their locations are shown in Figure 16 through Figure 19.

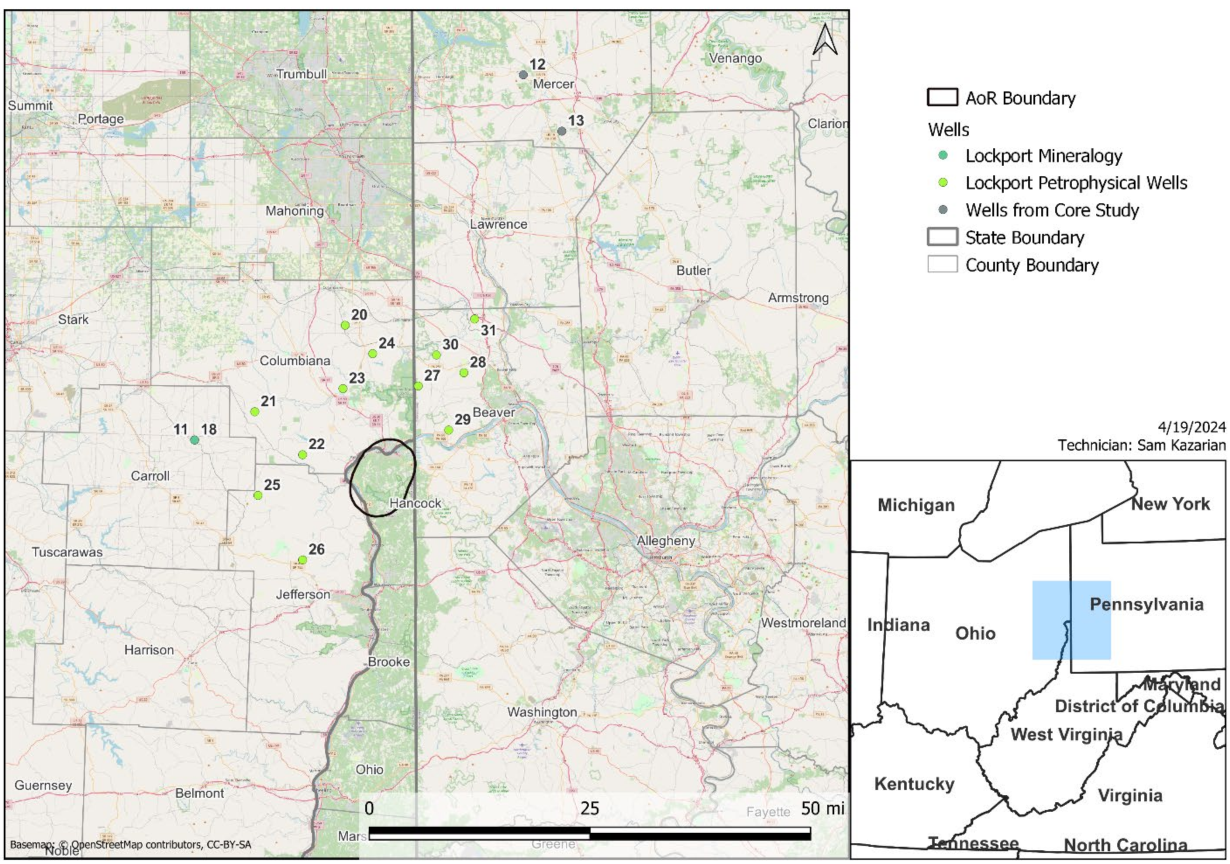

Figure 16:Location of wells used to characterize the Lockport Dolomite Group mineralogy (teal) and petrophysics (lime green) as well as the wells from the core study (gray). See Table 2 to match well numbers with API numbers, latitudes, and longitudes.

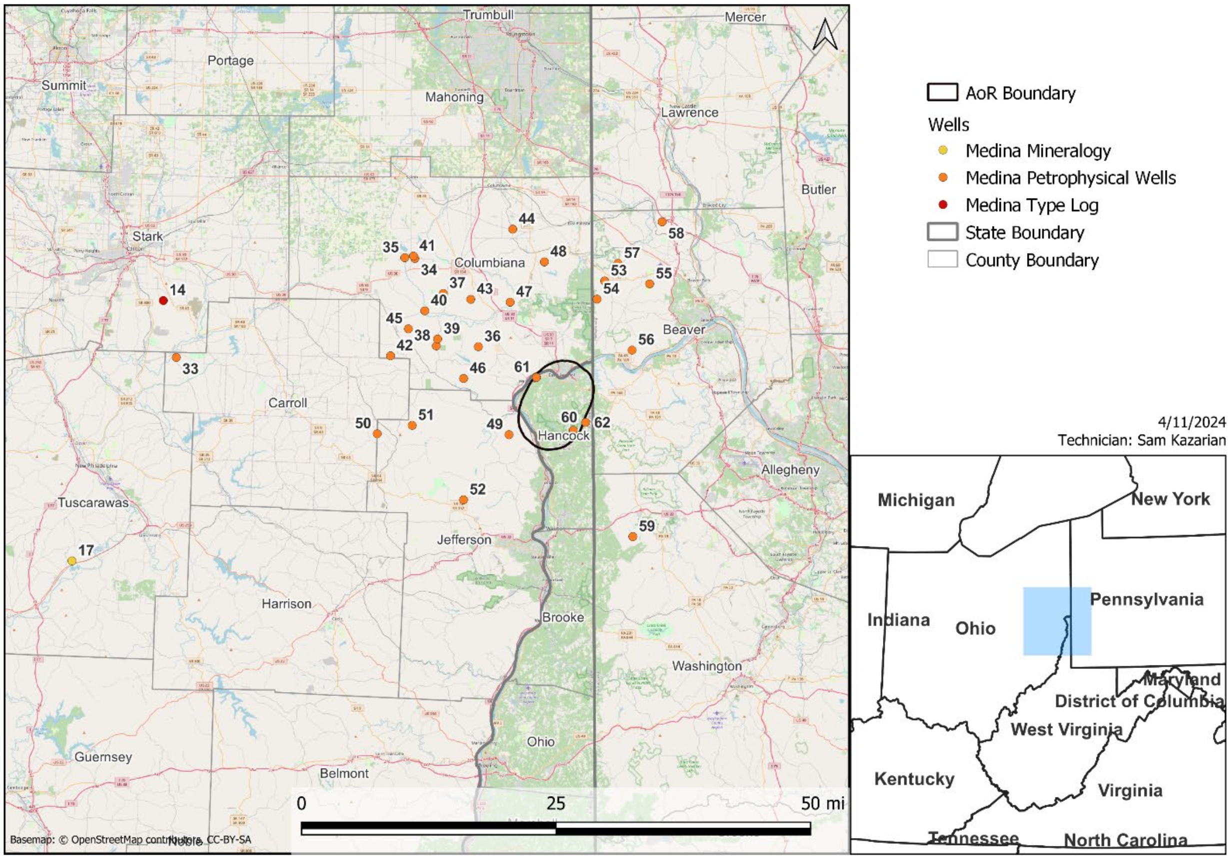

Figure 17: Location of wells used to characterize the Medina Group mineralogy (yellow) and petrophysics (orange), and the regional type log (red). See Table 2 to match well numbers with API numbers, latitudes, and longitudes.

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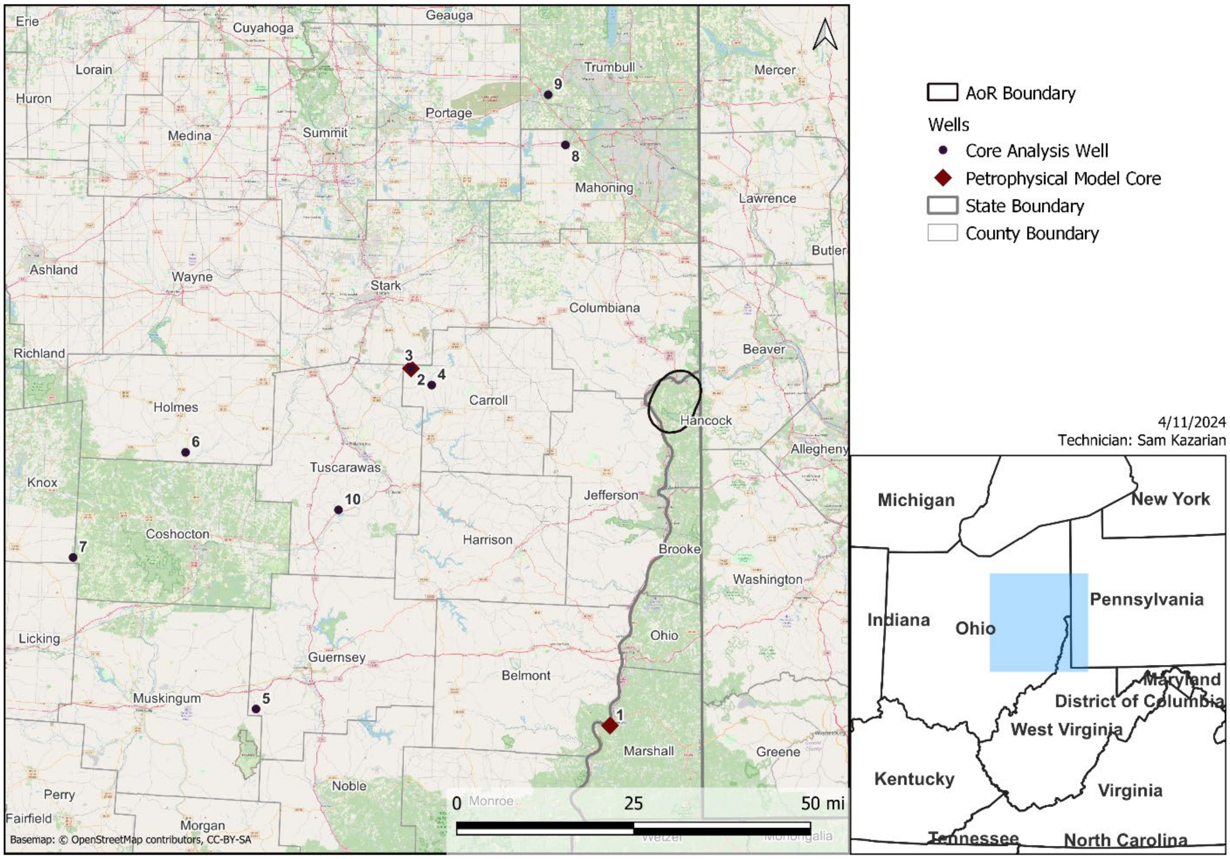

Figure 18: Location of wells with core used to characterize the Lockport Dolomite Group and the Medina. The black circles show the locations of core analysis data used in the model and the brown diamonds are wells with core used to build the petrophysical model. See Table 2 to match well numbers with API numbers, latitudes, and longitudes.

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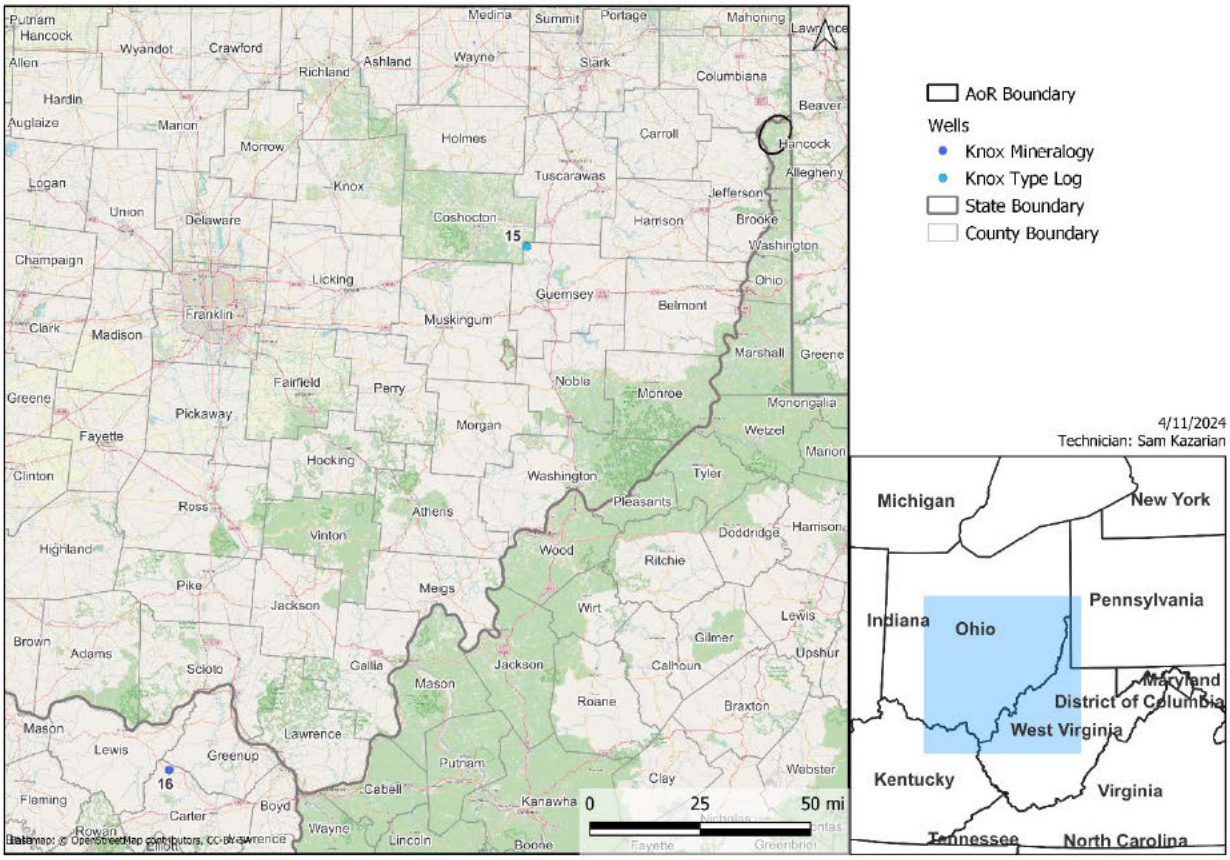

Figure 19: Location of wells used to characterize the Knox Group mineralogy (dark blue) and the type log (aqua). See Table 2 for API numbers, latitudes, and longitudes.

Table 2: List of well names, API numbers, latitude and longitudes for core, type logs, literature core studies, and petrophysical model logs used to build the geologic model.

Well Name and Number	API	Lat	Long	Well Number
Petrophysical Model Core				
MRCSP-FEGENCO 1	34013205860000	39.9128346	-80.7642922	1
SMITH B P & EVANS S T 4	34019202560000	40.6439492	-81.297143	3
Core Analysis Wells				
SMITH B P & EVANS S T 4	34019202560000	40.6439492	-81.297143	3
KAPLAN UNIT 3	34019204460000	40.61018	-81.2412	4
LINKHORN 1	34059209210000	39.9448517	-81.7066626	5
WAGERS WILLIAM 1	34075209900000	40.4690814	-81.9009046	6
WILT JOHN & EVELYN 1	34083212600000	40.2512566	-82.1989562	7
INTERSTATE INTERCHANGE 1	34099204320000	41.1019946	-80.8807876	8
SHERMAN WM C 1	34155200390000	41.2048016	-80.9274195	9
BELDEN BRICK UNIT (OHIO GEOLOGICAL SURVEY CO2) 9 (1)	34157253340000	40.353705	-81.4899615	10

Well Name and Number	API	Lat	Long	Well Number
Wells from Core Study (Lockport Dolomite Group)				
Great Lakes Energy Ocel #1 well in Carroll County, Ohio	34019219720000	40.638621	-80.993042	18
Johnson #1 well in Mercer County, PA	37085214680000	41.235710	-80.278039	12
Baker #1 well at Kilgore pool, Mercer County, PA	37085216960000	41.142730	-80.195044	13
Medina Type Log				
Sickafoose-Morris #1	34151220180000	40.724857	-81.321837	14
Knox Type Log				
AEP #1 Mountaineer Power Plant	34059241140000	40.207174	-81.654079	15
Knox Mineralogy				
KGS Hanson Aggregates 1	16043001050000	38.469552	-83.132597	16
Medina Mineralogy				
BELDEN BRICK UNIT (OHIO GEOLOGICAL SURVEY CO2) 9 (1)	34157253340000	40.353705	-81.489962	17
Lockport Mineralogy				
Great Lakes Energy Ocel #1 well in Carroll County, Ohio	34019219720000	40.638621	-80.993042	18
Lockport Petrophysical Wells				
MRCSP-FEGENCO 1	34013205860000	39.9128346	-80.7642922	19
COLBOURNE UNIT 1	34029216560000	40.8263292	-80.667427	20
ALBANESO 24-14-4 8H	34029217050100	40.684917	-80.863286	21
JANIE TRUST 5-12-3 1H	34029217060000	40.6141223	-80.7603322	22
KERNICH 3-10-2 1H	34029217240000	40.722447	-80.672836	23
CARNEY 17-7-1- 3H	34029217270000	40.7796295	-80.6083972	24
BROWN 36-3 10H	34081205070000	40.547562	-80.8566	25
DENOON 5-10-3 3H	34081205130000	40.4415108	-80.7609847	26
JAMES THARP 3H	37007203050000	40.726239	-80.510225	27
ROLLING ACRES 8H	37007203070000	40.747528	-80.4115	28
FERREBEE BEA	37007203110000	40.653472	-80.445194	29
POWELL BEA 6H	37007203180000	40.776861	-80.470583	30
WALL BEA 3H	37007203520000	40.835639	-80.3875	31
Medina Petrophysical Wells				
MRCSP-FEGENCO 1	34013205860000	39.9128346	-80.7642922	32
SMITH B P & EVANS S T 4	34019202560000	40.6439492	-81.297143	33
DONALD SELL UNIT 1	34029206070000	40.7850788	-80.8510498	34
FRANK MURRAY #3	34029206480000	40.7861729	-80.8699857	35
CLARENCE E. WILLIAMS #1A	34029206680000	40.6593033	-80.7324988	36
R HILL	34029207190000	40.7352959	-80.7977871	37
SOLOMON AQUILA E 21750	34029214760000	40.6606261	-80.8110942	38
A.L BURTON. HEIRS	34029215070000	40.670391	-80.8086462	39
H & S THOMPSON 1	34029215470000	40.7104938	-80.8325185	40
ALLIANCE/SEI UNIT	34029216040000	40.7885146	-80.8536301	41

Well Name and Number	API	Lat	Long	Well Number
SUMMITCREST INC	34029216270000	40.6465978	-80.8967211	42
SOWARDS UNIT # 1-K	34029216370000	40.7267275	-80.7465809	43
OSBOURNE #1	34029216560000	40.8263292	-80.667427	44
ALBANESO 24-14-4 8H	34029217050100	40.684917	-80.863286	45
JANIE TRUST 5-12-3 1H	34029217060000	40.6141223	-80.7603322	46
KERNICH 3-10-2 1H	34029217240000	40.722447	-80.672836	47
CARNEY 17-7-1- 3H	34029217270000	40.7796295	-80.6083972	48
J. & J. JACKSON E T AL 1	34081204610000	40.5339639	-80.6759156	49
ALLENDER J & W 1-17	34081204830000	40.5356865	-80.9218305	50
BROWN 36-3 10H	34081205070000	40.547562	-80.8566	51
DENOON 5-10-3 3H	34081205130000	40.4415108	-80.7609847	52
DAVID THOMPSON	37007203030000	40.752028	-80.495778	53
JAMES THARP 3H	37007203050000	40.726239	-80.510225	54
ROLLING ACRES 8H	37007203070000	40.747528	-80.4115	55
FERREBEE BEA	37007203110000	40.653472	-80.445194	56
POWELL BEA 6H	37007203180000	40.776861	-80.470583	57
WALL BEA 3H	37007203520000	40.835639	-80.3875	58
STARVAGGI #1	37125222780000	40.388075	-80.445975	59
MINESINGER 1	47029000800000	40.539846	-80.555906	60
GLOBE REFRACTORIES INC. 1	47029000860000	40.615273	-80.624307	61
RUGH HILLCREST FARMS #1	47029000870000	40.55099	-80.532662	62

Tri-State CCS, LLC licensed a total of ~250 linear miles of existing 2D seismic lines from Evans Geophysical that transect the project area (Figure 20). These data were used to interpret site-specific and regional geologic structure, to determine lateral continuity, and build the geologic inputs used for computational modeling. The seismic data included six lines that provided data to refine the structural interpretation of the project area. Additionally, seismic data were used to confirm the lateral continuity of the injection and confining zones.

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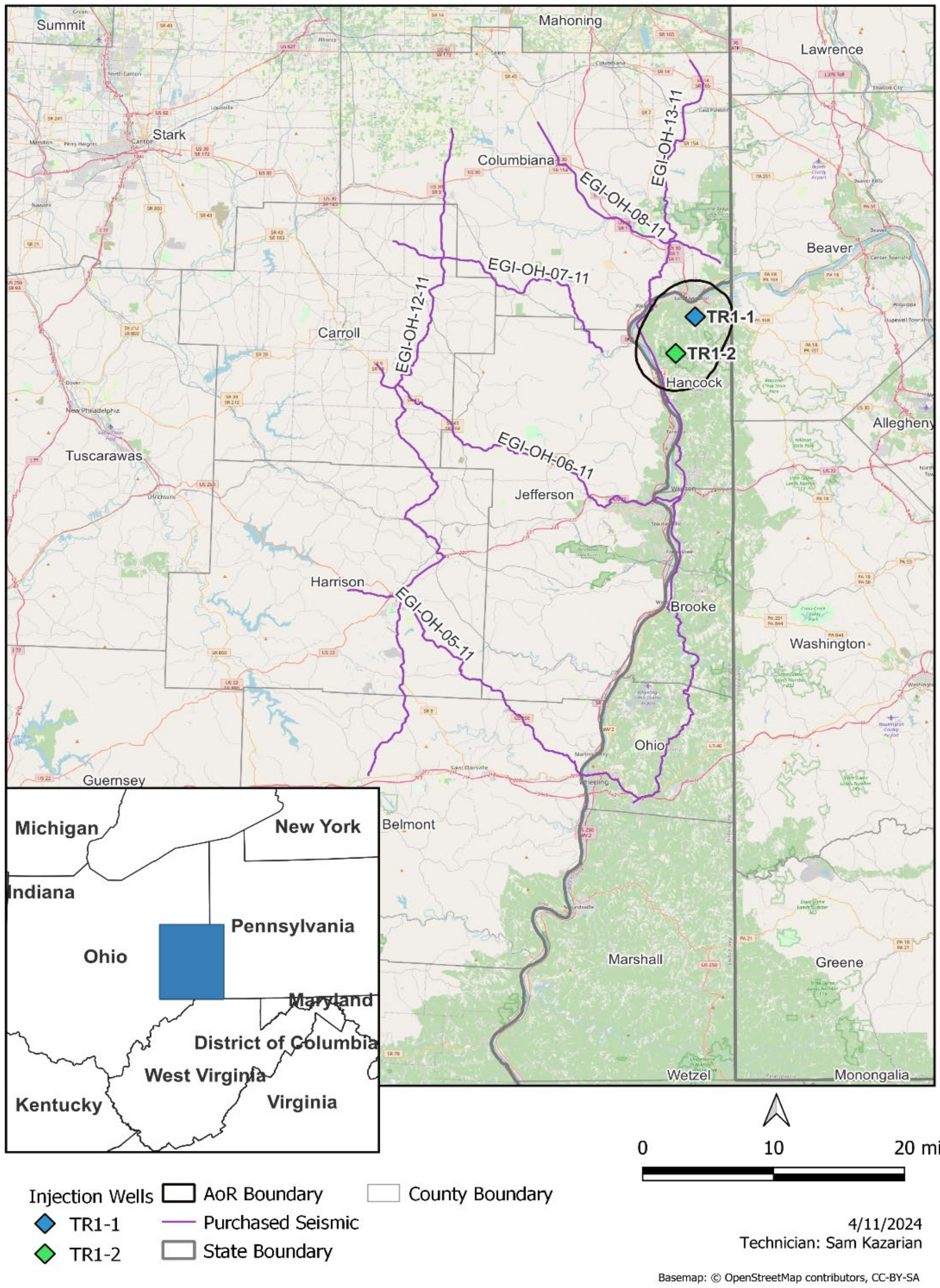

Figure 20: Location of the six 2D seismic lines used in the Tri-State CCS Hub subsurface assessments. Note: 2D seismic data were licensed from Evans Geophysical.

A synthetic seismogram was created to tie the seismic data to the well data. During the synthetic seismogram creation, the 2D seismic lines were tied to sonic measurements taken in the Birney Roy 1 well (Figure 21) to correlate the structural interpretation of the project area to the porosity and permeability model developed using the well log data.

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Geologic formations were then mapped on the 2D seismic data (Figure 20), and structure and isopach maps were created using both the well log tops and 2D seismic data. Together, these data sets were used to build a 3D Static Earth Model (SEM) in the Petrel geological modeling software suite representative of the geologic and petrophysical characteristics within the Tri-State CCS Hub. The areal extent of the 3D SEM is shown in Figure 34, Figure 36, Figure 37, Figure 40, and Figure 42 in subsection 2.4 of this Application Narrative.

2.2. Maps and Cross Sections of the AoR [40 CFR 146.82(a)(2), 146.82(a)(3)(i)]

The project consists of two primary injection complexes: the Lockport Injection Complex (LIC) and the Medina Injection Complex (MIC). The regional cross section in Figure 23 and the cross sections confined to the injection complexes and the model domain in Figure 24, Figure 25, and Figure 26 highlight the regional and local lateral continuity and thickness of both the Lockport Dolomite Group and the Medina Group. In addition, the Salina Group, the primary confining zone, and the Rochester Shale Formation and the Queenston Shale confining zones also exhibit regional and local lateral continuity and consistent thickness. Further discussion of the regional geology, primary seal thickness and lateral extent, injection zone thickness and lateral extent and other site-specific geologic characteristics is discussed in subsection 2.1 and subsection 2.4, respectively, of this Application Narrative.

The Gamma Ray and the petrophysical character of both the Lockport Dolomite Group and the Medina Group in the Static Earth Model (SEM) domain is consistent in both the dip and the strike direction; however, there are fewer Lockport wells with petrophysical analysis and, thus, more uncertainty in the characterization of the interval. The lowermost USDW, the Mauch Chunk Formation is approximately 5000 ft above the Top of the Salina Group and is shown in Figure 23. Further discussion of the petrophysics of the LIC and the MIC is in subsection 2.5 of this Application Narrative, and further discussion of the Mauch Chunk Formation continues in subsection 2.7 of this Application Narrative.

The Highlandtown Fault is the only regional fault in the project area and passes through the AoR. However, it does not pose a threat to containment for this project due to its location far below the injection zones and lower confining zone. Interpretation of 2D seismic across the fault shows that its tip line ends stratigraphically in the Knox Group, greater than 2000 ft below the Queenston Formation, which is a lower confining zone for the project (Figure 22 and Figure 23). Information concerning the faults and fractures and their spatial relation to the injection wells is further discussed in subsection 2.3 of this Application Narrative.

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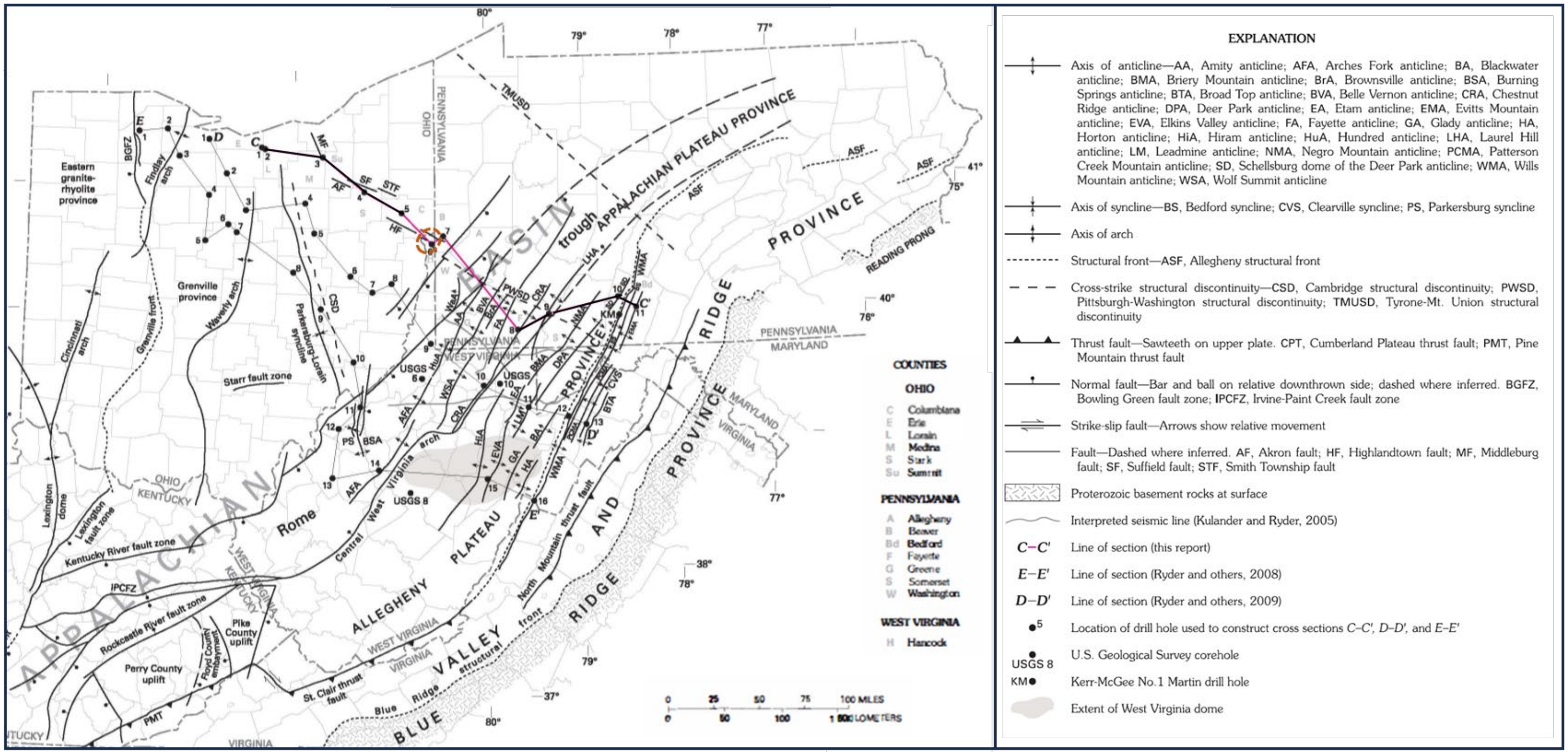
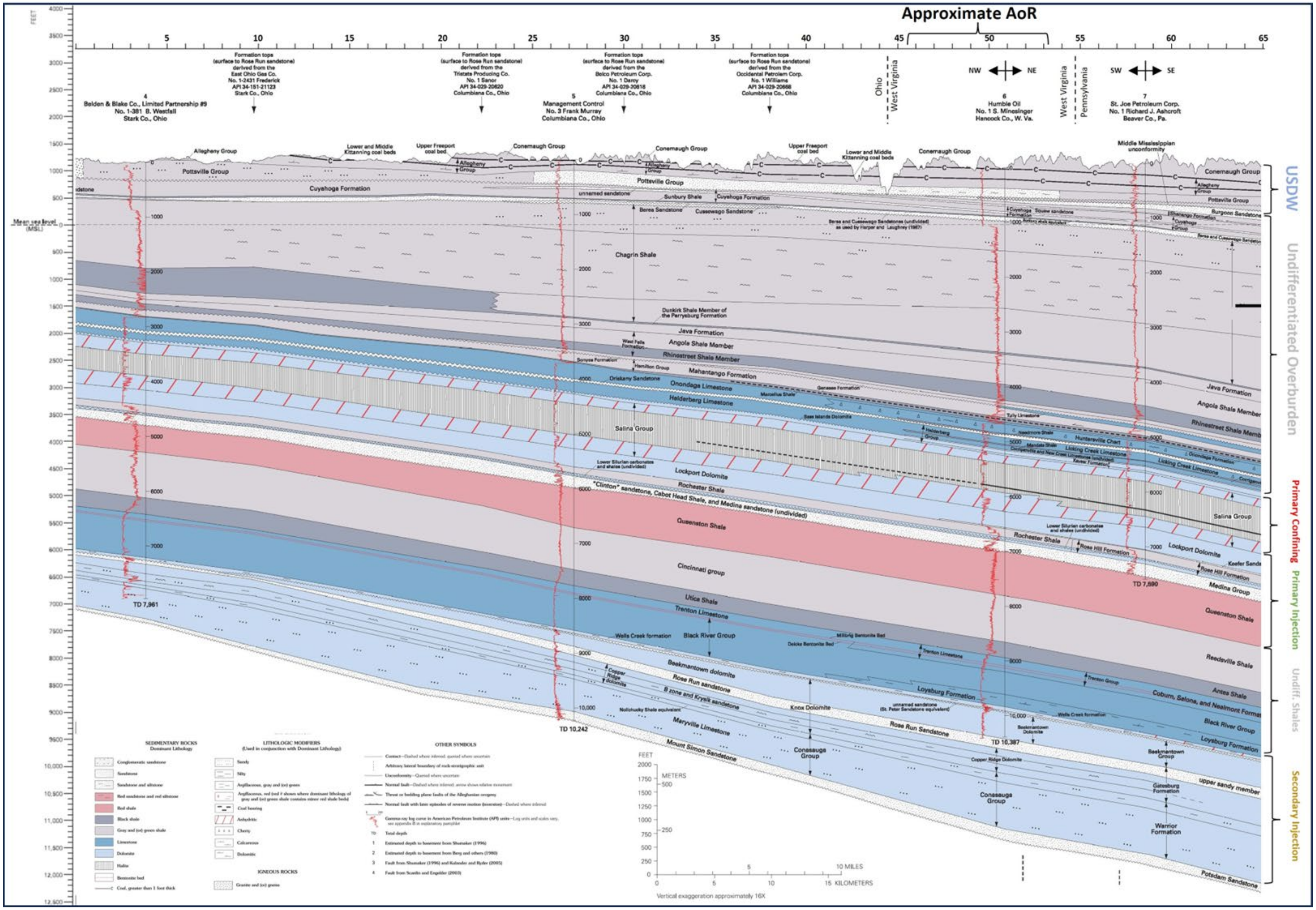


Figure 22: Base Map of the Appalachian Region and structural features with the cross section in Figure 23 shown in red. The approximate AoR is outlined in the dashed orange circle. Modified from Ryder et al, 2012.

Figure 23: (Below) Regional cross section from ground level to the Cambrian Mt. Simon through the AoR (Figure 22 shows position of the cross section with respect to the AoR). Modified from Ryder et al, 2012.


Approximate AoR
NW NE
SW SE
Ohio
West Virginia
Pennsylvania
Belden & Blake Co., Limited Partnership #9
No. 1-381 B. Westfall
Stark Co., Ohio
Management Control
No. 3 Frank Murray
Columbiana Co., Ohio
Humble Oil
No. 1 S. Minesinger
Hancock Co., W. Va.
St. Joe Petroleum Corp.
No. 1 Richard J. Ashcroft
Beaver Co., Pa.
Mean sea level (MSL)
Allegheny Group
Pottsville Group
Cuyahoga Formation
Conemaugh Group
Chagrin Shale
Dunkirk Shale Member of the Perrysburg Formation
Java Formation
Angola Shale Member
Rhinestreet Shale Member
Mahantango Formation
Onondaga Limestone
Helderberg Limestone
Salina Group
Lockport Dolomite
Rochester Shale
"Clinton" sandstone, Cabot Head Shale, and Medina sandstone (undivided)
Queenston Shale
Cincinnati group
Utica Shale
Trenton Limestone
Black River Group
Wells Creek formation
Beekmantown dolomite
Rose Run sandstone
B zone and Krysik sandstone
Knox Dolomite
Loysburg Formation
Maryville Limestone
Mount Simon Sandstone
Conasauga Group
Rose Run Sandstone
Reedsville Shale
Antes Shale
Coburn, Salona, and Nealmont Formations
Warrior Formation
Gatesburg Formation
upper sandy member
Potsdam Sandstone
TD 7,961
TD 10,242
TD 15,387
TD 7,590
USDW
Undifferentiated Overburden
Primary Confining
Primary Injection
Undiff. Shales
Secondary Injection
SEDIMENTARY ROCKS
LITHOLOGIC MODIFIERS
OTHER SYMBOLS
IGNEOUS ROCKS
10 MILES
15 KILOMETERS
Vertical exaggeration approximately 16X

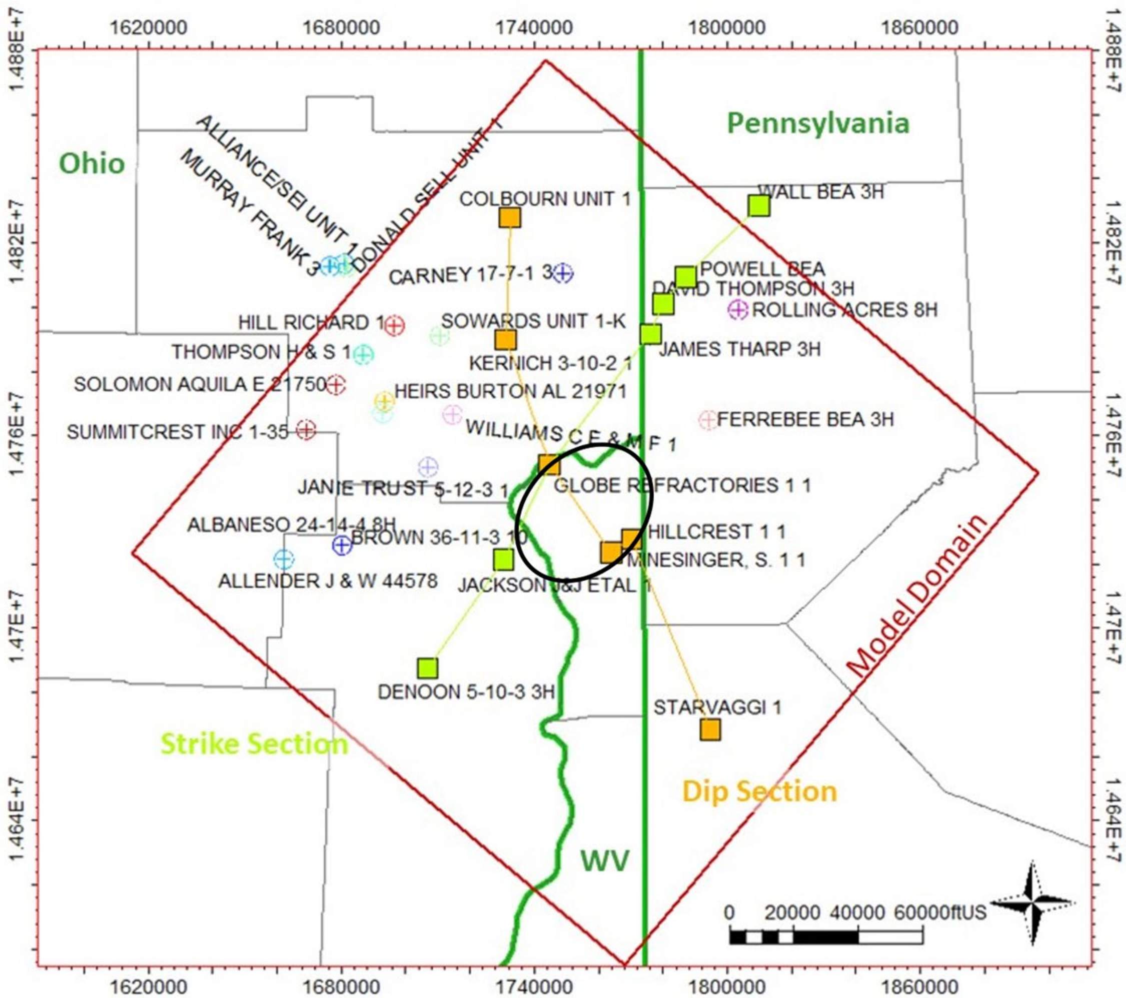


Figure 24: Base Map of the project model domain with the AoR (black), petrophysical wells included in the SEM build, the N-SE dip cross section (orange; Figure 25), and the NE-SW strike cross section (green; Figure 26) highlighted.

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2.3. Faults and Fractures [40 CFR 146.82(a)(3)(ii)]

Faulting local to the proposed injection well locations in Hancock County include the Highlandtown fault zone and several unnamed compressional faults which are observed by 2D reflection seismic data in the region. The geologic history of the Highlandtown fault zone is further discussed in subsection 2.1.10.2 of this Application Narrative. The north-south oriented 2D seismic line, OH-13-11, traverses Hancock County directly to the west of the proposed injection well sites (Figure 27) and images several faults and related folds in the subsurface.

Two distinct styles of faults are observed in Hancock County, this includes Cambrian to Permian age normal faulting associated with the Highlandtown fault zone (D on Figure 28) and later Paleozoic age compressional faulting with related fault-propagation folds (A, B, C, and E on Figure 28).

The Highlandtown fault zone as imaged on seismic line A-A' (OH-13-11), is a south-dipping high-angle normal fault that is rooted in Precambrian age basement rocks (D on Figure 28). The tip-line of the fault is not observed stratigraphically above the Knox Group and extends dipping steeply into basement rocks (Figure 28). A small amount of differential compaction or fault related accommodation is observed stratigraphically above the fault and may influence sediment deposition as young as Permian in age (D on Figure 28); similar observations are discussed in Root and Onasch (1999).

Several unnamed faults and fault-related folds are observed along seismic line A-A' (OH-13-11) in Hancock County and northward into Ohio (Figure 28). The observed structures are interpreted as compressional faults with fault-related anticlinal folding (A, B, C, and E on Figure 28). Anticlinal fault-related folds are well developed through the lower Paleozoic stratigraphy of the basin and ceased development by the end of deposition of the Medina group (A, B, C, and E on Figure 28). The faults related to fold development of structures A, B, and C on Figure 28 are interpreted to extend to or just above the Knox group sediments with displacement across the top Knox group horizon ranging from 0 to approximately 100 feet. The fault trace and observable displacement related to structure E on Figure 28 are interpreted to extend to depths of ~9,500 ft and are the shallowest faults observed in the area. Compressional faulting is attributed to east-west directed shortening during the Pennsylvanian-Permian age Alleghanian orogeny (see subsection 2.5.6.2 for further discussion).

Overall, Paleozoic age faults observed in the area range between 5,000 and 3,500 feet below the top of the lower primary injection zone of the Medina Group and the confining zone of the Rochester shale formation (Figure 28). While anticlines associated with faulting are expressed through the stratigraphy up to and including the Medina group (E on Figure 28), the Medina group interval rests well above any observable faulting in Hancock County. Paleozoic faulting is therefore not considered a risk to containment of either the Medina group or Lockport Dolomite group injection zones due to the vertical distance from observed faults and the target injection zones, and lack of deformation above the Median group stratigraphic interval.

Identification of any fractures or fracture networks that may be a risk to containment are beyond the resolution of the seismic reflection data available but will be one of the many factors addressed in the collection of geophysical and well data associated with this permit application (see the discussion of data collection related to geomechanics in subsection 2.5.6.1 below). These data collection efforts and associated studies will further our understanding of fault stability and examine the possibility that fracture networks may provide preferential fluid flow conduits. Additional uncertainties in the identification of faults or geologic structures not identified on the available 2D seismic reflection data will be addressed in the collection of 3D seismic and well data under the CarbonSAFE Initiative.

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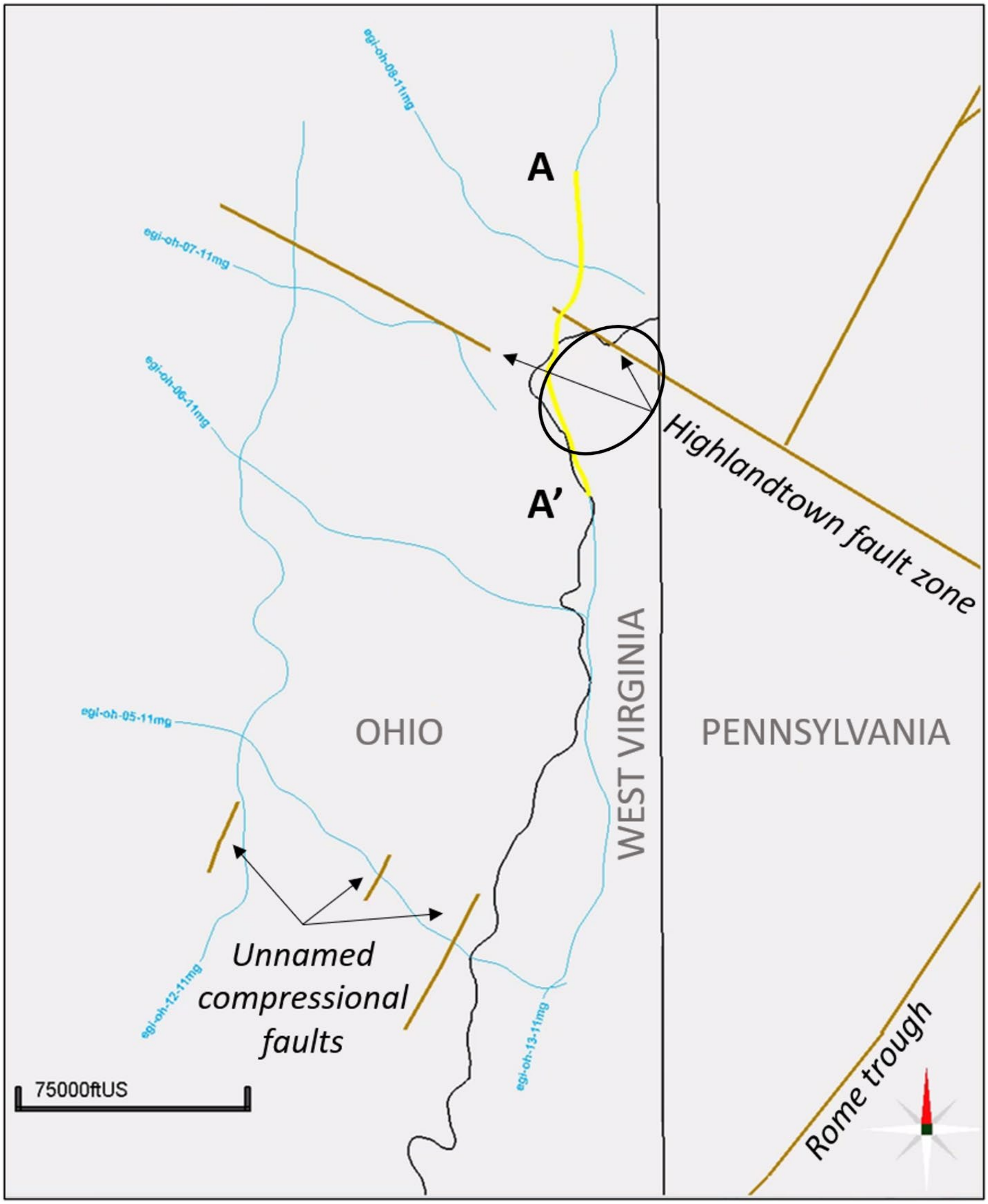

Figure 27: Location map of faults (gold) and 2D reflection seismic lines (blue). Location of cross-section A-A' (Figure 28) is delineated by the yellow portion of line egi-oh-13-11mg. The AoR is delineated by the black oval.

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2.4. Injection and Confining Zone Details [40 CFR 146.82(a)(3)(iii)]

The stratigraphy in the project area is composed of ~12,000 ft of sediments on top of Precambrian basement, ranging in age from Cambrian up to Pennsylvanian (Virgilian) at the surface (Figure 29). Freshwater aquifers occupy porous units within the Pennsylvanian and Upper Mississippian, and historic oil production has been largely from Lower Mississippian sandstones. Recently, unconventional oil and gas production has been established in the Middle Devonian and Upper Ordovician.

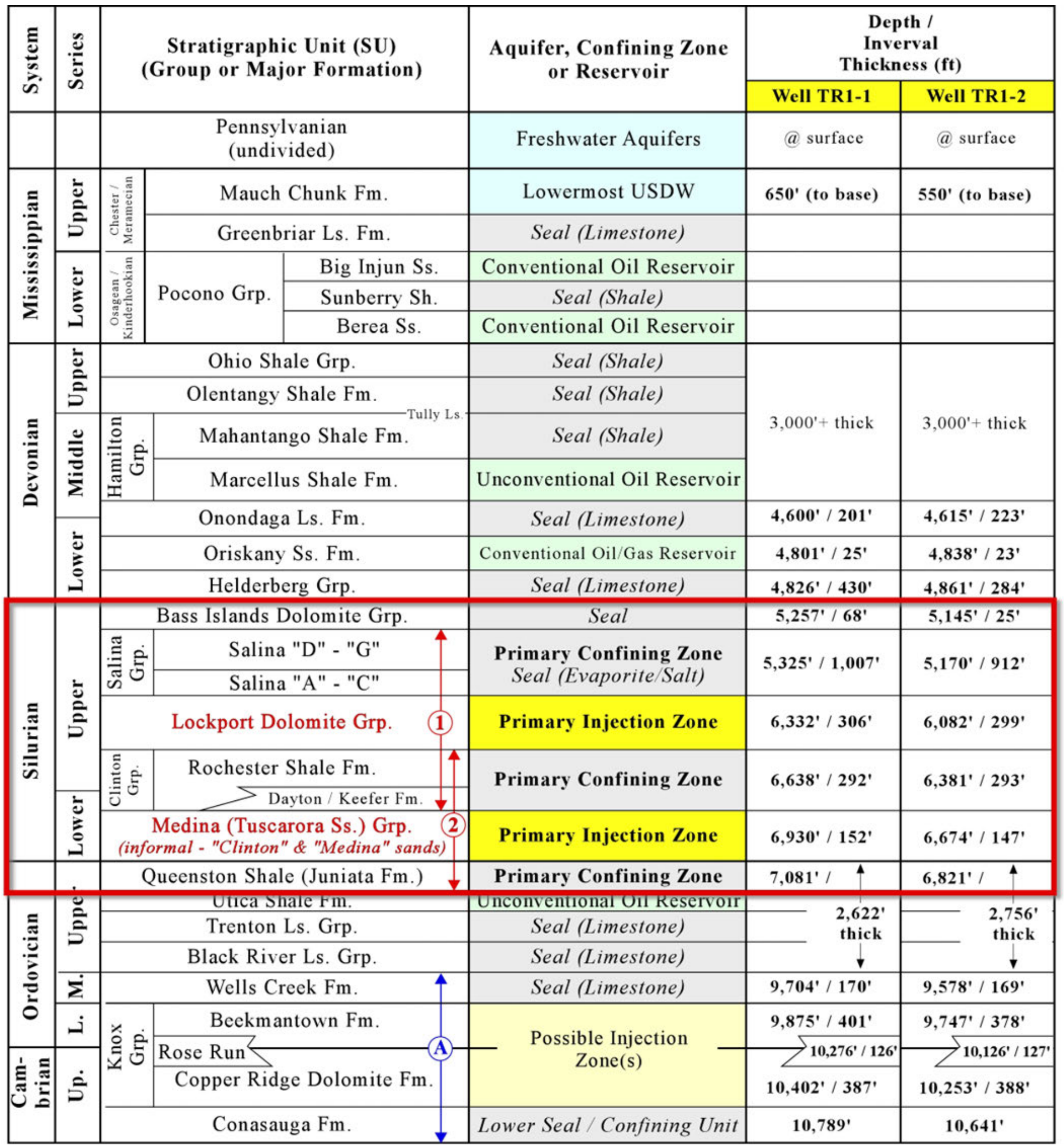

Figure 29: Generalized stratigraphic column for the project. Proposed Primary Injection Complexes: 1 - Lockport Injection Complex; 2 - Medina Injection Complex; secondary Possible Injection Complexes: A - Oriskany Injection Complex; B - Knox Injection Complex. (*Depth is to

the top of the Stratigraphic Unit (SU), except where noted.) Modified from Childs, 1985; Patchen et al., 1985b; Riley et al., 2010; Wickstrom et al., 2005; WVGES, 2019.

Subsurface analysis in the project area indicates several stacked, porous reservoirs with sufficient confining seals for sequestration. These intervals exist beneath the 2800 ft MD threshold for storage of supercritical CO_2 (sCO_2) and are, likewise, greater than 1,000 vertical feet from known producing oil reservoirs. Three potential injection complexes, each composed of an upper confining zone, a lower confining zone, and an injection zone, have been identified (Figure 29). There are two primary injection complexes proposed in this application: (1) CCS System 1: the Lockport Injection Complex (LIC) and (2) CCS System 2: the Medina Injection Complex (MIC). There is also an alternate injection complex, to be evaluated after data collection and evaluation from the CarbonSAFE stratigraphic well: CCS System A, the Knox Injection Complex (KIC). Throughout this permit, when referring to the entire injection complex, the nomenclature outlined above will be used, and when describing or indicating specific intervals, the Group, Formation, or appropriate formal interval (i.e., “Shale”) name will be used.

2.4.1. CCS System 1: Lockport Injection Complex (LIC)

The LIC is composed of, from top to base: the Salina Group, which forms the primary confining zone, the Lockport Dolomite Group, which is the objective injection zone, and the Rochester Shale Formation, which forms the basal confining zone. All three stratigraphic units are Upper Silurian in age (Figure 29).

2.4.2. LIC Primary Confining Zone: Salina Group

The Salina Group is a series of regionally extensive interbedded shales, dolomites, and evaporites (Figure 30). These deposits extend across the Appalachian and Michigan basins and provide the seal for Niagaran oil and gas reef trends in the Michigan Basin (Carter et al., 2010; Coyle, 2022). Original subdivision of the units “A-G” was identified by Landes (1945) in the Michigan Basin and correlated to the Appalachian Basin by Ulteig (1964) and Rickard (1969). They were deposited in a restricted marine (A-G) to sabkha/peritidal and supratidal environment (D-G) as a result of the paleogeographic location in tropical latitudes, an arid long-term paleoclimate, and isolation/rain shadow from orogenic uplift (Clifford, 1973; Ettensohn, 2008).

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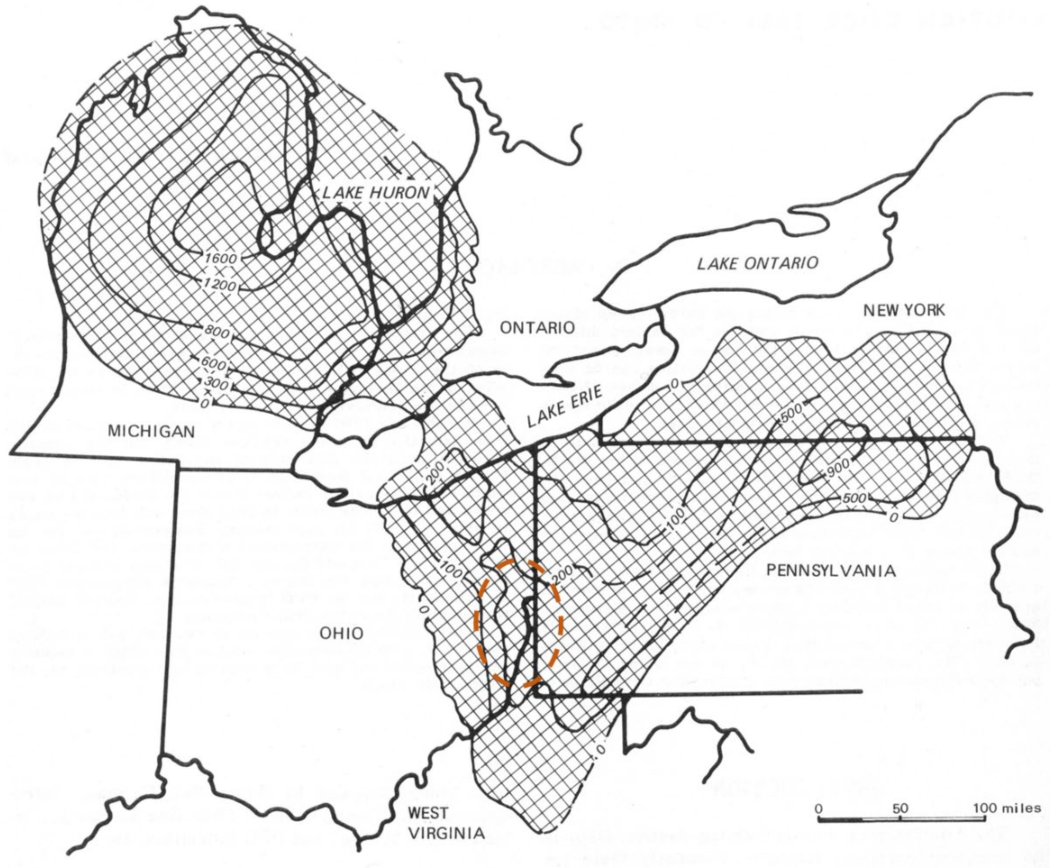

Figure 30: Regional extent and thickness of the Salina Group salt beds modified from Clifford (1973). The dashed circle is the approximate location of the Tri-State CCS Hub (map contour interval varies).

The Salina Group, named for the halite in this section, is divided into two intervals. The lower interval, called the "A-C" units, is known as the Vernon in New York and the upper Wills Creek in West Virginia (Rickard, 1969; Coyle, 2022). In the project area, this interval is composed predominantly of dolomite and shale beds, though some salt beds are present outside the area. The overlying "D-G" units are a thick section dominated by salt, evaporites, and shales. Figure 31 shows a cross-section from the Humble #1 Minesinger Well in Hancock County to the E. & W. #1 Peck well in Eire County, Ohio. This cross-section demonstrates that the E interval has a laterally continuous salt bed with an approximate thickness of 60 ft, and the F interval has numerous, thick, and laterally continuous salts in the project area. The "F4" salt can reach thicknesses of up to 120 ft in the project area and in the AoR (Figure 32; Clifford, 1972; Carter et al., 2017).

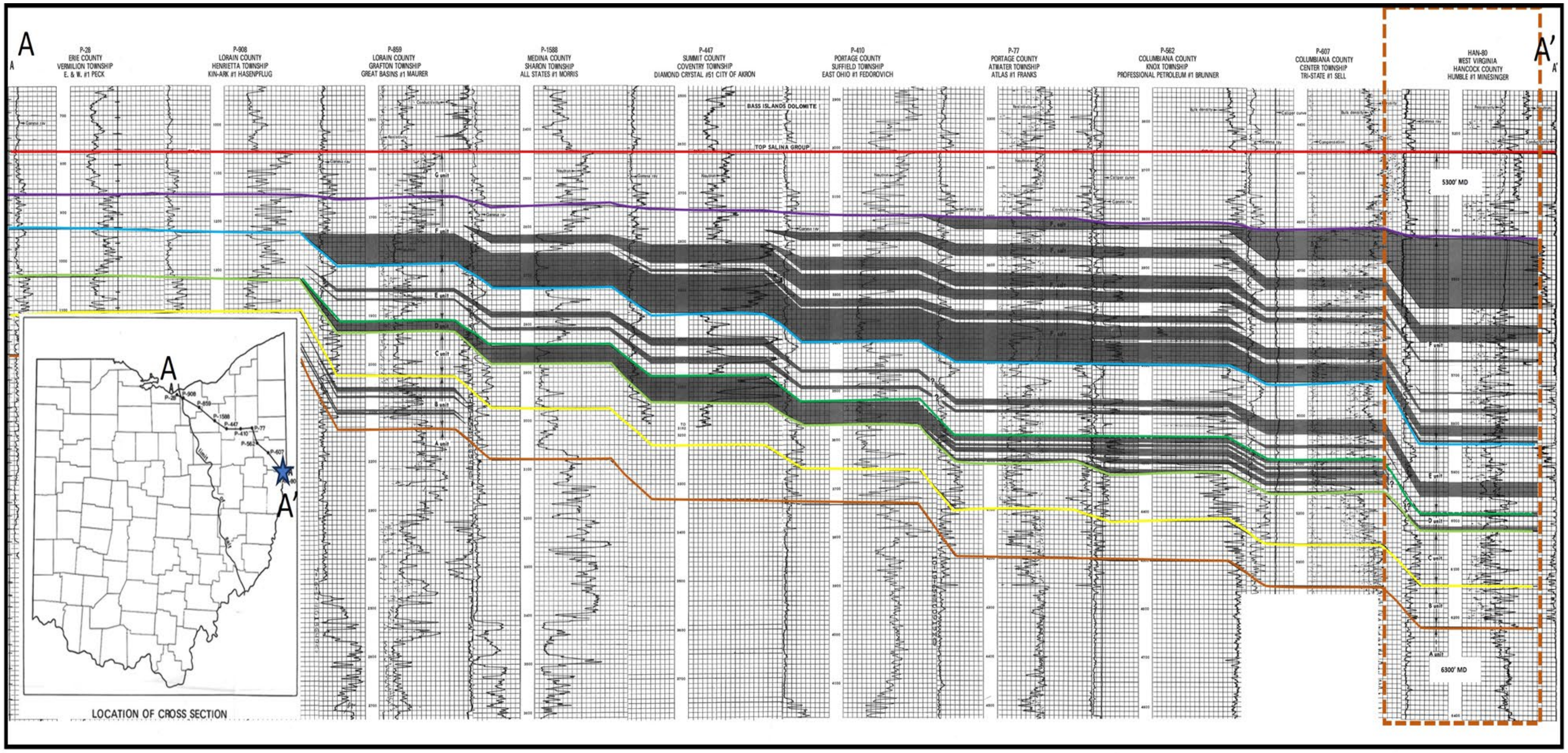

Figure 31: SE-NW Cross-section from Eire, County OH, to Hancock County, WV through the Salina Group. The dashed orange box is the Humble #1 Minesinger Well (location in Figure 17; subsection 2.1.10.5). Depths to the right are for the Minesinger well. Modified from Clifford, 1973. From Top to Base: The Top "G" unit (red), the Top "F" unit (Purple), the Top "E" unit (blue), the Top "D" unit (dark green), the Top "C" unit (light green), the Top "B" unit (yellow), the Top "A" unit (orange).

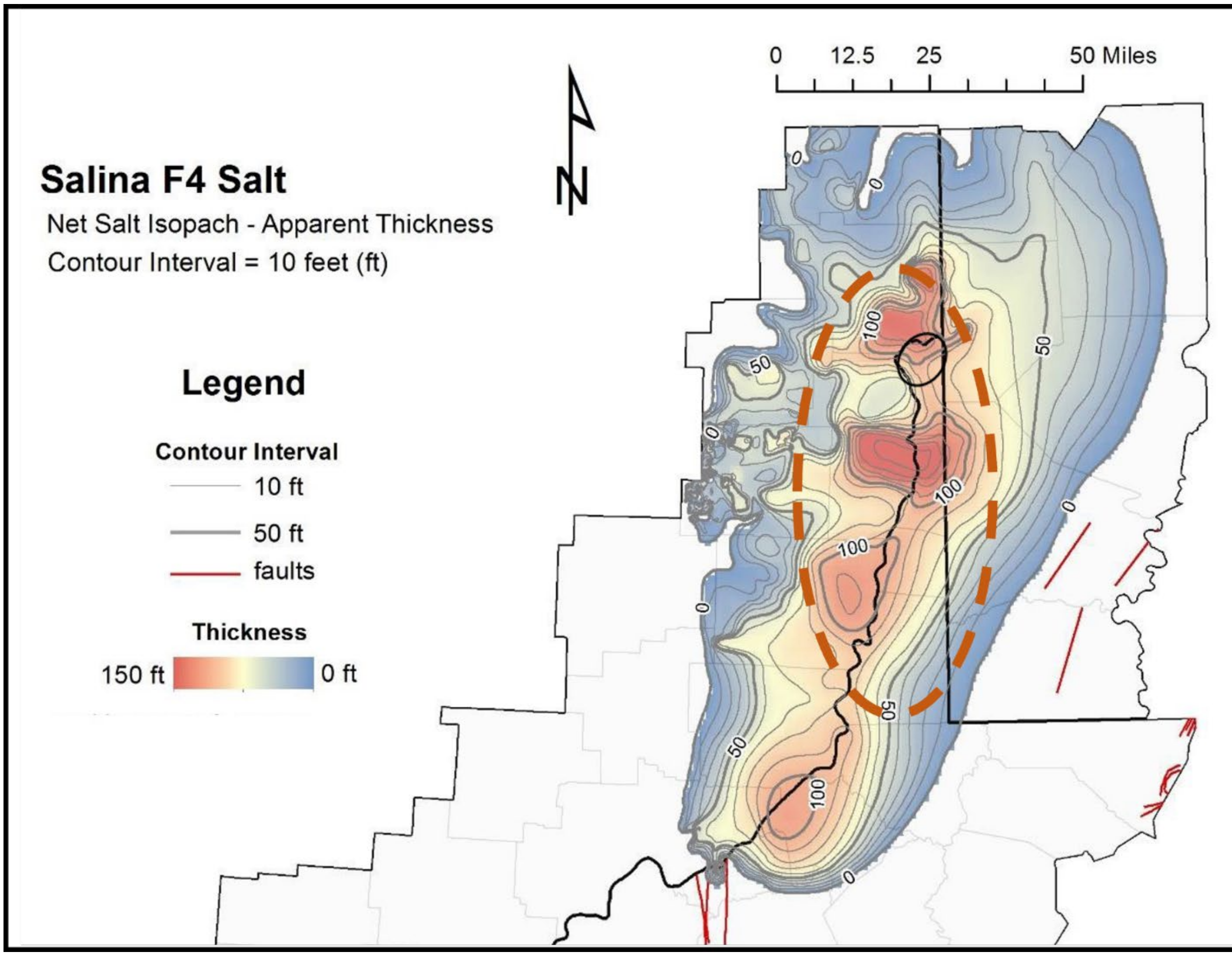

Figure 32: F4 Salt Thickness map in the Tri-State CCS Hub region (dashed oval) and project AoR (solid black oval). Modified from Carter et al., 2017.

There are multiple lines of evidence that support that the Salina Formation serves as an effective long-term seal for CO_2 injection. First, historical data from the oil and gas industry show that evaporites, such as those found in the Salina, have consistently acted as competent long-term seals; 14 of the world's 25 largest oil fields and 9 of the world's 25 largest gas fields are sealed by evaporites, despite evaporites constituting less than 2% of the world's sedimentary rocks (Warren, 2017). Additionally, a widely accepted guideline in the oil and gas industry suggests that a halite bed can function as a seal if it is at least 20 m (65.6 ft) thick. This is corroborated by the low permeabilities observed in evaporites, with halite typically exhibiting permeabilities on the order of 10^{-7} mD and anhydrite around 10^{-5} mD (Beauheim and Roberts, 2002).

Furthermore, studies have identified the F4 salt layer as possessing both the requisite halite purity and thickness (over 100 ft) necessary for solution mining and long-term storage of natural gas liquids in the relevant area (Carter et al., 2017). Lastly, the distinct geochemical fingerprint observed between regional petroleum systems younger than the Salinan evaporites and those predating them further bolster the argument for the Salina's efficacy as a long-term seal (Cole et al., 1987; Drozd and Cole, 1994; Swezey, 2002; Ettensohn, 2008).

Available core analyses from the MRCSP-FENGENCO 1 well (API# 3401320586; Figure 19 and Table 2; subsection 2.1.10.5) in Belmont County, Ohio are primarily from dolomite intervals in units A, B, F, and G of the Salina Group (Figure 33). There are no core measurements from the actual salt layers. Permeabilities from these cores range from <0.01 to 2.45 mD (average 0.3 mD), and measured porosities range from <1.0% to 13% (average 6.6 %). These units are stratigraphically older than the laterally continuous F4 salt and do not put containment at risk. Further discussion of the petrophysics continues in subsection 2.5 of this Application Narrative.

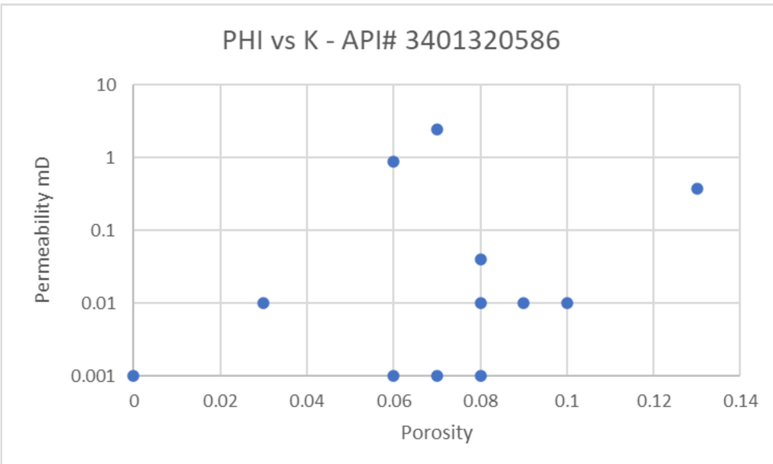

Figure 33: Core measured Porosity vs. Permeability from the MRCSP FENGENCO 1 well (API # 3401320586; well location is shown in Figure 19, Table 2 subsection 2.1.10.5).

In the project area, the Salina Group ranges in depth from -3000 ft (SSTVD) in the northwest, towards the Findlay Arch, and dips to the southeast to a depth of -6500 ft SSTVD (Figure 34). The Salina Group has an average thickness of 1050 ft across the project area (Figure 34) with slight thickening east and west of the proposed injection sites, corroborating Clifford (1973). The Top Salina interval is at a total measured depth of approximately 5800 ft to 6100 ft MD and has a total thickness range of 900 to 1,000 ft at the proposed injection wellsites.

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SALINA C GROUP

Structure	Isochore

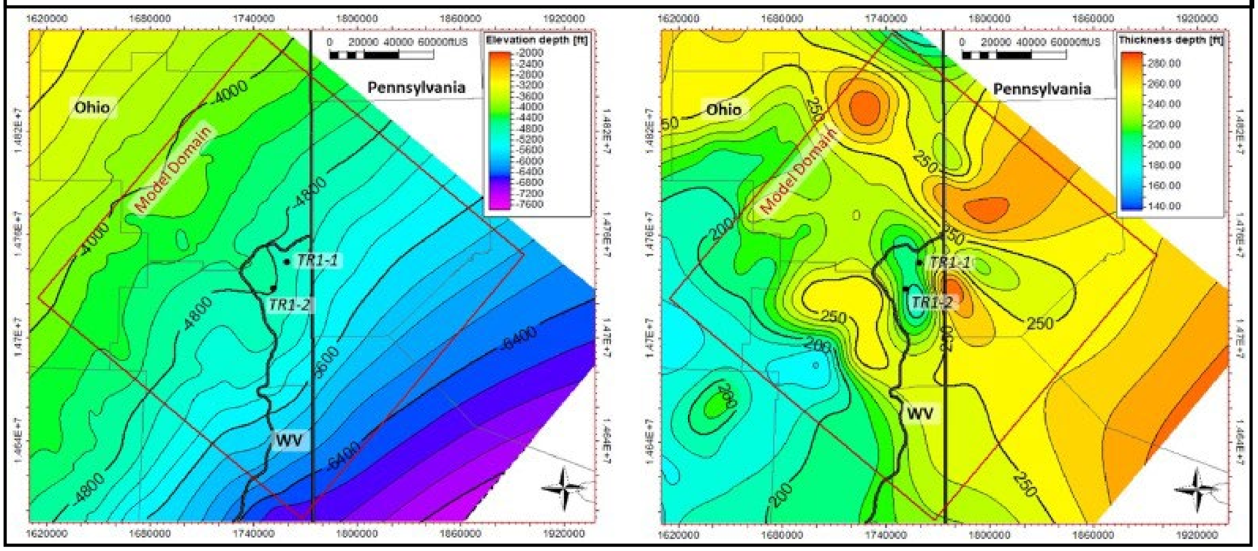

Figure 34: Top Structure (right) and isochore(left) of the Salina Group C interval (Structure C.I. = 200'; depths SSTVD; Isochore C.I. = 10') with the two potential injection sites shown in Hancock County, West Virgina. The SEM (Static Earth Model) domain is outlined in brown.

2.4.2.1. LIC Primary Injection Zone: Lockport Dolomite Group

The primary injection zone for the LIC is the Lockport Dolomite Group. The Lockport Dolomite Group, sometimes referred to as the McKenzie Formation (Horvath, 1970), is aerially extensive across the Appalachian Basin region and into Michigan (called the Niagara Group) and is deposited in similar paleogeographic, eustatic, and tectonic conditions to the Salina Evaporites (see subsection 2.4.2 above) (Carter et al., 2010; Ettensohn, 2008).

Regionally, the Lockport Dolomite Group dips to the southeast and has an average thickness range of 150 ft to 200 ft. A study in Eastern Ohio measured the maximum thickness of the Lockport at ~400 ft adjacent to the project area (Gupta et al., 2010; Wickstrom, 2010; Janssens, 1970; Carter et al., 2010). At the proposed injection sites, the Lockport Dolomite Group has a thickness of approximately 300 ft and occurs at measured depths between 6000 ft and 6350 ft (Figure 36).

This relatively thick section of carbonate is composed of a fine to coarsely crystalline, fossiliferous, slightly argillaceous dolostone, accumulated in a shallow epicontinental sea that stretched westward from New York to Ohio and south to Kentucky, extending along the Cincinnati-Findlay-Algonquin axis into the basins of Indiana, Illinois, and Michigan (Carter et al., 2010; Ettensohn, 2008). Carter et al. (2010) identified seven lithofacies types in core from the Lockport Dolomite Group, all indicative of shallow subtidal to nearshore deposition (Figure 35):

1. mixed intertidal to supratidal dolomite (with a mixed gray biostromal subfacies)
2. interreef or interbioherm dark dolomite
3. grainstone – shoals, banks, reef flanks, and inter-reef sediments

4. biohermal dolomite (reefs, bioherms, and patch reefs)
5. subtidal crinoidal dolomite
6. quartzose dolomite associated with barrier island
7. shallow subtidal shaley dolomite

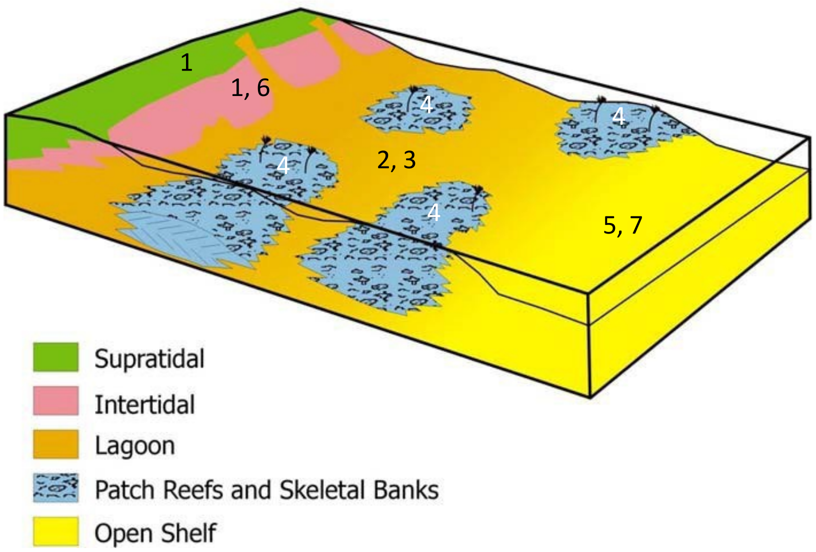

Figure 35: Cartoon depicting the regional facies patterns interpreted for the Lockport Dolomite in the Appalachian Basin. Numbers reflect the described facies in the text. Modified from Smosna et al., 1989.

Detailed core analysis was not available for the Lockport Dolomite Group near the proposed injection well sites. A study (Carter et al., 2010) of several cores in Mercer County, Pennsylvania and Caroll County, Ohio, as a part of the MRCSP Phase II Topical Report evaluating the CO_2 sequestration potential in the middle Devonian to the middle Silurian formations in the Appalachian Basin, was used to characterize the reservoir (locations shown in Figure 16 and Table 2; subsection 2.1.10.5).

Porosity types in the Lockport Dolomite Group include vuggy, moldic, inter/intraparticle, and intercrystalline porosity (Carter et al., 2010; Wickstrom et al., 2010). Early eogenic and syngenic diagenesis facilitated the creation of vugs and moldic pore textures, though much of the secondary porosity has been lost through burial diagenesis. Core and log analysis measure an average of 9% porosity in vuggy dolomites and between 1 and 3.5% in dolomites characterized with intracrystalline porosities. Average permeabilities in Lockport dolomites with intercrystalline permeability are measured at <0.1 mD, and vuggy permeability averages 3 to 10 mD but can be as high as 55 mD (Carter et al., 2010; Wickstrom et al., 2010). Fracture porosity and permeability are present in the Lockport Dolomite as well, enhancing reservoir petrophysics (Wickstrom et al., 2010). Cyclic stacking of reservoir facies in response to sea-level fluctuations yields opportunity for multiple disposal zones in the Lockport Dolomite Group (Figure 25, Figure 26, and Figure 46). Site-specific petrophysical analysis is discussed in subsection 2.5 of this Application Narrative.

LOCKPORT DOLOMITE GROUP

Structure	**Isochore**

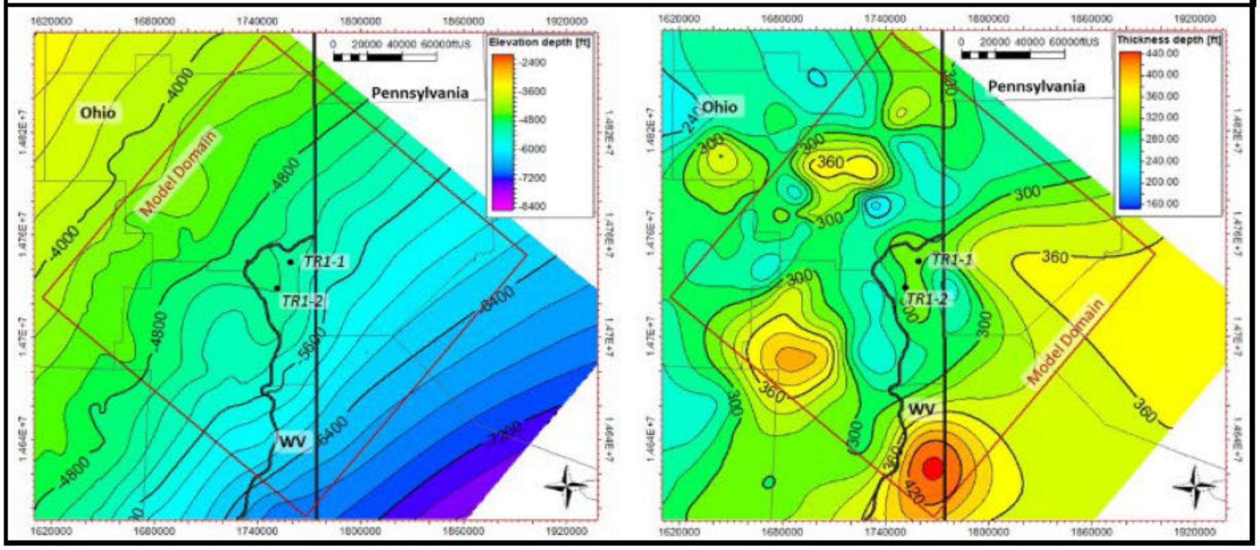

Figure 36: Top Structure (right) and isochore(left) of the Lockport Dolomite Group interval (Structure C.I. = 200'; depths SSTVD; Isochore C.I. = 20') with the two potential injection sites shown in Hancock County, West Virgina. The SEM domain is outlined in brown.

Measurements from four sidewall core samples in the Lockport Dolomite Group identify the mineralogy to be predominantly dolomite with minor quartz and illite (Table 3). Carter's 2010 study also documented pyrite and pyrobitumen, likely from diagenesis, in the sidewall core samples. Reactivity of the Lockport Dolomite Group mineralogy with the CO_2 stream is further addressed in subsection 2.8 of this Application Narrative.

Table 3: XRD results for sidewall core samples of the Lockport Dolomite Group from the Ocel #1 well, Carroll County, Ohio (Carter et al., 2010). Location is in Figure 15 , subsection 2.1.10.5.

Sample	**Totals**						
Depth (ft)	**Quartz**	**K-Spar**	**Plag.**	**Pyrite**	**Clays**	**Carb.**	**Other**
5422	13	0	0	1	2	84	14
5436	1	0	0	1	1	97	2
5460	1	0	0	1	2	96	2
5468	Tr	0	0	1	1	98	1
Average	4	0	0	1	1	94	5
Sample	**Totals**						
Depth (ft)	**Chlorite**	**Kaolinite**	**Illite**	**Smectite**	**Calcite**	**Dol/Ank**	**Siderite**
5422	Tr	0	2	0	0	84	Tr
5436	Tr	0	1	0	0	97	Tr
5460	Tr	0	2	0	0	96	Tr
5468	Tr	0	1	0	0	98	Tr
Average	Tr	0	1	0	0	94	Tr

2.4.2.2. LIC Primary (lower) Confining Zone: Rochester Shale Formation

The Rochester Shale Formation, known to drillers as the “Clinton Shale,” lies below the Lockport Dolomite Group and serves as the basal confining zone to the LIC, as well as the upper confining zone for the MIC discussed in subsection 2.4.3 below.

In West Virginia, Woodward (1941) identified the Rochester as the upper section of the Clinton Group. He and Folk (1962) characterized the shale as gray to black in color, thin-bedded, fissile, or platy, and interspersed with occasional dense, fossil-rich blue-gray micritic-biosparite limestone, deposited in a lagoonal environment associated with the time-correlative Keefer sandstone barrier bar. In New York and Ontario, Brett (1983) described the Rochester as a gray, fossiliferous, shaley mudstone with abundant interbedded carbonates indicative of storm-wave action on the southwards facing slope. He correlated it west to eastern Ohio and Kentucky where it grades into an argillaceous dolostone referred to as the “Bisher” in the literature (Horvath, 1969; Janssens, 1977). Janssen (1977) notes that the shale in the Rochester thins and becomes virtually absent near the western boundary of Hancock County. Here, it is underlain by the Dayton Formation: a non-argillaceous slightly glauconitic dolomite, though the GR log from the Minesinger 1 well indicates a thick shale with thin dolomite beds (Figure 25).

Subsurface log correlations show the shale is an average of 300 ft thick in the Hancock County area in WV (Figure 37), and across the model domain, the top of the Rochester Shale ranges in depth from -4800 to -7300 ft (SSTVD) (Figure 37). In the West Virginia northern panhandle, the shale is organic-lean and does not have high radioactivity on gamma ray log (average of 80 API units).

Porosity in the formation is generally less than 3%, and permeability is similar to other shales at less than 1×10^{-6} mD (Mudd et al., 2003). Given the lateral continuity and the impermeability of the shales, the Rochester Shale and its time-equivalents in the project area should serve as an effective base confining zone for the LIC and upper confining zone for the MIC.

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ROCHESTER SHALE FORMATION	
Structure	**Isochore**

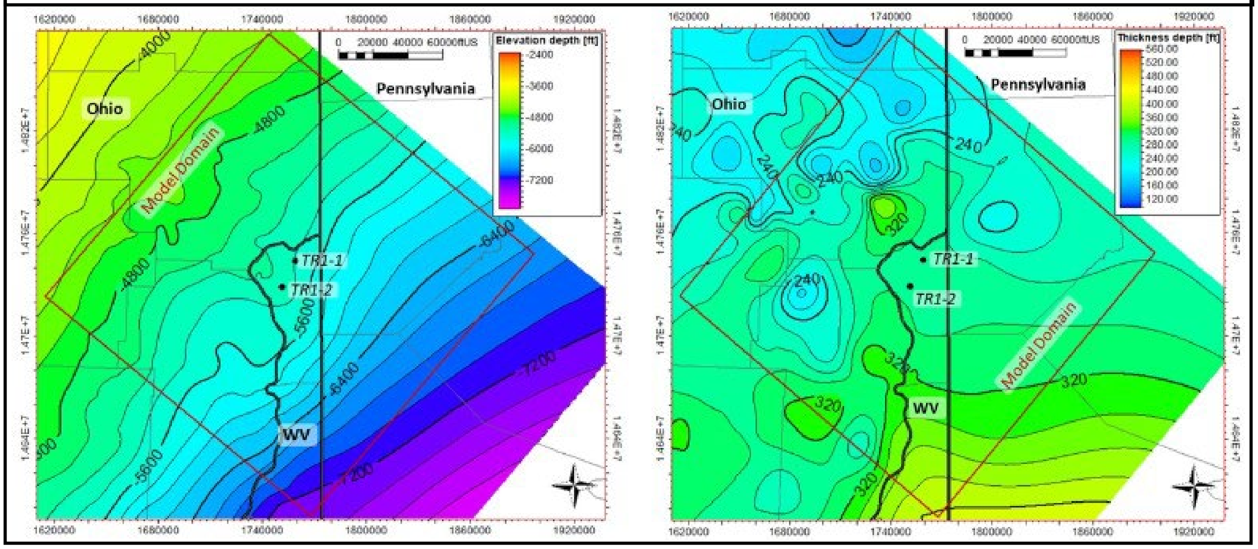

Figure 37: Top Structure (right) and isochore (left) of the Rochester Formation interval (Structure C.I. = 200'; depths SSTVD; Isochore C.I. = 20') with the two potential injection sites shown in Hancock County, West Virgina. The SEM domain is outlined in brown.

2.4.3. CCS System 2: Medina Injection Complex (MIC)

The second primary injection complex for consideration is the MIC; the MIC is composed of three units. The Upper Silurian Rochester Shale Formation forms the upper seal and confining zone (Figure 29, arrow 2). The Medina Group, which is a series of stacked sandstones in the Lower Silurian, is informally referred to as the "Clinton" sandstone and is the projected injection zone(s) (Wickstrom, 2010). At the base, the thick, Ordovician-aged Queenston Shale/Juniata Formation, comprises the lower confining member of the MIC.

2.4.3.1. MIC Primary (upper) Confining Zone: Rochester Shale

The upper confining zone for the MIC is the same basal confining unit for the LIC and is addressed in subsection 2.4.2.2 above.

2.4.3.2. MIC Primary Injection Zone: Sandstone in the Medina Group

Correlation of sandstones in the Lower Silurian of the Appalachian Basin historically have been problematic due to nomenclature inconsistencies in stratigraphic terminology from state to state. Multiple names for age-equivalent zones (Figure 38) in the literature have led to confusion and cross-correlation of stratigraphic units. Sandstones in this interval have been referred to as Tuscarora, Grimsby, Whirlpool, and informally the "Medina" and "Clinton" sandstones, the latter including drillers terminology.

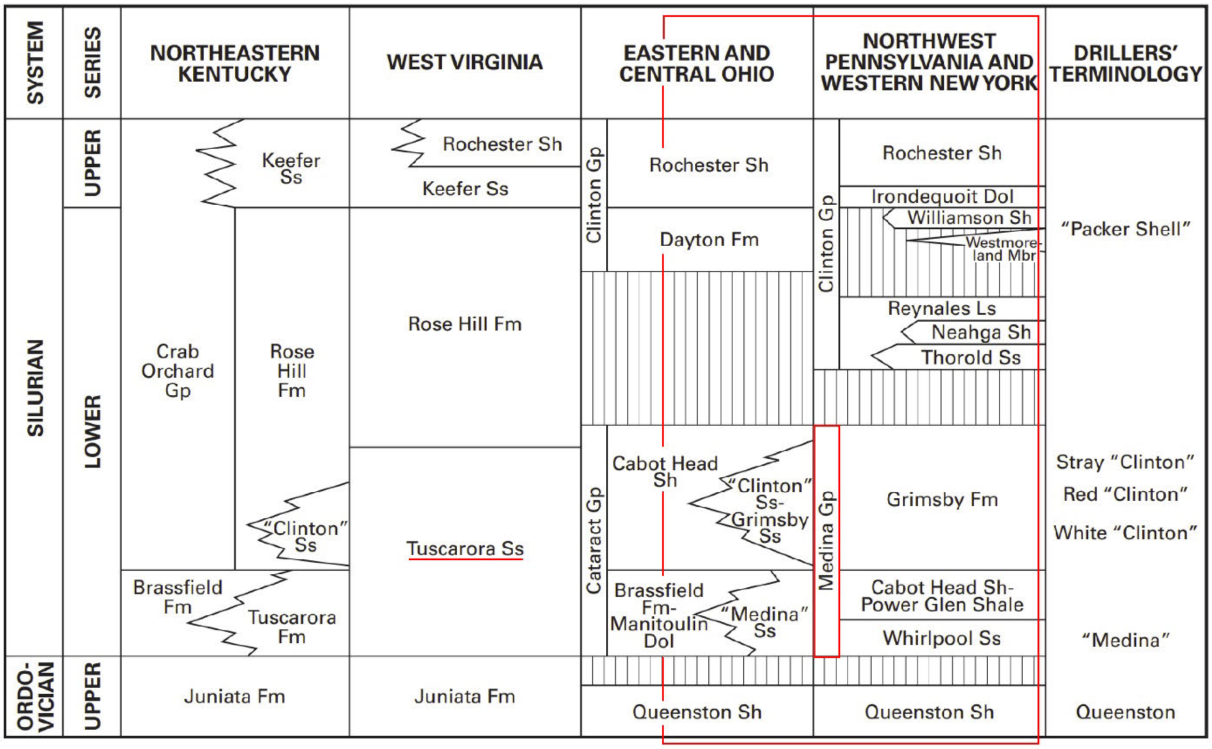

Figure 38: Stratigraphic correlation chart for the project area illustrating varying terminology for age equivalent sands. For this permit, the nomenclature for Eastern Ohio is recognized, and the interval is referred to as the Medina Group (Riley et al., 2010).

For the purpose of this permit, the MIC injection interval will be referred to as the Medina Group of Eastern Ohio and northwest Pennsylvania. The Medina Group is composed of the Whirlpool Sandstone, the overlying Cabot Head Shale, and the interfingering Grimsby ("Clinton" and "Medina") reservoir sandstone(s), as is illustrated by the type log by Riley et al. (2010) from eastern Ohio in Figure 39.

The Medina Group is an unconformity-bound wedge of Lower Silurian clastics deposited in the Appalachian foreland basin. These deposits represent a low frequency (3rd or 4th order) cycle of deposition in which transgressive and high-stand systems tracts are preserved (Castle, 1998). The lower approximate one-half of the Medina Group is composed of the Whirlpool (Medina) Sandstone and the Lower Cabot Head (Power Glen) Shale and is recognized as the transgressive systems tract (TST) for this cycle. The Whirlpool transgressive sandstone is composed of white to light gray, red, fine to very fine-grained quartzose sand that is moderately to well sorted (Wickstrom et al., 2010). This sandstone is gradational up into the Lower Cabot Head Shale and is recognized by the increase in gamma ray response on log (Figure 39). The Lower Cabot Head Shale is dark green to black, marine shale, with thin quartzose, silt and sand laminations that increase in number and thickness towards the upper part of the unit (Wickstrom et al., 2010). The Lower Cabot Head Shale interval is interpreted to represent marine deposition on the shelf during continued eustatic sea-level rise. Sandstone beds do occur in this unit, particularly eastward towards the Taconic highlands, but are of more local extent and probably storm-deposited shelf bars formed below the normal wave base (Castle, 1998).

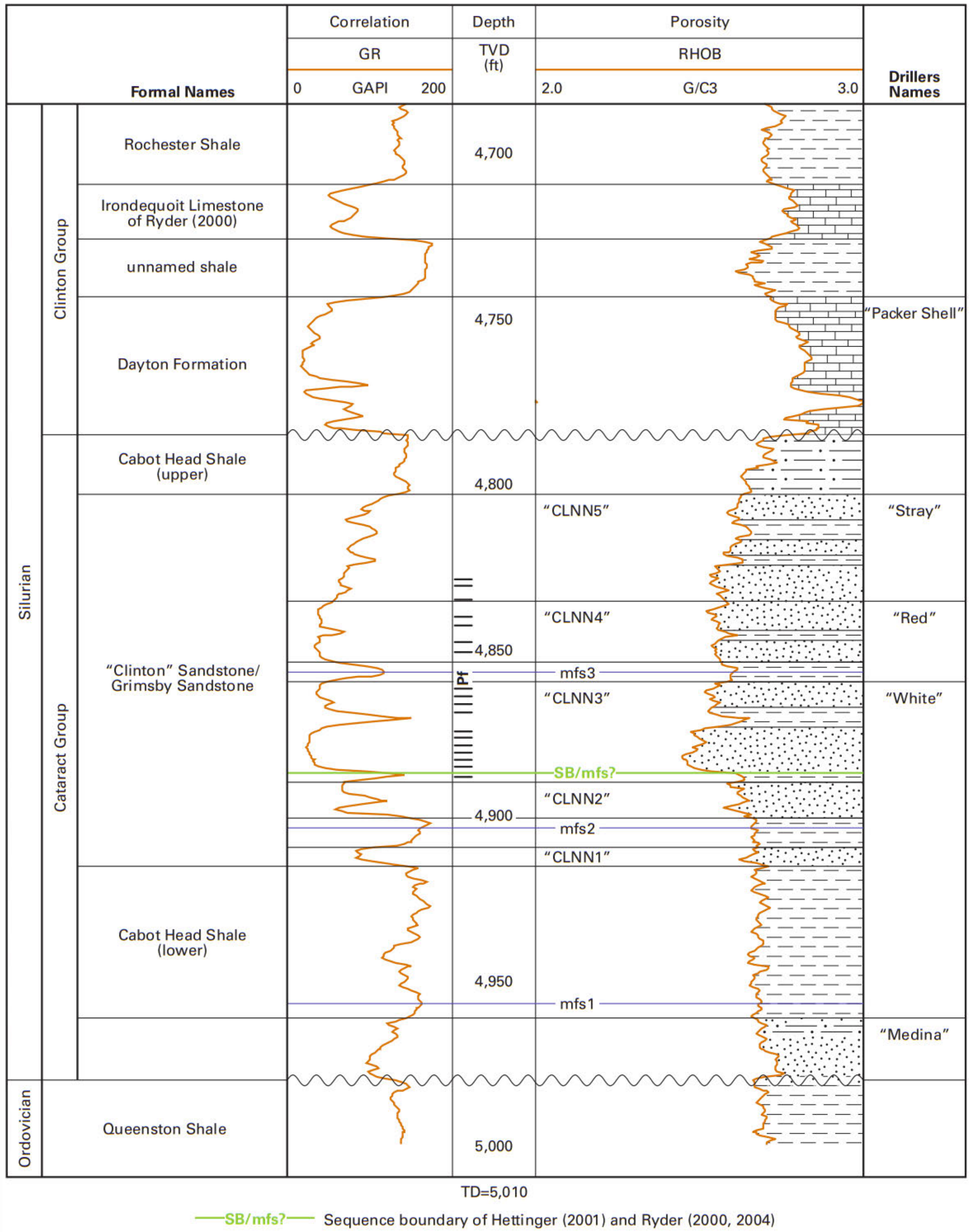

Figure 39. Type log from Riley et al., 2010, of the stratigraphy in the East Canton oil field in Stark County, Ohio (location shown in and Table 2 of subsection 2.1.10.5) which directly translates to the project area. The Cataract Group correlates to the Medina Group, as shown in Figure 38 above.

The upper one-half of the Medina Group is represented by the Grimsby ("Clinton") Sandstone and overlying Upper Cabot Head Shale and is recognized as the high-stand systems tract (HST) for this cycle. The sandstones in the Grimsby Formation are composed of very fine to medium-grained, monocrystalline, quartzose rocks with silty shale interbeds (Wickstrom et al., 2005). The upward, rapidly gradational, change from the Lower Cabot Head Shale into the sandstone rich Grimsby Formation is due to uplift and erosion along the Taconic highlands to the southeast, which initiated a forced regression into the HST. These sandstones were deposited in marine, shoreface/shoreline, and deltaic environments in response to episodic northwest progradation and shallowing, associated with relative base-level drop across the project area (Castle, 1998; Wickstrom et al., 2010). The Upper Cabot Head Shale is composed of argillaceous sandstones and muds interpreted to be intertidal, coastal plains deposits (Castle, 1998). These sediments mark the final shallowing of the Medina Group prior to exposure at the top of the unit; i.e., pre-Dayton Formation transgression.

The Medina Group has multiple sandstone targets for sequestration with interbedded confining zones that segregate the sands into individual flow-units (Figure 38). The basal Whirlpool Sandstone is typically of poor reservoir quality due to carbonate and dolomite cement (Riley et al., 2010) and is not discussed here; however, this interval will be evaluated for injection viability in the CarbonSAFE stratigraphic test well and during pre-operational testing. The Grimsby / "Clinton" sandstones are objective injection intervals based on their rich history of oil and gas production, from eastern Ohio to northwestern Pennsylvania.

The "Clinton" sandstones are typically "tight" with respect to porosity and permeability due to early cementation, primarily by silica (quartz overgrowths) as well as accessory hematite, chlorite, carbonate, and evaporite minerals. Porosity is variable based on their heterolithic sand facies. Porosity types include relict primary porosity to microporosity, intra constituent, and secondary porosity from the dissolution of unstable cement components (Wickstrom et al., 2010; Riley et al., 2010). Wickstrom and others (2005) reported a porosity range of 2 to 23% in the "Clinton" sands, with an average of 7.8%. Measurement from core data near the project area yields an average porosity of ~5%, and permeabilities average ~10 mD. Reported permeabilities within the sandstones range from less than 0.1 mD to 40 mD, although some producing oil fields averaged 100 mD with peaks in excess of 200 mD (Wickstrom et al., 2010). Fracture porosity and permeability exist, but distribution is poorly understood (Riley et al., 2010). Based on historic oil and gas production, as well as gas storage in "Clinton" sandstone reservoirs, the Medina Group holds good potential for sequestration of miscible CO_2 but due to lithologic variations, detailed characterization of sands will be needed and will be addressed in the pre-operational testing.

Framework grain analysis of rotary sidewall cores from the Ohio Division of Geological Survey CO_2 No. 1 well in Tuscarawas County, Ohio (location shown in Figure 17 of subsection 2.1.10.5), east of the AoR (Wickstrom et al., 2011), classify the Medina Group injection interval (referred to as the Clinton) as a Quarzarenite/Sublitharenite with minor feldspar and lithic fragments (<8%) (Table 4). Cement accounts for 14-18% of the total point count and are predominantly quartz overgrowths with secondary pore filling clays. XRD analysis corroborates the framework grain analysis with 85-92% quartz, 5-13% clay, and minor percentages of other minerals (Table 5). This analysis suggests that there are few mineral constituents that will react with the injected CO_2 stream, though the literature suggests the cements are variable: e.g., quartz, hematite, and carbonate, which may cause dissolution and precipitation of different mineral species. In addition, mineralogic information specific to the project area will be collected during pre-operational testing and as a part of the data collection for the CarbonSAFE stratigraphic well.

Table 4: Framework Grain Analysis for the Medina Group at the Ohio Division of Geological Survey CO_2 No. 1 well in Tuscarawas County, Ohio (location shown in Figure 17 and Table 2 of subsection 2.1.10.5). Modified from Wickstrom et al., 2011.

Measured Depth (ft):	4771	4790	4840
Sample Number:	1-3R	1-5R	1-9R
Grain Size avg(mm):	0.1	0.11	0.15
Grain size Range (mm):	<0.01-0.32	<0.01-0.38	0.03-0.32
Sorting:	Moderately well	Moderate	Well
Rock Type:	Quartzarenite	Sublitharenite	Sublith./Subark.
Quartz:	68	51	68
Feldspar:	1	3	2
Lithic FR:	1	4	2
Accessory Grains:	tr	2	1
Environmental Indicators:	2	3	tr
Detrital Matrix:	5	16	0
Cement/Replacement:	18	14	18
Porosity:	5	6	9
TOTALS:	**100**	**99**	**100**

Table 5: XRD analysis for RSWC collected in the Medina Group at the Ohio Division of Geological Survey CO2 No. 1 well in Tuscarawas County, Ohio (location shown in Figure 17 and Table 2 of subsection 2.1.10.5). Modified from Wickstrom et al., 2011.

Measured Depth (ft):	4771	4790	4840
Sample Number:	1-3R	1-5R	1-9R
Chlorite	1	3	1
Kaolinite	1	1	Tr
Illite	3	8	4
Mx I/S	Tr	1	Tr
Total Clay	**5**	**13**	**5**
Calcite	Tr	Tr	0
Dol/Ank	0	Tr	2
Siderite	Tr	Tr	Tr
Total Carbonates	**Tr**	**Tr**	**2**
Quartz	92	85	90
K-spar	1	1	1
Plag.	1	1	1
Pyrite	1	Tr	1
Hematite	Tr	0	0
Barite	0	0	0
Total Other Minerals	**95**	**87**	**93**

Based on the SEM, the top of the Medina Group in the project area ranges in depth from –5000 ft (SSTVD) to the northwest in Ohio to –7700 ft (SSTVD) to the southeast in West Virginia; average depth in the vicinity of the proposed injection wells is ~ -5650 ft (SSTVD) (Figure 40). Gross thickness of the Medina Group in the Tri-State CCS Hub is relatively uniform, averaging ~180 ft to 200 ft (Figure 40).

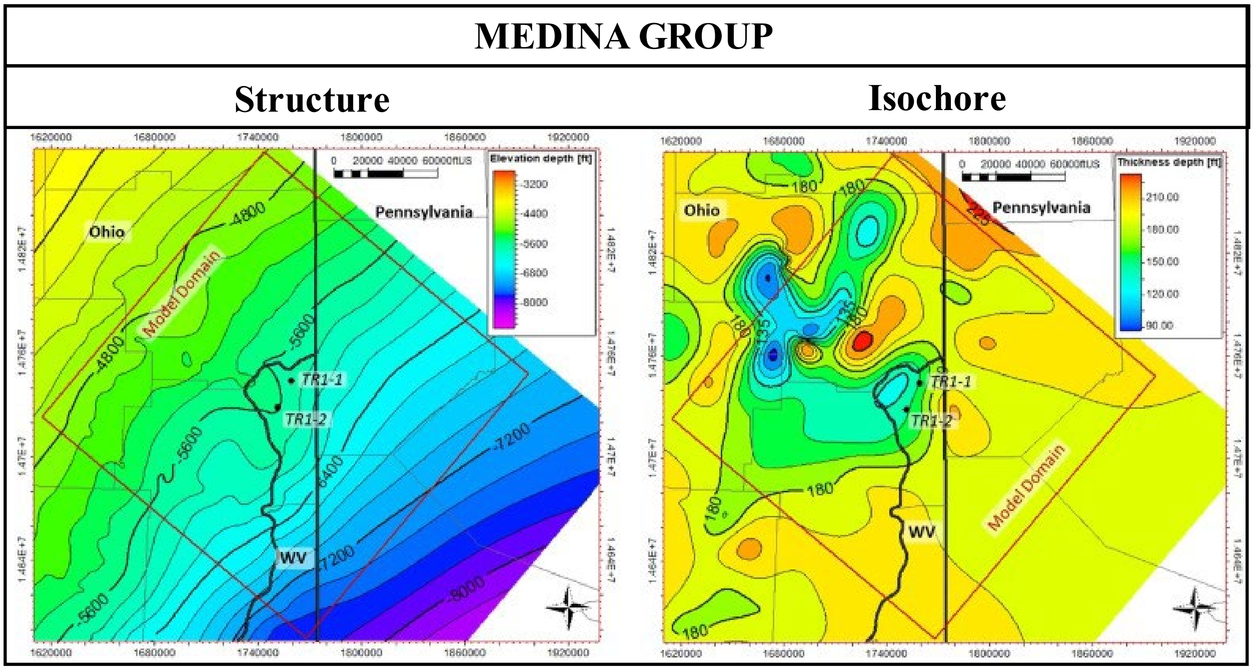

Figure 40: Top Structure (right) and isochore (left) of the Medina Group interval (Structure C.I. = 200'; depths SSTVD; Isochore C.I. = 15') with the two potential injection sites shown in Hancock County, West Virgina. The SEM domain is outlined in brown.

2.4.3.3. MIC Primary (lower) Confining Zone: Queenston (Juniata) Shale Formation

The Queenston Shale Formation (OH, PA, NY, ON), also referred to as the Juniata Shale Formation (WV, PA, VA, NY), or the Sequatchie Formation (KY, TN), lies beneath the Medina Group and serves as basal confining zone for the MIC (Figure 29). Regionally, it has been interpreted as a fluvial and subaerial delta shedding off the Taconic highlands, coined the "Queenston Delta Complex," into transitional and shallow marine environments (Figure 41; Blue, 2011; Brogly, 1984; Dennison, 1976). Brogly (1984) described it at outcrops in Southern Ontario as a siltstone with between 40-70% carbonate, non-aeolian sands, and some gypsum deposited in a supratidal mudflat fed by sediment from a N-S river, while further south, in outcrop in West Virginia, the Juniata is described as a heterolithic red mudstone with coarsening sandstones and conglomerates deposited in the transitional tidal flat to shoreface (Blue, 2011). Figure 41 shows the proposed injection location in Hancock County coinciding with the transition between the coarser, more subaerial deposited Juniata and the transitional marine Queenston Shale (Blue, 2011).

The Queenston Shale Formation is in excess of 1500 ft and at a depth of ~-5800 ft (SSTVD) in the project area (Figure 42). In addition, a study investigating the depth of penetration of variable fluids with different viscosities in Queenston shale of southern Ontario measured the hydraulic conductivity of the Queenston Shale as 1.9×10^{-9}, which would classify it as impermeable (Al-Maamori, et al., 2017). Based on the shale's vast thickness and low permeability, the Queenston Shale will serve as an effective bottom seal for the MIC.

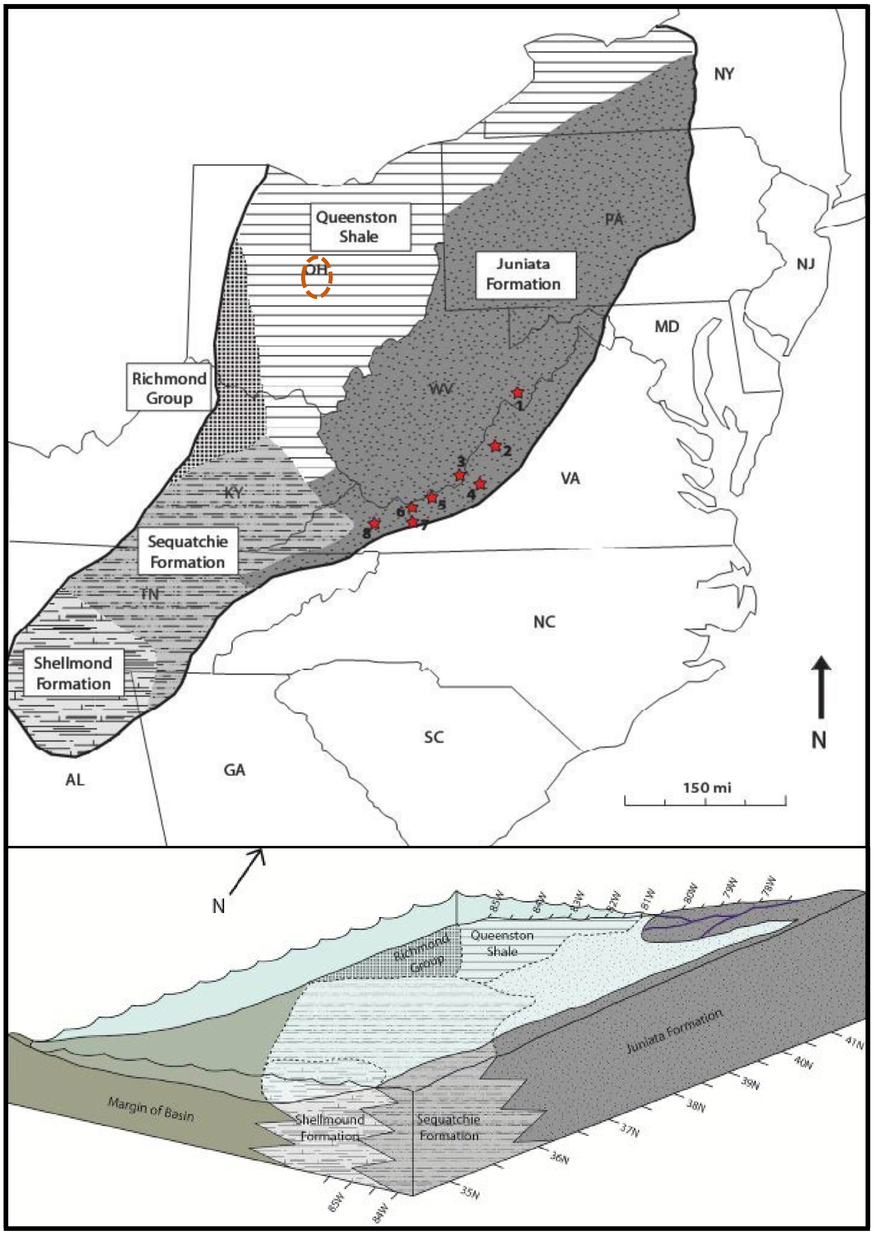

Figure 41: (Upper) Map of late Ordovician formations in the Appalachian Basin. (Lower) Modified from Dennison, 1976 and Blue, 2011. The Tri-State CCS Hub location is indicated with a red dashed circle.

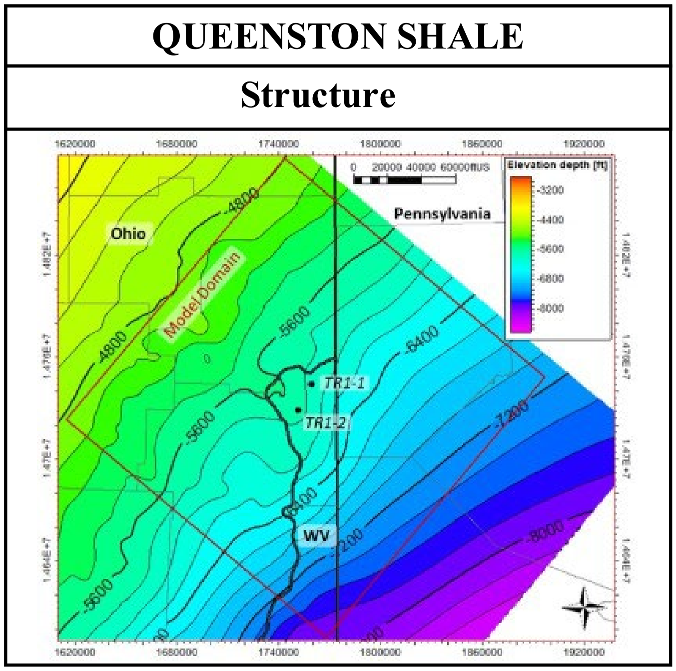

Figure 42: Top Structure of the Queenston Shale interval (C.I. = 200'; depths SSTVD) with the two potential injection sites shown in Hancock County, West Virgina. The SEM domain is outlined in brown.

2.4.3.4. Secondary Injection Complex for Consideration: Knox Injection Complex (KIC)

Another stratigraphic interval, the Cambro-Ordovician Knox Group (and members therein), is being considered as a secondary injection zone along with the Lockport Dolomite and Medina Groups. This anticipated injection complex complete with upper and lower confining zones is shown in Figure 29 (arrow A). The Knox Group has been the subject of study for CO_2 sequestration (e.g., Wickstrom et al., 2008; Skeen, 2010; Gupta et al., 2020) and will be evaluated in the CarbonSAFE stratigraphic test well.

The Cambro-Ordovician Knox Group, and age-equivalents in other parts of the U.S., has been the subject of evaluation for CO_2 sequestration, e.g., the Illinois Basin (Kirksey et al., 2014) and the Midcontinent region (Watney and Holubnyak, 2017), the Ohio River Valley (Gupta et al., 2005), and likewise, is present in the project area. Here, the Knox Group is composed of three major formations, from bottom to top, the Copper Ridge Dolomite, the Rose Run Sandstone, and the Beekmantown Dolomite. Cumulative isopach mapping from the SEM illustrates the Knox to be ~1000 ft thick near the proposed injection wells and rapidly thickens to the south-southeast, to >1600 ft (Figure 44).

The Knox dolomite section is predominantly well-cemented with little to no permeability; however, discrete zones of porosity and permeability exist and are traceable over distance (Greb et al., 2008). The evaluation of the Rose Run Sandstone for the Ohio River Valley CO_2 Storage Project by Gupta et al. (2005) recorded a similar pattern (Figure 43). Porosity was as high as 12% in the sandstone facies, whereas the intervening dolomitic sandstones were closer to 5%. The measured permeabilities mimicked this pattern alternating between highs of as much as 70 mD and lows of 0.001 mD. The presence of porous units with intervening non-porous and impermeable zones (‘aquitards’) offers opportunity for numerous intra-Knox sequestration targets as individual flow units, similar to the Wellington Project area in the Midcontinent (Watney and Holubnyak, 2017) and the Ohio River Valley CO_2 Storage Project (Gupta et al., 2005) but could also inhibit injectivity. Regionally, the upper confining member to the Knox Group is composed of the Wells Creek Formation and the tight limestones of the Black River and Trenton Limestone Groups (Figure 29). At its base, the Knox is confined by tight carbonates of the Conasauga Formation.

The Rose Run is a fine to medium grained quartzose to subarkosic, moderate to well sorted sandstone with dolomitic cement in the Appalachian Basin from samples taken in northern Kentucky, western West Virginia, and eastern Ohio (Bowersox, 2021). Illite, feldspars, and detrital carbonate occur in varying amounts. XRD analysis shows the Rose Run to be composed of 71.1% quartz, 20.9% pore-filling dolomite cement, 2.1% illite/smectite clays and micas, 5.4% authigenic potassium feldspar, and other trace minerals in northern Kentucky at the KGS 1 Hanson Aggregates well (Bowersox, 2021; location shown in Figure 19 and Table 2 in subsection 2.1.10.5).

The thick carbonates in the Knox, as well as the sandstones of the Rose Run, offer tremendous potential for sequestration of miscible CO_2 but at this time is considered a secondary sequestration objective due to a paucity of data in the region (Perry et al., 2022). Data collection in the AoR, and particularly including the CarbonSAFE stratigraphic well and seismic acquisition, will enable a full evaluation and vetting of potential disposal in the Knox Group in the area.

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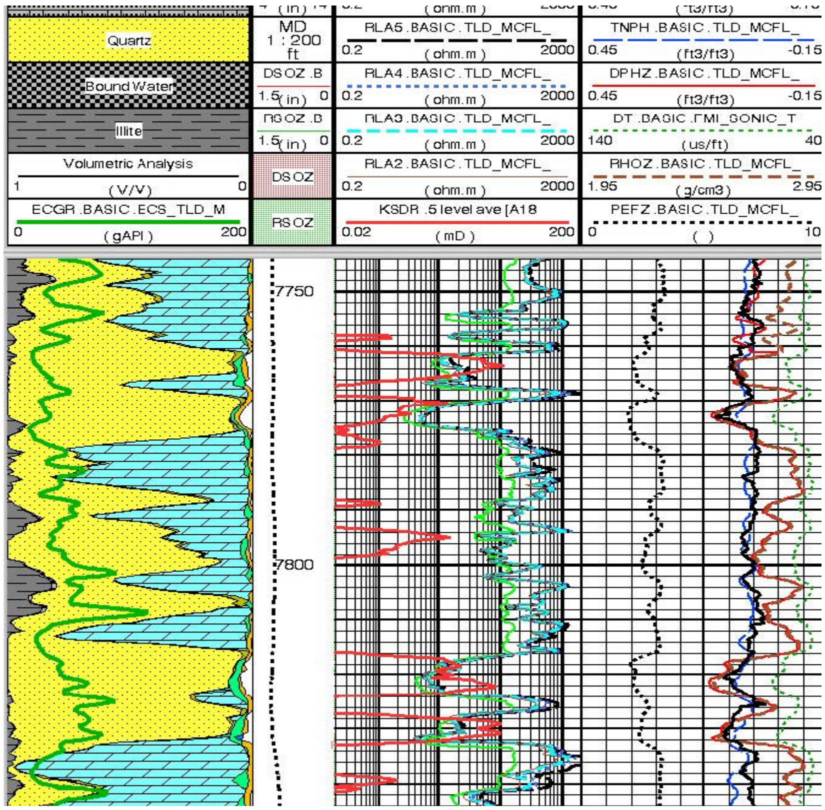

Figure 43: Wireline log for a section of the Rose Run Sandstone studies for the Ohio River Valley CO_2 Storage Project. Left track – lithology and gamma ray; middle track – resistivity and NMR permeability; right track – density-neutron, NMR and acoustic logs. (from Mudd et al., 2003)

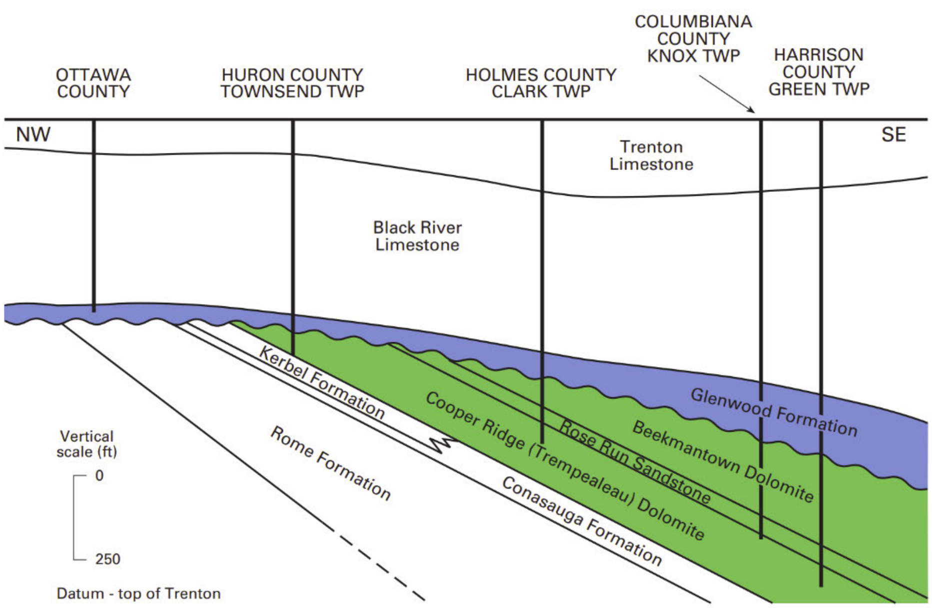

Figure 44. Diagram illustrating the regional thinning, and truncation, of the Knox Group, from the project area to the northwest into north-central Ohio, over the Findlay Arch (Wickstrom et al., 2008).

2.4.3.5. Uncertainties & Additional Required Information

Given the sparsity of subsurface data in the project area, data collection will be imperative to appropriately characterize the injection and confining zones. Subsurface characterization in Hancock County, WV using wireline logs, whole and rotary sidewall core, and 3D seismic will be performed prior to the start of injection. These data will be collected for the CarbonSAFE stratigraphic well. Additional whole rock data and logging and testing data will be collected as part of the pre-operational testing for the project (see Pre-Operational Testing Plan). Successful collection of downhole data and core and the subsequent tests and measurements will provide greater clarity around current uncertainties in lithology and facies, reservoir properties, including capillary pressure and relative permeability, and mineralogy.

2.4.3.6. Regional Estimated Injection Zone Storage Capacity

Prospective storage resource estimates for the project were calculated for the Carbonate and Sandstone reservoirs using the methodology detailed in Goodman et al. (2011) and Goodman et al. (2016) for saline formations. This methodology generates storage resource estimates using equations (1) and (2) (from Goodman, 2016):

$$G_{CO2} = A_t h_g \emptyset_{total} \rho_{CO2} E_{Saline} \qquad \text{(Equation 1)}$$

where,

$$E_{Saline} = E_A E_h E_{\emptyset} E_V E_D \qquad \text{(Equation 2)}$$

Prospective storage resource estimates were calculated in Excel using average properties across all reservoir formations within the project area. For the Lockport, Beekmantown, and Copper Ridge Dolomites, gross formation statistics were used to obtain physical characteristics used for the resource estimate. Sandstone intervals were isolated for the Medina and Rose Run formations, and average physical characteristics were calculated for a resource estimate. Due to limited availability of site-specific data, values from the 2017 version of the DOE-NETL CO_2 SCREEN tool were used to calculate saline storage efficiency factors. All physical inputs, storage efficiencies, and assumptions are shown in Table 6. The resource estimate suggests that all reservoir formations may be able to store between 434.1 (P10) to nearly 2190 (P90) MMt of CO_2. Table 7 details the results of the prospective storage resource calculations.

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Table 6: Parameters used for Calculating Storage Resource Estimates for Reservoir Formations. Note: CO2 density is based on reservoir conditions using regional gradients. ESaline Storage Efficiency = EvEd (volumetric displacement efficiency) + Ephi (effective porosity) +Eh (net-to-gross thickness). Ean/at (Net-to-total area) is assumed to be 1. Efficiency values obtained from 2017 version of NETL CO2 Screen Tool for respective depositional environment.

Resource Estimate Inputs						
Attribute		**Lockport Dolomite Grp**	**Medina Grp**	**Beekmantown Dolomite**	**Rose Run Sandstone**	**Copper Ridge Dolomite**
Mean Reservoir Thickness (m)		367.61	142	567	27	337
Mean Porosity (%)		3	5	3	3	3
Mean CO_2 Density (lb/ft^3)		44	44.1	44.4	44.4	44.5
Area (mi^2)		820				
Depositional Environment		Dolomite Unspecified	Clastic Shallow Shelf	Dolomite Unspecified	Clastic Peritidal	Dolomite Unspecified
Saline Storage Efficiency	**P10**	0.02	0.022	0.02	0.018	0.02
	P50	0.049	0.068	0.049	0.057	0.049
	P90	0.0917	0.162	0.0917	0.1423	0.0917

Table 7: Cumulative and probabilistic scenarios for prospective storage resource estimates for all reservoir formations based on the SEM values.

Reservoir		**Total CO_2 (MMt)**			**Total CO_2 (MMt/mile^2)**		
		P10	**P50**	**P90**	**P10**	**P50**	**P90**
LIC	Lockport Dolomite	102.1	247.6	461.2	0.02	0.048	0.09
MIC	Medina Sandstone	71.5	221.1	526.4	0.014	0.043	0.103
KIC	Beekmantown Dolomite	159.2	386.1	719	0.031	0.076	0.141
	Rose Run Sandstone	6.8	21.8	53.9	0.001	0.004	0.011
	Copper Ridge Dolomite	94.5	229.2	426.8	0.018	0.045	0.083
Total Summed Storage		**434.1**	**1105.8**	**2187.3**	**0.084**	**0.216**	**0.428**

2.5. Geomechanical and Petrophysical Information [40 CFR 146.82(a)(3)(iv)]

2.5.1. Salina Group Confining Zone Petrophysical Analysis

The Salina Group comprises a group of generally impermeable shales, dolomite, and salts with variable internal stratigraphy. No porosity and permeability data were available from the salt layers; however, permeability of interbedded salts is often taken to be 0 in petrophysical analyses and for this analysis was considered to be approximately 1 nD. One well near the AoR (API No. 34013205860000; see well no. 1 location in Figure 18) provided core data in the Salina Group that could be used in the petrophysical analysis (Figure 45). This data comes from the dolomitic layers in the Vernon (Units A and B), Syracuse (Unit F), Camillus (Unit G) and Bass Islands/Bertie. There are no data points from the actual salt layers. The permeability ranges from 0 to 2.45 mD, averaging 0.3 mD. These measurements are corroborated by the measurements from publicly available core analyses (Table 8; Figure 18). Porosity and permeability data from the Stark County well did not have corresponding logs and therefore could not be used in the petrophysical analysis. Site-specific data collection from the CarbonSAFE stratigraphic test well and during the pre-operational testing program will provide additional detail on the specific internal variability of the Salina Group.

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2.5.2. Lockport Dolomite Group Injection Complex Petrophysical Analysis

Minimal core data was available for constructing a petrophysical model of the Lockport Dolomite Group. Four samples from two wells were available, of which the two from API No. 34013205860000 (Table 8; see well no. 1 location in Figure 18) were used in the analysis. Given the paucity of data, geophysical well logs, including the gamma ray, bulk density, and neutron porosity logs, were used to build a petrophysical model and yield porosity estimates. Carter et al., 2010 provided nine porosity and permeability data points from the Lockport Dolomite Group from two wells, the Johnson #1 in Pennsylvania, and the Ocel #1 in Ohio (see well nos. 12 and 18 locations in Figure 16). This data set was used to model permeability as a function of porosity in the Lockport Dolomite Group.

The data set in this petrophysical analysis included a total of 13 sample points (four from the database and 9 from publications) through the Lockport Dolomite Group. To match the petrophysical model to core, one well (API No. 34013205860000) with geophysical well logs and core data was used, with two samples within the Lockport Dolomite Group.

Given our current best estimate approach, we utilized a basic three-mineral system to estimate the mineralogy of the Lockport Dolomite Group. The gamma ray curve provided insights into clay content, and in the absence of photoelectric factor logs, we employed a neutron density cross plot to determine the relative abundance of calcite and dolomite. While the model yielded reasonable results, the limited availability of mineralogic and porosity data prevents a rigorous comparison with core-derived values. Recognizing this uncertainty, we plan to address it during the pre-operational testing program for the injection wells by collecting additional mineralogic, porosity, permeability, and facies data. The carbonate lithology is variable throughout the Lockport Dolomite Group, as shown in Figure 46, and the low number of core measurements means the understanding of this variability and its correlation to logs is incompletely understood. It is expected that the pre-operational testing program will add significantly to the understanding of the mineralogical system and its calibration to core, and the petrophysical model will be updated if significant changes are found from the current petrophysical model.

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2.5.3. Rochester Shale Formation Confining Zone Petrophysical Analysis

The Rochester Shale Formation comprises two members, the lower Lewiston Member and the upper Burleigh Hill Member. Both members are predominantly mudstone with some more carbonate-rich sections (Figure 47). The mudstone packages of the lower and upper section are 46 ft and 194 ft thick, respectively, with local variation possible within a few feet. Porosity and permeability have been assigned to the Rochester Shale Formation based on log evaluation. Two different log evaluation approaches have been used to assess the porosity and permeability, focused on the mudstone sections. The porosity of both members is found to be approximately 1%, and using Yang and Aplin (2010), this yields a corresponding permeability of < 0.001 nD, or < 2 nD using Byrnes (2005).

The more carbonate-rich sections of the Rochester Shale Formation have marginally higher porosity and permeability than is seen in the mudstone sections, up to 0.3 nD and 500 nD using

Yang and Aplin (2010) and Byrnes (2005), respectively. However, this permeability is still quite low and is not expected to be vertically or horizontally connected.

Claimed as PBI

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2.5.4. <u>Medina Group Injection Complex Petrophysical Analysis</u>

Nine wells with core data, including some combination of bulk density, grain density, porosity, water saturation, and permeability, were used to build the petrophysical models. The locations of these wells range from approximately 16 to 68 miles from the project area. Of the nine, only two wells, API Nos. 34019202560000 and 34013205860000 (20 and 25 miles from the project area, respectively), had geophysical well logs to test the fit of the model against core data. Based on geophysical well log response, the core data covered a gradient from low porosity silty mudstone/mudstone to higher porosity clean sandstone. The core data set did not include any mineralogy data.

Thirty-one wells (including the two wells with core data) had sufficient well log data over the Medina Group to produce and run a petrophysical model and estimate porosity and permeability. Data from the gamma ray and bulk density logs were used to calculate these parameters. Permeability calculations in the Medina Group were made using equations defined by Byrnes (2005) using data generated by Castle and Byrnes (1998, 2005) on the Medina Group in northwestern Pennsylvania, adjacent to TR1-1 and TR1-2.

The data set included a total of 428 sample points through the Medina Group section. To match the petrophysical model to core, two wells with geophysical well logs and core data were used, API No. 34019202560000 with 93 samples and API No. 34013205860000 with 7 samples across the Medina Group (Figure 48; see well no. 3 and no. 1 in Figure 18 for locations, respectively).

A basic two-mineral system was used to estimate the mineralogy of the Medina Group section. The gamma ray curve was used to estimate clay content and the balance was assigned to quartz. Such a model was able to adequately match porosity (and grain density) data where available, suggesting the assumptions of basic mineralogy are representative of the formation. Using this two-mineral system, the top of the section is notably less permeable and is estimated to have a higher clay content than the lower Medina Group, which is consistent with the core measurements from the two different parts of the section.

Mineralogic data will be collected from the CarbonSAFE stratigraphic test well and during the pre-operational testing program at the injection locations to verify the model. The additional mineralogical detail collected during pre-operational testing will provide information about the variation in clay types and give insight into the likely impact on matrix behavior in the injection zone.

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2.5.5. Queenston Shale Confining Zone Petrophysical Analysis

The Queenston Shale is a regionally extensive shale, which is also referred to as the Juniata Shale Formation (WV, PA, VA, NY) or the Sequatchie Formation (KY, TN). In the project area, the deposition coincides with transitional marine shales and the subaerial facies of the Juanita Shale (heterolithic red mudstone with coarsening sandstones and conglomerates deposited in the transitional tidal flat to shoreface). The Queenston Shale is more than 1500 ft thick in the project area, with generally low porosity and permeability associated with the shale members of the unit.

Few local core-based measurements of the Queenston Shale are available, with only one well (API No. 34013205860000; Table 8; see well no. 1 in Figure 18 for location) having porosity and permeability reported (3% and 0 mD, respectively). Nevertheless, the extensive thickness of the shale is expected to form a robust confining unit. Site-specific data collection from the CarbonSAFE stratigraphic test well and during the pre-operational testing program will provide additional detail on the specific internal variability of the Queenston Shale and provide detailed petrophysical information on the different members.

Table 8:Core-based porosity and permeability measurements for confining and injection units. Location and API no. in Figure 18 and Table 2.

Formation	Porosity (decimal)	no. pts.	Permeability (mD)	no. pts.	Wells
Salina Group	0.06	11	0.12	10	1
Lockport Dolomite Group	0.045	4	1.42	3	2
Rochester Shale Formation	0.06	1	0	1	1
Medina Group	0.048	412	9.99	272	15
Queenston Shale	0.03	1	0	1	1

2.5.6. <u>Geomechanics</u>

2.5.6.1. Proposed Geomechanical Studies

A series of geomechanical studies under the CarbonSAFE initiative will be conducted to address key questions regarding the geomechanical properties of the confining zone intervals. Cores collected from the stratigraphic test well proposed for this program will provide measurements of rock strength and ductility for the confining zone intervals. The following geotechnical tests will be conducted on each confining zone interval:

- Triaxial compression – ductility;
- Triaxial compression – failure;
- Mohr-Coulomb criterion - failure envelope analysis; and
- Brazilian test - tensile analysis.

The stratigraphic test well and core samples will also allow for detailed fracture analysis. Pore pressure of the confining zones and in situ local stress measurements will also be made available with the stratigraphic test well.

2.5.6.2. Regional Stress State

Orientation of the maximum horizontal stress state in the region is available from a variety of data sets and compiled in the world stress map and regional studies of the Appalachian basin (Morris et al., 2017; Heidbach et al., 2018; Brudzinski and Kozlowska, 2019). The orientation of the maximum horizontal stress in northern West Virginia is generally ENE-WSW and exhibits a mix of tensors from focal mechanism solutions that place it in the strike-slip or thrust faulting regime (Morris et al., 2017). According to Morris et al. (2017), the combination of coexisting thrust-faulting and strike-slip faulting regimes indicates that the intermediate principal stress component (σ_2) is closer in magnitude to the minimum principal stress component (σ_3) than it is to the maximum principal stress component (σ_1), and that the stress difference ratio (φ) is less than 0.5, where $\varphi=(\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$.

2.6. Seismic History [40 CFR 146.82(a)(3)(v)]

The USGS ANSS (Advanced National Seismic System) Comprehensive Earthquake Catalog network was used to provide the historical seismicity record for the AoR locally and regionally (USGS, 2023). Regional historical seismicity was considered for a 50-mi radius around the approximate center of the AoR for a 40-year time period (extending from March 1983 to March 2024) with a magnitude greater than M2.5 (Figure 51) (USGS, 2023).

The project is located within an area of relatively low seismicity. In the AoR, there is no known source of natural seismicity that would compromise the containment of CO_2. The surrounding region of the northern tip of West Virginia, southeastern Ohio, and southwestern Pennsylvania has a very low risk of damaging seismic activity, while western Ohio lies on the edge of the New Madrid Seismic Zone and the Anna Seismic Zone, and northeastern Ohio contains the Northeast Ohio Seismic Zone, both of which have increased activity (Dart and Hansen, 2008). However, very few of the earthquakes that have historically occurred are known to be associated with faults (Dart and Hansen, 2008). Pennsylvania has a very low risk of seismic activity, and Southern West Virginia touches the outer edge of the Giles County Seismic Zone, though it is unlikely that it will have an effect on the project area (Figure 49and Figure 50).

The USGS-published National Seismic Hazard Map shows the frequency of damaging earthquake shaking expected in a 10,000-year period (Figure 49). Based on this information, the AoR is considered to have the lowest risk of damaging earthquakes on the scale, with fewer than two expected within a 10,000-year period. The surrounding region also has a comparatively low risk of two to four damaging earthquakes expected within a 10,000-year period. According to the USGS, damaging earthquakes are identified as those that have a of Modified Mercalli Intensity (MMI) level VI (6) or higher. They are characterized by "strong" shaking and "*felt by nearly everyone, many awakened. Some heavy furniture moved; few instances of fallen plaster. Damage slight"* (USGS, 2023).

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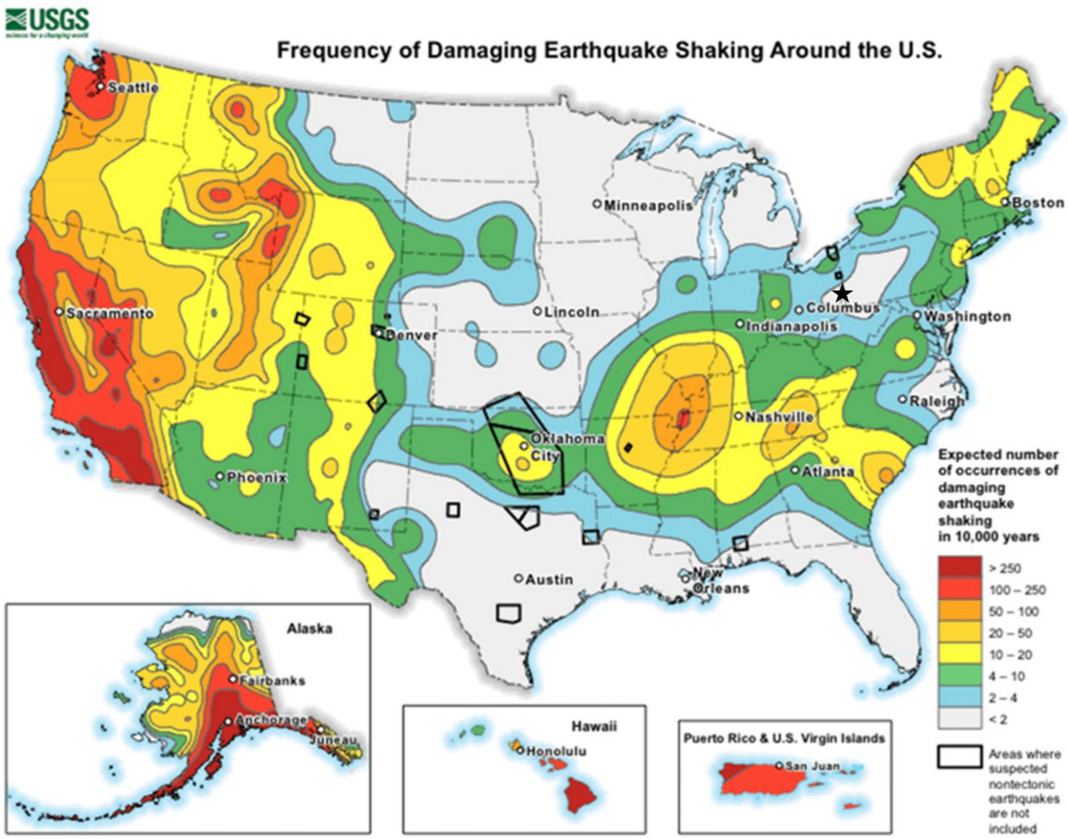

Figure 49: USGS Seismic Hazard Map, showing the frequency of damaging earthquake shaking within a 10,000-year period (Petersen et al., 2008). The project is indicated by the star on the map in the tri-state region of West Virginia, Ohio, and Pennsylvania.

The Appalachian Basin of Eastern Ohio, where the project is located, is a region of low natural seismicity, with any earthquakes that do occur being of low magnitude. Peak ground acceleration (as a percentage of the gravity constant 9.8 m/s^2) with a 2% likelihood of being exceeded within a 50-year period is illustrated for the region in Figure 50. The peak ground acceleration for the project area is estimated to be 4 to 6 percent of gravity, which would correlate to a Modified Mercalli Intensity of IV-V (light to moderate shaking with limited damage to unstable or delicate objects).

Historically, the Northeast Ohio seismic zone, north of the AoR, has recorded few moderate earthquakes per decade, but felt earthquakes have been reported more frequently in recent decades, likely due to induced activity. The largest earthquake in this zone, with a magnitude of 5.0, occurred in 1986. This seismic event created Modified Mercalli intensities of VI in the region. Another damaging earthquake with a magnitude of 5.2 occurred in 1998 in northwestern Pennsylvania, just east of the border with Ohio (Dart and Hansen, 2008). Within 50 miles of the injection locations, there have been four earthquakes in the last 40 years (Figure 51). The location, magnitude, and distance from the AoR for each of these earthquakes is in Table 9.

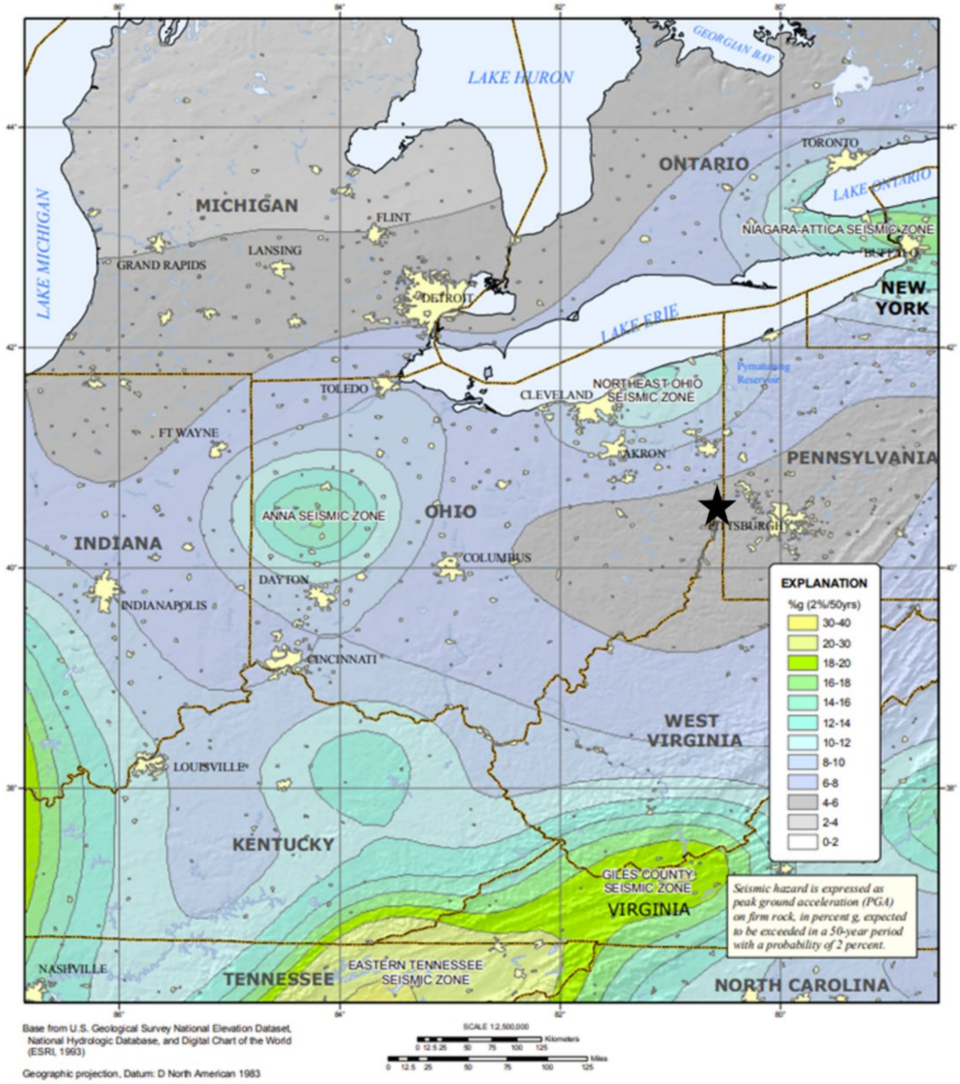

Figure 50: Seismic Hazard Map of Ohio and surrounding states from the USGS National Seismic Hazard Maps illustrating the peak ground acceleration with a 2% likelihood of being exceeded within a 50-year period (U.S. Geological Survey). The project is indicated with a star on the map.

The Emergency and Remedial Response Plan includes information on conducting a formal risk assessment of potential risk scenarios, including microseismic events that could potentially be associated with industrial activities.

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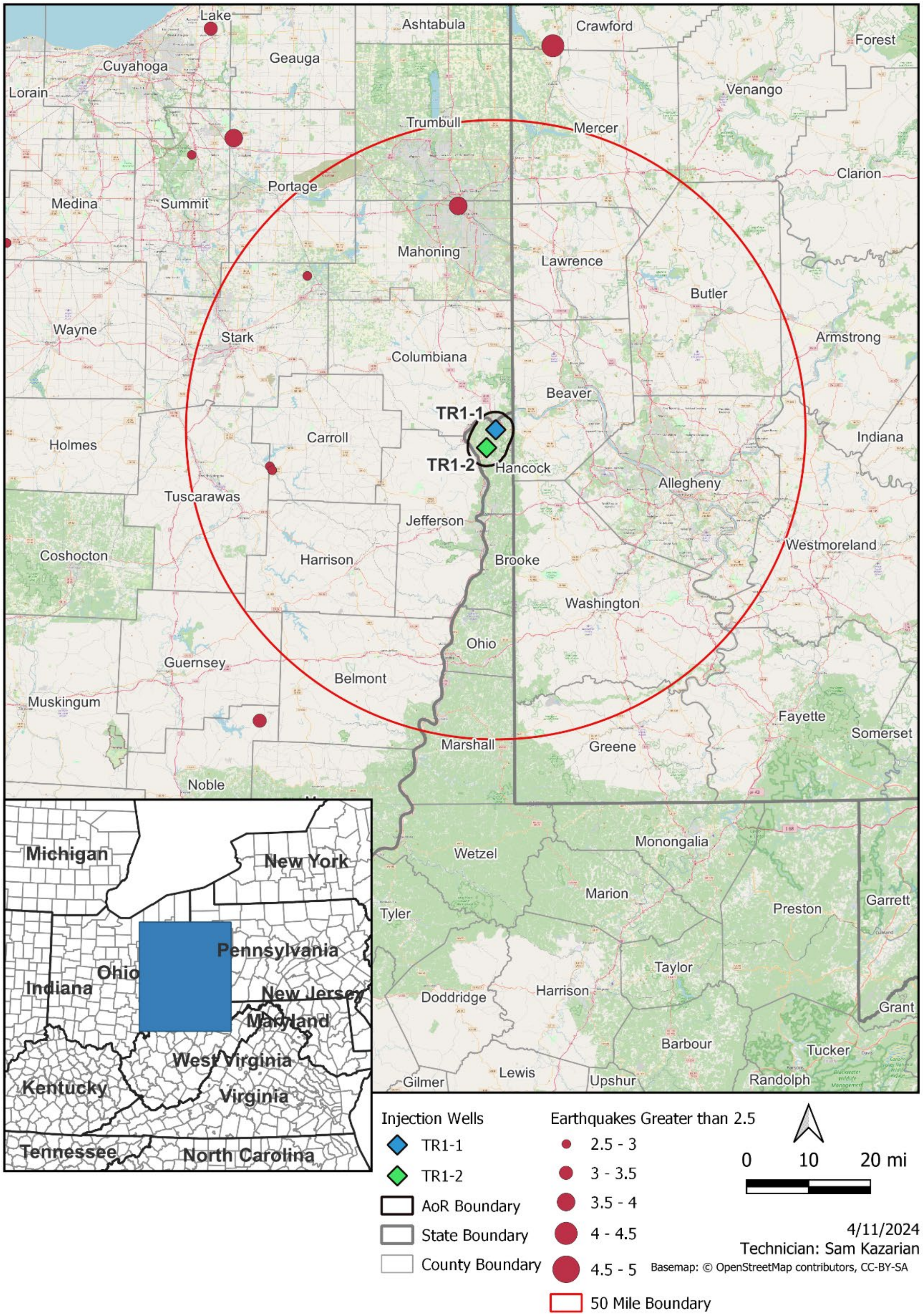

Figure 51: Local seismic events within 50 miles of the AoR.

Table 9: Seismic events within 50 miles of the AoR over a 40-year period.

Date	Latitude	Longitude	Depth (ft)	Magnitude	Distance to AoR (mi)
11/19/2021	40.5121	-81.2650	16404.2	2.6	32.2
10/28/2021	40.5029	-81.2577	16404.2	2.6	31.8
12/31/2011	41.1215	-80.6843	16404.2	4	33.9
8/7/2000	40.9580	-81.1510	16404.2	2.9	36.1

Since the early 2010s, the Eastern Ohio area of the Appalachian Basin has experienced a significant increase in induced seismic activity, which has been linked with the operations associated with the intensification of unconventional gas extraction conducted in the basin (Skoumal, 2018; Brudzinski and Kozłowska, 2019), more specifically, hydraulic fracturing and the disposal of the wastewater associated with production from the Utica Shale (Skoumal, 2018). Several known occurrences of induced seismicity have occurred in and around Youngstown, OH, approximately 35 miles north of the AoR. This seismicity is concentrated in a corridor from eastern Ohio and into central West Virginia, which may be due to geologic variations in the subsurface or extraction operations.

Several regional studies have documented the importance of the proximity to Precambrian basement when considering the possibility of induced microseismicity as related to wastewater disposal wells and hydraulic fracturing. In general, the low permeability of the Precambrian basement rock as compared to the relatively higher permeability of fractured basement rocks and pre-existing faults is interpreted to be a key factor in the potential for fault reactivation (Morris et al., 2017). Additionally, the proximity to critically stressed and optimally oriented faults that are pre-existing in basement lithologies is thought to impact the likelihood of induced recordable seismicity (Skoumal et al., 2018). Considering these factors, Skoumal et al. (2018) suggests that injection within 3,280 ft, or 1000 m, of basement has the greatest risk of inducing seismicity. The Medina Group injection complex, the deepest target in the project, is greater than 4,000 ft above the Precambrian basement rocks and, therefore, is not interpreted to be a risk for induced microseismicity.

To date, there have been no known induced seismic events in Hancock Co., WV, and the historical seismicity record suggests that the proposed storage location is not in a seismically hazardous location. Thus, loss of containment due to seismicity is considered a low risk.

2.7. Hydrologic and Hydrogeologic Information [40 CFR 146.82(a)(3)(vi), 146.82(a)(5)]

The project location is in the Ohio River Watershed, within the Upper Ohio HUC 8 subbasin (05030101). This subbasin covers an area of approximately 3,540 square miles. The AoR is located entirely within the Appalachian Plateau physiographic province, which consists of nearly horizontal consolidated sedimentary rocks.

Surface waters have eroded the rocks in the areas to form the steep hills and deeply incised valleys that characterize the land surface. Surface water features are dominated by the Ohio River and large tributaries. There are two basic categories of groundwater sources in this area, Quaternary

Alluvial aquifers and Lower Pennsylvanian and Upper Mississippian age sedimentary bedrock aquifers of the Appalachian Plateaus. The Quaternary Alluvial aquifers are generally unconfined and consist of unconsolidated gravel, sand, silt, and clay. The bedrock aquifers are generally confined and comprise consolidated stratigraphic units gently dipping to the southeast, with relatively flat lying, slightly folded, interbedded sandstone, conglomerate, siltstone, shale, and coal, with local beds of limestone and dolomite (Wunsch, 1992). A cross-section view of the Appalachian Plateau near the AoR is shown in Figure 52.

Bedrock aquifers are grouped into four units in this discussion: the Conemaugh Group, the Allegheny Formation, the Pottsville Group, and the Mauch Chunk Formation. Each of these units has various layers of aquifer and aquitard materials described further in the following subsections. Overall, the hydrology of the region is largely influenced by seasonal precipitation, snowmelt, and groundwater recharge.

2.7.1. Hydrogeologic Description

The following description of freshwater aquifers in the area, which comprise the Underground Sources of Drinking Water (USDW), is explained from youngest to oldest formation, or in this case shallowest to deepest. This section describes the generalized stratigraphic section from the ground surface to the bottom of the Mauch Chunk Formation, considered to contain the base of freshwater, and is also defined as the lowermost USDW in the AoR. An illustration of this stratigraphic section is shown as Figure 53.

EPA defines a USDW as having less than 10,000 ppm Total Dissolved Solids (TDS). Water quality samples from bedrock aquifers in the area are sparce and mostly from shallow (<200 ft bgs) sampling points. None of these samples was found to exceed 10,000 ppm TDS. Thus, the determination of the lowermost USDW for the project was based on saltwater/freshwater interface mapping done by the USGS in 1980 (Foster, 1980), lithologic well logs from the West Virginia oil and gas well database, and historical oil/gas extraction and subsequent brine water injections to deeper formations.

2.7.2. Quaternary Alluvium

The uppermost aquifer unit in the AoR is the unconsolidated quaternary alluvial deposits of the Ohio River and its tributaries. This aquifer is the most productive unit in the area and has a median transmissivity of 4,800 ft^2/d (Kozar, 2001). Most of the Public Water Supply systems in the area utilize this aquifer for their water supply. Alluvium, consisting of stream-deposited or glacially deposited sand, clay, and gravel typically overlain by fluvial silts and clays, is found in the river terraces within the Ohio Valley. The thickness of the alluvium commonly ranges from 25 to 100 ft and may exceed 140 ft (Puente, 1985).

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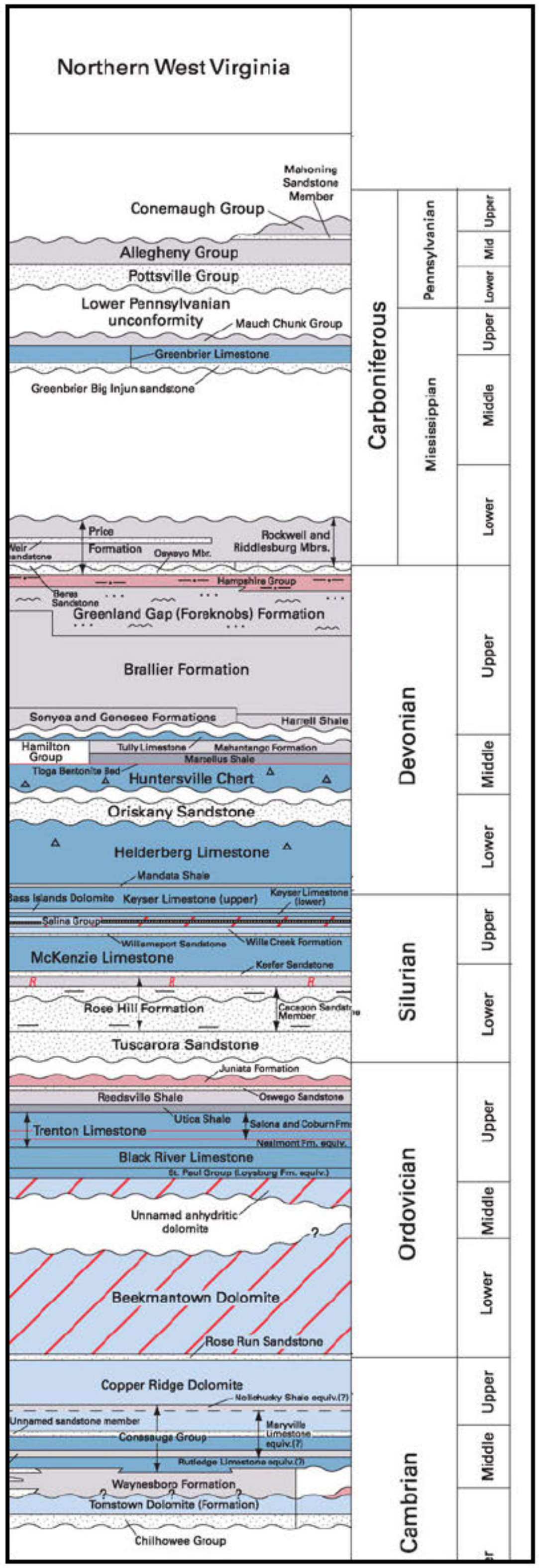

Figure 52: Conceptual geologic cross-section in area near the AoR. Adapted from USGS map (Ryder, 2009).

System	Series	Stratigraphic Unit	Sub-Units	Notes	Lithology
Pennsylvanian	Upper	**Conemaugh Group**			Cyclic sequences of red and gray shale, siltstone and sandstone, with thin limestones and coals. Mostly mudstone.
	Middle	**Allegheny Group**			Cyclic sequences of sandstone, siltstone, shale, limestone, and coal. Mostly sandstone
	Lower	**Pottsville Group**			Predominantly sandstones, some of which are conglomeratic
			Sharon Sandstone	Previously Identified lowermost USDW in Ohio	
Mississippian	Upper	**Mauch Chunk Group**		*Lowermost USDW*	Mostly red, gray, and dark-gray shale, gray and red sandstone, and gray to dark-gray limestone
	Middle	**Greenbriar Group**	Greenbriar Limestone		Limestone
			Big Injun Sandstone	Conventional Oil Reservoir	Sandstone
	Lower	**Price Formation**	Sunbury Shale		Shale
			Berea Sandstone	Conventional Oil Reservoir	Sandstone

Figure 53: Conceptual stratigraphic column from the AoR illustrating the freshwater aquifers and lowermost USDW. Please refer to Figure 29 for the full stratigraphic column.

2.7.2.1. Conemaugh Group

In the AoR, the Conemaugh Group consists of the Casselman and Glenshaw formations. The Conemaugh Group is Upper Pennsylvanian in age. The group mainly consists of mudstones with cyclic sequences of red and gray shale, siltstone, and sandstone, with thin limestones and coals (Cardwell, 1968). The group is mostly non-marine in origin. Within the AoR, the Conemaugh Group outcrops and subcrops through most of the area, making up most of the higher topography areas. Incised valleys in the major drainageways expose the underlying Allegheny Group. The Conemaugh Group extends from the base of the Pittsburgh coal to the top of the Upper Freeport coal. The group also includes the Elk Lick, Bakerstown, and Mahoning coals, as well as the Ames and Brush Creek Limestones.

2.7.2.2. Allegheny Group

The Allegheny Group comprises mostly sandstone with cyclic sequences of siltstone, shale, limestone, and coal (Cardwell, 1968). The group is Middle Pennsylvanian in age and is known as a major coal bearing unit. The Group includes the Freeport, Kittanning, and Clarion coals. The group extends from the top of the Upper Freeport coal to the top of the Homewood Sandstone. Within the area, the thickness of this group can exceed 300 ft.

2.7.2.3. Pottsville Group

The Pottsville Group consists of predominantly sandstones, some of which are conglomeratic (Cardwell, 1968). The group includes the Kanawha, New River, Sharon, and Pocahontas formations. Drillers in the area commonly refer to the basal sandstone unit as the Salt Sands. The base of this unit ranges from approximately 400 to 600 ft bgs within the AoR.

To the north of the project, along the Ohio River in Columbiana County, Ohio, the Pennsylvanian Sharon Sandstone of the Pottsville Group (sometimes referred to as the Salt Sands), was identified as the lowermost USDW with a depth range of ~250 to 500 feet bgs (Riley, 2012).

2.7.3. Mauch Chunk Formation

The Mauch Chunk Formation contains mostly red, gray, and dark-gray shale, gray and red sandstone, and gray to dark-gray limestone (Cardwell, 1968). This group consists of the Bluestone Formation, Princeton Sandstone, and Hinton Formation. In the area, this group is about 150 to 250 ft thick and is underlain by the Big Injun Sandstone of the Greenbriar Formation. The base of this formation ranges from approximately 500 to 800 ft bgs within the AoR. The Big Injun Sandstone has been used as an oil and gas production unit with subsequent brine water injections within the AoR, so it is assumed that water quality below the Mauch Chunk is non-potable with high TDS values.

The Mauch Chunk Fomation is traditionally seen as an aquitard, with the majority of the group consisting of low permeability shales. A conservative assumption was made to select the Mauch Chunk Formation, which is below the Pottsville Group, as the lowermost USDW until depth-specific water quality samples are obtained. Approximately 4600 feet separates the lowermost USDW from the top of the injection formations (Figure 29). The depth of the base of the lowermost USDW and USDW TDS concentrations will be identified and defined through fluid sampling and analysis from the project's stratigraphic test well and during pre-operational testing of the injection wells.

2.7.4. Groundwater Flow and Principal Aquifer Zones

Groundwater flow paths in the area are relatively short. Groundwater within the shallow Quaternary Alluvium generally flows from higher elevation to lower elevations, towards the major drainageways, ultimately discharging to the Ohio River. Groundwater within the bedrock aquifer systems similarly flows from areas of higher elevation to areas of lower elevation, towards the major surface drainageways, but taking a longer and deeper path. The groundwater in these bedrock aquifers flows approximately perpendicular to local tributary streams, through an intricate network of stress-relief fractures and interconnected bedding-plane separations, commonly in a stair-step pattern (Wyrick, 1981). The groundwater within the bedrock likely discharges locally to surface water or may recharge to subregional or regional aquifers (Kozar, 2012). Nevertheless, enhanced permeability of bedrock in valleys, due to stress relief fractures, may result in groundwater flow parallel to and beneath local tributary streams before ultimately discharging to surface-water bodies (Kozar, 2012). The deeper bedrock aquifers usually contain much older water, which is usually brackish and has not been flushed by shallow groundwater circulation.

Water level data and potentiometric surface data were not available for Hancock County. Therefore, County-wide maps of potentiometric surface were obtained from neighboring Columbiana and Carroll Counties, Ohio (Angle, 2006 and Sprowls, 2007). These maps regionally illustrate the potentiometric surface mirroring the topographic surface, where water flows from higher elevations to lower elevations in both the surficial alluvial aquifers and deeper bedrock formations. Figure 54 shows the generalized groundwater flow directions within the AoR.

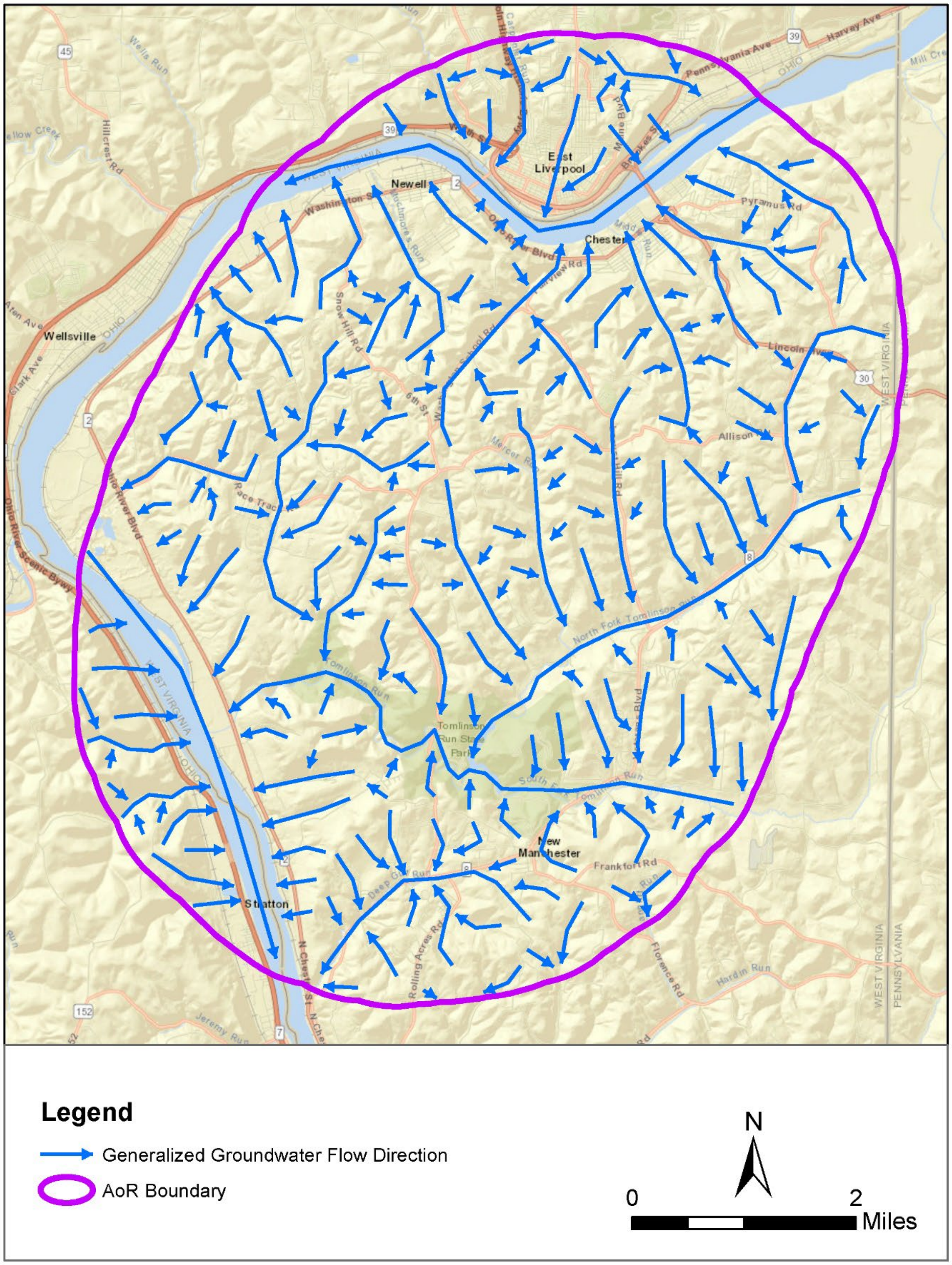

Figure 54: Generalized groundwater flow directions within the AoR.

2.7.5. Drinking Water Wells in the AoR

In West Virgina, well completion records are not publicly accessible and are housed within each county's Health Department. Landowners contacted within the West Virginia portion of the AoR indicate that there are domestic wells present. A public water supply report estimated that domestic water withdrawals in Hancock County serve a population of 2,400, with 98% of the water coming from groundwater sources (Atkins, 2004). As the project moves forward, information from well completion records within the West Virgina section of the AoR will be compiled from landowners and Hancock County Health Department records and submitted to the UIC Program Director prior to seeking authorization to inject.

Water well completion records were obtained from within the AoR in Ohio and Pennsylvania, 55 records from Columbiana County, Ohio, 32 from Jefferson County, Ohio, and 1 from Beaver County, Pennsylvania. A map showing the location of these wells is in Figure 55. It is important to note that these are counts of completion records, not active domestic wells, as some may be for monitoring wells or abandoned or never finished with a pump. For example, the record obtained from Beaver County, Pennsylvania is for a 1-inch diameter monitoring well that is not used for water production. Of the 87 records obtained from Ohio, 20 are characterized as drinking water wells, with 18 categorized as domestic wells and 2 categorized as municipal wells. Of the 87 records from Ohio, a further 21 do not have a listed well use, and the remaining 46 are categorized as commercial, dewatering, monitoring, other, or recovery wells. Within the listed 18 domestic well records in Ohio, 5 are using the quaternary alluvial aquifer, and 13 are in the deeper bedrock aquifers, which have depths ranging from 20 to 505 ft bgs. Table 10 summarizes the information contained within these well records.

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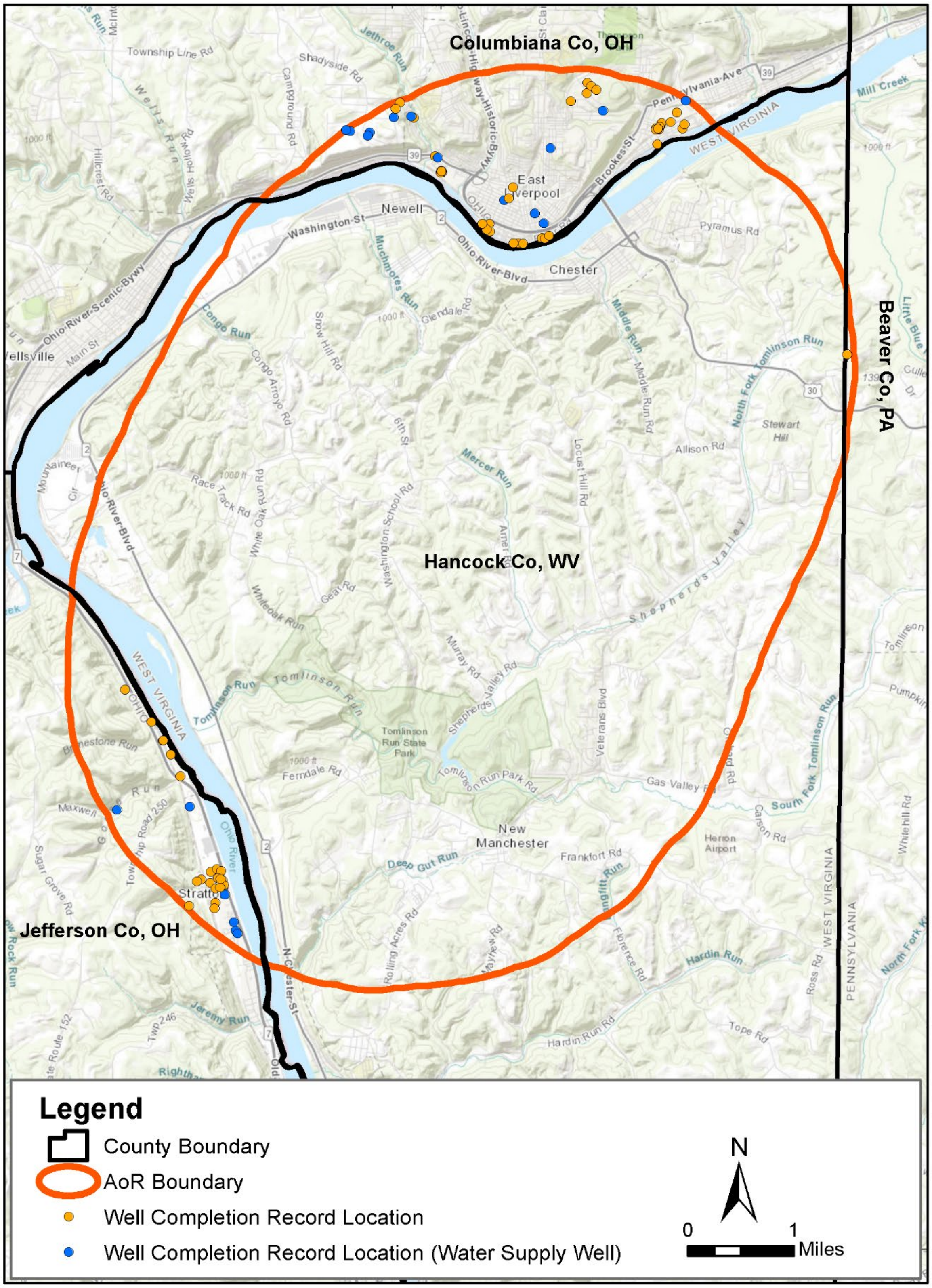

Figure 55: Location of groundwater wells within the AoR. Note groundwater well locations are not publicly accessible in West Virginia.

2.7.6. Water Quality in the AoR

Water quality within the AoR varies with depth and geologic formation. Near the surface, in the alluvial aquifer along the Ohio River, data collected from the USGS between 1950 and 1985 show water is generally very hard with a median hardness of 220 mg/L. Median concentration of manganese in the alluvium was measured at 340 mg/L. The Ohio Alluvial aquifer was also found to be high in iron (Ferrell, 1987). The same study showed high median values of manganese in water from Mississippian bedrock aquifers and high iron in Lower Pennsylvanian aquifers. Additionally, the study found that groundwater containing concentrations of chloride over 250 mg/L underlie most of West Virginia at depths of about 300 ft below major streams (Ferrell, 1987).

Wells tapping the alluvial sediments in the area typically do not contain indicator bacteria such as fecal coliform and total coliform because flow of water through the sediments tends to filter out bacteria (Jeffords, 1945). However, dissolved chemical contaminants, such as volatile organic compounds (VOCs) and nitrate, are typically not removed by sediments (Chambers, 2012). Given the potential for alluvial aquifers to receive significant recharge from adjacent rivers and given the capacity for the alluvial sediments to act as microbial filters, alluvial aquifers have a low intrinsic susceptibility to microbial contaminants but a high intrinsic susceptibility to VOCs, nitrate, or other chemicals released or spilled at or near the surface (Kozar, 2016).

Previous mapping in West Virginia shows contours for the base of the fresh water and the top of the saline water using information gathered from oil and gas drilling logs (Foster, 1980). It is noted that the data used in producing these maps was not quantitative but, instead, relied on the field determination of either fresh or saline water by drillers in the field and reported on their logs. These maps indicate that the top of the saline water is between 400 and 500 ft amsl in the AoR (approximately the same elevation as the top of the Mauch Chunk Formation).

Groundwater wells located in valleys generally have higher alkalinity, pH, and TDS. Sodium (Na), pH, alkalinity, chloride (Cl), and TDS concentrations increase with well depth, while calcium and magnesium decrease. Generally, there is little difference in water quality and water type between different geologic units, with dominantly calcium bicarbonate composition in most areas, followed by a sodium bicarbonate water type (Harkness, 2017).

Typically, only the first 10 to 30 ft of a well that taps consolidated bedrock aquifers in West Virginia is cased. The rest of the well typically is an open borehole that ranges from 10 to several hundred feet in depth and usually is 6 in. in diameter. Water typically is derived from several water bearing zones because of the lithologic variability of the aquifers. The amounts and chemical properties of the water from each zone can be different; thus, the quality of water pumped from a well depends on which zones are tapped and the proportion of water derived from each zone (Kozar, 2012).

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Table 10: Groundwater well completion reports from within the AoR.

Record Number	State	County	Static Water Level	Test Rate (GPM)	Aquifer Type	Total Depth	Depth to Bedrock	Well Use	Completi on Date	Latitude	Longitude
35848	Ohio	Columbiana			SANDSTONE	51	31			40.62230	-80.57902
541708	Ohio	Columbiana	15	20	SHALE	80	60		11/30/1978	40.63063	-80.54871
71365	Ohio	Columbiana	120	12	ROCK	120			4/27/1950	40.63369	-80.59952
63469	Ohio	Columbiana			SHALE	120	50		4/10/1952	40.63535	-80.56595
35845	Ohio	Columbiana			SANDSTONE	120	30			40.63169	-80.59701
345754	Ohio	Columbiana	40	6	SANDSTONE	120			1/22/1966	40.63447	-80.54821
755904	Ohio	Columbiana	60	11	SANDSTONE	138	3		3/22/1993	40.63288	-80.60026
577954	Ohio	Columbiana	45	40	SHALE	140	4			40.62648	-80.59310
217230	Ohio	Columbiana	60	30	SANDSTONE	141	49		1/9/1959	40.63418	-80.56890
415546	Ohio	Columbiana	46	20	SHALE	152	46		5/23/1974	40.63580	-80.56430
600277	Ohio	Columbiana	125	12	SHALE	210	7		11/24/1982	40.62844	-80.55326
607653	Ohio	Columbiana		8	SHALE	250	10		10/20/1981	40.62844	-80.55326
415545	Ohio	Columbiana	104	63	SHALE	174	24	COMMERCIAL	5/7/1974	40.63632	-80.56524
415543	Ohio	Columbiana	87	60	SHALE	295	25	COMMERCIAL	5/7/1974	40.63675	-80.56589
743322	Ohio	Columbiana	6	35	GRAVEL	100		DOMESTIC	1/10/1992	40.63447	-80.54821
545019	Ohio	Columbiana		5	SANDSTONE	120	15	DOMESTIC	8/12/1978	40.62772	-80.57245
755932	Ohio	Columbiana	80		SANDSTONE	125		DOMESTIC	2/22/1994	40.62975	-80.60837
755923	Ohio	Columbiana	95		SANDSTONE	131	3	DOMESTIC	8/11/1993	40.62958	-80.60487
900405	Ohio	Columbiana	60	6	SANDSTONE	140	18	DOMESTIC	8/7/2013	40.63297	-80.56305
833356	Ohio	Columbiana	85	25	SHALE	150	3	DOMESTIC	6/25/1996	40.62058	-80.58067
755912	Ohio	Columbiana	110	15	SANDSTONE	150		DOMESTIC	7/29/1993	40.62988	-80.60912
737010	Ohio	Columbiana	90		SANDSTONE	150	3	DOMESTIC	11/12/1991	40.63167	-80.60063
956858	Ohio	Columbiana	80	4	UNKNOWN	225		DOMESTIC	8/20/2003	40.61876	-80.57504
888974	Ohio	Columbiana	115	10	SANDSTONE	230		DOMESTIC	6/11/1999	40.62630	-80.59263
890177	Ohio	Columbiana	185	30	SANDSTONE	235		DOMESTIC	11/20/1998	40.63184	-80.59750

Record Number	State	County	Static Water Level	Test Rate (GPM)	Aquifer Type	Total Depth	Depth to Bedrock	Well Use	Completi on Date	Latitude	Longitude
944281	Ohio	Columbiana	180	3	LIMESTONE	260		DOMESTIC	3/19/2002	40.61742	-80.57343
854898	Ohio	Columbiana	294	2	SHALE	505		DOMESTIC	5/29/1998	40.62916	-80.60526
2034910	Ohio	Columbiana			SAND & GRAVEL	15		MONITOR	9/13/2011	40.61725	-80.58452
898392	Ohio	Columbiana	13		SANDSTONE	18	9	MONITOR	9/21/2000	40.61728	-80.58323
993360	Ohio	Columbiana				22		MONITOR	5/25/2005	40.61545	-80.57372
993361	Ohio	Columbiana				22		MONITOR	5/26/2005	40.61540	-80.57328
2034907	Ohio	Columbiana			SAND & SILT	25		MONITOR	9/13/2011	40.61625	-80.58311
2034909	Ohio	Columbiana			SAND & SILT	25		MONITOR	9/13/2011	40.61652	-80.58367
2034912	Ohio	Columbiana			SILT & SAND	25		MONITOR	9/14/2011	40.61467	-80.57803
2034913	Ohio	Columbiana			SILT & SAND	25		MONITOR	9/14/2011	40.61471	-80.57886
2034914	Ohio	Columbiana			SILT & SAND	25		MONITOR	9/14/2011	40.61463	-80.57718
993359	Ohio	Columbiana				25		MONITOR	5/23/2005	40.63280	-80.54977
993362	Ohio	Columbiana				28		MONITOR	5/26/2005	40.61578	-80.57247
993356	Ohio	Columbiana				30		MONITOR	5/24/2005	40.63133	-80.55250
993358	Ohio	Columbiana				35		MONITOR	5/23/2005	40.63123	-80.54845
993357	Ohio	Columbiana				37		MONITOR	5/24/2005	40.63150	-80.55093
2069530	Ohio	Columbiana	38		SAND	42		MONITOR	7/18/2018	40.62080	-80.57980
2029310	Ohio	Columbiana	35.5		SAND	42		MONITOR	8/30/2010	40.62430	-80.59185
2029408	Ohio	Columbiana	35.5		SAND	42		MONITOR	8/30/2010	40.62430	-80.59185
2029409	Ohio	Columbiana	37		SAND	42		MONITOR	8/30/2010	40.62427	-80.59203
2029410	Ohio	Columbiana	32		CLAY	42		MONITOR	9/2/2010	40.62420	-80.59210
2029416	Ohio	Columbiana	35		SAND	42		MONITOR	8/31/2010	40.62445	-80.59198
2029417	Ohio	Columbiana	35		SAND	42		MONITOR	8/31/2010	40.62440	-80.59190
2000178	Ohio	Columbiana	28		SAND	46		MONITOR	9/29/2005	40.63085	-80.55280
2000179	Ohio	Columbiana			SAND	46		MONITOR	9/28/2005	40.63045	-80.55303
2000177	Ohio	Columbiana	35		SAND	47		MONITOR	9/28/2005	40.63065	-80.55355
2015666	Ohio	Columbiana	36		GRAVEL & SAND	50		MONITOR	2/7/2008	40.63047	-80.55323

Record Number	State	County	Static Water Level	Test Rate (GPM)	Aquifer Type	Total Depth	Depth to Bedrock	Well Use	Completi on Date	Latitude	Longitude
2015667	Ohio	Columbiana	36		GRAVEL & SAND	50		MONITOR	2/7/2008	40.63045	-80.55348
2015668	Ohio	Columbiana	36		GRAVEL & SAND	50	4	MONITOR	2/8/2008	40.63058	-80.55313
2015665	Ohio	Columbiana	38		GRAVEL & SAND	50		RECOVERY WELL	2/6/2008	40.63052	-80.55332
66009	Ohio	Jefferson	26	6	SAND & GRAVEL	48			5/20/1950	40.52352	-80.63558
66013	Ohio	Jefferson	26	6	SAND & GRAVEL	48			5/20/1950	40.52352	-80.63558
217201	Ohio	Jefferson	40	30	SAND & GRAVEL	60			7/21/1958	40.52713	-80.63349
100095	Ohio	Jefferson	58	12	SAND & GRAVEL	60			6/30/1953	40.54122	-80.63746
197552	Ohio	Jefferson	36	15	SAND & GRAVEL	70			6/29/1957	40.52691	-80.63423
139206	Ohio	Jefferson	42	4	SHALE	82	29		5/4/1955	40.55298	-80.64752
112552	Ohio	Jefferson	61	2	SANDSTONE	88	83		8/21/1953	40.54608	-80.64065
66020	Ohio	Jefferson	54.3	4	ROCK	89	57		8/11/1950	40.54863	-80.64269
181950	Ohio	Jefferson	77		SAND & GRAVEL	102			1/11/1958	40.54610	-80.64058
2014022	Ohio	Jefferson	13		CLAY/SAND/GR AVEL	35	32	DEWATERING	9/17/2007	40.52722	-80.63000
2014023	Ohio	Jefferson	13		CLAY/SAND/GR AVEL	37		DEWATERING	9/17/2007	40.52722	-80.63000
2014019	Ohio	Jefferson	13		CLAY	40		DEWATERING	9/17/2007	40.52722	-80.63000
2014020	Ohio	Jefferson	40		GRAVEL/SAND/ CLAY	52		DEWATERING	9/17/2007	40.52722	-80.63000
2020890	Ohio	Jefferson	40		SAND/CLAY/GR AVEL	70	60	DEWATERING	9/17/2007	40.52326	-80.63104
139210	Ohio	Jefferson	25		SAND & GRAVEL	50		DOMESTIC	5/24/1955	40.52025	-80.62715
139212	Ohio	Jefferson	20		SAND & GRAVEL	50		DOMESTIC	5/24/1955	40.52141	-80.62751
66019	Ohio	Jefferson	25	6	GRAVEL	52		DOMESTIC	8/5/1950	40.53708	-80.63569
139211	Ohio	Jefferson	18		SAND & GRAVEL	53		DOMESTIC	5/24/1955	40.51982	-80.62683
213750	Ohio	Jefferson	14	4	SANDSTONE	59	20	DOMESTIC	6/22/1964	40.53652	-80.64875

Record Number	State	County	Static Water Level	Test Rate (GPM)	Aquifer Type	Total Depth	Depth to Bedrock	Well Use	Completi on Date	Latitude	Longitude
2057791	Ohio	Jefferson	37		SAND & GRAVEL	60		MONITOR	4/25/2016	40.52859	-80.63069
2057796	Ohio	Jefferson	36		SAND & GRAVEL	60		MONITOR	5/4/2016	40.52597	-80.63091
2057790	Ohio	Jefferson	38		SAND & GRAVEL	65		MONITOR	4/28/2016	40.52819	-80.63174
2057798	Ohio	Jefferson	43		SAND & GRAVEL	65		MONITOR	4/27/2016	40.52739	-80.63050
2057789	Ohio	Jefferson	41		SAND & GRAVEL	70		MONITOR	5/16/2016	40.52672	-80.63180
2057792	Ohio	Jefferson	41		SAND & GRAVEL	70		MONITOR	5/26/2016	40.52836	-80.62990
2057794	Ohio	Jefferson	44		SAND & GRAVEL	70		MONITOR	5/17/2016	40.52709	-80.62963
2057795	Ohio	Jefferson	36		SAND & GRAVEL	70		MONITOR	5/19/2016	40.52640	-80.62941
2057797	Ohio	Jefferson	39		SAND & GRAVEL	70		MONITOR	5/3/2016	40.52608	-80.63006
2057799	Ohio	Jefferson	37		SAND & GRAVEL	70		MONITOR	5/2/2016	40.52399	-80.63089
256234	Ohio	Jefferson	38	500	SAND & GRAVEL	80		MUNICIPAL	10/18/196 0	40.52605	-80.62958
256236	Ohio	Jefferson	35.83	500	SAND & GRAVEL	80		MUNICIPAL	11/2/1960	40.52511	-80.62918
2016512	Ohio	Jefferson	30.4	100	SAND/GRAVEL/ BOULDERS	82		OTHER	5/13/2008	40.54417	-80.63917
503020	PA	Beaver				60		MONITOR		40.59997	-80.51869

2.8. Geochemistry [40 CFR 146.82(a)(6)]

2.8.1. Baseline Fluid Chemistry

Average salinity was calculated, and initial fluid chemistry data were collected from the USGS Produced Water Database for the USDWs, the injection zones, and the confining zones and are shown in Table 11 and Table 12 (Blondes et al., 2019). The database was filtered to include regional data from the states of Ohio, Pennsylvania, eastern Kentucky, and West Virginia (Figure 56). Anomalous and outlier data points were investigated to determine validity, and in some cases, these data points were removed from the dataset due to their high uncertainty. Fluid samples will be acquired during the construction of injection wells as part of the Pre-Operational Testing Plan as well as during the construction of the CarbonSAFE stratigraphic test well to validate or update these data.

The USGS sampling data indicate that the Lockport Dolomite Group (primary injection zone) has an average TDS of 264,717 mg/L, whereas the Salina Group (primary confining zone) averages 256,156 mg/L. No TDS measurements were available for the Rochester Shale, and the calculated average TDS of the Medina Group (primary injection zone) is 266,865 mg/L. TDS measurements for the Queenston Shale (Juniata Fm.) in the project area were unavailable, but in the state of New York, the average salinity is recorded at 216,383 mg/L. The Knox injection complex (secondary injection zone), including the Beekmantown Dolomite and Rose Run Formation, have an average TDS > 300,000 mg/L (Table 11). The brines of the intended injection complexes and USDWs are predominantly Na^+ and Cl^- with secondary Ba^{2+}, HCO_3^-, Ca^{2+}, K^+, Mg^{2+}, and SO_4^{2-}. For reference, initial fluid chemistry data collected from the USGS National Produced Waters Geochemical Database for the USDWs, the injection zones, and the confining zones are shown in Table 12.

Table 11: Regional Total Dissolved Solids data for the Primary and Secondary injection complexes. There is no data for the Rochester Formation and data from the Queenston Shale is described in the text above).

Total Dissolved Solids			
Formation Type	**Formation**	**TDS (mg/L)**	**n =**
Primary Confining (LIC)	Salina Group	256156	12
Primary Injection (LIC)	Lockport Dolomite Group	264717	11
Primary Injection (MIC)	Medina Group	266865	376
Secondary Confining/Injection (KIC)	Beekmantown Dolomite	379676	1
Secondary Injection (KIC)	Rose Run Sandstone	320833	13
USDW	Conemaugh Group	22008	6
USDW	Allegheny Group	15825	2
USDW	Pennsylvanian (undiff)	36421	6
USDW	Pottsville Group/Salt Sand	71394	172
LUSDW	Mauch Chunk Formation	81410	27
Formation below LUSDW	Greenbriar Formation	156678	10

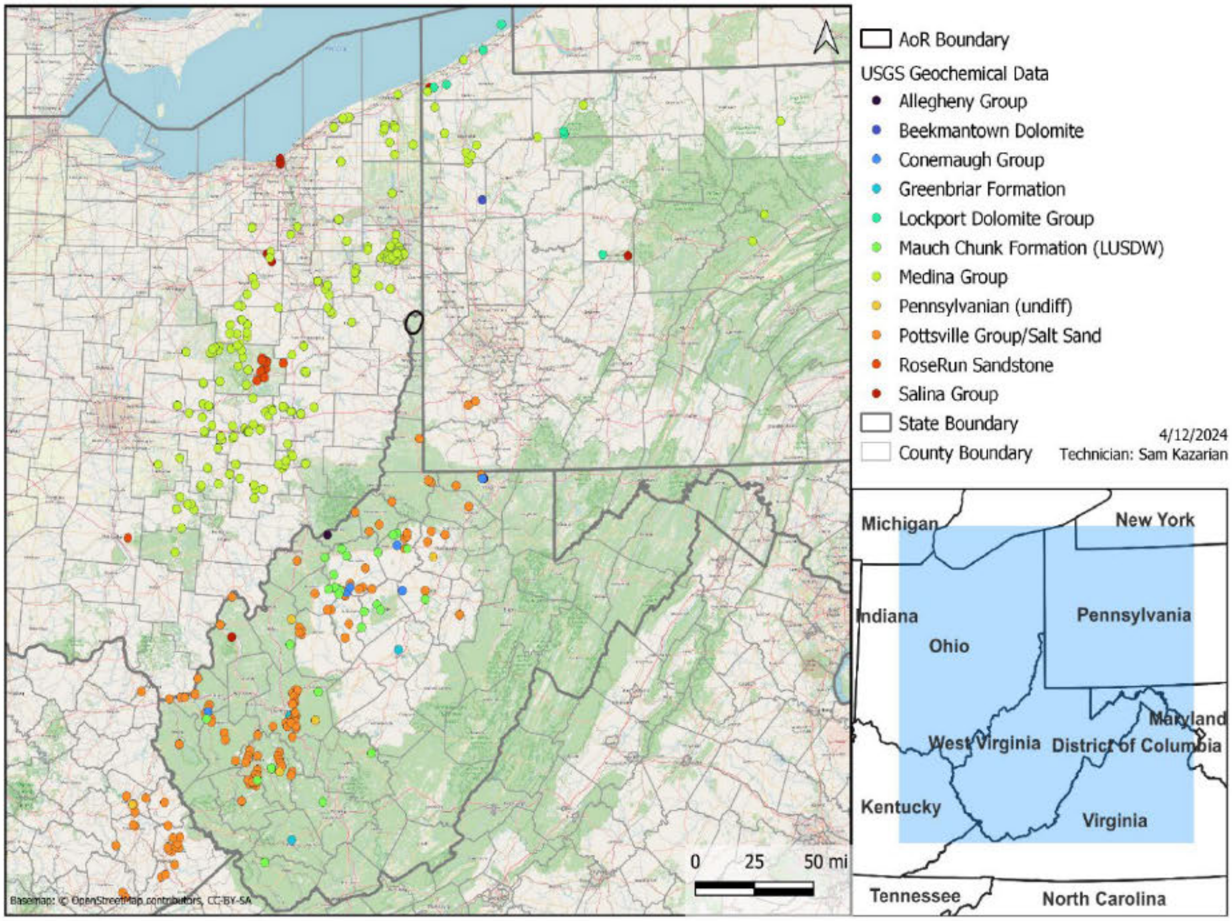

Figure 56: Location map of regional baseline fluid chemistry data from the USGS National Produced Waters Geochemical Database (2019).

Table 12: Regional Baseline Fluid Chemistry data for the primary and secondary injection complexes and USDWs from USGS (National Produced Waters Geochemical Database, 2019).

Baseline Fluid Chemistry					
Parameter/Constituent	Primary (LIC)		Primary (MIC)	Secondary (KIC)	
	Salina	Lockport	Medina	Beekmantown	Rose Run
pH	6.1	6.56	5.53	1.21	5.46
Ba^{2+}	700	--	22.2	--	--
HCO^{3-}	211.3	98.9	91.3	208.0	44222.9
Ca^{2+}	17296.5	25202.5	33238.1	52889.0	65977.8
Cl^{-}	158758.5	143949.4	164034.6	232741.0	154436.1
K^{+}	3438.1	2930.7	1637.8	--	77536.725
Mg^{2+}	3012.2	4907.0	4055.8	6100.0	56486.9
Na^{+}	76927.0	71421.2	59121.6	78824.0	56382.5
SO_4^{2-}	1971.8	647.6	409.4	93.0	780.5

Baseline Fluid Chemistry						
Parameter/ Constituent	Underground Source of Drinking Water					
	Conemaugh Group	Allegheny Group	Pennsylvanian (undiff)	Pottsville Group/ Salt Sand	Mauch Chunk (LUSDW)	Green-briar
pH	--	--	--	6.9	--	--
Ba^{2+}	53.3	40.0	--	382.2	646.4	--
HCO^{3-}	--	--	--	211.0	594.0	68.5
Ca^{2+}	1070.0	250.0	1358.0	5161.4	6603.4	13631.7
Cl^-	13055.0	9345.0	--	42878.1	52914.4	96744.4
K^+	62.4	45.0	15762.0	490.8	252.0	414.8
Mg^{2+}	295.3	185.5	97.0	1066.3	1467.4	3192.0
Na^+	6758.8	5825.0	374.0	19770.0	23674.0	41177.4
$SO4^{2-}$	45.2	167.5	8134.0	35.9	68.3	524.6

2.8.2. Fluid-Rock Interactions

A literature review was conducted to evaluate the potential for reactivity between the fluid and solid phases during injection into the LIC and MIC. There are no studies on the primary injection intervals, so analog studies were reviewed based on the mineralogy of the intended injection complexes discussed in subsection 2.4 of this Application Narrative. Though not being proposed for injection with this application, the reactivity of the secondary injection interval, the KIC, has been studied and is summarized below.

2.8.2.1. Lockport Injection Complex

There are currently no studies investigating the fluid-rock reactivity of the Lockport Dolomite. Wang et al. (2013) investigated the reactivity of the mineral dolomite ($CaMg(CO_3)_2$) with water-saturated CO_2 in a series of laboratory experiments performed at 55 and 110 °C to mimic reservoir conditions and at 220 °C to accelerate the reactions at laboratory time scales. Wang concluded that dolomite exhibits no reaction with anhydrous supercritical CO_2 but dissolves and precipitates carbonate minerals when exposed to water-saturated supercritical CO_2. The main drivers for the morphology and composition of the mineral precipitates are temperature and reaction time, though heterogeneity in dolomite mineralogy was not studied. Further, mineral dissolution and precipitation could have an effect on the hysteresis of drainage and imbibition, rock wettability, and capillary pressure, which affect the flowability and trapping of CO_2. The magnitude of these effects was not measured in the study.

2.8.2.2. Medina Injection Complex

Minimal quartz chemical dissolution and subsequent porosity changes due to CO_2 injection are expected in the MIC during the life of the project. Mineralogical analysis, discussed in subsection 2.4.3.2 of this Application Narrative, suggests few reactive minerals and cements in the MIC. Feldspars and pyrite are minor constituents, and XRD measured trace amounts of carbonate present in the formation that are unlikely to significantly alter the reservoir matrix during the project. Literature suggests some variability in the cement type and variable interstitial shale beds, so there is the possibility of the presence of reactive minerals (see subsection 2.4.3.2 of the Application Narrative). To date, no work has been performed to model the reactivity of the Medina sandstones with supercritical CO_2. Future testing to address this uncertainty is discussed below.

2.8.2.3. Knox Injection Complex

Zerai et al. (2005) modeled the equilibrium and kinetic reactions of the Rose Run Sandstone mineralogy and brine under no-flow conditions. Equilibrium modeling highlighted the critical role of albite, K-feldspar, and glauconite dissolution, with siderite and dawsonite precipitation, in CO_2 mineral trapping in the Rose Run. The dominant precipitated minerals were quartz, muscovite, and microcline, which have opposing negative and positive effects of lowering the injectability or improving sealing capacity. These results are sensitive to both the brine composition and site-specific mineralogy, in addition to temperature and CO_2 fugacity. The kinetic modeling indicated that solubility trapping was key over short timescales, and CO_2 mineral trapping was significant over longer (100,000 years) timescales. The modeling showed that the mineralogy of the Rose Run Sandstone is suitable for significant mineral trapping of CO_2, though the reactions are sensitive to the brine-rock ratio, CO_2 pressure, and the reaction rates. Further modeling for the project will be performed upon site-specific data collection.

2.8.3. Planned Testing and Modeling

The data utilized for evaluating geochemical interactions within the Lockport Dolomite and the Medin Group siliciclastic reservoirs are regional and not specific to the project area. Consequently, following the completion of pre-operational testing and logging and data collection for the CarbonSAFE stratigraphic well, it will be determined if reactive transport modeling should be conducted.

Tri-State CCS, LLC will acquire whole core and sidewall core samples from the proposed injection zones to determine the petrophysical and mineralogical properties of the LIC and MIC (see Pre-Operational Testing Plan). Mineralogical analysis will determine the type percent composition of potentially reactive minerals within the Lockport Dolomite Group, the Medina Group siliciclastics, and the Knox Group at the proposed injection locations.

Tri-State CCS, LLC also plans to gather fluid samples from the injection zone and shallower zones to establish a baseline geochemical description of reservoir fluids. Collected fluid samples are planned to be used to develop synthetic brine compositions to run core flooding studies to assess possible interactions between injected CO_2, reservoir matrix, and in-situ brine. Fluid samples will allow pre- and post- CO_2 injection analysis to determine the changes in brine chemistry, which can be compared with reservoir samples subjected to geochemical testing to assess changes in the rock matrix. If Tri-State CCS, LLC determines geochemical changes to reservoir rock or fluids are prominent as concluded from these tests, a reactive transport model can be built and coupled with the current reservoir model to assess long term fate of injected CO_2 as it is related to mineralogical changes in the reservoir.

2.9. Site Suitability [40 CFR 146.83]

Based on all available data and research presented in this Application Narrative, the project area meets the suitability requirement outlined in the regulations for CO_2 injection. The LIC consists of the Salina Group as the primary confining zone, the Lockport Dolomite as the injection target, and the Rochester Shale, which acts as the lower confining unit for the Lockport Dolomite and the upper confining unit for the MIC. The remainder of the MIC consists of the Medina Group sandstones as the lower injection target and the Queenston Shale as the lowest confining unit.

The Lockport Dolomite is laterally continuous, averages 300 ft in thickness, and is lithologically variable. It exhibits seven main facies types: (1) mixed intertidal to supratidal dolomite (with a mixed gray biostromal subfacies), (2) interreef or interbioherm dark dolomite, (3) grainstone - shoals, banks, reef flanks, and inter-reef sediments, (4) biohermal dolomite (reefs, bioherms and patch reefs), (5) subtidal crinoidal dolomite, (6) quartzose dolomite associated with barrier island, and (7) shallow subtidal shaley dolomite. The reservoir quality is linked to both the initial depositional facies and diagenetic alteration, which can either occlude or enlarge pores. This variability results in reported ranges of porosities from 1 to 9% and permeabilities of < 0.01 mD to 55 mD. Wireline logs, core, and petrophysical evaluation from wells in the nearby subsurface resulted in an average model porosity of ~6% and an average permeability of ~1 mD.

The MIC is a series of interbedded sandstones, shales, and siltstones, with minor carbonates. They were shed from the Taconic highlands, in a fluvial-deltaic to shallow marine environment, recording 3-4 marine incursions and a sea-level change, as evidenced by the different sand intervals. The sandstones vary in quality due to quartz cementation. Reported porosities range from 2 to 23%, and permeabilities range from 1 mD to 40 mD, with some oil fields reporting as high as 200 mD. In the project's model domain, the average porosity is ~5%, and average permeability is 8 mD.

Static earth modeling and simulation of the project area resulted in a total injection volume of 2.19 MMt CO_2 in the LIC and 4.85 MMt CO_2 in the MIC for the potential injection locations over 30 years. Due to the low porosity and permeability in the nearby area, the CO_2 plume does not migrate far from the injection site (~ 1 mile radius) in the 30-year injection period and 50-year PISC period. Using the US-DOE-NETL methods, it was calculated that the LIC has the potential to be able to sequester P10:102.1, P50: 247.6, P90: 461.2 MMt of CO_2. The MIC has the potential to be able to sequester P10: 71.5, P50: 221.1, P90 526.4 MMt of CO_2. Detailed local reservoir characterization from the CarbonSAFE stratigraphic test well will de-risk the current uncertainties, and data collection from the pre-operational testing for the injection wells will narrow the uncertainty range prior to injection.

Literature review and regional well log analysis indicate the project's confining zone will provide long-term containment of CO_2. The primary confining zone, the Salina Group, consists of laterally extensive, tight dolomites and thick bedded salts and anhydrites across multiple states. This interval is >1000 ft thick in total with a >120 ft thick F4 salt, locally, and has acted as a barrier with two distinct geochemical fingerprints between the petroleum systems younger than the Salina Group and those older than the Salina Group. The Rochester Shale, which sits above the MIC and below the LIC, is >300 ft thick, laterally continuous throughout the region, and reported as impermeable (1xE-6 mD). Finally, the Queenston Shale has a thickness >1000 ft, has been measured as impermeable, and is laterally continuous across the basin. These confining zones and their historical longevity are robust indicating that secondary confining zone identification is unnecessary.

No faults were identified though 2D seismic interpretation, or literature search, that offset the Salina Group or create leakage pathways to the lowermost USDW. There are, however at least four confirmed legacy oil and gas wells that penetrate the caprock within the AoR as seen in Figure 41 of subsection 4.1 of the Area of Review and Corrective Action Plan. These wells are addressed in the plan, along with those wells without depth data, to ensure that the legacy wells are not conduits for potential leakage.

Literature review of the fluid chemistry, injection and confining zone mineralogy, and analogs for the injection complexes suggest that the siliciclastic intervals will have minimal reaction with the injected CO_2. Laboratory analysis of anhydrous CO_2 interaction with dolomite suggests no reaction, but dolomite dissolves and alternate carbonate minerals precipitate when the CO_2 is water saturated. The rate and magnitude of these reactions will be evaluated in the future CarbonSAFE site characterization and pre-operational testing for these systems. Surface and well infrastructure materials are being designed using CO_2 compatible materials and techniques, and the proposed CO_2 stream is dry (98% CO_2); thus, no adverse interactions are anticipated. Corrosion testing prior to construction will take place to confirm material compatibility.

3. <u>Summary of Other Plans</u>

3.1. Area of Review and Corrective Action Plan

The information and files submitted in the Area of Review and Corrective Action Plan satisfy the federal requirements of 40 CFR 146.84. This plan addresses how the project AoR is delineated and uses corrective action techniques to address all deficient artificial penetrations and other features that compromise the integrity of the confining zone above the injection zone. The AoR encompasses the entire region surrounding the project's injection wells where USDWs may be endangered by injection activity.

The computational model describes modeling of the subsurface injection of CO_2 into the LIC and MIC at the project injection wellsites. The STOMPX-CO2 simulator was used to assess the development of the CO_2 plume, the pressure front, and the long-term outcome of the injected CO_2. Simulation indicated that the maximum extent of the pressure front will be larger than the maximum extent of the CO_2 plumes over the lifetime of the project. Therefore, the AoR for the project is defined as the maximum extent of the threshold pressure front (220 psi), which occurs at the end of injection, with an additional 1-mile buffer to account for uncertainties in the subsurface data. This plan details the computational modeling, assumptions that were made, and site characterization data that the model was based on to satisfy the requirements of 40 CFR 146.84(c).

There are 469 existing oil and gas wellbores and 88 known water wells within the AoR. Per 40 CFR 146.82(a)(4), wells that penetrate the injection or confining zone within the AoR must be tabulated. None of the water wells penetrate the injection or confining zones, but there are up to 293 oil and gas wellbores that may penetrate the primary confining unit within the AoR, four of which have records confirming their depth and 289 for which records of depth are not available. Tri-State CCS, LLC proposes a sequential corrective action strategy based on temporal evolution of the threshold pressure boundary, beginning prior to injection and ending in the 25th year of injection.

Tri-State CCS, LLC will review the AoR annually during the injection phase and once every five years during the post-injection phase to ensure the initial model predictions are adequate for predicting the extent of the CO_2 plume and pressure front.

AoR and Corrective Action GSDT Submissions

GSDT Module: AoR and Corrective Action
Tab(s): All applicable tabs

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☐ Tabulation of all wells within AoR that penetrate confining zone ***[40 CFR 146.82(a)(4)]***
☐ AoR and Corrective Action Plan ***[40 CFR 146.82(a)(13) and 146.84(b)]***
☐ Computational modeling details ***[40 CFR 146.84(c)]***

3.2. Financial Responsibility

Tri-State CCS, LLC has prepared the Financial Assurance Demonstration to comply with federal requirements at 40 CFR 146.85. The plan estimates costs of project activities and provides information on financial instruments that Tri-State CCS, LLC will use to demonstrate Financial Assurance for the following activities: (1) Corrective Action; (2) Injection Well Plugging; (3) Post-Injection Site Care; (4) Site Closure; and (5) Emergency and Remedial Response. The estimated costs of each of these activities are presented in Table 13 below.

Table 13: Cost Estimates for Activities to be Covered by Financial Responsibility.

Activity	Total Cost ($)	Timeline of Coverage
Corrective Action	$60,409,275	2026-2057
Plugging Injection Wells	$2,134,484	2062
Post-Injection Site Care	$12,555,500	2057-2106
Site Closure	$2,352,700	2106
Emergency and Remedial Response	$12,683,760	2026-2057

Tri-State will execute a combination of financial instruments prior to construction of the injection wells. These financial instruments will cover the costs of one emergency leakage event as discussed in the Emergency and Remedial Response Plan, all of the costs of injection well plugging as discussed in the Injection Well Plugging Plan, all of the costs of corrective action as discussed in the Area of Review and Corrective Action Plan, and all of the costs of 50 years of post-injection site care and site closure as discussed in the Post-Injection Site Care and Site Closure Plan.

Financial Responsibility GSDT Submissions
GSDT Module: Financial Responsibility Demonstration ***Tab(s):*** Cost Estimate tab and all applicable financial instrument tabs Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ Demonstration of financial responsibility ***[40 CFR 146.82(a)(14) and 146.85]***

3.3. Injection Well Construction

The project's injection wells, TR1-1, and TR1-2, will be newly drilled and are designed to accommodate the mass of CO_2 that will be delivered to the project and the subsurface characteristics of the CO_2 injection intervals. Injection well construction is further described in the following plans that are part of this application: (1) Stimulation Program and (2) Construction Details.

3.3.1. Proposed Stimulation Program [40 CFR 146.82(a)(9)]

The Stimulation Program describes the stimulation measures that the project may use to mitigate drilling-induced damage near the wellbore without interfering with containment. It is expected to effectively clear the perforated interval of fines, perforation charge residue, and debris from cement or casing. Additionally, stimulation serves to eliminate drilling mud filtrate and dissolved minerals present in the formation. This process is common, as the untreated presence of these elements can lead to elevated downhole injection pressures and diminished injectivity, underscoring the significance of thorough treatment. Specific stimulation fluids, additives, and diverters will be based on injection well site conditions after pre-operational testing is complete and at the time that it is determined that stimulation is needed. At least 30 days in advance of proposed stimulation, Tri-State CCS, LLC will submit to the UIC Program Director details on the purpose of stimulation, procedures, and stimulation fluids to be used and their anticipated volumes and concentrations.

3.3.2. Construction Procedures [40 CFR 146.82(a)(12)]

Construction Details describes the analysis conducted and proposed designs for injection wells TR1-1 and TR1-2 that ensure the prevention of the movement of fluids into or between USDWs, that allow the use of testing devices and workover tools, and that allow continuous monitoring of the annulus space between the injection tubing and long string casing, in compliance with 40 CFR 146.86.

TR1-1 well design assumes 3.5-inch outer diameter (OD) tubing, a maximum wellhead pressure of 1,773 psia, and maximum injection rates of 40 Mt/y into the LIC and 100 Mt/y into the MIC. The design involves multiple casing strings at varying depths, including a 16-inch conductor casing set at approximately 150 feet bgs, a 9.625-inch surface casing set at around 1,800 feet bgs within a 12.25-inch borehole, a 7-inch-long string casing set at approximately 7,200 feet bgs, and a 3.5-inch deep (injection) tubing string set at approximately 6,931 feet bgs, equipped with a sliding sleeve for the upper injection zone. The proposed well schematic for TR1-1 is in Figure 9 of the Construction Details.

TR1-2 well design assumes 3.5-inch OD tubing, maximum wellhead pressure of 1,765 psia, and maximum injection rates of 40 Mt/y into the LIC and 80 Mt/y into the MIC. The design comprises various casing strings: a 16-inch conductor casing set at approximately 150 feet below bgs; a 9.625-inch diameter surface casing set at around 1,800 feet bgs within a 12.25-inch borehole; a 7-inch diameter long casing set about 130 feet below the top Queenston Shale (approximately 6,950 feet bgs) inside an 8.75-inch borehole; and a 3.5-inch diameter deep (injection) tubing string set at roughly 6,675 feet bgs, equipped with a sliding sleeve for the upper injection zone. The proposed well schematic for TR1-2 is in Figure 19 of the Construction Details.

All casing strings will be cemented to the surface, and corrosion-resistant alloys, such as 13Cr, will be used for wetted sections. Borehole diameters allow sufficient clearance for cement sealing along the entire length of the casing string, with materials selected based on corrosion resistance and adherence to mechanical specifications outlined in design inputs, subject to finalization based on the latest materials testing results from relevant standards bodies. Summaries of the casing program for TR1-1 and TR1-2 are in Table 6 and Table 18 of the Construction Details, respectively. Properties of casing and tubing material are in Table 7 of the Construction Details. Packer specifications are in Table 9 and Table 21 for TR1-1 and TR1-2, respectively.

Measures are in place to prevent exceeding fracture gradients or mandated injection pressures. Adjustments may be made based on future reservoir characterization. The final nodal analysis recommends a tubing configuration and operational parameters to ensure pressure and rate limitations are met while considering factors such as zonal isolation and well integrity.

3.4. Pre-Operational Testing Plan

The Pre-Operational Testing Program is designed to meet the requirements of 40 CFR 146.87, including the establishment of an accurate baseline dataset of pre-injection site conditions, verification of depths and physical characteristics of the injection and confining zones, and assurance of conformance with injection well construction requirements in 40 CFR 146.86. The pre-operational formation testing program will be implemented at both injection wells to verify the chemical and physical characteristics of the injection zones and confining zones.

The pre-operational testing program will include a combination of wireline logging and side-wall coring. In addition, formation geohydrologic testing will be completed to verify injectivity of the storage formation. Fracture pressure will be determined using the formation testing tool and minifrac tests in the observation wells, which help limit borehole rugosity and provide the highest probability of achieving a mechanically sound cement installation in the injection wells.

The pre-operational testing program will determine or verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the Salina Group (primary confining zone), the Lockport Dolomite Group (upper injection zone), the Rochester Shale Formation (confining zone), the Medina Group (lower confining zone), the Queenston Shale (basal Confining zone), and other relevant geologic formations. In addition, formation fluid characteristics will be obtained from the Lockport Dolomite Group and the Medina Group to establish baseline data against which future measurements may be compared. Reports detailing the results and interpretations of all testing operations will be provided to the UIC Program Director following conclusion of analysis and before the start of CO_2 injection operations.

After completing the characterization and testing, the borehole will be completed as an injection well. Mechanical integrity tests (e.g., wireline and pressure tests) will verify well construction and integrity. Cement bond, variable density, and temperature logs will be run after long string casing is cemented in place to verify the quality of the cement job.

Pre-Operational Logging and Testing GSDT Submissions
GSDT Module: Pre-Operational Testing ***Tab(s):*** Welcome tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ Proposed pre-operational testing program ***[40 CFR 146.82(a)(8) and 146.87]***

3.5. Well Operation

The Summary of Requirements – Class VI Operating and Reporting Conditions describes the operational design developed to adhere to 40 CFR 146.82(a)(7), 146.82(a)(10), and 146.88 and provides a plan for safe injection into TR1-1 and TR1-2.

Tri-State CCS, LLC seeks to safely inject CO_2 at average rates of 140 Mt/y and 120 Mt/y in injection wells TR1-1 and TR1-2, respectively, while maintaining well integrity and remaining below 90% of the fracture pressure. The maximum injection pressure was modeled as 3,900 psia and 3,800 psia in the LIC for injection wells TR1-1 and TR1-2, respectively. This is below 90% of the fracture pressure and will not risk fracturing the confining zone. TR1-1 will be used to inject 40 Mt/y into the LIC and 100 Mt/y into the MIC. Injection well TR1-2 will be used to inject 40 Mt/y into the LIC and 80 Mt/y into the MIC. Operating conditions for TR1-1 and TR1-2 are detailed in Table 1 and Table 2, respectively, of the Summary of Requirements.

Each injection well will be monitored to ensure safe operations, in compliance with 40 CFR 146.88(e)(2). Operational safety monitoring includes continuous monitoring of the injection pressure at the wellhead and bottomhole, continuous monitoring of the pressurized annulus, continuous fiber optic temperature monitoring along the well, and corrosion coupon monitoring to identify corrosion. Each of these monitoring systems is fully described in Sections 4.0 and 5.0 of the Testing and Monitoring Plan.

All automatic shutdowns will be investigated prior to bringing injection back online to ensure that no integrity issues were the cause of the shutdown. If an un-remedied shutdown is triggered or a loss of mechanical integrity is discovered, Tri-State CCS, LLC will immediately investigate and identify, as expeditiously as possible, the cause of the shutdown. Please refer to Appendix A of the Emergency and Remedial Response Plan for response actions if mechanical integrity is lost.

Tri-State CCS, LLC will monitor and maintain mechanical integrity of each injection well at all times. Well maintenance and workovers will be part of normal operations to keep each injection well in a safe operating condition. Procedures for well maintenance will vary depending on the nature of the procedure and will be monitored to ensure mechanical integrity.

Contingency plans will be in place to identify situations where potential plant and/or process upset conditions may occur and take appropriate measures which are protective to the local area and the environment by shutting in the wells and monitoring their pressure fall-off. Operational contingency plans for the injection wells include potential downtime periods when annual injection well testing, maintenance, well service, and stimulation occur. Further information on operational contingency plans can be found in Section 5 of the Summary of Requirements.

The CO_2 will be sourced from industrial facilities and power plants located in the Tri-State area and transported by pipeline to the Tri-State CCS Hub. The CO_2 will be in the liquid or supercritical phase as it enters the wellhead and will transition to a supercritical phase in the wellbore. The injectate stream composition coming into the storage field will vary throughout the injection phase of the project. To account for this, Tri-State CCS, LLC plans to continuously monitor the CO_2 stream chemical composition to ensure it meets minimum composition specifications that will be refined when sources are finalized, and capture equipment is operational (see Section 3 of the Testing and Monitoring Plan). Minimum specifications of the CO_2 injection stream are in Table 3 of the Summary of Requirements.

Due to the anticipated low water content within the CO_2 stream, CO_2-induced corrosion affecting well components is not likely - as noted by the U.S. EPA well construction guidance (US EPA, 2012). Tri-State CCS, LLC will monitor for potential corrosion induced by the injectate as outlined in Section 5 of the Testing and Monitoring Plan.

Tri-State CCS, LLC will submit semi-annual operating reports to the UIC Program Director during the injection period. Reporting requirements are detailed in Section 6 of the Summary of Requirements.

3.6. Testing and Monitoring Plan

The Testing and Monitoring Plan describes how Tri-State CCS, LLC will monitor the project to verify that it is not endangering USDWs, pursuant to 40 CFR 146.90. Additionally, the monitoring and testing data will be used to track the CO_2 plume and pressure front, validate and refine geological models and simulations used to forecast the distribution of the CO_2 within the storage zone, support AoR re-evaluations, and demonstrate non-endangerment. The Quality Assurance and Surveillance Plan meeting the requirement of 40 CFR 146.90(k) is provided as an Appendix to the Testing and Monitoring Plan.

In addition to monitoring the injection wells, Tri-State CCS, LLC plans to drill and monitor up to eight observation wells for the project: two in-zone observation wells in the Lockport Dolomite and Medina Groups, two above-zone observation wells in the Oriskany Formation, two lowermost USDW observation wells in the Mauch Chunk Formation, and two shallow USDW wells in the Pennsylvanian unit. A summary of these wells and their approximate depth is in Table 1 of the Testing and Monitoring Plan. Proposed monitoring activities and frequencies for these wells are summarized in Table 3 of the Testing and Monitoring Plan.

The Testing and Monitoring Plan will utilize direct and indirect monitoring technologies that will monitor:

- Injectate composition per Section 3 of the Testing and Monitoring Plan (40 CFR 146.90(a));
- Operational parameters per Section 4 of the Testing and Monitoring Plan (40 CFR 146.90(b));
- Corrosion of well materials and components per Section 5 of the Testing and Monitoring Plan (40 CFR 146.90(c));
- Any migration of CO_2 or brine above the confining zone per Section 6 of the Testing and Monitoring Plan (40 CFR 146.90(d));
- USDW groundwater quality per Section 6 of the Testing and Monitoring Plan (40 CFR 146.95(f)(3)(i) and 146.90(d));
- Well integrity over the injection phase of the project per Section 7 of the Testing and Monitoring Plan (40 CFR 146.89(c) and 146.90(e));
- Near well-bore environment using pressure fall-off testing per Section 8 of the Testing and Monitoring Plan (40 CFR 146.90(f)); and
- Development of the CO_2 plume and pressure front in the storage formation over time per Section 9 of the Testing and Monitoring Plan (40 CFR 146.90(g)).

Testing and Monitoring GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** Testing and Monitoring tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ Testing and Monitoring Plan ***[40 CFR 146.82(a)(15) and 146.90]***

3.7. Injection Well Plugging

The Injection Well Plugging Plan describes the process Tri-State CCS, LLC proposes to plug injection wells TR1-1 and TR1-2 in conformance with federal requirements at 40 CFR 146.92 and 146.93(e) and state requirements at 47 CSR 13-13.4 and 13-14.7.f. After the injection period, the injection wells will be plugged or converted to observation wells for up to five years to monitor in-zone reservoir conditions post-injection.

The plugging process and materials are designed to prevent unwanted fluid movement, resist corrosion caused by CO_2/water mixtures, and safeguard USDWs. Prior to plugging, the final bottom-hole pressure of the injection wells will be measured, and a buffered fluid (brine) will be used to flush and fill the wells to maintain pressure control. The measured bottom-hole pressure and temperature will guide the selection of the appropriate weight of brine to stabilize the well and may inform decisions regarding the blend of cement needed to plug the well and address considerations such as preventing leak-off or premature setting. An external MIT will be conducted before plugging. If mechanical integrity is compromised, repairs will be made before proceeding with plugging operations.

The injection tubing, strings, and gauges will be removed from the wells. If the packer cannot be removed after flushing, it will be cut from the tubing and left in the well. The injection zones will be plugged using the retainer method and squeezing cement into the perforations. Balanced plugs will be used to isolate the remainder of the well. CO_2-resistant cement will be used in the injection and confining zones and Class A neat cement or equivalent will be used in shallower plugs.

Tri-State CCS, LLC will submit updates to the plan, notifications, and reports as detailed in subsection 5.1 of the Injection Well Plugging Plan.

Injection Well Plugging GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** Injection Well Plugging tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ Injection Well Plugging Plan ***[40 CFR 146.82(a)(16) and 146.92(b)]***

3.8. Post-Injection Site Care (PISC) and Site Closure

The Post-Injection Site Care and Site Closure Plan describes the activities that Tri-State CCS, LLC will perform to meet the requirements of 40 CFR 146.93. The Post-Injection Site Care (PISC) timeframe will begin when all CO_2 injection ceases and ends with site closure. Tri-State CCS, LLC provides a plan demonstrating a 50-year PISC timeframe as discussed in the Area of Review and Corrective Action Plan. No alternative PISC timeframe is requested at this time. Tri-State CCS, LLC will monitor groundwater quality and track the position of the CO_2 plume and pressure front after the end of injection operations. Tri-State CCS, LLC may not cease post-injection monitoring until a demonstration of non-endangerment of USDWs has been approved by the UIC Program Director pursuant to 40 CFR 146.93(b)(3). Following approval for site closure, Tri-State CCS, LLC will plug all observation wells, restore the site to its original condition, and submit a site closure report and associated documentation. The Site Closure Plan is detailed in Section 6 of the Post-Injection Site Care and Site Closure Plan.

The PISC plan includes groundwater quality monitoring and plume and pressure front tracking during the post-injection phase. Data collected during the post-injection phase will be used as evidence for protection of groundwater resources, pressure front stabilization, and CO_2 plume stabilization in the non-endangerment demonstration required for site closure. These, along with other activities described in the plan will meet the requirements of 40 CFR 146.93(b)(1). Details of proposed post-injection monitoring are in Tables 5, 6, and 7 of the Post-Injection Site Care and

Site Closure Plan, The results of all post-injection phase testing and monitoring will be submitted annually, within 60 days after the anniversary of the date on which injection ceased.

PISC and Site Closure GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** PISC and Site Closure tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ PISC and Site Closure Plan ***[40 CFR 146.82(a)(17) and 146.93(a)]***

3.9. Emergency and Remedial Response Plan

The Emergency and Remedial Response Plan (ERRP) describes actions that Tri-State CCS, LLC will take to address an emergency in the AoR that may cause movement of the injection fluid or formation fluid in a manner that may endanger an USDW during the construction, operation, or post-injection site care periods, pursuant to 40 CFR 146.82(a)(19) and 146.94.

Examples of potential risks include: (1) injection or observation well integrity failure, (2) injection well monitoring and/or surface equipment failure, (3) natural disaster, (4) fluid leakage into a USDW, (5) CO_2 leakage to USDW or land surface, or (6) an induced seismic event. In the case of one of the listed risks, site personnel, project personnel, and local authorities will be relied upon to implement this ERRP. Tri-State CCS, LLC will communicate to the public any event that requires an emergency response, as described in the ERRP, to ensure that the public understands what happened and whether there are any environmental or safety implications. This will include a detailed description of what happened, any impacts to the environment or other local resources, how the event was investigated, what actions were taken, and the status of the remediation.

If Tri-State CCS, LLC obtains evidence that the injected CO_2 stream and/or associated pressure front may cause an endangerment to a USDW, Tri-State CCS, LLC will perform the following actions:

1. Initiate shutdown plan for the injection well(s).
2. Immediately notify the Project Manager during construction or Operations Manager during operations.
3. Take all steps reasonably necessary to identify and characterize any release.
4. Notify the 24-hour Emergency Contact (Appendix B of the ERRP) followed by the UIC Program Director within 24 hours of the emergency event, per 40 CFR 146.91(c).
5. Implement applicable portions of the approved ERRP.

The emergency contact list in Appendix B of the ERRP will be updated annually at a minimum, and the ERRP will be reviewed at least once every five years following its approval as well as within one year of an AoR reevaluation and following any significant changes to the injection process or the injection facility or an emergency event. Periodic training will be provided, not less than annually, to construction personnel, well operators, project safety personnel, environmental personnel, the operations manager, and corporate communications. The training plan will record that the necessary personnel have been trained and possess the required skills to perform their relevant emergency response activities described in the ERRP.

Emergency and Remedial Response GSDT Submissions
GSDT Module: Project Plan Submissions ***Tab(s):*** Emergency and Remedial Response tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ Emergency and Remedial Response Plan ***[40 CFR 146.82(a)(19) and 146.94(a)]***

3.10. Injection Depth Waiver and Aquifer Exemption Expansion

No injection depth waiver or aquifer exemption expansion is being requested in this application.

3.11. Optional Additional Project Information [40 CFR 144.4]

Because the project is receiving federal funding under the CarbonSAFE initiative, potential impacts to natural resources will be evaluated through the National Environmental Policy Act (NEPA) process with the U.S. Department of Energy as the Lead Agency. Permanent surface impacts of the project will be limited to about 1 acre at each well site, while temporary surface impacts during construction will be about 4 acres at each well site. No demolition of existing structures is planned for the project at this time.

The following is provided to help with determining other federal laws that may be applicable to development of the project:

- No national wild and scenic rivers protected under the Wild and Scenic Rivers Act are found within the AoR.
- There are 17 properties in the AoR listed or eligible for listing in the National Register of Historic Places under the National Historic Preservation Act of 1966; one is within the 80-year plume (Figure 57).
- U.S. Fish and Wildlife Service's Information for Planning and Consultation tool indicates that there are two federally listed threatened or endangered species protected under the Endangered Species Act that may be present in the AoR: Indiana bat and northern long-eared bat. Tri-colored bat is proposed for listing and may also be present in the AoR.
- The AoR is not within a coastal zone protected under the Coastal Zone Management Act.

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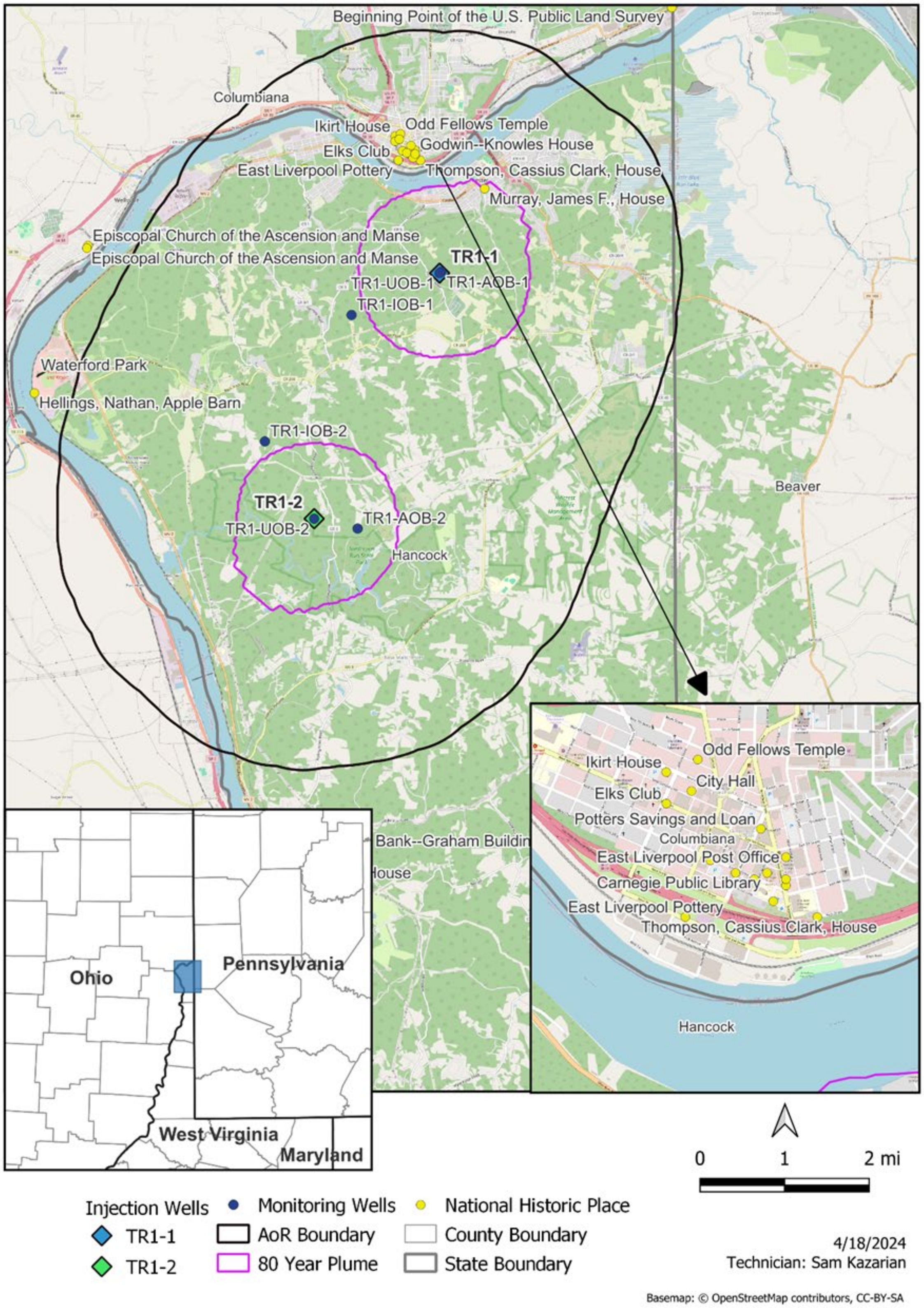

Figure 57: Map of the AoR, injection and monitoring wells, 80-year plume, and national historic places.

3.12. Other Information

No other information is included in the permit application at this time.

However, Tri-State CCS, LLC will provide any other information requested by the UIC Program Director, or new or updated information that is not specifically requested/required but may be useful for the permit application. This section fulfills the requirement at 40 CFR 146.82(a)(21).

4. References

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