

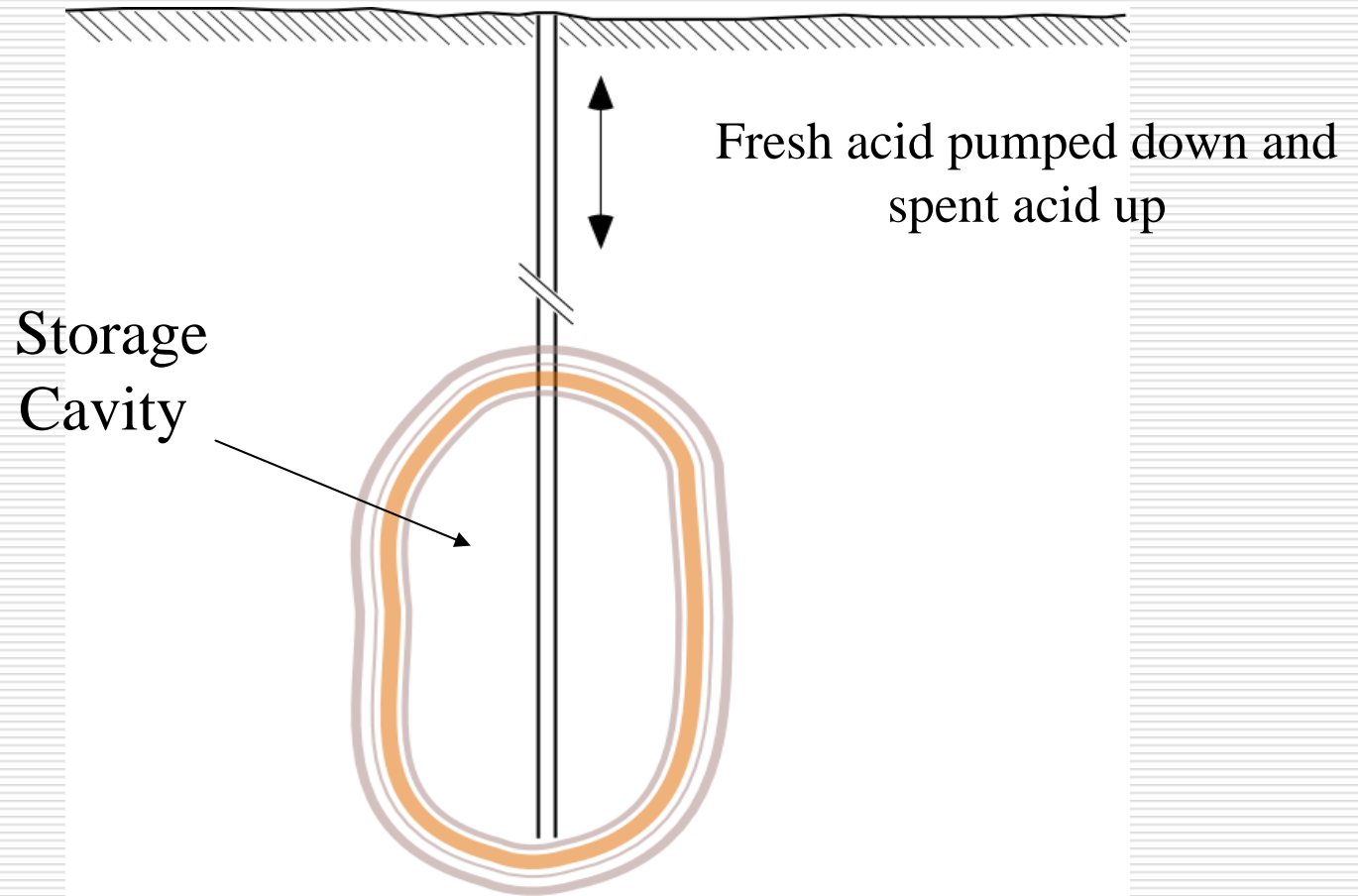
An Assessment of Carbonate Formations in the Appalachian Basin for Gas Storage via Acid Dissolution

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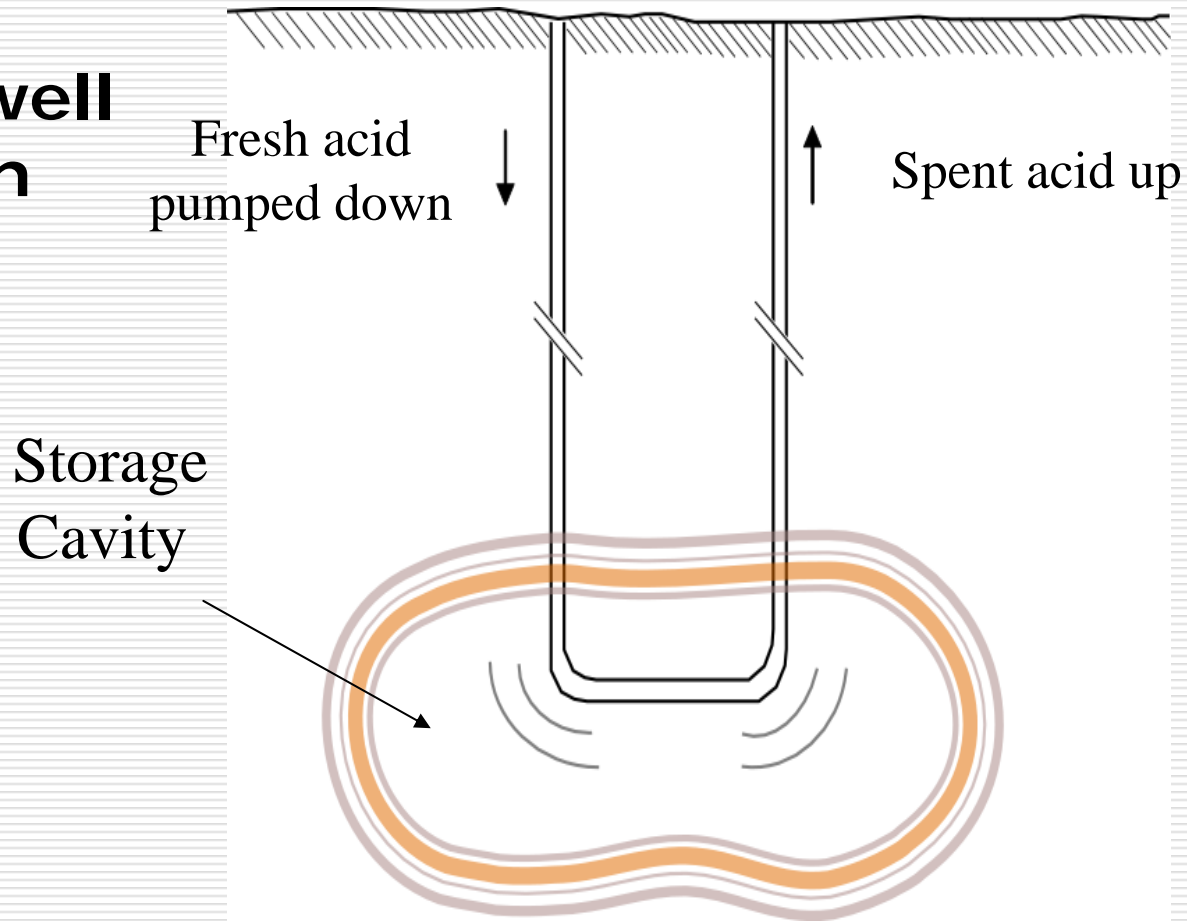
Background

One-well Design



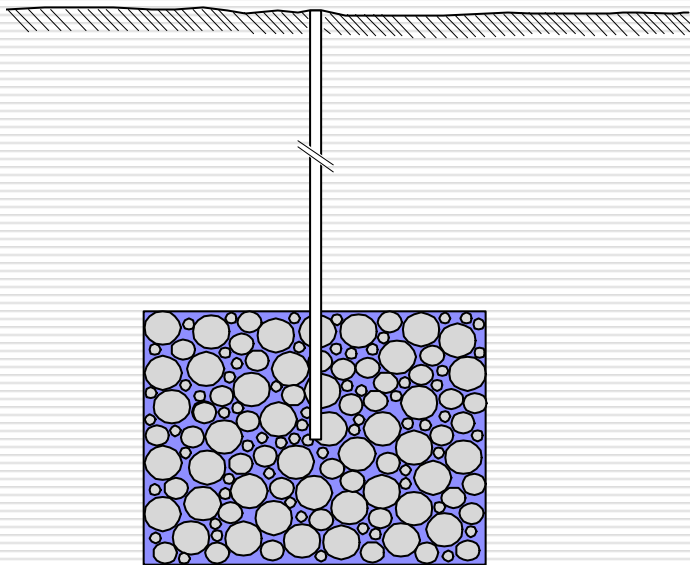
Background

Two-well Design

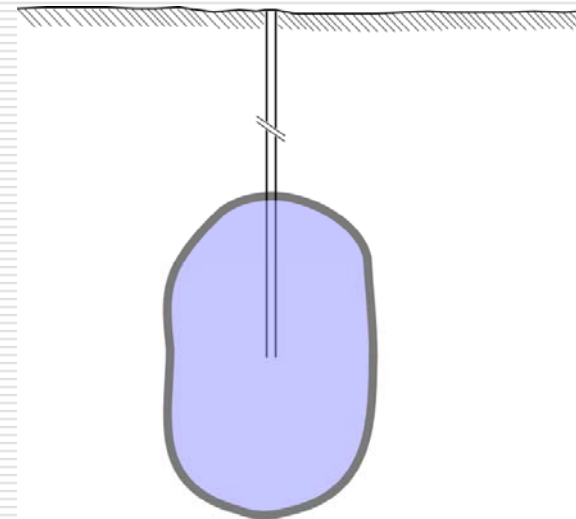


Characteristics of Underground Storage

- Converted oil & gas fields
- Converted aquifers



- Cavern storage (including carbonate cavern storage)



- High deliverability
 - High cycling frequency
 - Low cushion gas
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Previous Work

- An economic assessment was performed to establish optimum rock type and properties.
 - State by state geologic analysis was performed to identify potentially suitable areas for implementing acid dissolution.
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Purpose

- Identify suitable areas on a regional scale where acid dissolution may be implemented.
 - Relate these suitable areas to regional geology.
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Method

□ Basin analysis:

- Assess regional occurrence of the selected carbonate units meeting geologic and economic requirements.
- Identify tectonic features' effects on the occurrence of carbonate formations.

□ Local site investigations:

- Assess the lithology and suitability of the carbonate formation or formations at a specific site using geophysical logs.
-

Geologic Background

- Appalachian Basin is classified as a foreland basin, which formed on the cratonic side of the collision zone during lithospheric flexure.¹
- Three major carbonate depositional events, occurring prior to or at the onset of the three major orogenies.
 1. Middle Ordovician Carbonates- prior to Taconic Orogeny.
 2. Lower Devonian/Middle Devonian Carbonates- prior to and during the Acadian Orogeny.
 3. Upper Mississippian Carbonates- prior to Alleghanian Orogeny.

¹ Dickinson, 1974; Allen et al., 1986, 1991; Klein, 1991; Sinclair, 1997

Carbonate Formations of the Appalachian Basin

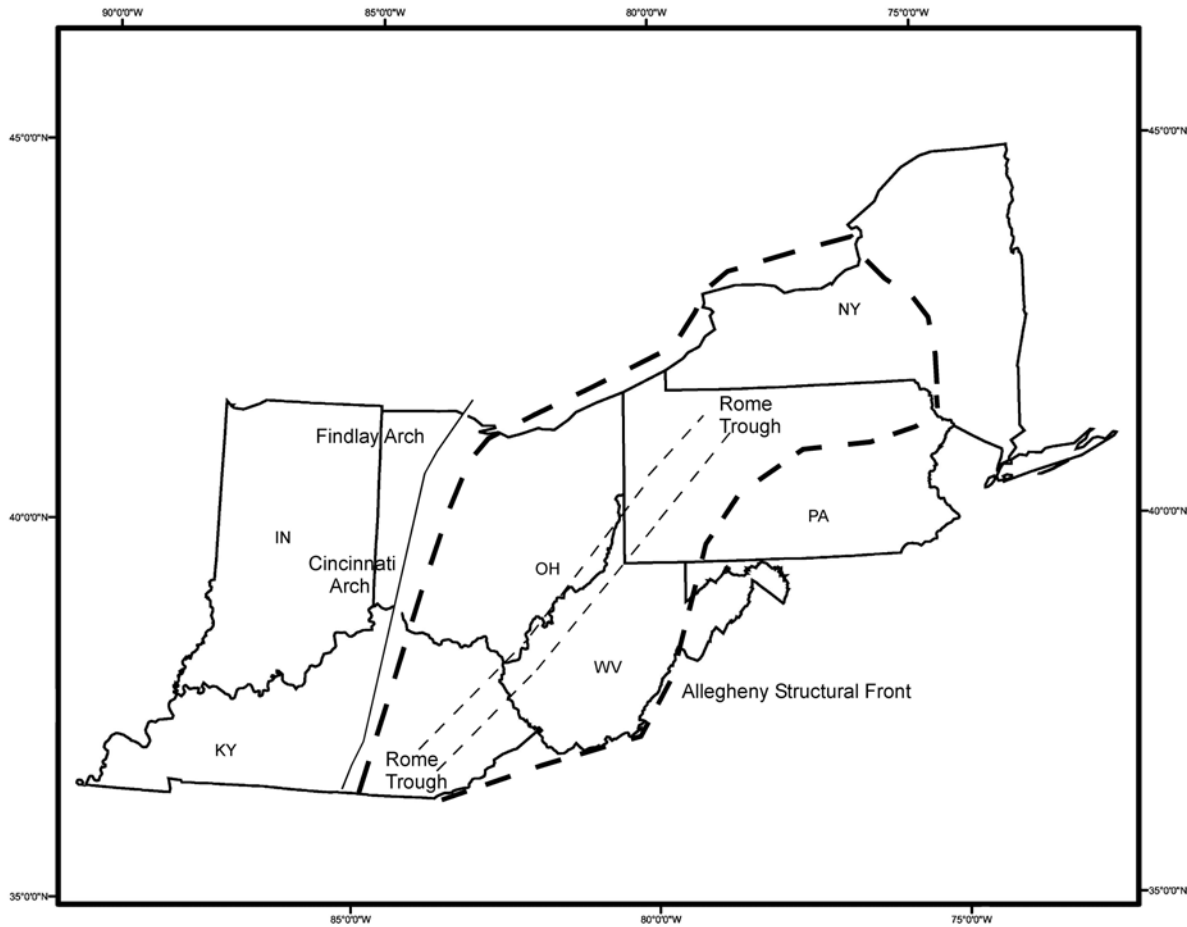
Age	Formation Name
Upper Mississippian	Greenbrier Limestone
Middle Devonian	Onondaga Limestone
Upper Silurian–Lower Devonian	Helderberg Group
Upper Silurian (Entire Silurian in Indiana)	Lockport Dolomite
Middle Ordovician	Trenton Group
Middle Ordovician	Black River Group
Upper Cambrian–Lower Ordovician	Knox Group

Basin Evolution

- The Appalachian Basin was affected by three major orogenies, which represent a cyclical pattern for evolution of the foreland basin.
 - Pre-collision quiescence and initial subsidence.*
 - Early orogenic collision and subsidence.
 - Middle to late orogenic uplift and subsidence.
 - Post collisional waning tectonism. ²

* Represents stage at which major carbonate units are deposited.

Major Basin Tectonic Features:

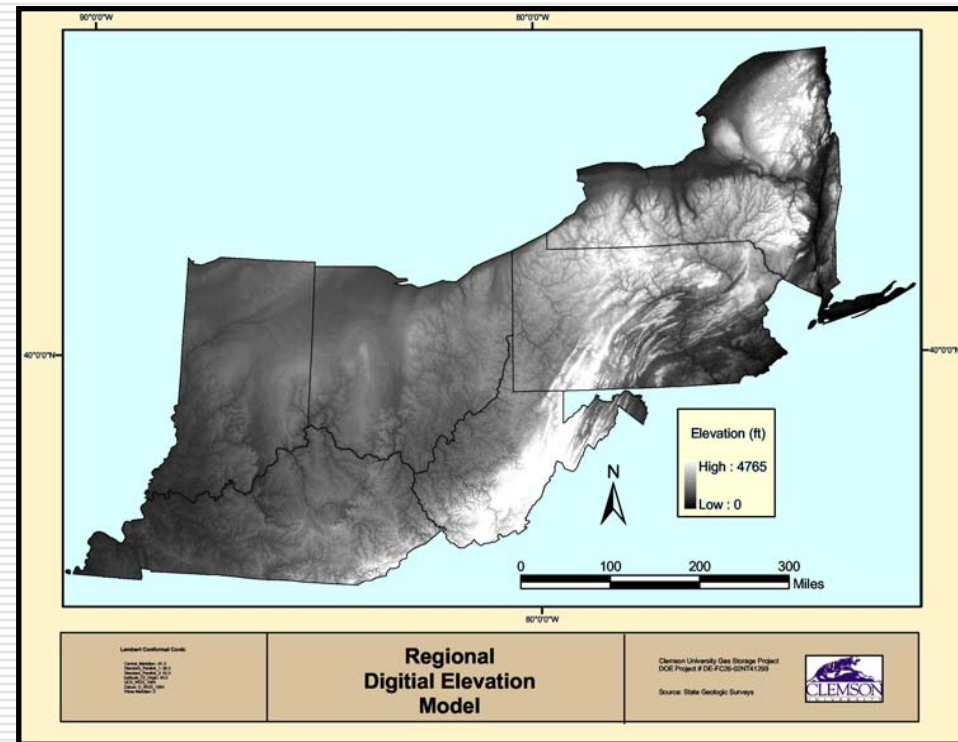


Effects of Major Tectonic Structures

- Cincinnati and Waverly Arches:
 - Source of uplift/erosion of sedimentary strata, resulting in decreased formation thicknesses or total erosion of formations.
 - Rome Trough:
 - Provides additional accommodation for carbonate deposition.
 - Resulted in localized fracturing of formations as a result of periodic normal fault activation.
 - Allegheny Structural Front:
 - Source of severe folding, faulting, and fracturing.
 - Eastern boundary of the Appalachian foreland basin.
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Basin Analysis: Methods

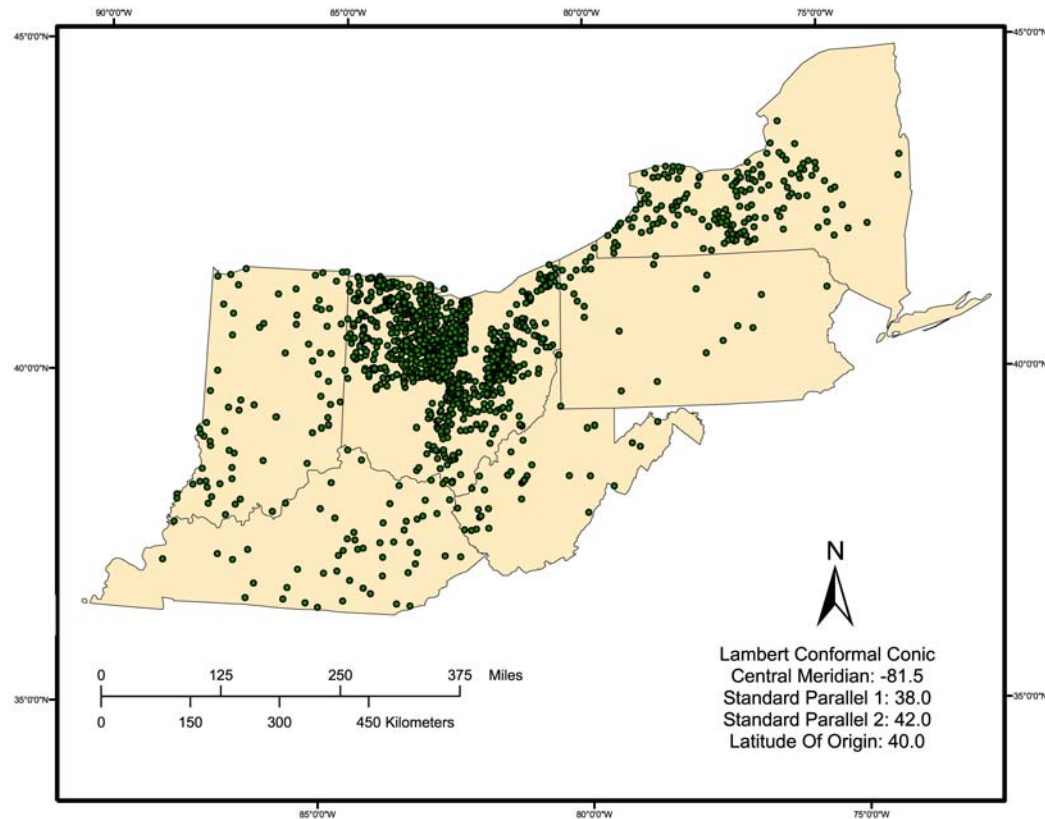
- Data were obtained from several state geologic surveys and industry partners. These data included locations, formation tops, and formation thickness. These data augmented the existing database used in previous work.³
- DEM data were obtained from the USGS on a 1° scale and combined to form a basin-wide DEM.



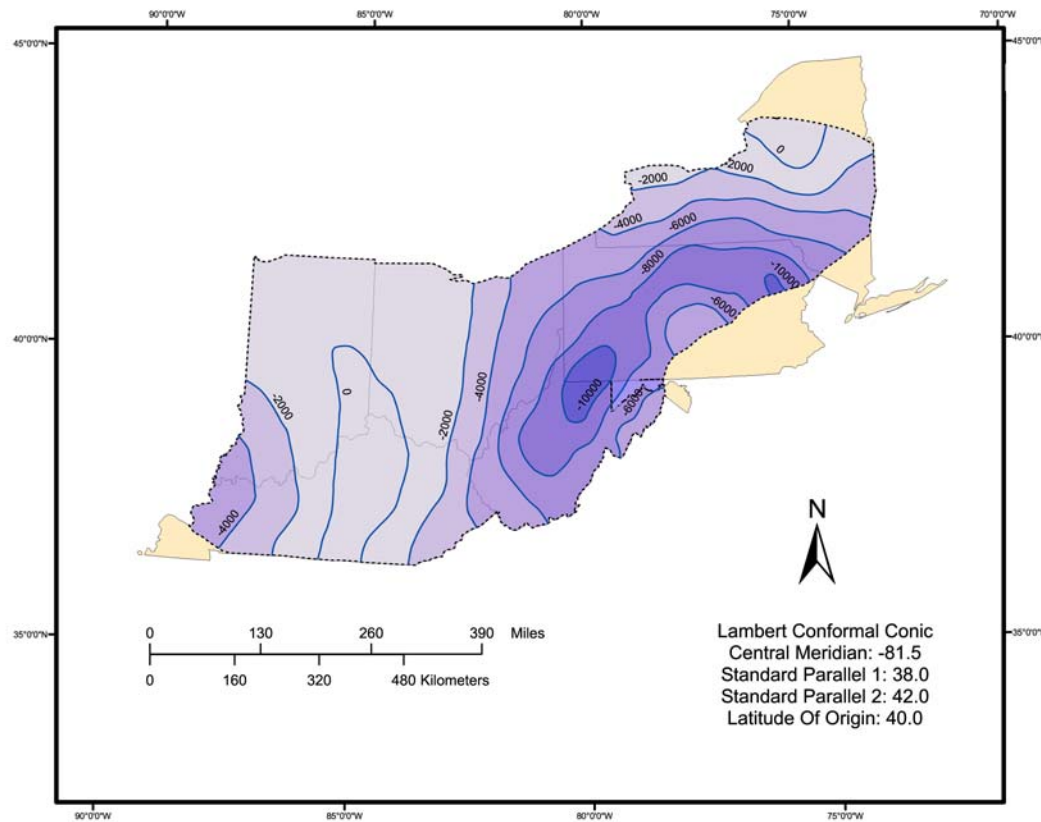
Basin Analysis: Methods

- Interpolation and smoothing techniques were used in GIS to create structure and thickness maps.
 - Depth maps were constructed in GIS by subtracting the structure maps from the basin DEM.
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Basin Analysis: Well Control Map for the Trenton Group

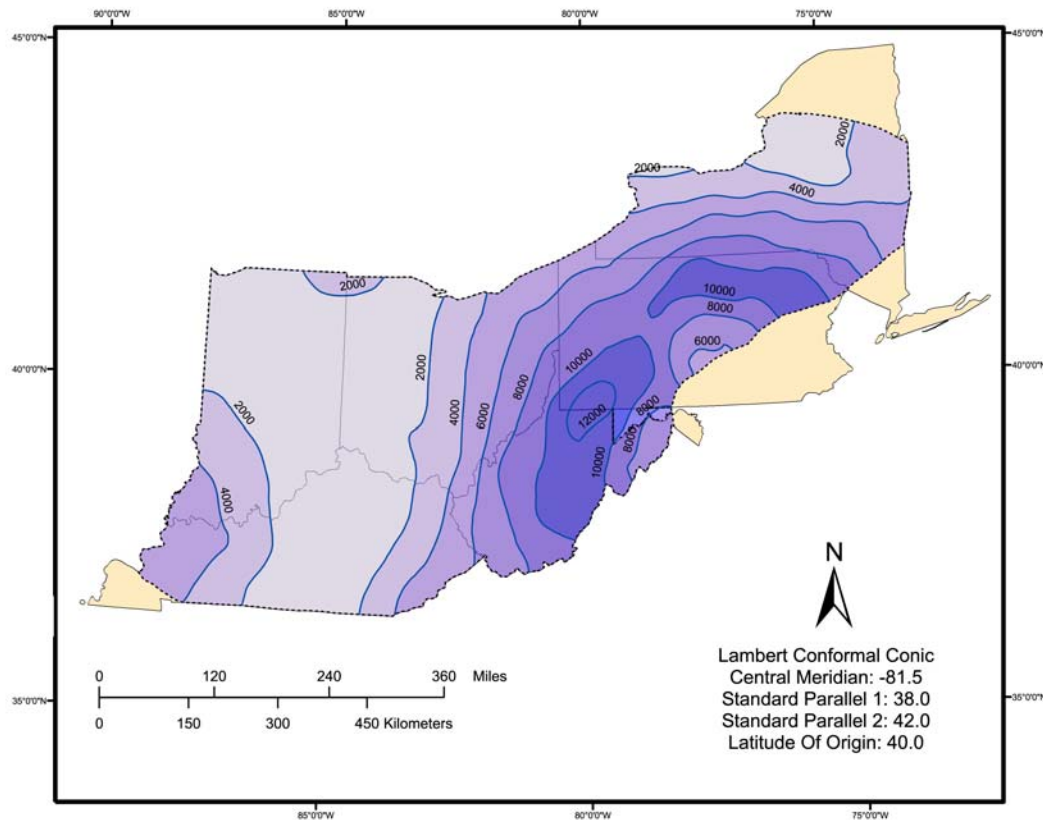


Basin Analysis: Structure Contour Map of the Trenton Group



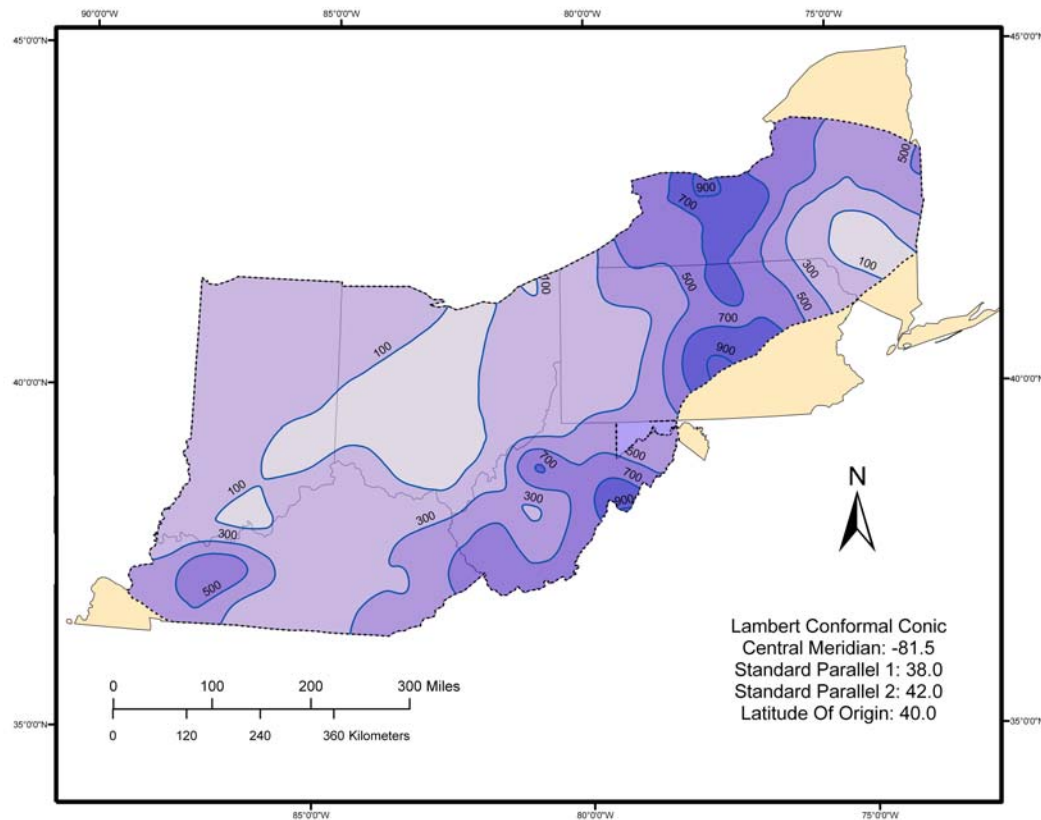
Datum is mean sea-level, sub-sea elevations are in feet, and the contour interval is 2000 feet.

Basin Analysis: Depth Contour Map of the Trenton Group



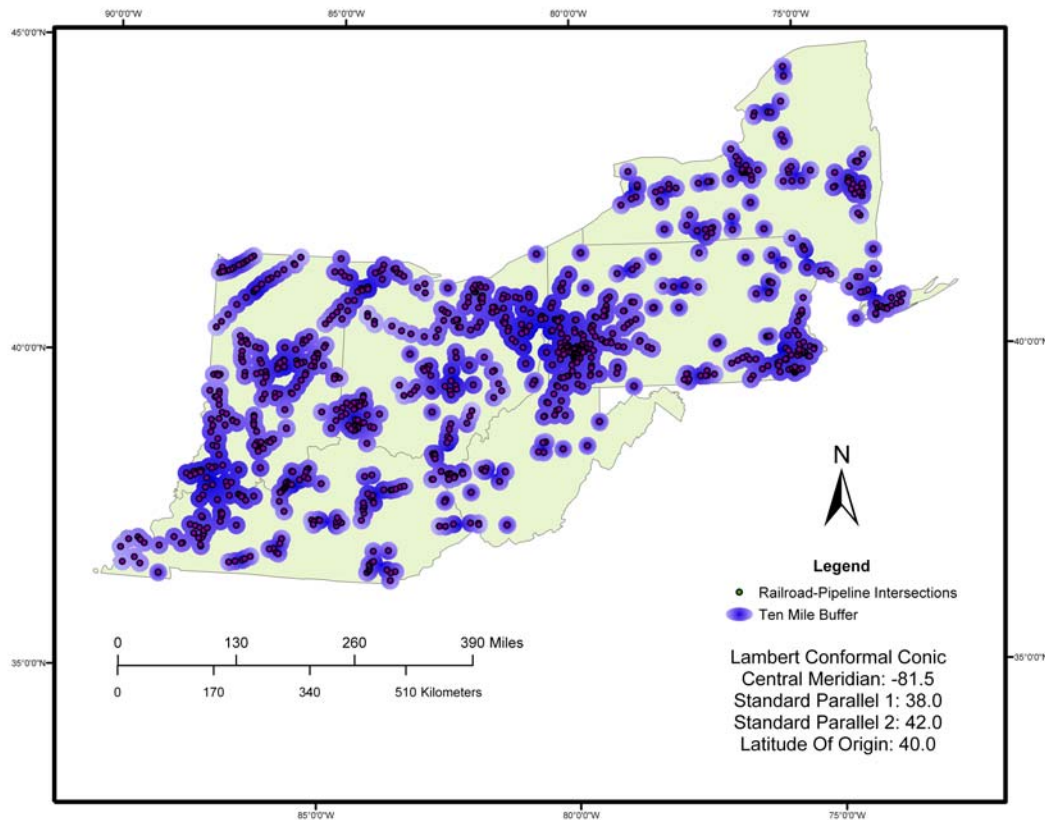
Depth maps were constructed by subtracting the structure map from the DEM. Depths are given in feet, and the contour interval is 2000 feet.

Basin Analysis: Thickness Contour Map of the Trenton Group

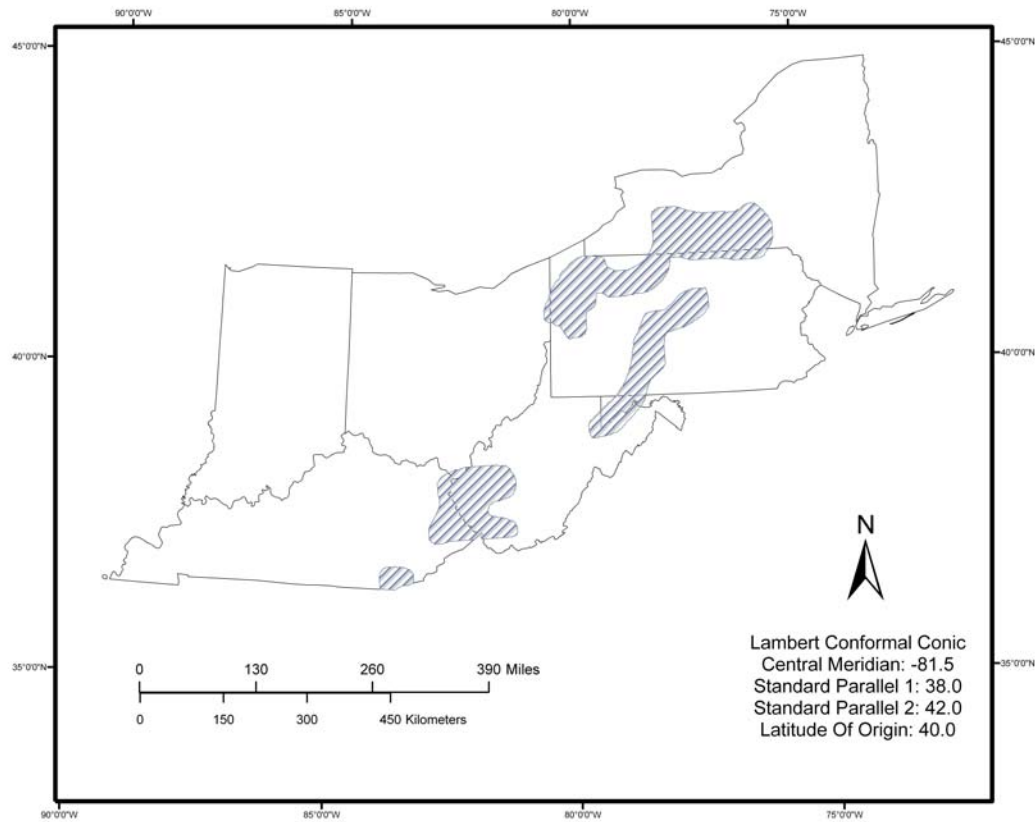


Thicknesses are in feet and the contour interval is 200 feet.

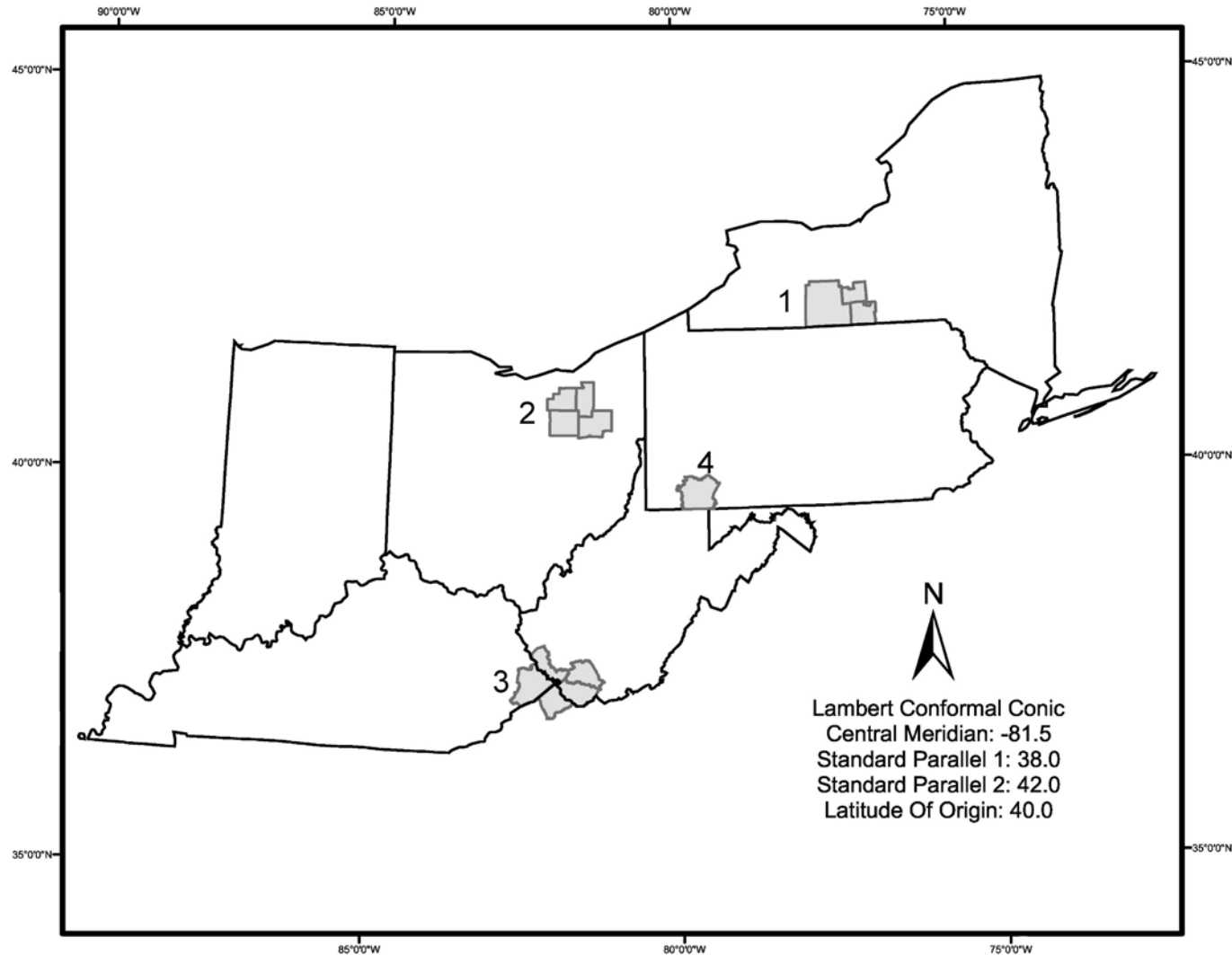
Basin Analysis: Railroad-Pipeline Intersections



Basin Analysis: Suitability Map of the Trenton Group



Basin Analysis: Summary

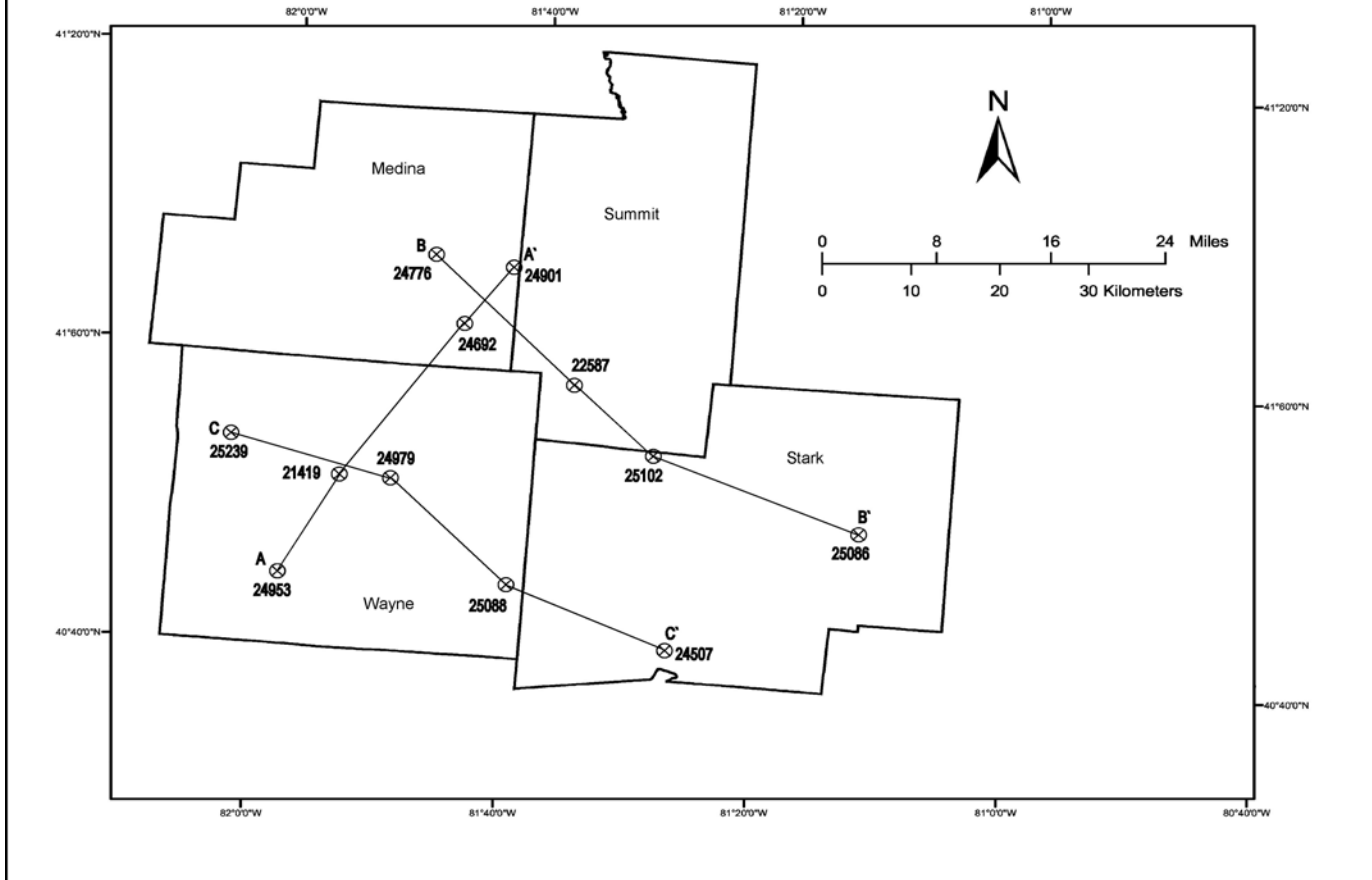


1-Trenton-Black River Gps. in southern NY, **2**- Trenton-Black River Gps. in northeastern OH, **3**- Greenbrier Ls. in eastern KY and southwestern WV, and **4**- Helderberg Gp. in southwestern PA.

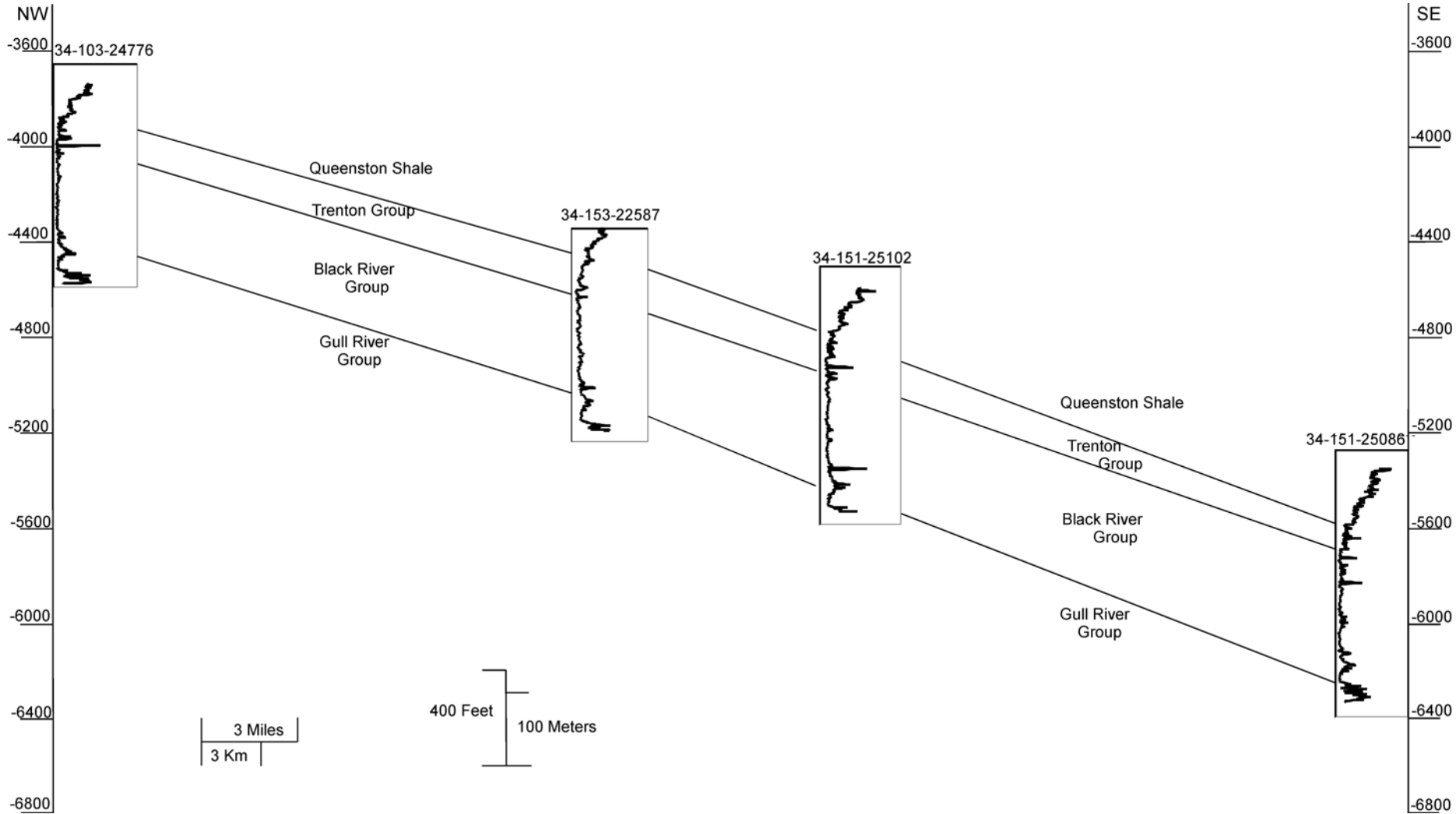
Local Site Investigation: Methodology

- Included an in-depth examination of lithology, geology, and stratigraphy to assess the suitability of acid dissolution implementation.
 - Construction of cross-sections and localized formation structure maps to convey stratigraphy and local geology.
 - Use of geophysical logs to examine lithology of the formation.
 - Caliper, gamma ray, bulk density, neutron porosity, and photoelectric logs were used.
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Local Analysis: Ohio Index Map

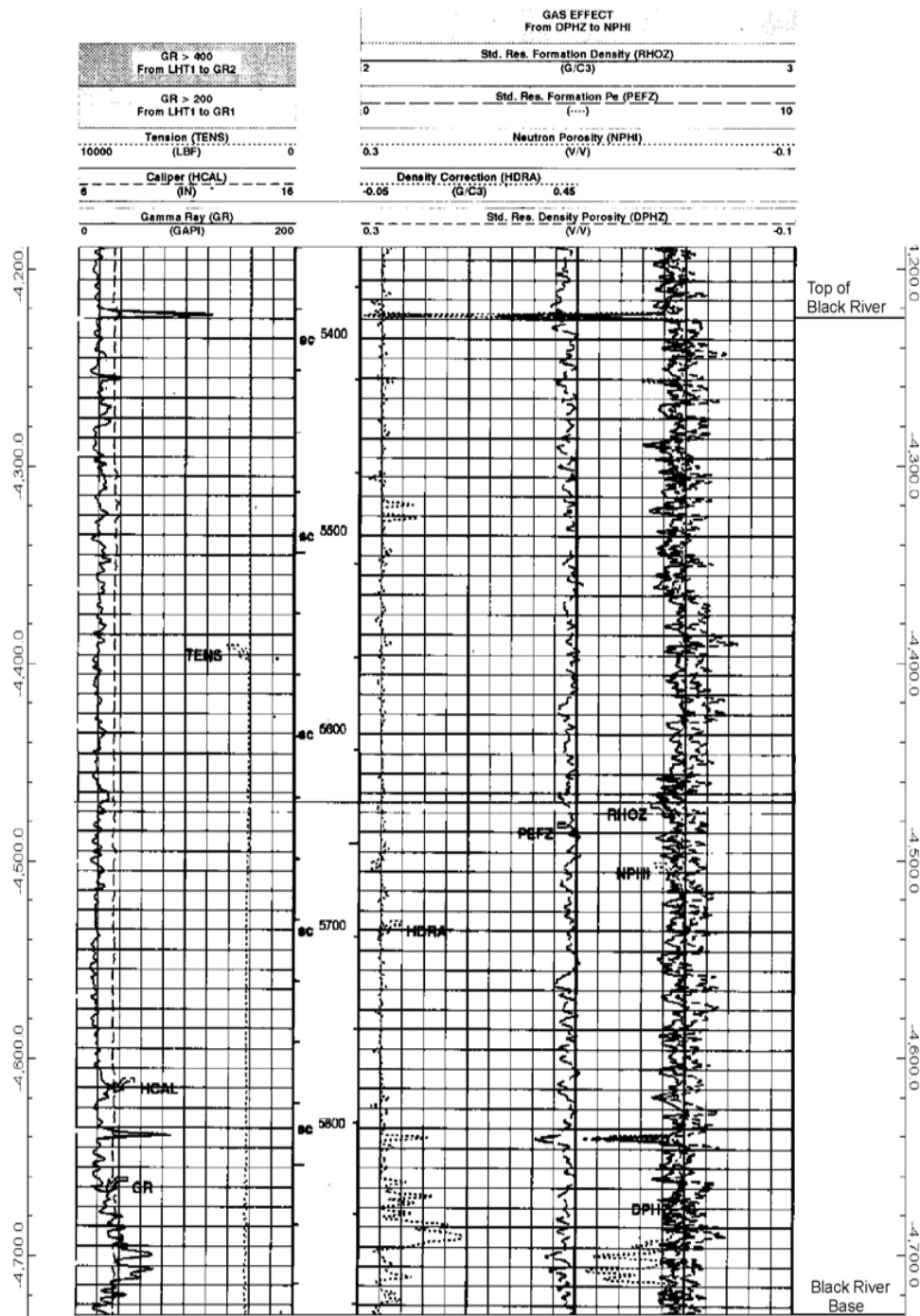


Local Analysis: Ohio Cross-section B-B'



Black River Gp.

- Log Suite from well 34-103-24901, taken from cross-section A-A`.
- Sub-sea elevations are given on the sides in feet.
- Logged depth is given in the center in feet.



Local Site Analysis: Ohio Summary

Formation/ Location	Occurrence of Sand	Occurrence of Shale	Occurrence of Dolomitic Zones	Occurrence of Fracture Zones
Trenton Group	Rare	Common	Rare	Rare
Black River Gp.	Rare	Rare	Rare	Rare

Rare indicates observed between 0% and 30% of the time in logs.

Common indicates observed between 30% and 70% of the time in logs.

Abundant indicates observed between 70% and 100% of the time in logs.

Local Site Summary

Formation/ Location	Occurrence of Sand	Occurrence of Shale	Occurrence of Dolomitic Zones	Occurrence of Fracture Zones
Greenbrier/ Southwestern WV and eastern KY	Common	Abundant- restricted to upper part of unit.	Rare	Rare
Helderberg Gp./ Southwest PA	Common- restricted to upper part of unit.	Rare	Rare	Abundant on anticlines to Rare off anticlines
Trenton Gp/ Southern NY	Rare	Rare	Common- restricted to lower portion of unit.	Common
Trenton Gp/ Northeastern OH	Rare	Common	Rare	Rare
Black River Gp./ Southern NY	Rare	Rare	Common	Common
Black River Gp./ Northeastern OH	Rare	Rare	Rare	Rare

Rare indicates observed between 0% and 30% of the time in logs.

Common indicates observed between 30% and 70% of the time in logs.

Abundant indicates observed between 70% and 100% of the time in logs.

Conclusions

- The basin analysis indicated suitable areas for the five limestone formations, where implementation of acid dissolution was suitable.
 - Local site studies confirmed suitability within the following specific areas.
 - The Greenbrier Ls. in western WV and eastern KY.
 - The Helderberg Gp. in southwestern PA.
 - The Trenton Gp. in southern NY.
 - The Black River Gp. in northeastern OH.
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Acknowledgments

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 - Cabot Oil and Gas
 - Columbia Natural Resources

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QUESTIONS ?
