APPALACHIAN STORAGE HUB (ASH) STUDY

Reservoir Characterization, Rating Parameters and Ranking Efforts

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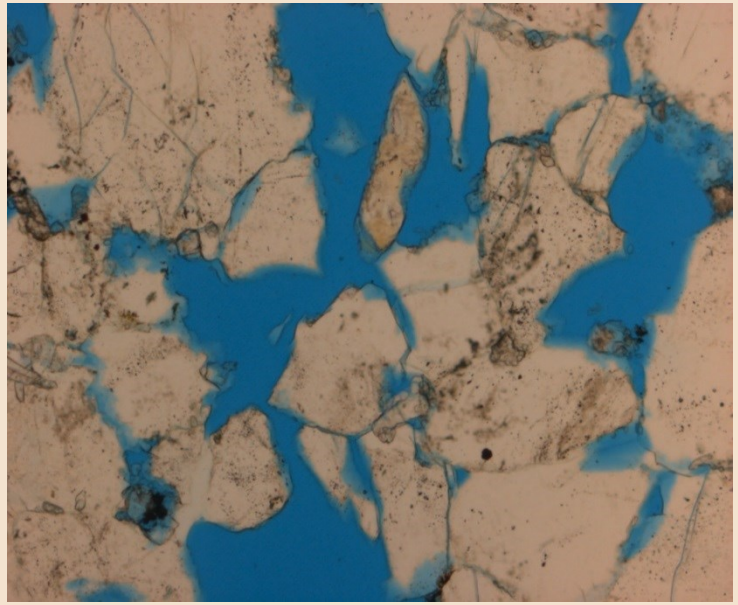
GEOLOGIC INTERVALS OF INTEREST

System/Age	Interval	Description	Storage Type
Mississippian	Greenbrier Limestone	Limestone comprised of multiple carbonate facies	Mined-rock cavern
Lower Mississippian-Devonian	Keener to Berea	Multiple sandstones of variable location, thickness and extent	Depleted gas reservoirs
Upper Devonian	Venango, Bradford and Elk groups	Multiple sandstones of variable location, thickness and extent	Depleted gas reservoirs
Lower Devonian	Oriskany Sandstone	Regionally persistent sandstone	Depleted gas reservoir
Upper Silurian	Salina Group	Bedded salt formations	Salt cavern
Upper Silurian	Newburg sandstone	Localized sandstone equivalent to Salina C interval	Depleted gas reservoir
Lower Silurian	Clinton/Medina Group	Multiple sandstones of variable location, thickness and extent	Depleted gas reservoirs
Lower Ordovician - Upper Cambrian	Rose Run-Gatesburg sandstones	Regionally persistent sandstone	Depleted gas reservoirs

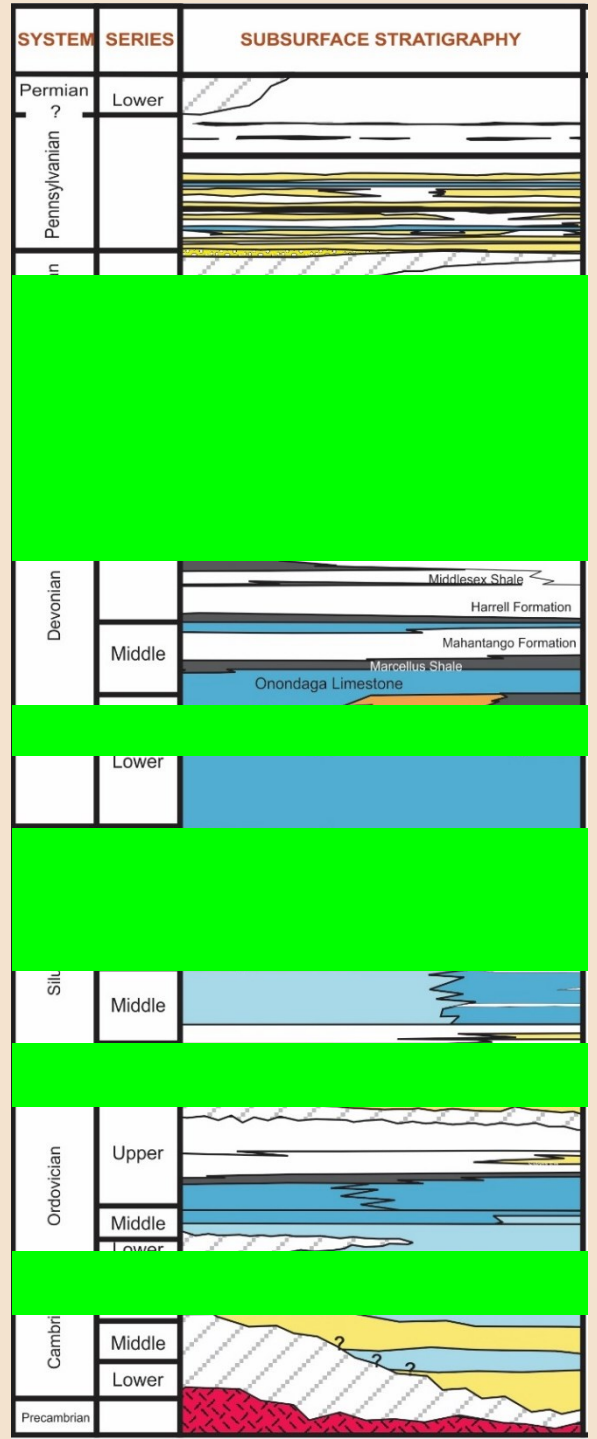
RESERVOIR CHARACTERIZATION

- Identify stratigraphic units or reservoirs with the best geologic and geomechanical properties to ensure long-term, secure storage of ethane and other NGLs
- Legacy data compilation
- Mapping
- Petrophysical calculations
- Qualitative thin section analyses



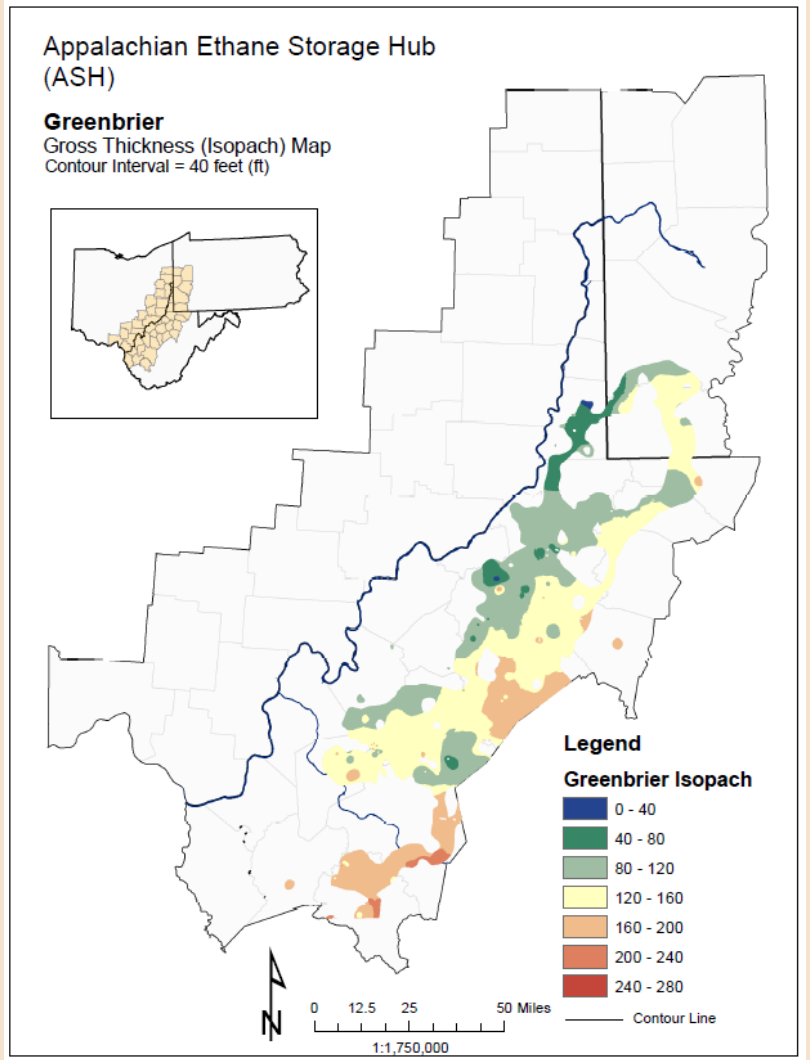
RESERVOIR CHARACTERIZATION EFFORTS

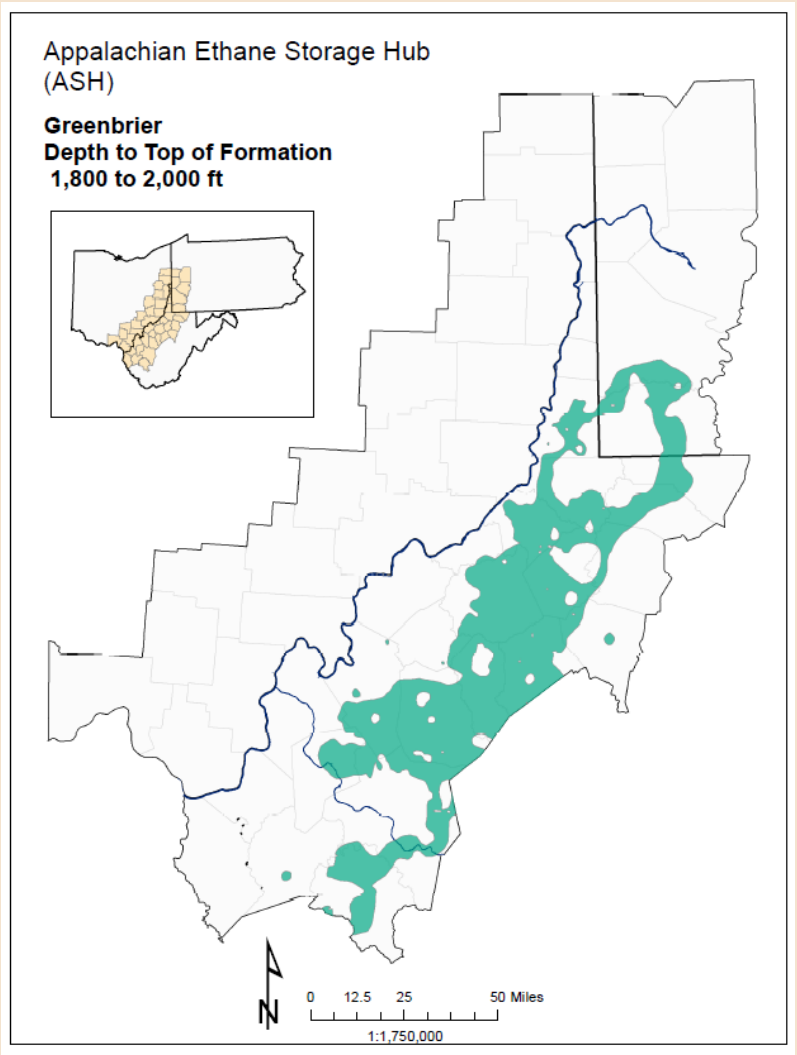
- Unique characterization efforts for each type of storage container
  - Depth – structure maps
  - Thickness – isopach maps
  - Extent – facies evaluation (Greenbrier) and clean vs. "dirty" salt intervals (Salina F4)
  - Preliminary assessment – screened field-level data for 2,700+ depleted gas reservoirs



GREENBRIER LIMESTONE (MINED-ROCK CAVERNS)

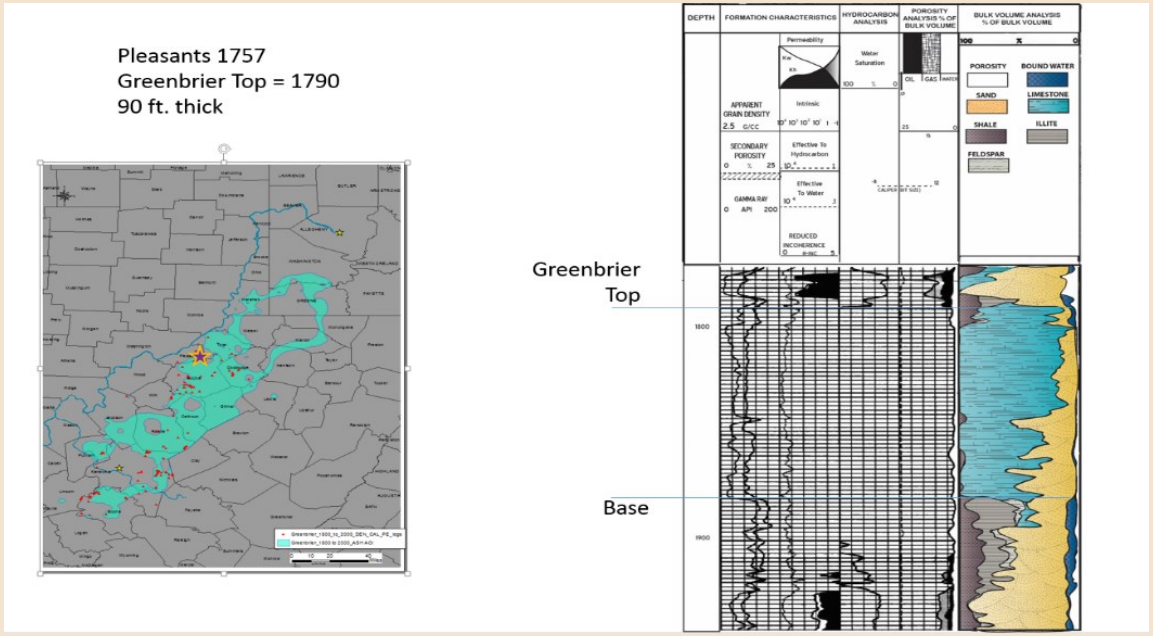
- Prepare regional structure and isopach contour maps
- Optimum net thicknesses – ≥40 ft
- Optimum depths – 1,800 – 2,000 ft

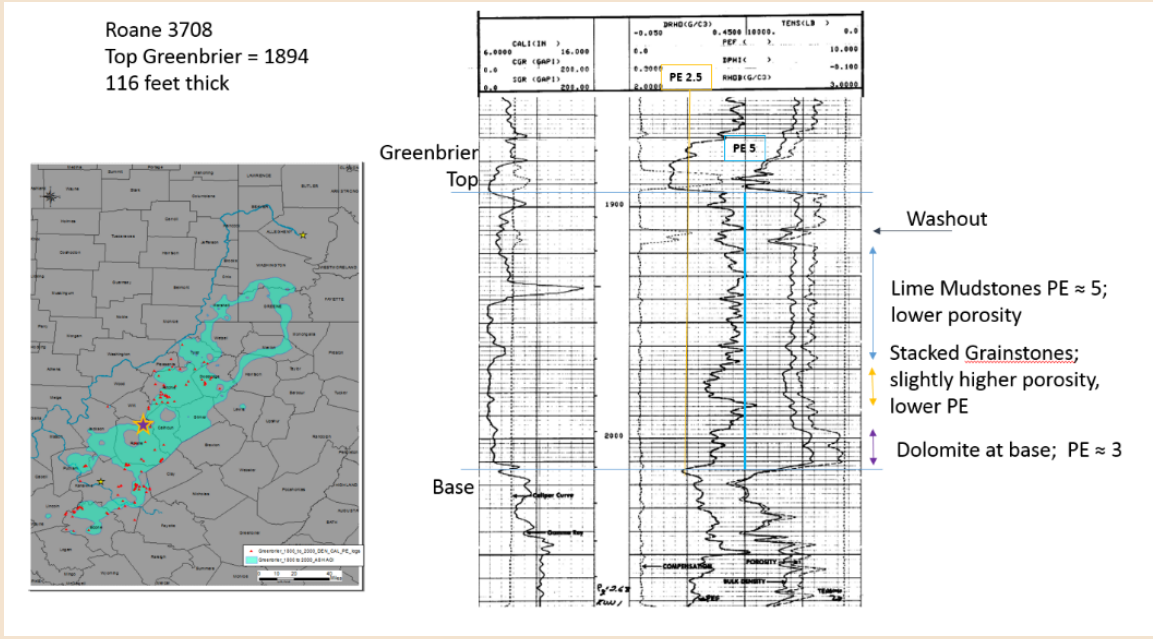




GREENBRIER LIMESTONE (MINED-ROCK CAVERNS)

- Increase data density by interpreting geophysical logs
- Bulk density, density porosity and photoelectric factor give indication of lithology

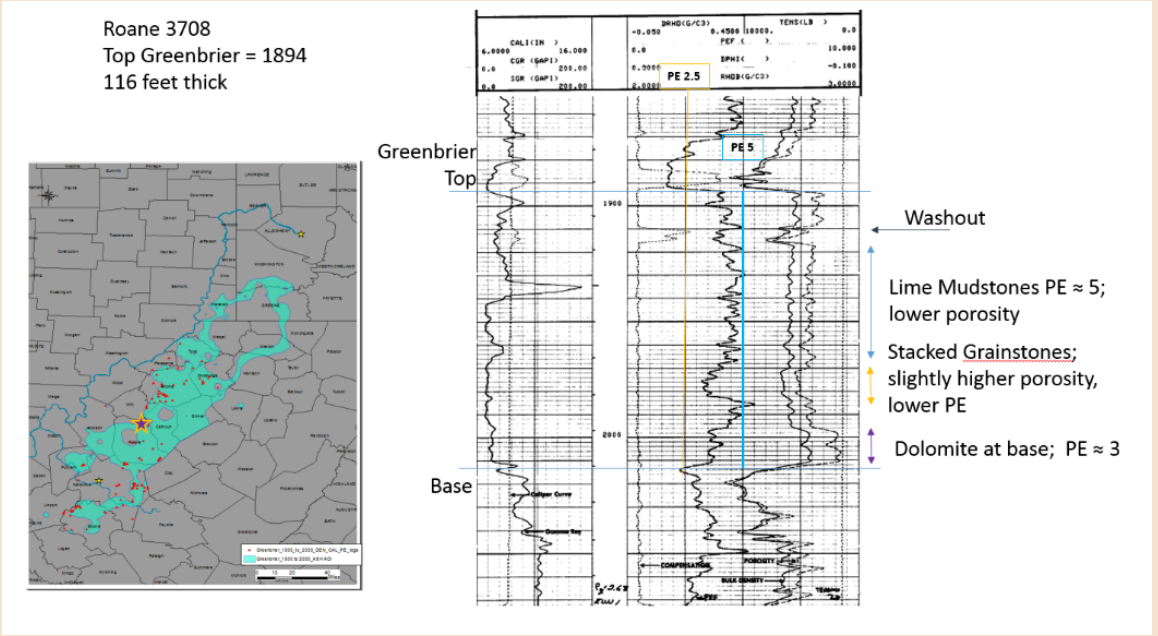


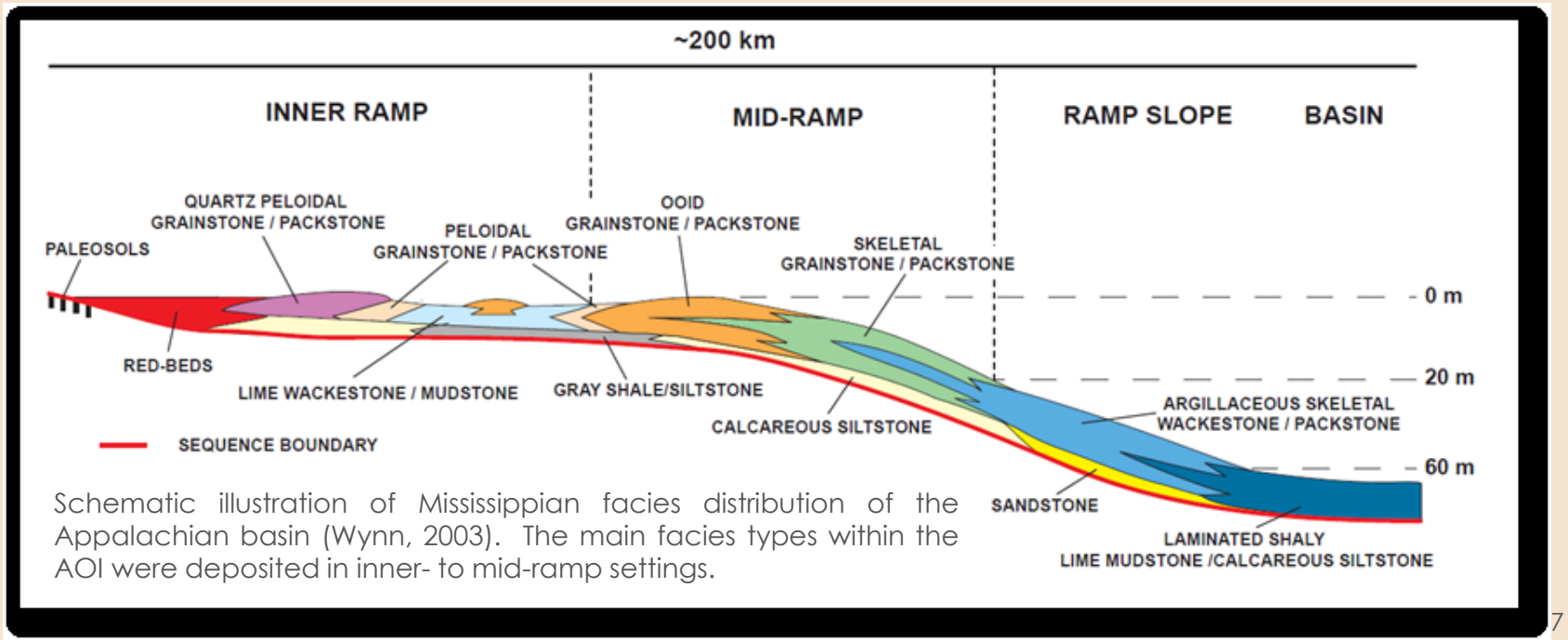


GREENBRIER LIMESTONE (MINED-ROCK CAVERNS)

- Characterize facies using geophysical logs (digital and raster) and drillers' descriptions

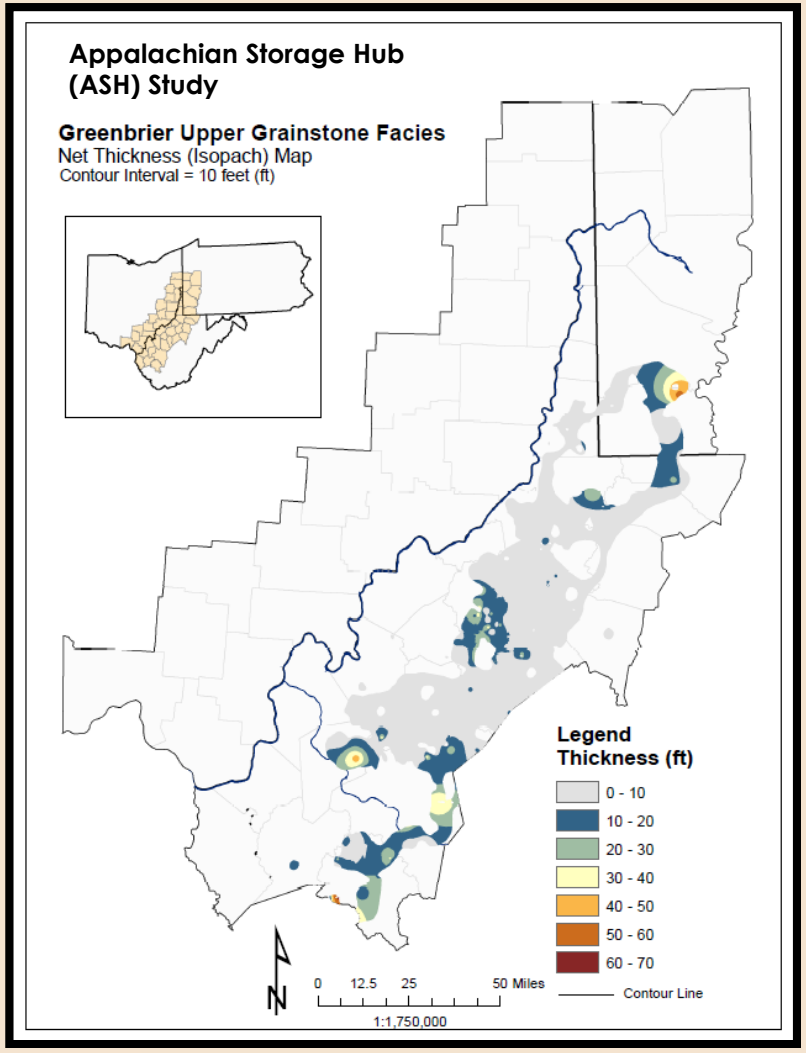
- Carbonate ramp environment of deposition

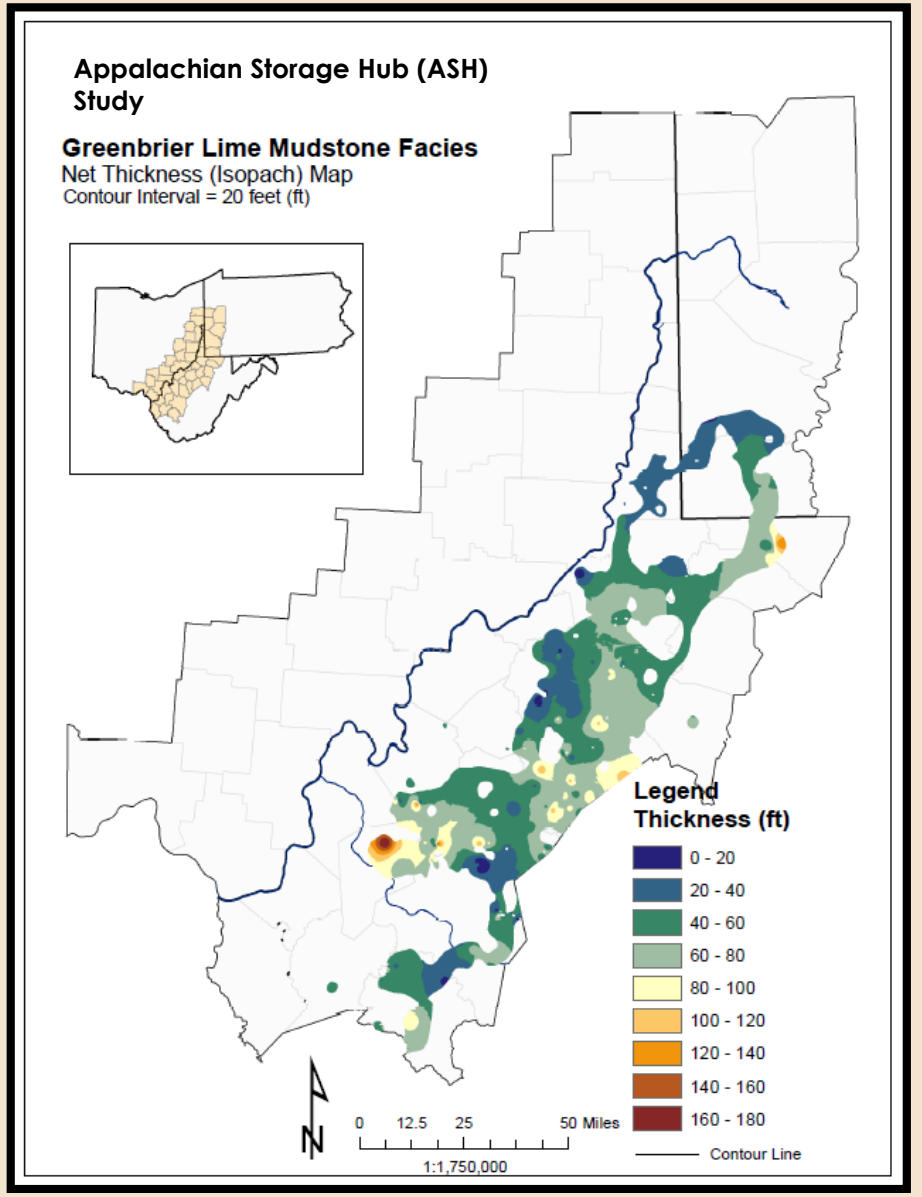


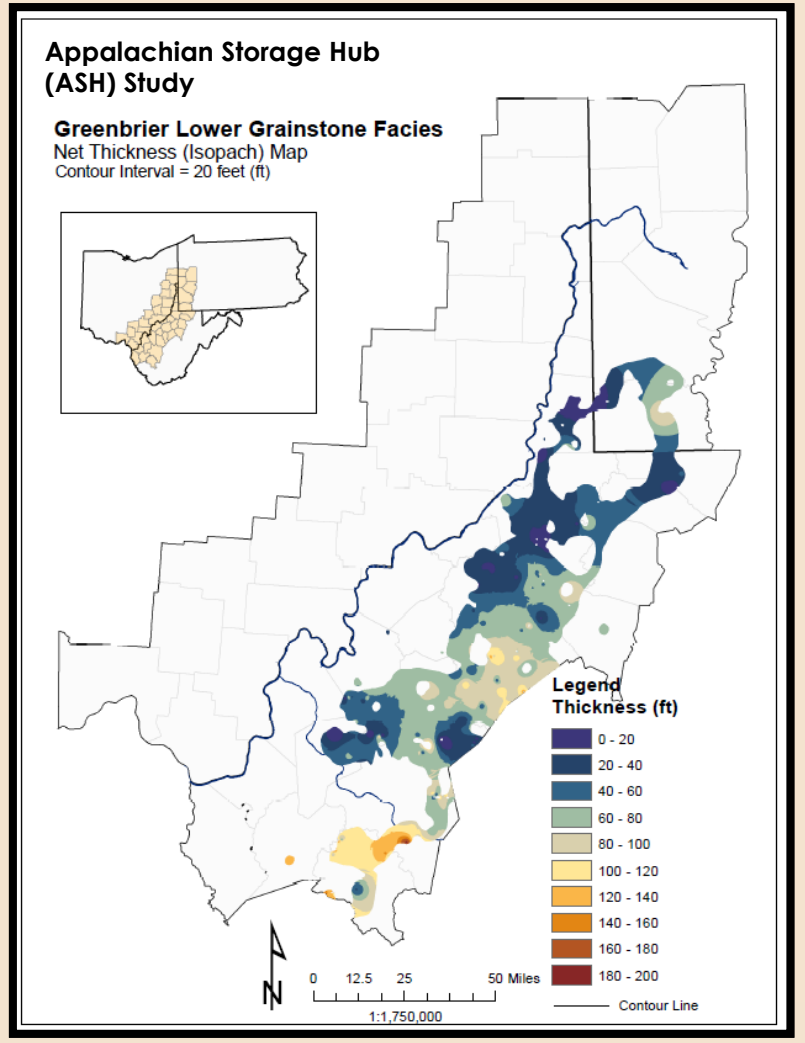


Schematic illustration of Mississippian facies distribution of the Appalachian basin (Wynn, 2003). The main facies types within the AOI were deposited in inner- to mid-ramp settings.

GREENBRIER LIMESTONE – THREE FACIES

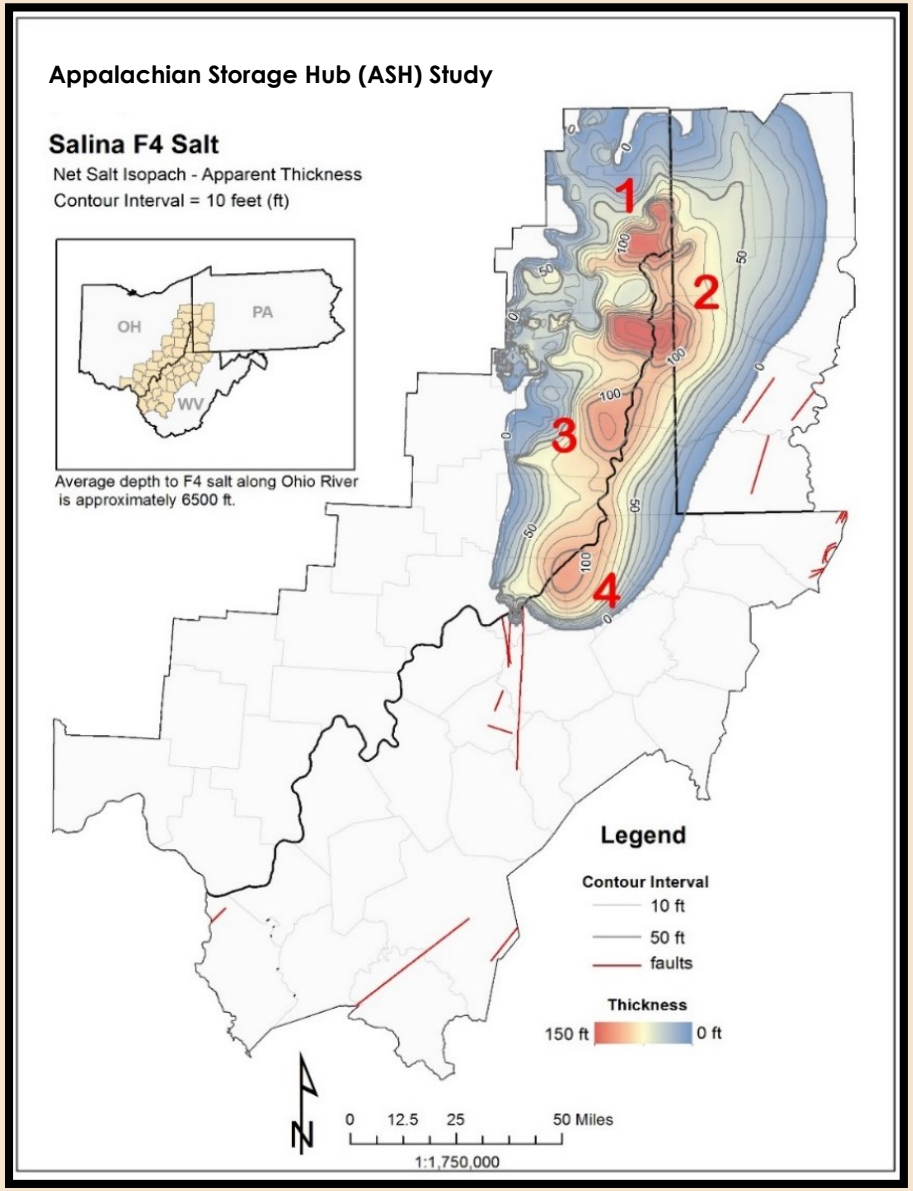






SALINA F4 SALT (SALT CAVERNS)

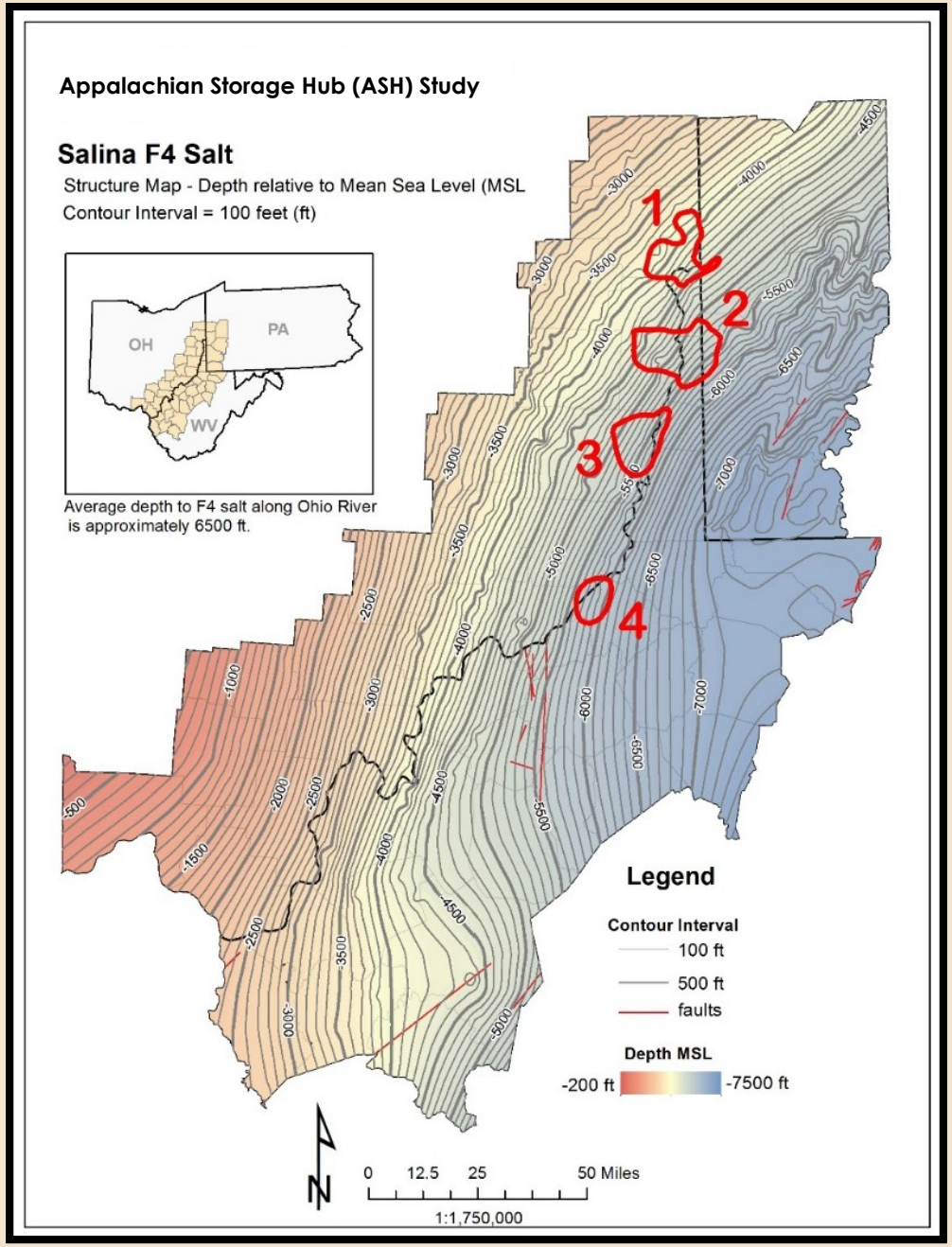
- Regional correlation and mapping efforts determined that the F4 Salt was the only Salina member likely to occur in thicknesses ≥100 ft
- Four areas (numbered sequentially from north to south) with net thicknesses ≥100 ft



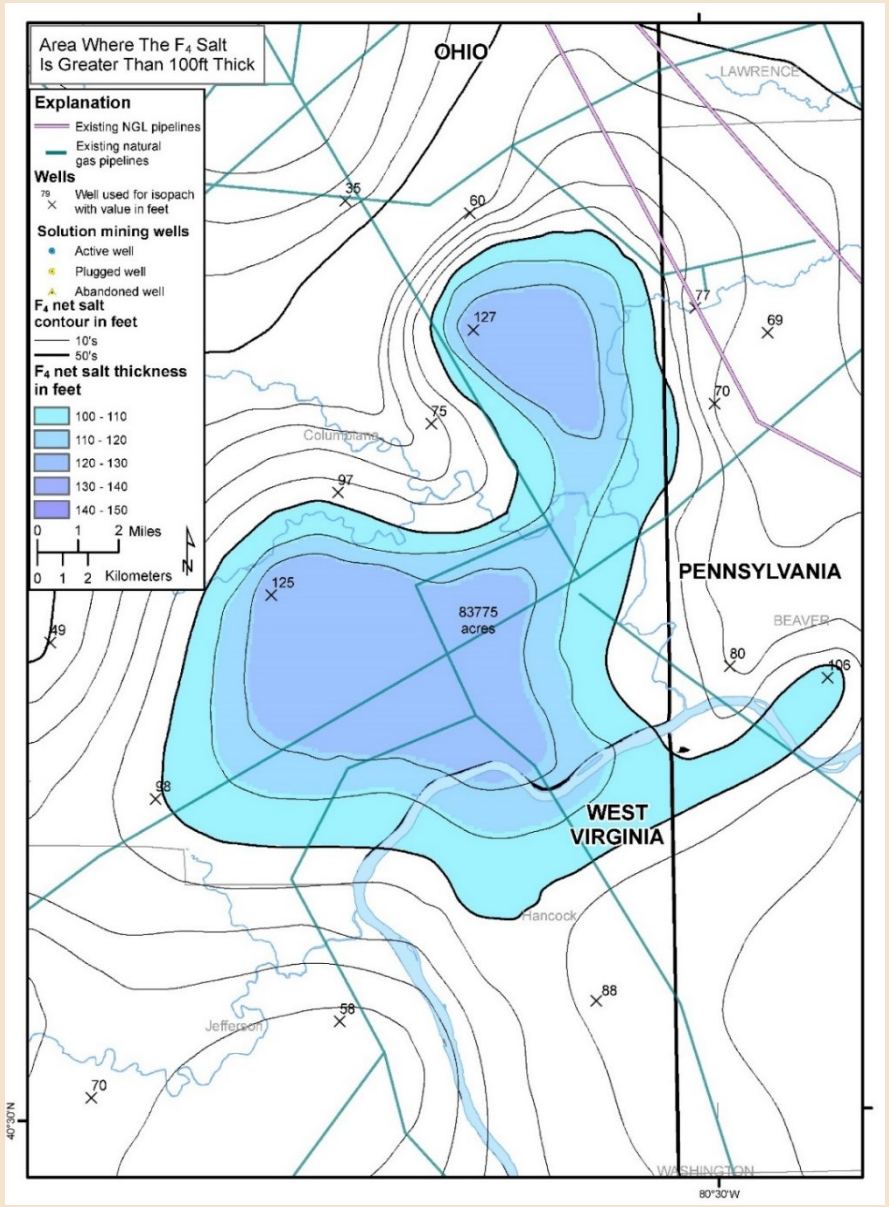
SALINA F4 SALT: DEPTH

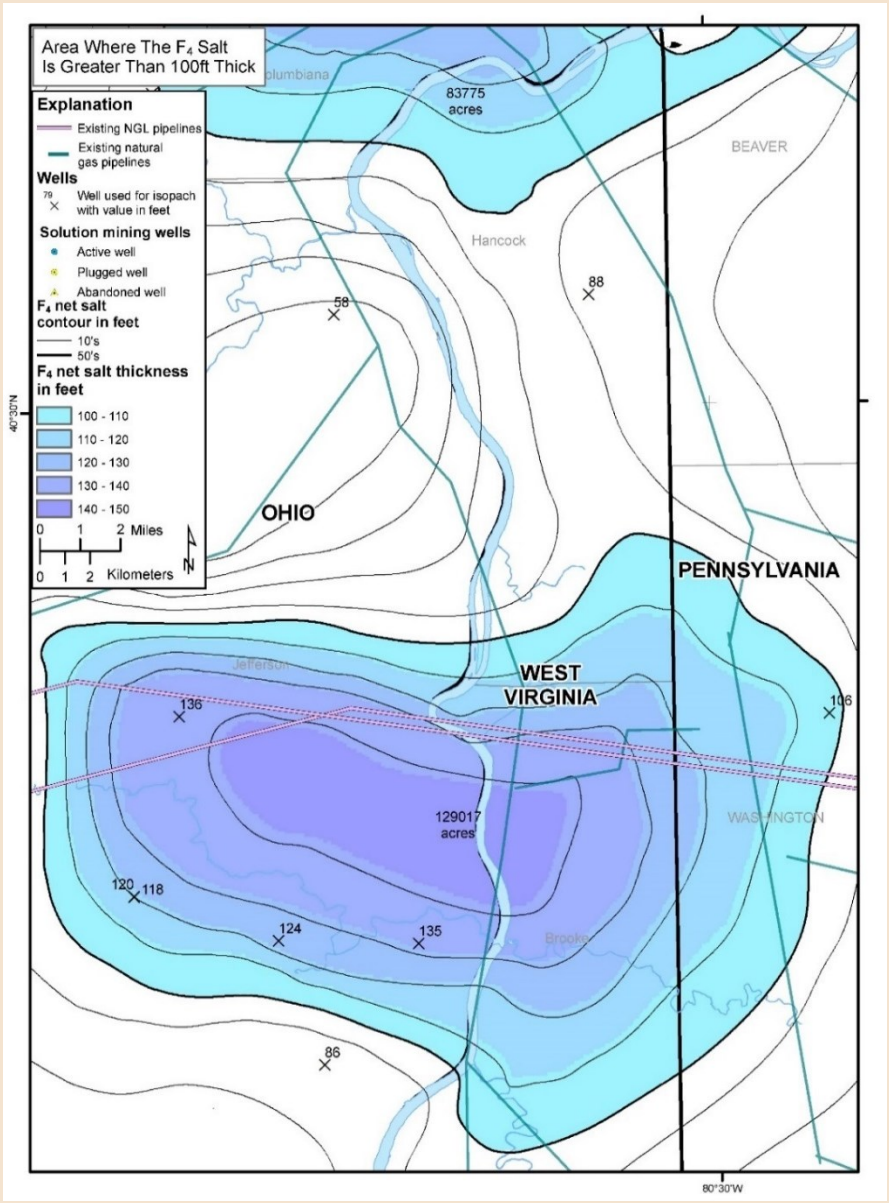
- Below deepest occurrence of fresh drinking water
- Not penetrated by many gas wells that could provide vertical migration routes
- Increase in salt plasticity limits lower cavern depths to <7,000 ft

Area	1	2	3	4
Average Depth (ft)	5,300	6,200	6,650	6,600

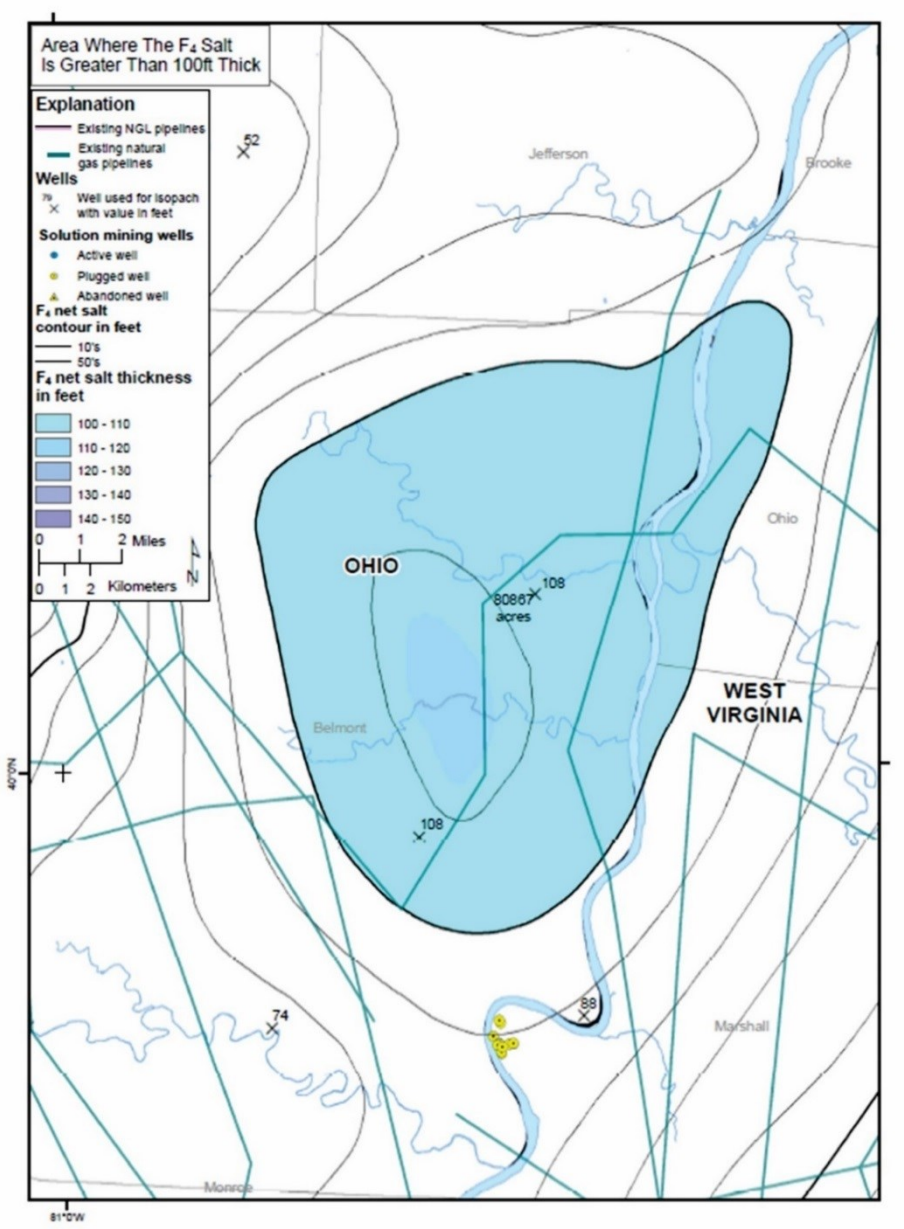


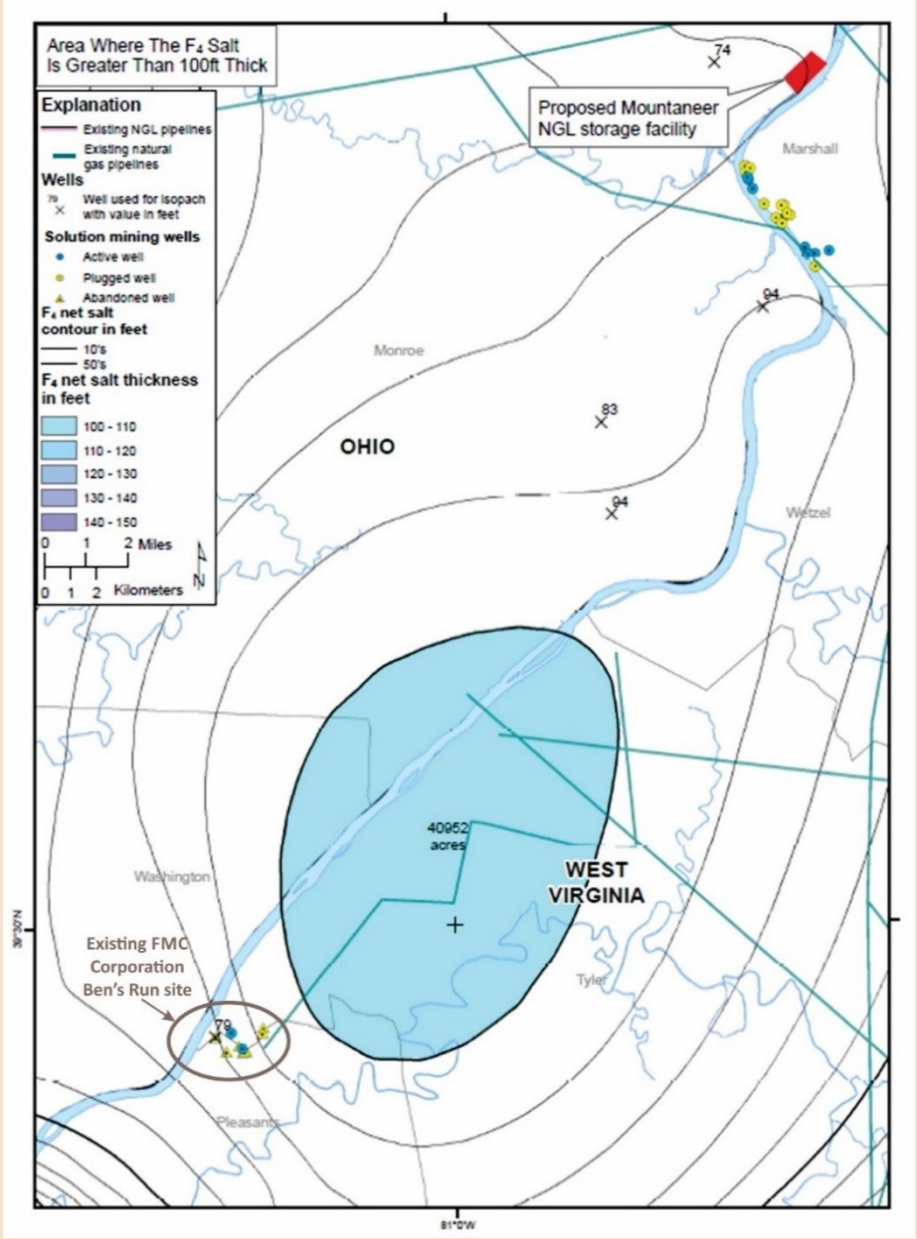
SALINA F4 SALT: AREAS 1 AND 2





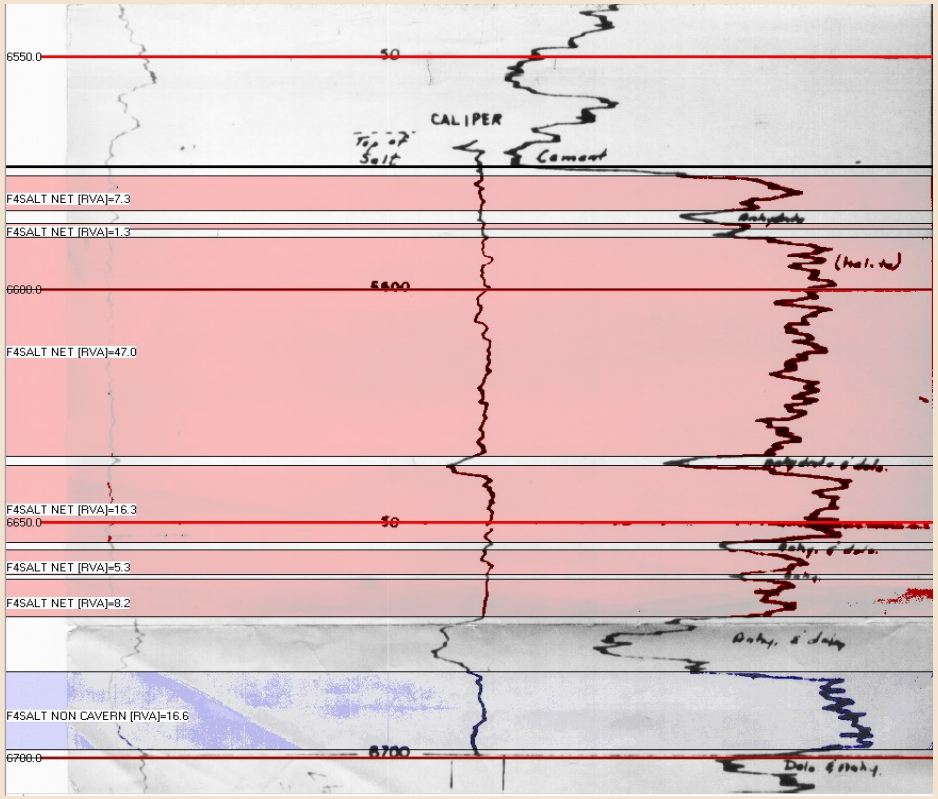
SALINA F4 SALT: AREAS 3 AND 4





SALINA F4 SALT (SALT CAVERNS)

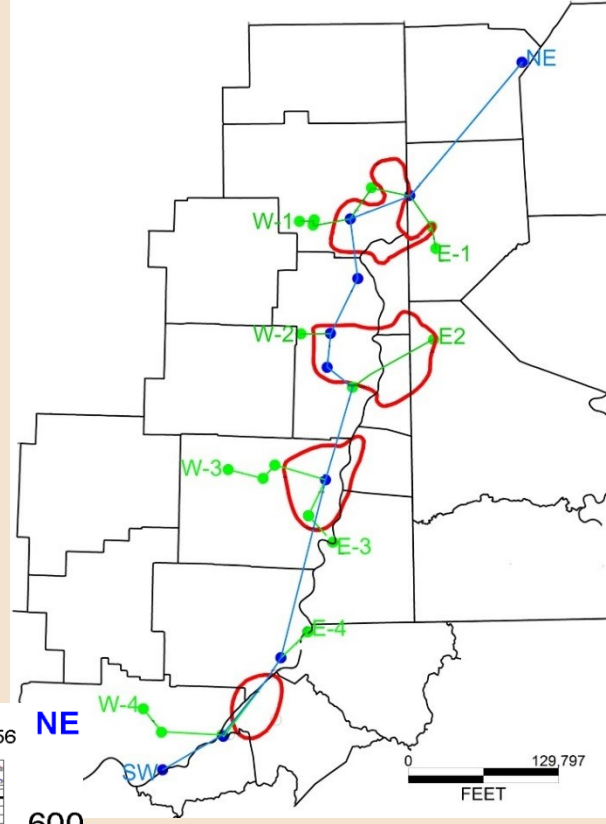
GEOPHYSICAL LOGS

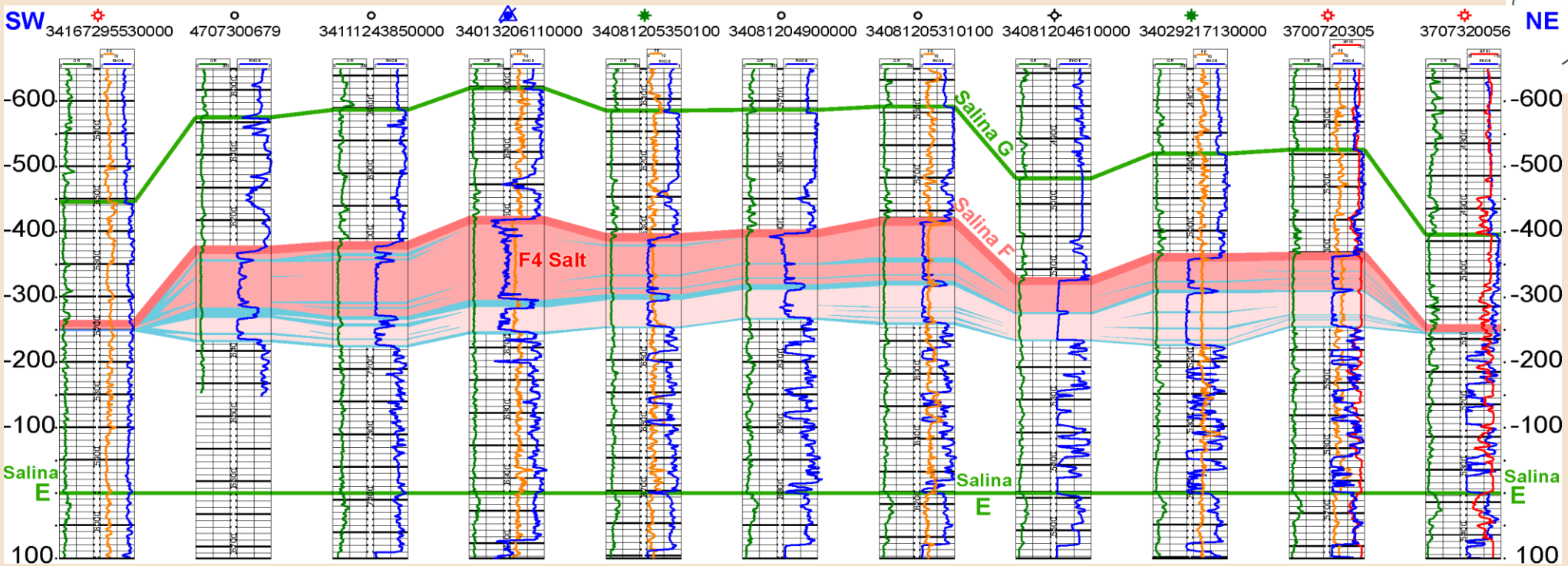


SALT CORE SAMPLES

SALINA F4 SALT: NET THICKNESS

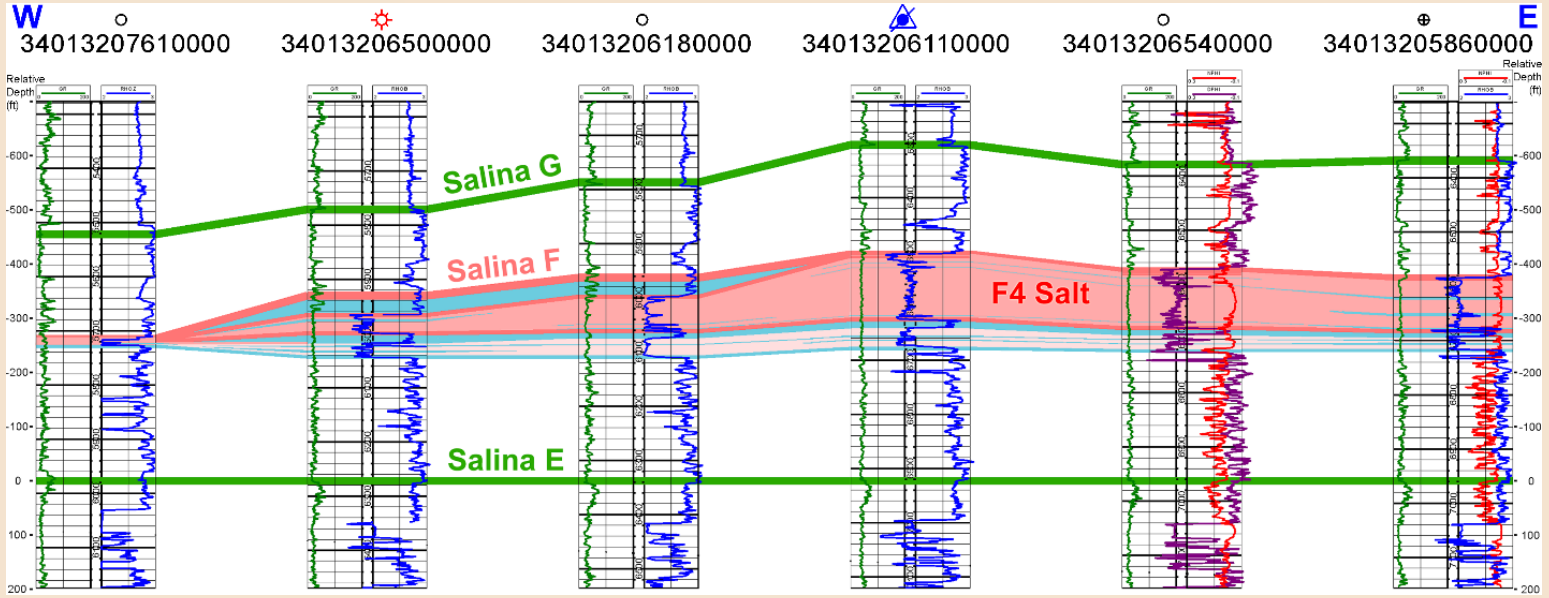
- Upper F4 Salt vs. lower salt
- Interbedded dolomite and anhydrite within larger salt package





SALINA F4 SALT: EXTENT

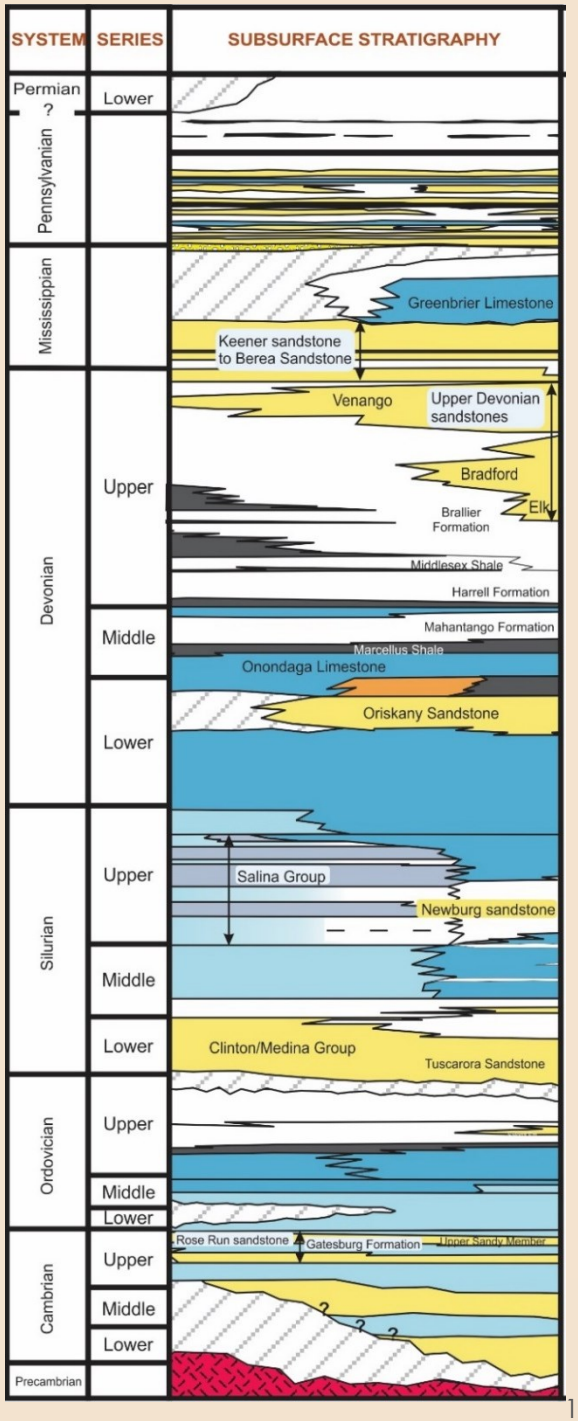
- Interbedded nature of salt with anhydrite and dolomite ("dirty" salt) is more extensive outside the 100-ft footprint
- Lateral migration pathways
- Roof collapse
- Casing integrity issues



- Pressure, temperature and cavern shape primarily affect cavern stability

PRELIMINARY ASSESSMENT OF DEPLETED GAS RESERVOIRS

- 2,700+ fields with sandstone reservoir data
- Of these, ~1,500 fields were ≥2,000 ft deep
- Preliminary rating efforts were used to pare down this dataset for more focused work



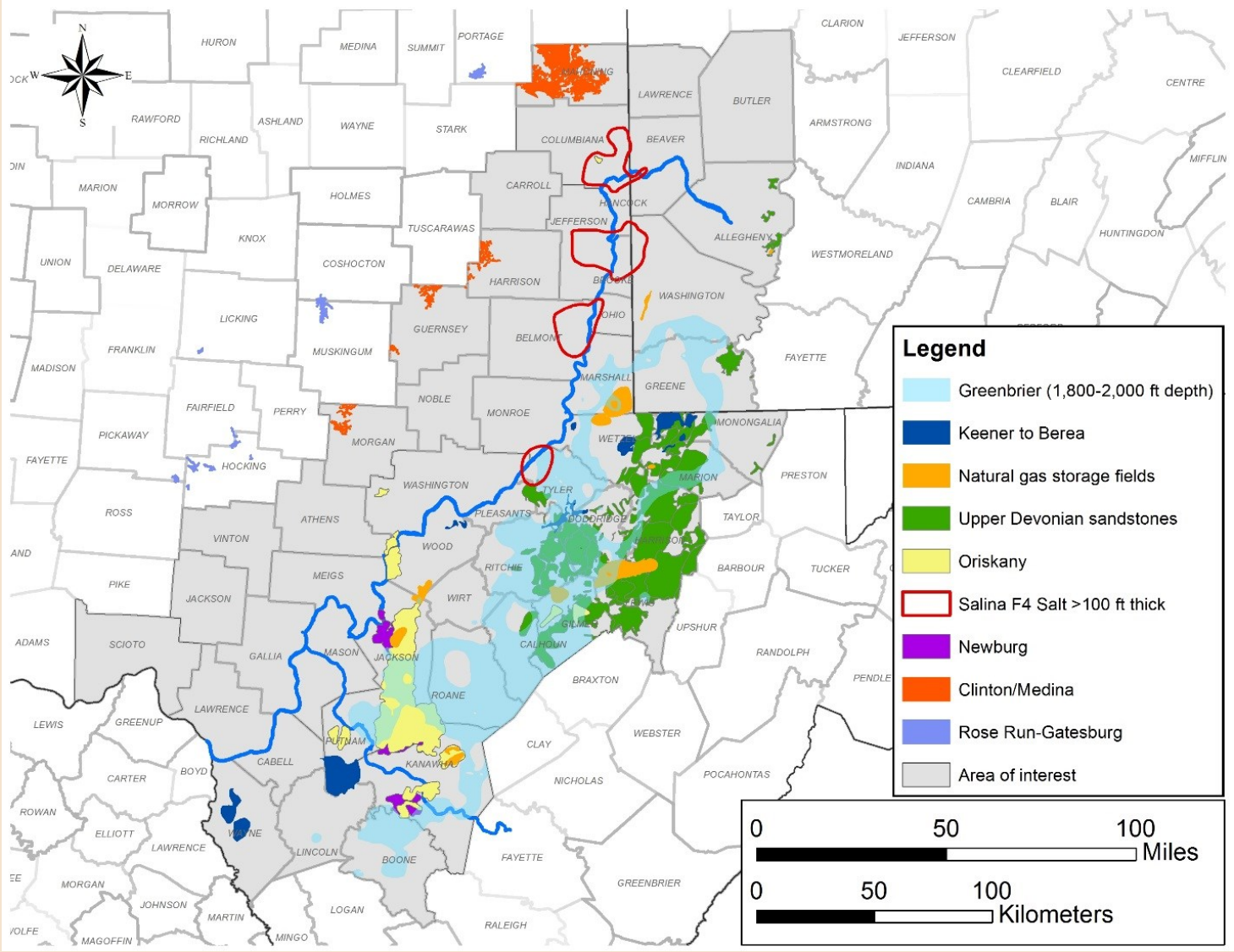
PRELIMINARY ASSESSMENT OF DEPLETED GAS RESERVOIRS

- Preliminary rating criteria
  - Distance to infrastructure
  - Acreage
  - Average depth
  - Average porosity
  - Net thickness
  - Permeability
  - Pressure
  - Stacked opportunity
  - Mode CO_2 storage

Criterion	Description	Range of Values
Distance to infrastructure >30 mi >20 mi but <=30 mi >5 mi but <=20 mi <=5 mi	Proximity of field to any of the existing or proposed pipeline infrastructure, as illustrated in Figure 4-26	 0 1 2 3
Acreage <=500 ac >500 ac but <=1,000 ac >1,000 ac but <=5,000 ac >5,000 ac	Measured size (or "footprint") of a field (ac)	 0 1 2 3
Average depth <=2,000 ft >5,000 ft >2,000 ft but <=3,500 ft >3,500 ft but <=5,000 ft	Average depth (ft) at which a field stores/stored natural gas, based on multiple wells completed in that field	 0 1 2 3

RESULTS OF PRELIMINARY ASSESSMENT

- 113 depleted gas fields
- 12 natural gas storage fields
- 5 limestone areas
- 4 salt areas



DETAILED RATING CRITERIA

Mined-Rock Caverns	Salt Caverns	Depleted Gas Reservoirs	Gas Storage Fields
Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure
Acreage	Acreage	Acreage	Acreage
Average depth	Average depth	Average depth	Average depth
Net Thickness	Net Thickness	Net Thickness	Net Thickness
Trap integrity	Trap integrity	Trap integrity	Trap integrity
Legacy well penetrations	Legacy well penetrations	Legacy well penetrations	Legacy well penetrations
Stacked opportunity	Stacked opportunity	Stacked opportunity	Stacked opportunity
	Pressure	Pressure	Pressure
		Average Porosity	Average Porosity
		Permeability	Permeability
		Mode CO_2 storage	Mode CO_2 storage
		Estimated cumulative gas production	Working gas capacity

RATING MINED-ROCK AND SALT CAVERNS

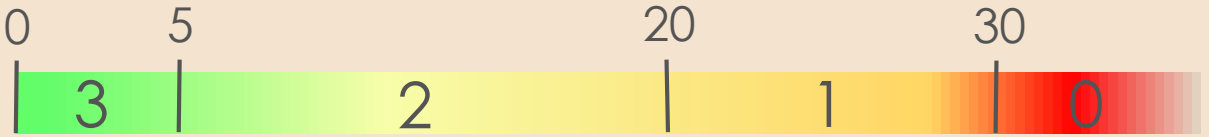
Mined-Rock Caverns	Salt Caverns	Depleted Gas Reservoirs	Gas Storage Fields
Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure
Acreage	Acreage	Acreage	Acreage
Average depth	Average depth	Average depth	Average depth
Net Thickness	Net Thickness	Net Thickness	Net Thickness
Trap integrity	Trap integrity	Trap integrity	Trap integrity
Legacy well penetrations	Legacy well penetrations	Legacy well penetrations	Legacy well penetrations
Stacked opportunity	Stacked opportunity	Stacked opportunity	Stacked opportunity
	Pressure	Pressure	Pressure
		Average Porosity	Average Porosity
		Permeability	Permeability
		Mode CO_2 storage	Mode CO_2 storage
		Estimated cumulative gas production	Working gas capacity

RATING DEPLETED GAS RESERVOIRS/FIELDS

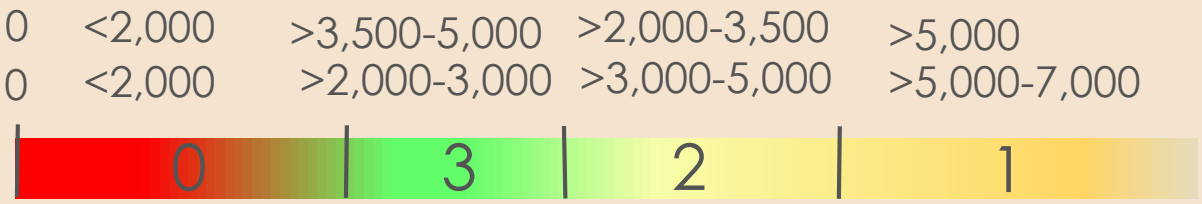
Mined Rock Caverns	Salt Caverns	Depleted Gas Reservoirs	Gas Storage Fields
Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure
Acreage	Acreage	Acreage	Acreage
Average depth	Average depth	Average depth	Average depth
Net Thickness	Net Thickness	Net Thickness	Net Thickness
Trap integrity	Trap integrity	Trap integrity	Trap integrity
Legacy well penetrations	Legacy well penetrations	Legacy well penetrations	Legacy well penetrations
Stacked opportunity	Stacked opportunity	Stacked opportunity	Stacked opportunity
	Pressure	Pressure	Pressure
		Average Porosity	Average Porosity
		Permeability	Permeability
		Mode CO_2 storage	Mode CO_2 storage
		Estimated cumulative gas production	Working gas capacity

DETAILED RATING CRITERIA

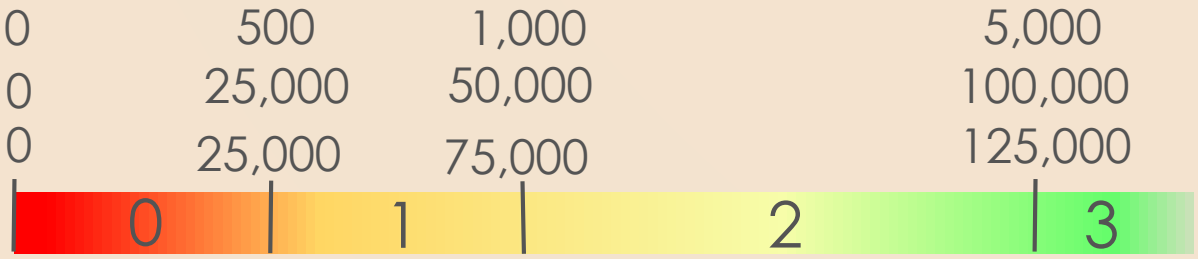
Distance to Infrastructure (mi):



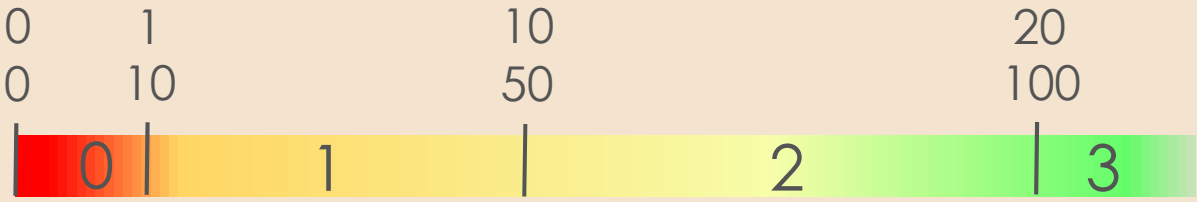
Average depth (ft) (gas fields):
(salt caverns):



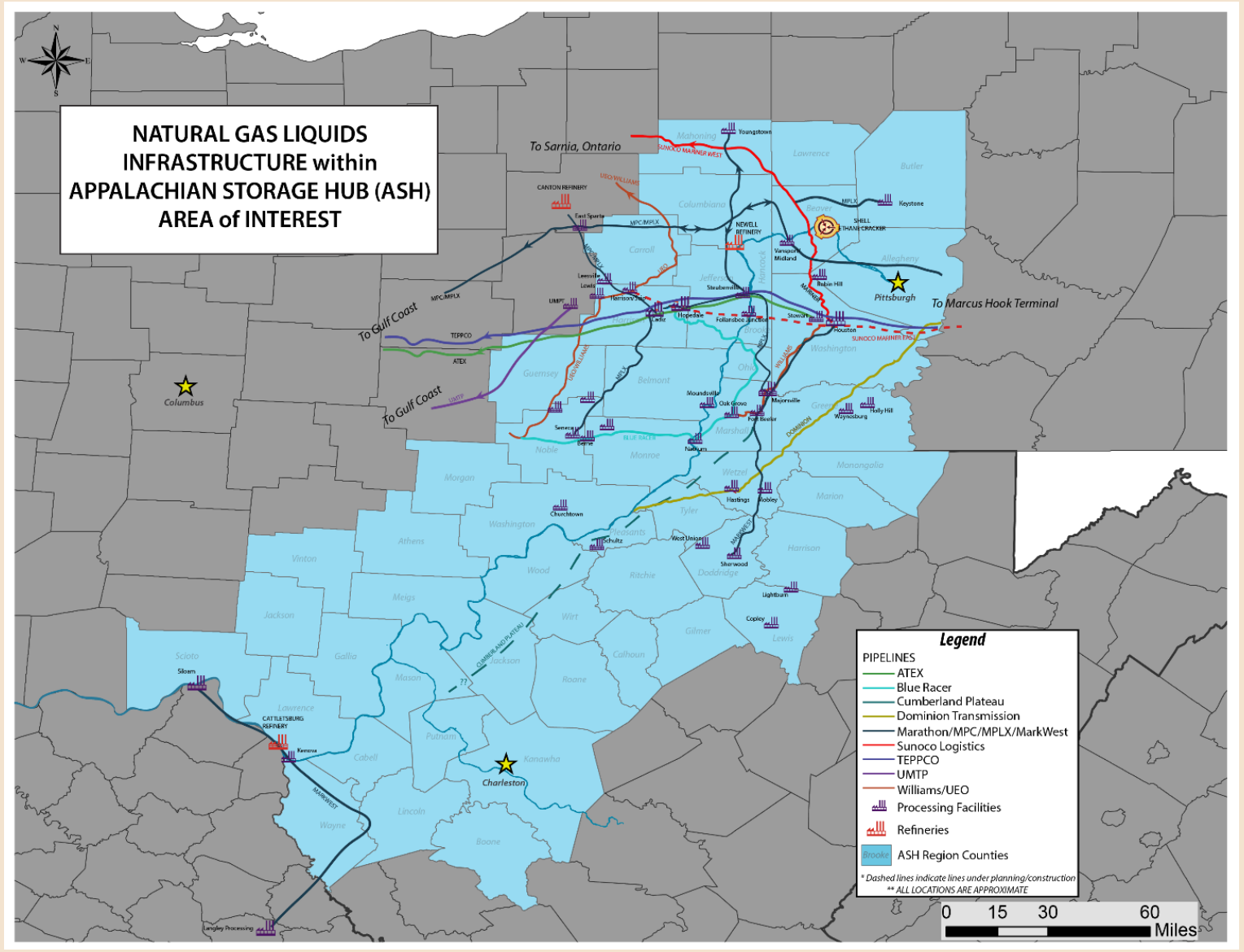
Acreage (ac) (gas fields):
(salt caverns):
(mined-rock caverns):



Net thickness (ft)(gas fields):
(salt caverns):

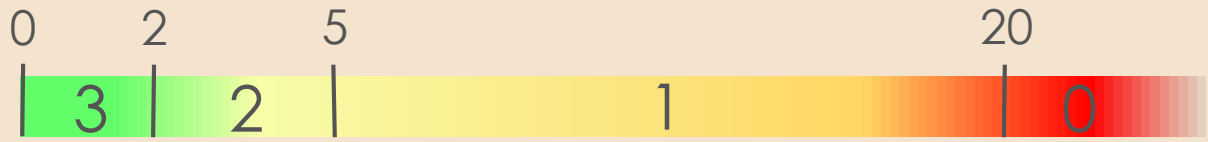


DISTANCE TO INFRASTRUCTURE



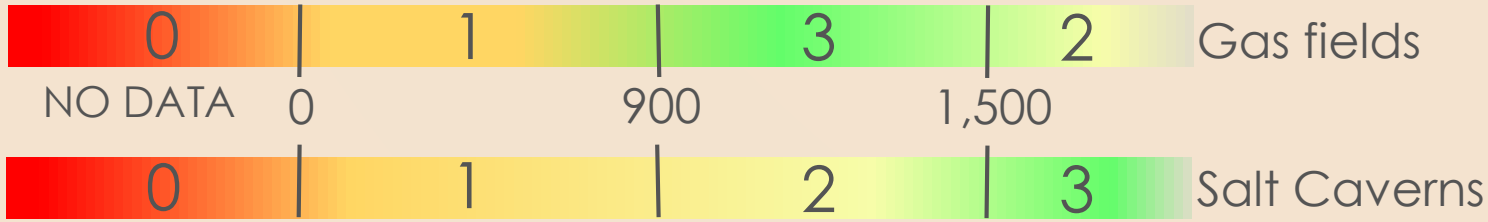
DETAILED RATING CRITERIA

Legacy well penetrations (no. wells per 1,000 acres):

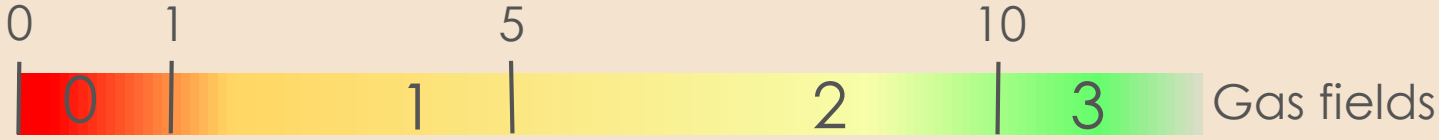


Stacked opportunity:

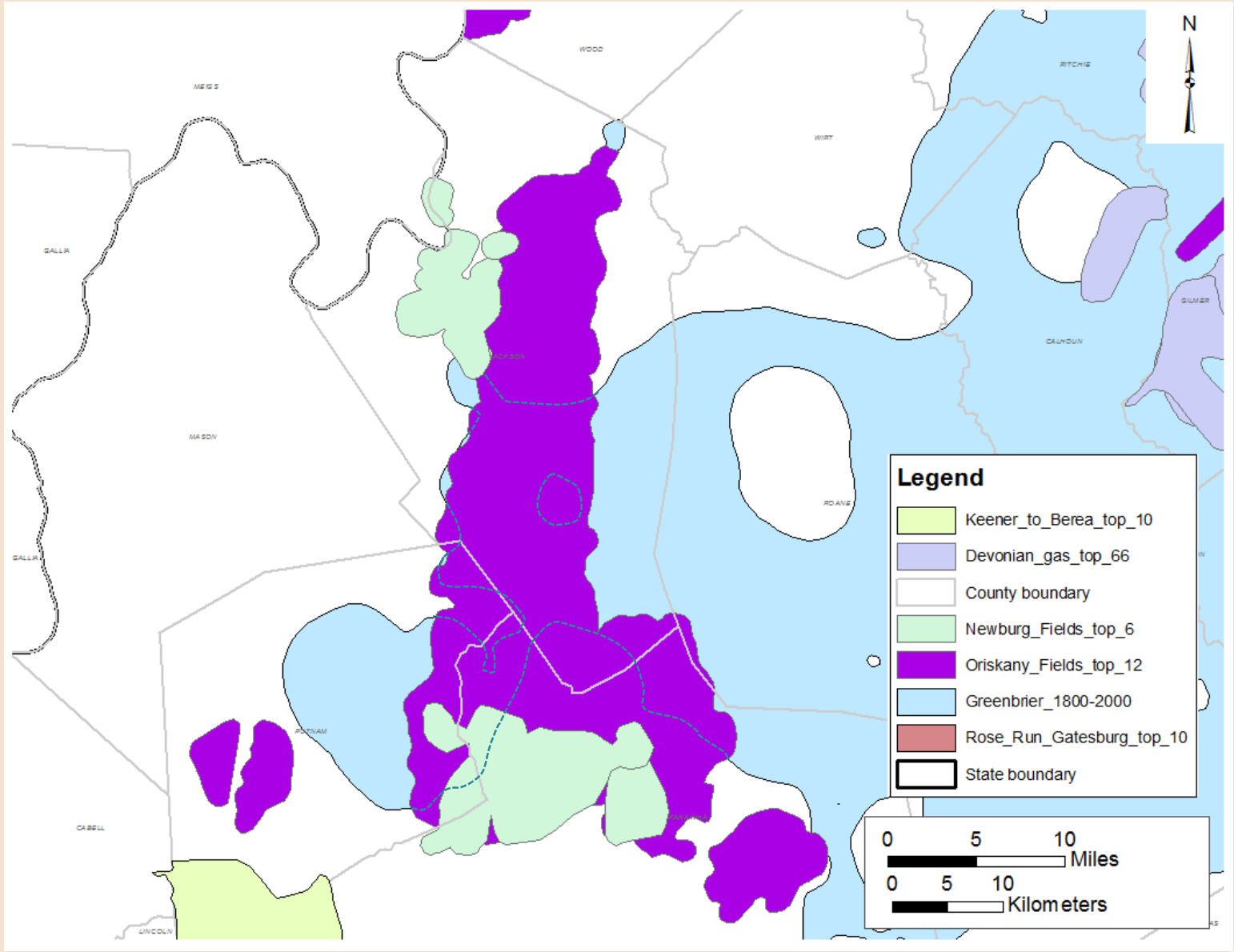
Pressure (psi):



Average porosity (%):

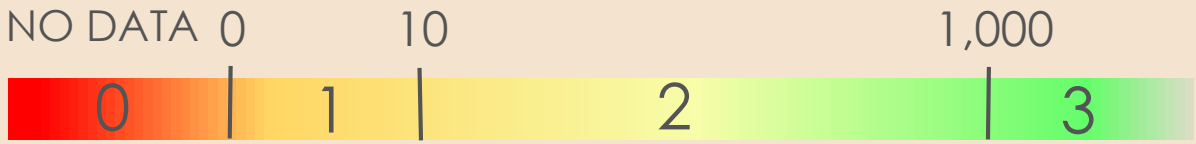


STACKED OPPORTUNITY RATINGS



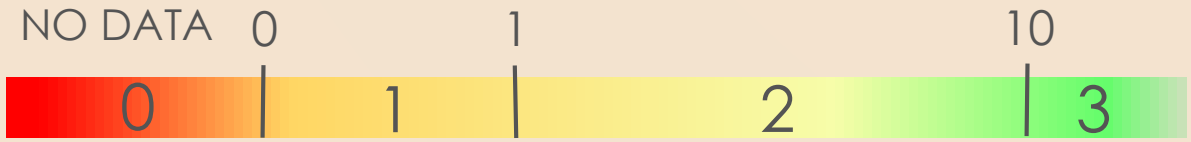
DETAILED RATING CRITERIA

Permeability (mD):

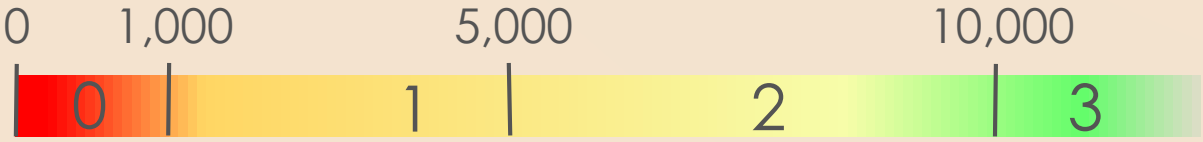


Mode CO_2 storage (tons):

Estimated cumulative gas production (BCF) (gas fields):

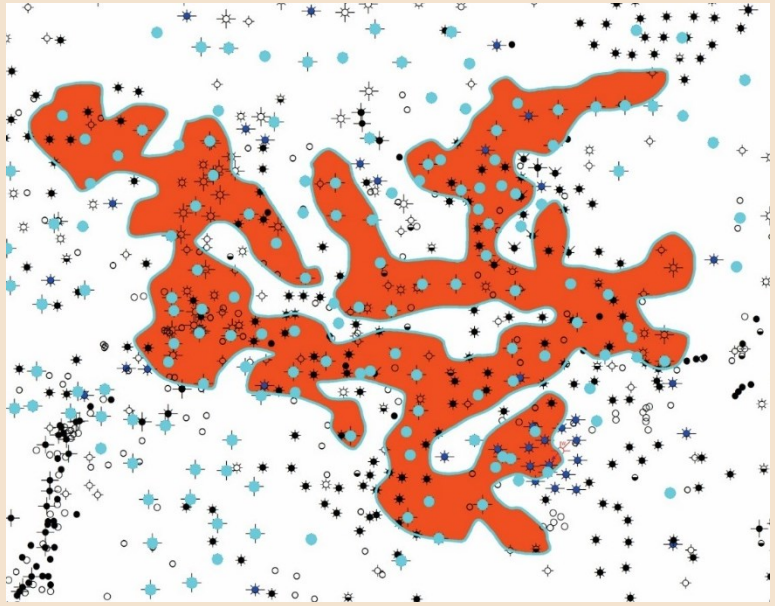


Working gas capacity (MMCF) (storage fields):

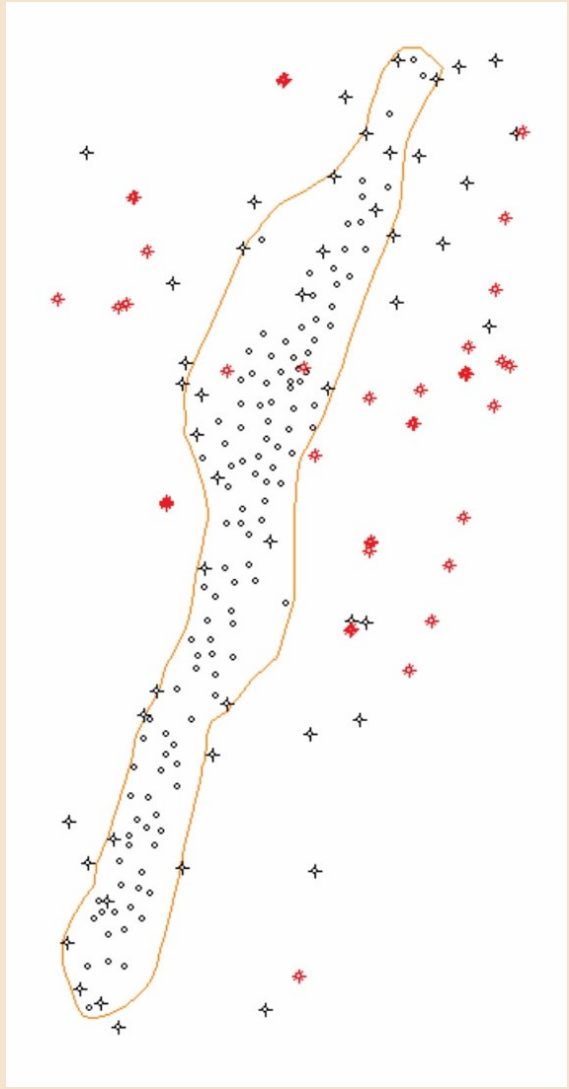


TRAP INTEGRITY RATING CRITERIA

- No data **0**
- Limited data on trap characteristics **1**
- Inferred lithologic and/or structural closure **2**
- Documented lithologic and/or structural closure **3**

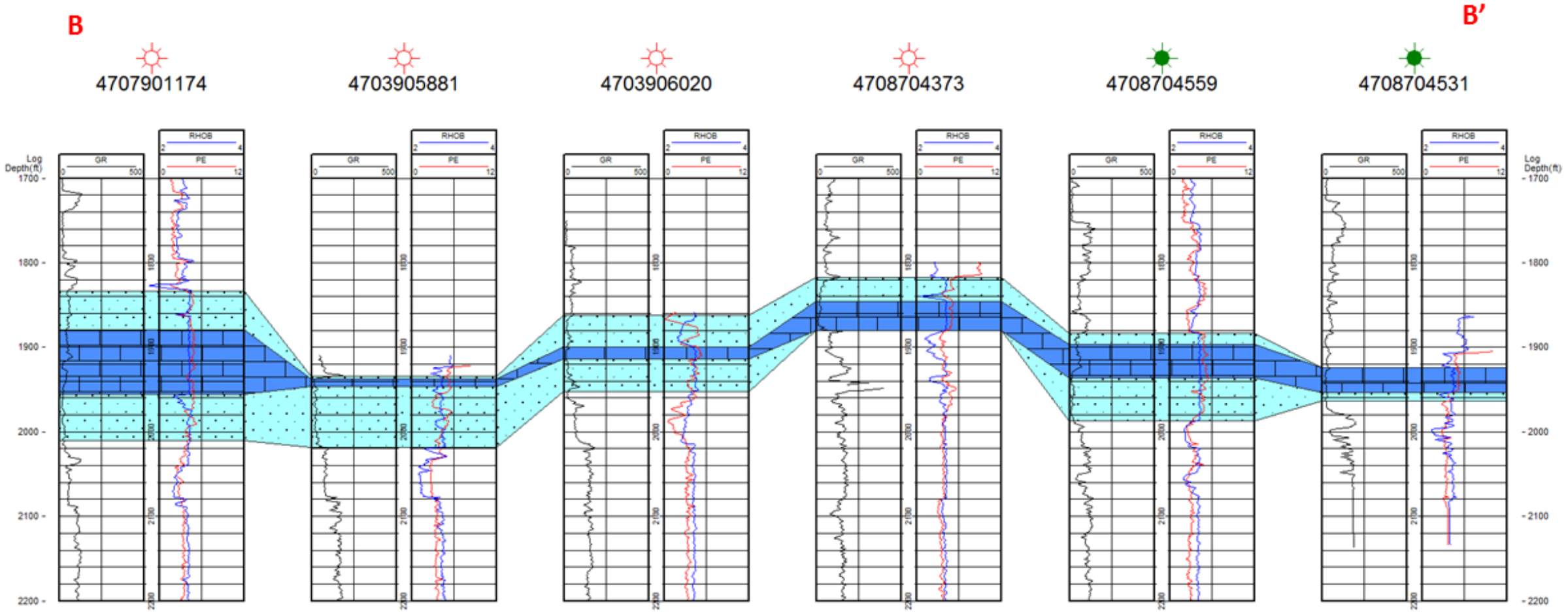


Trap integrity - 0



Trap integrity - 3

TRAP INTEGRITY RATINGS



'Good' trap

No top Trap

'Good' trap

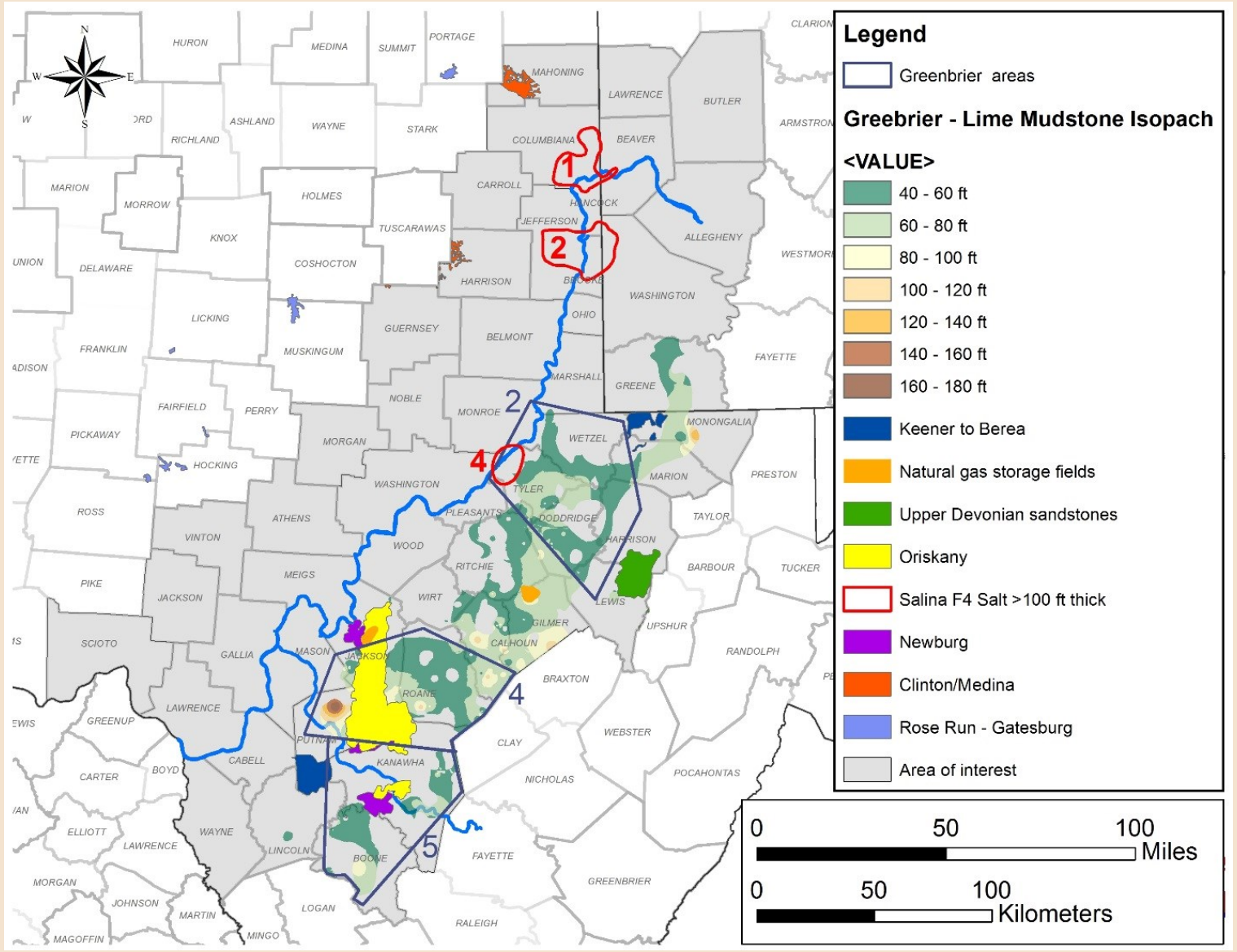
No bottom trap

'Okay' trap

No trap

DETAILED RATING RESULTS

- 30 opportunities
  - ➢22 depleted gas fields
  - ➢3 salt areas
  - ➢3 mined-rock areas
  - ➢2 natural gas storage fields



DETAILED RATING RESULTS – TABULAR FORMAT

Container Type	Field/Location	Geologic Interval	Rating Result
Mined-Rock Cavern	5	Greenbrier	19
	4	Greenbrier	16
	2	Greenbrier	15
Salt Cavern	1	Salina F4 Salt	15
	2	Salina F4 Salt	15
	4	Salina F4 Salt	15
Natural Gas Storage Field	RIPLEY	Oriskany	24
	RACKET-NEWBERNE (SINKING CREEK)	Venango	22
Depleted Gas Reservoirs	MAPLE-WADESTOWN	Keener to Berea	23
	BURDETT-ST. ALBANS	Keener to Berea	22
	CONDIT-RAGTOWN	Keener to Berea	22
	ABBOTT-FRENCH CREEK	Venango	25
	WESTON-JANE LEW	Elk	24
	CAMPBELL CREEK	Oriskany	25
	ELK-POCA (SISSONVILLE)	Oriskany	24
	NORTH RIPLEY	Newburg	27
	ROCKY FORK	Newburg	27
	KANAWHA FOREST	Newburg	27
	COOPER CREEK	Newburg	25
	CANTON CONSOLIDATED	Clinton/Medina	25
	CANTON CONSOLIDATED	Clinton/Medina	24
	CANTON CONSOLIDATED	Clinton/Medina	24
	RAVENNA-BEST CONSOLIDATED	Clinton/Medina	24
	DUMM RIDGE	Rose Run-Gatesburg	18
	DUMM RIDGE	Rose Run-Gatesburg	18
	FRAZEYBURG	Rose Run-Gatesburg	18
	RANDOLPH	Rose Run-Gatesburg	18
	KIRKERSVILLE	Rose Run-Gatesburg	17
	DUMM RIDGE	Rose Run-Gatesburg	17
	ROCKBRIDGE	Rose Run-Gatesburg	17

DETAILED RATING CRITERIA

Mined-Rock Caverns	Salt Caverns	Depleted Gas Reservoirs	Gas Storage Fields
Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure	Distance to Infrastructure
Acreage	Acreage	Acreage	Acreage
Average depth	Average depth	Average depth	Average depth
Net Thickness	Net Thickness	Net Thickness	Net Thickness
Trap integrity	Trap integrity	Trap integrity	Trap integrity
Legacy well penetrations	Legacy well penetrations	Legacy well penetrations	Legacy well penetrations
Stacked opportunity	Stacked opportunity	Stacked opportunity	Stacked opportunity
	Pressure	Pressure	Pressure
		Average Porosity	Average Porosity
		Permeability	Permeability
		Mode CO_2 storage	Mode CO_2 storage
		Estimated cumulative gas production	Working gas capacity

RANKING EFFORTS USED NORMALIZED RATINGS TO COMPARE AMONG STORAGE CONTAINER TYPES

- Distance to infrastructure
- Acreage
- Average depth
- Net thickness
- Trap integrity
- Legacy well penetrations
- Stacked opportunities

FINAL RANKING RESULTS

Ranking	Container Type	Field/Location	Geologic Interval	Normalized Rating
1	mined-rock cavern	5	Greenbrier	19
2	depleted gas reservoir	NORTH RIPLEY	Newburg	16
2	depleted gas reservoir	ROCKY FORK	Newburg	16
2	depleted gas reservoir	KANAWHA FOREST	Newburg	16
2	mined-rock cavern	4	Greenbrier	16
3	depleted gas reservoir	CAMPBELL CREEK	Oriskany	15
3	mined-rock cavern	2	Greenbrier	15
3	salt cavern	1	Salina F4 Salt	15
3	salt cavern	2	Salina F4 Salt	15

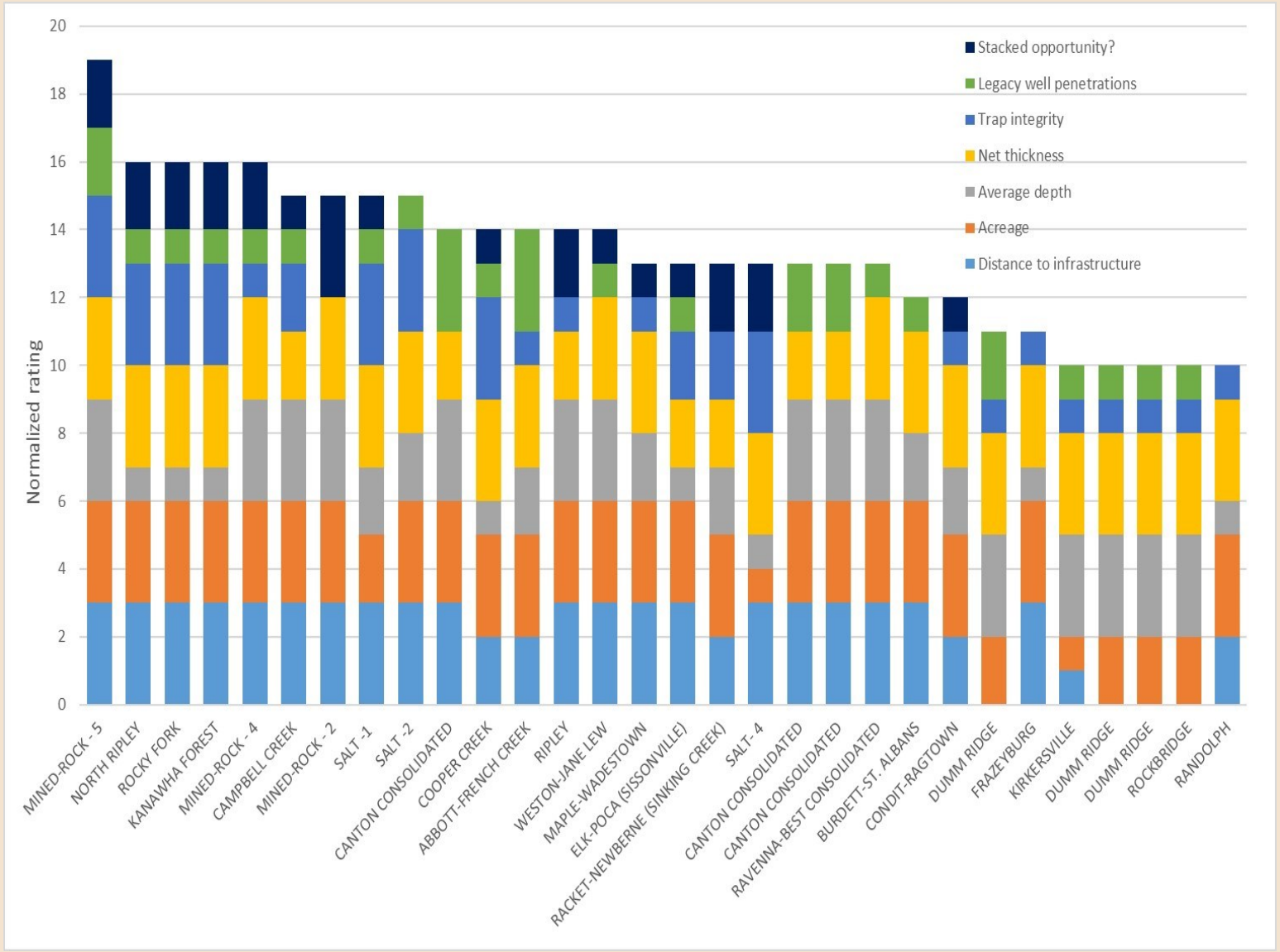
Ranking	Container Type	Field/Location	Geologic Interval	Normalized Rating
1	mined-rock cavern	5	Greenbrier	19
2	depleted gas reservoir	NORTH RIPLEY	Newburg	16
2	depleted gas reservoir	ROCKY FORK	Newburg	16
2	depleted gas reservoir	KANAWHA FOREST	Newburg	16
2	mined-rock cavern	4	Greenbrier	16
3	depleted gas reservoir	CAMPBELL CREEK	Oriskany	15
3	mined-rock cavern	2	Greenbrier	15
3	salt cavern	1	Salina F4 Salt	15
3	salt cavern	2	Salina F4 Salt	15
4	depleted gas reservoir	WESTON-JANE LEW	Elk	14
4	depleted gas reservoir	CANTON CONSOLIDATED	Clinton/Medina	14
4	depleted gas reservoir	COOPER CREEK	Newburg	14
4	depleted gas reservoir	ABBOTT-FRENCH CREEK	Venango	14
4	natural gas storage field	RIPLEY	Oriskany	14
5	depleted gas reservoir	MAPLE-WADESTOWN	Keener to Berea	13
5	depleted gas reservoir	ELK-POCA (SISSONVILLE)	Oriskany	13
5	gas storage field	RACKET-NEWBERNE (SINKING CREEK)	Venango	13
5	salt cavern	4	Salina F4 salt	13
4	depleted gas reservoir	CANTON CONSOLIDATED	Clinton/Medina	13
5	depleted gas reservoir	CANTON CONSOLIDATED	Clinton/Medina	13
5	depleted gas reservoir	RAVENNA-BEST CONSOLIDATED	Clinton/Medina	13
6	depleted gas reservoir	BURDETT-ST. ALBANS	Keener to Berea	12
6	depleted gas reservoir	CONDIT-RAGTOWN	Keener to Berea	12
7	depleted gas reservoir	DUMM RIDGE	Rose Run-Gatesburg	11
7	depleted gas reservoir	FRAZEYBURG	Rose Run-Gatesburg	11
8	depleted gas reservoir	KIRKERSVILLE	Rose Run-Gatesburg	10
8	depleted gas reservoir	DUMM RIDGE	Rose Run-Gatesburg	10
8	depleted gas reservoir	DUMM RIDGE	Rose Run-Gatesburg	10
8	depleted gas reservoir	ROCKBRIDGE	Rose Run-Gatesburg	10
8	depleted gas reservoir	RANDOLPH	Rose Run-Gatesburg	10

FINAL RANKING RESULTS

Average depth

Favorable trap integrity

Stacked opportunities



RANKING RESULTS - EXAMPLE

Rating Criteria	Campbell Creek	Kanawha Forest	Red House
Distance to infrastructure	3	3	3
Average depth	3	3	3
Acreage	3	3	3
Net thickness	2	2	1
Trap integrity	2	2	1
Legacy well penetrations	1	1	1
Stacked opportunity	1	1	1
Pressure	*2*	*2*	*2*
Average Porosity	*2*	*2*	*2*
Permeability	*0*	*0*	*0*
Mode CO_2 storage (computed)	*3*	*3*	*3*
Estimated cumulative gas production (BCF)	*3*	*0*	*2*
Detailed rating totals	25	22	22
Normalized totals	*15*	*15*	*13*

SUMMARY

- **Mined-rock caverns**

  Greenbrier Limestone
  - Depth
  - Thickness
  - Facies distribution

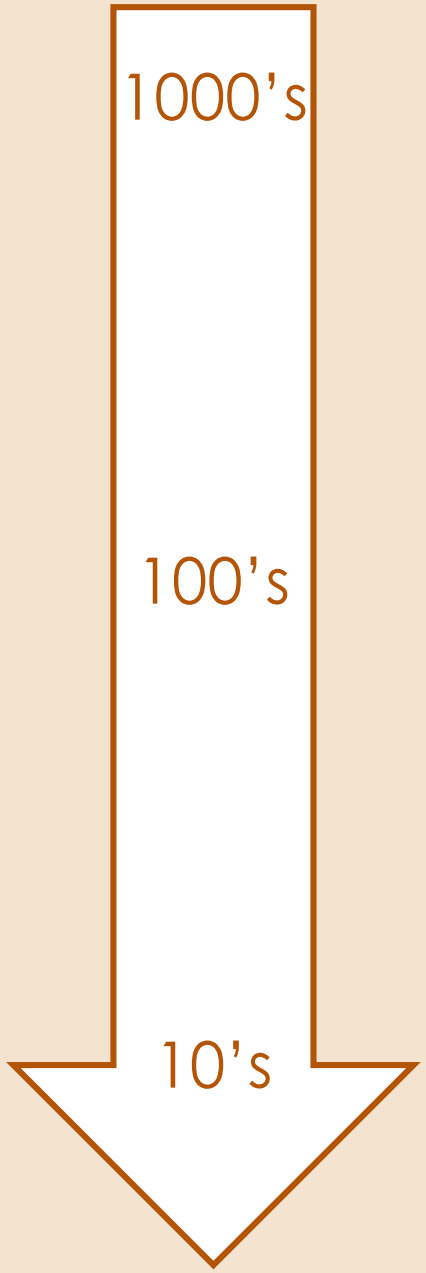
- **Salt Caverns**

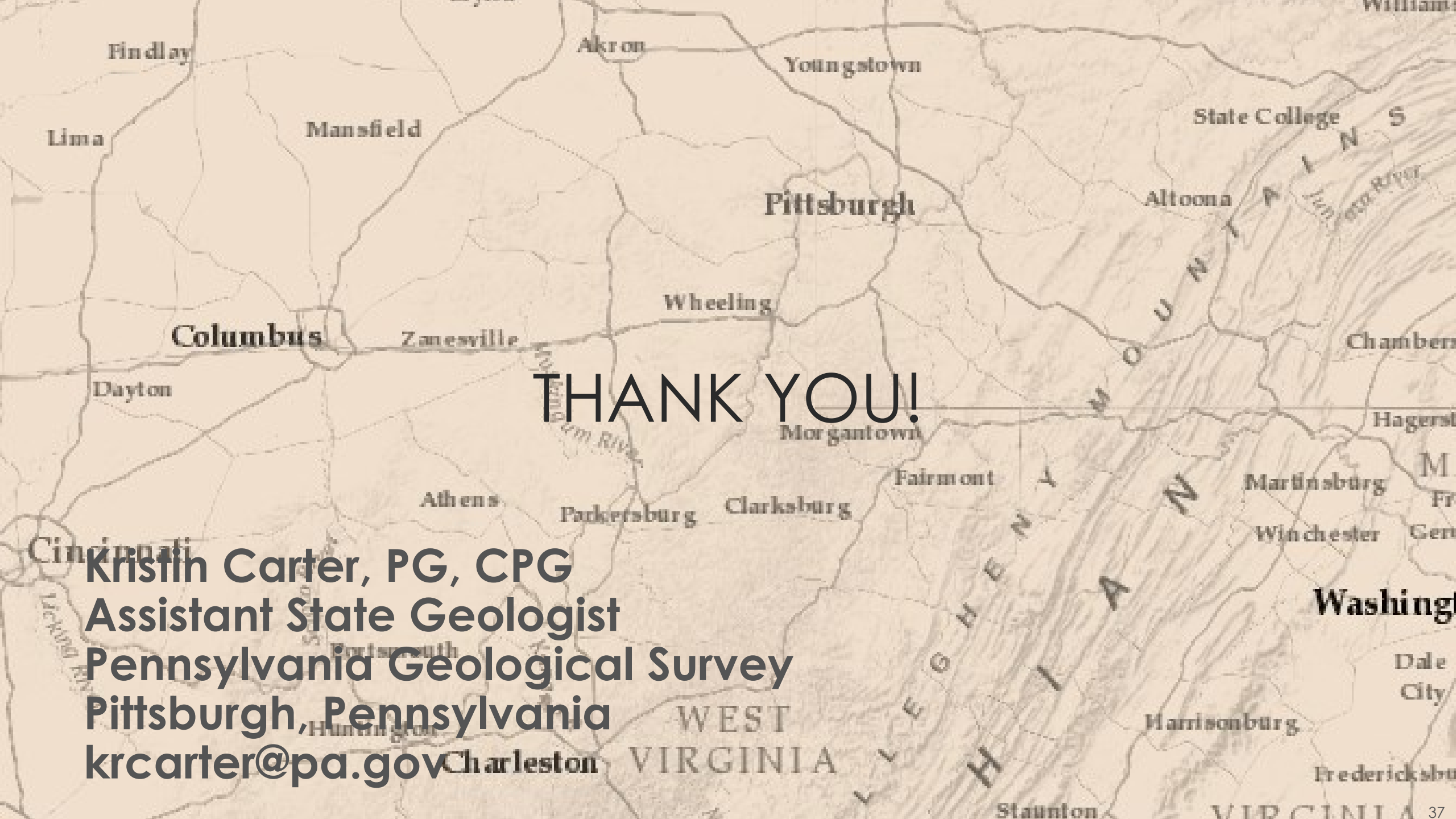
  Salina Group salts
  - Depth
  - Thickness
  - Extent

- **Depleted gas reservoirs/natural gas storage fields**

  Devonian-Cambrian age units
  - Reservoir data compilation
  - Preliminary assessment (through rating)

- **Detailed rating and ranking efforts**
  - Criteria for each storage type
  - Detailed rating results
  - Normalized ratings used for ranking purposes





THANK YOU!

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