Integrated Sub-Basin Scale Exploration for Carbon Storage Targets: Advanced Characterization of Geologic Reservoirs and Caprocks in the Upper Ohio River Valley*

Erica Howat[1], Neeraj Gupta[1], Mark Kelley[1], Jared Hawkins[1], Autumn Haagsma[1], Isis Fukai[1], Amber Conner[1], Oladipupo Babarinde[1], Glenn Larsen[1], Joel Main[1], Caitlin McNeil[1], Jacqueline Gerst[1], and E. Charlotte Sullivan[2]

Search and Discovery Article #30492 (2017)**
Posted March 13, 2017

*Adapted from oral presentation given at AAPG Eastern Section Meeting, Lexington, Kentucky, September 25-27, 2016

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Abstract

The goal of this study was to collect and analyze geologic data for assessment of CO_2 storage feasibility in the parts of Appalachian Basin covering eastern Ohio and the adjacent Midwestern area. The deep geology is relatively unknown as the formations are not prospective for oil and gas development. As such, very few deep wells have been drilled, logged and tested.

The research characterized potential caprocks and reservoirs. This required integration of numerous data sources including publicly available wireline logs, core data and production records, new log and core data through synergistic partnerships with local operators, the purchase of available seismic volumes and data from 10 new brine disposal wells in Ohio. Data collection included advanced wireline logs and core that helped characterize geomechanical, lithological, mineralogical, and geochemical properties of reservoirs and caprocks.

Basin scale mapping was performed to characterize structure, extent, and depths for selected geologic zones from Ordovician, Cambrian, and Precambrian formations. Petrophysical parameters including net to gross thickness, porosity, porosity feet and porosity-permeability relationships were evaluated for each formation. Petrophysical results indicated a formation's suitability as a storage resource or sealing formation. Conclusions suggest that both sands and carbonates in the Appalachian Basin are potential storage resources. The discontinuous nature of individual formations means that a series of stacked reservoirs and seals are needed to form the basis of the basin scale geologic carbon sequestration system. Ongoing static and dynamic modeling will demonstrate the ability of the stacked reservoir system to function for long-term CO_2 storage.

Erica Howat
Battelle Memorial Institute
September 2016

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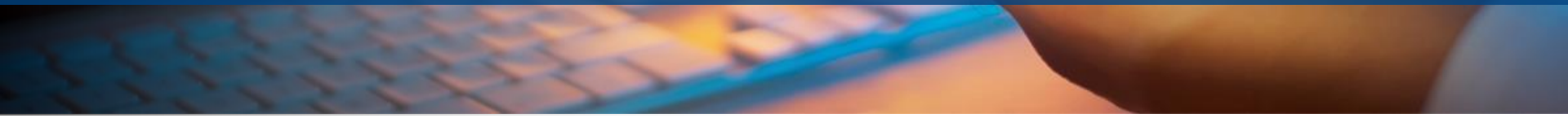

American Association of Petroleum Geologists Fall Eastern Regional Meeting 2016

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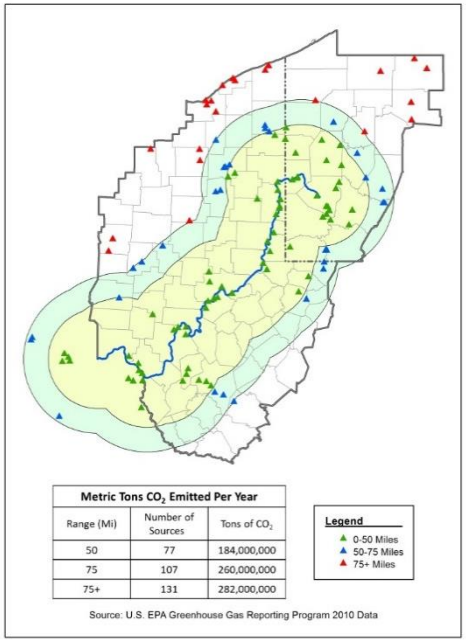
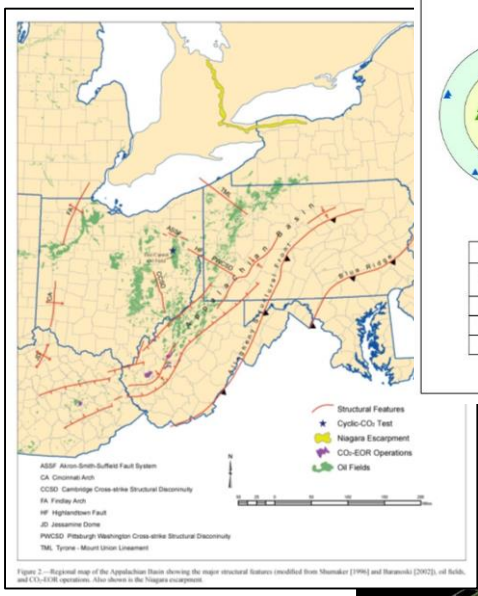
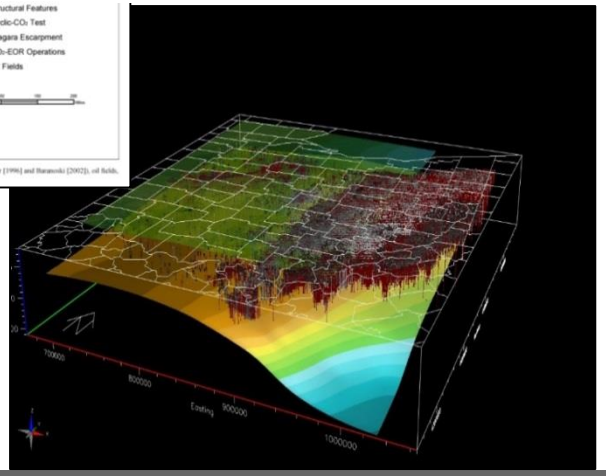
Assessment of CO_2 storage/utilization in Ohio and adjacent areas

- An estimated 200 million tonnes of CO_2 are emitted a year within 75 miles of the Ohio River from point sources
- While significant oil and gas exploration has occurred in the region, there are many uncertainties
  - Much of the production is from historical wells
  - Little exploration has occurred in the Ordovician-Cambrian Section
  - Little is known about the regional extent of carbonate storage capacity
- Projects co-funded by Ohio Coal Development Office and DOE Over 10 years; Jointly with Ohio Geological Survey

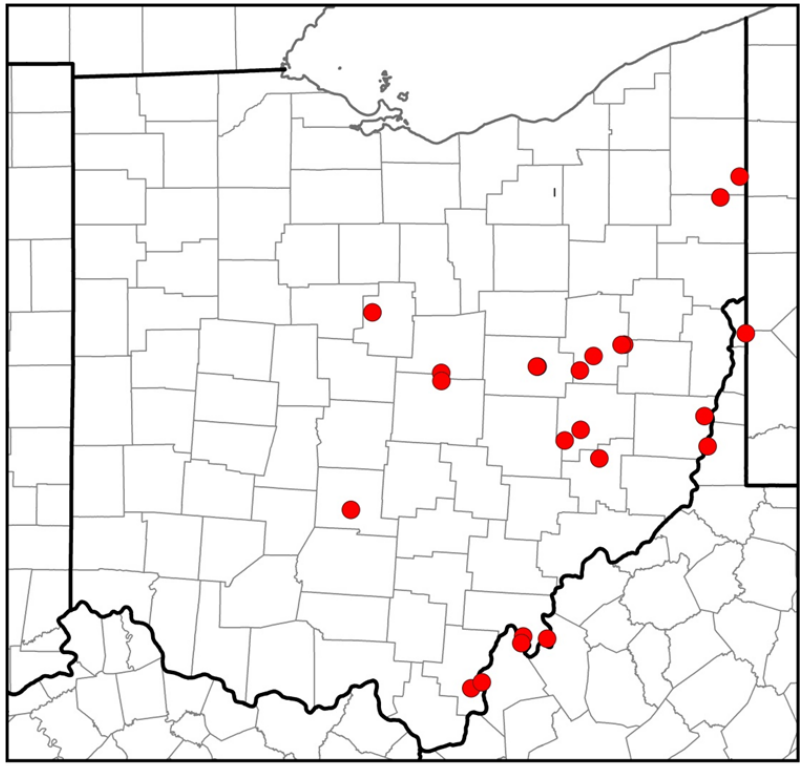






Characterizing Carbonate Formations for CCUS Projects

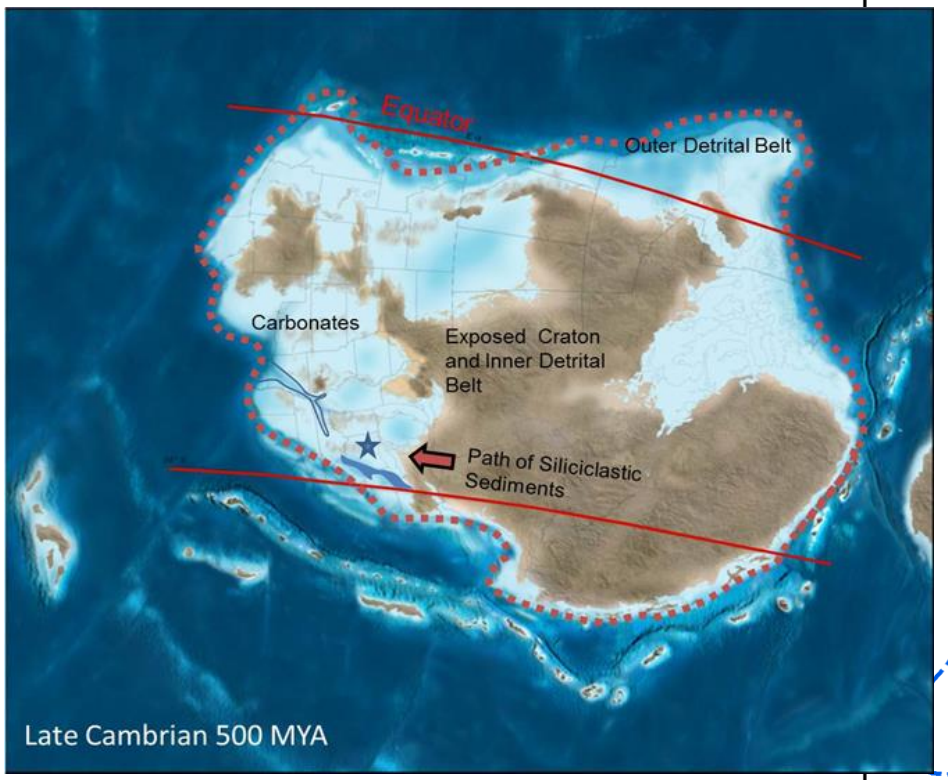
- Determine extent of potential reservoirs and caprocks
- Characterize and map petrophysical and geomechanical properties
- Gather new data through piggyback opportunities
- Develop new methodologies to characterize complex reservoirs
- Assess storage and EOR feasibility



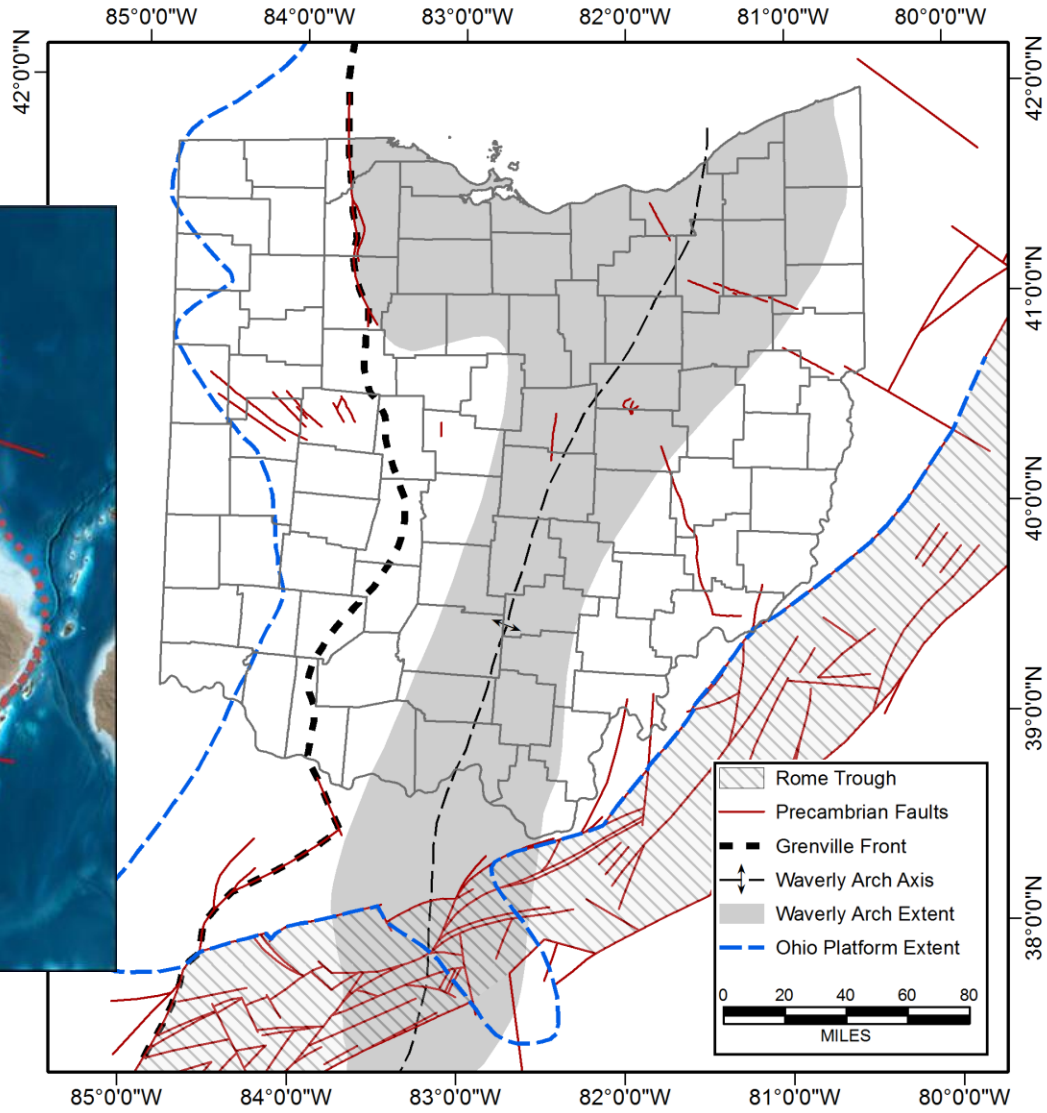
MRCSP Piggyback Wells

GEOLOGIC CONTEXT

Geologic Context

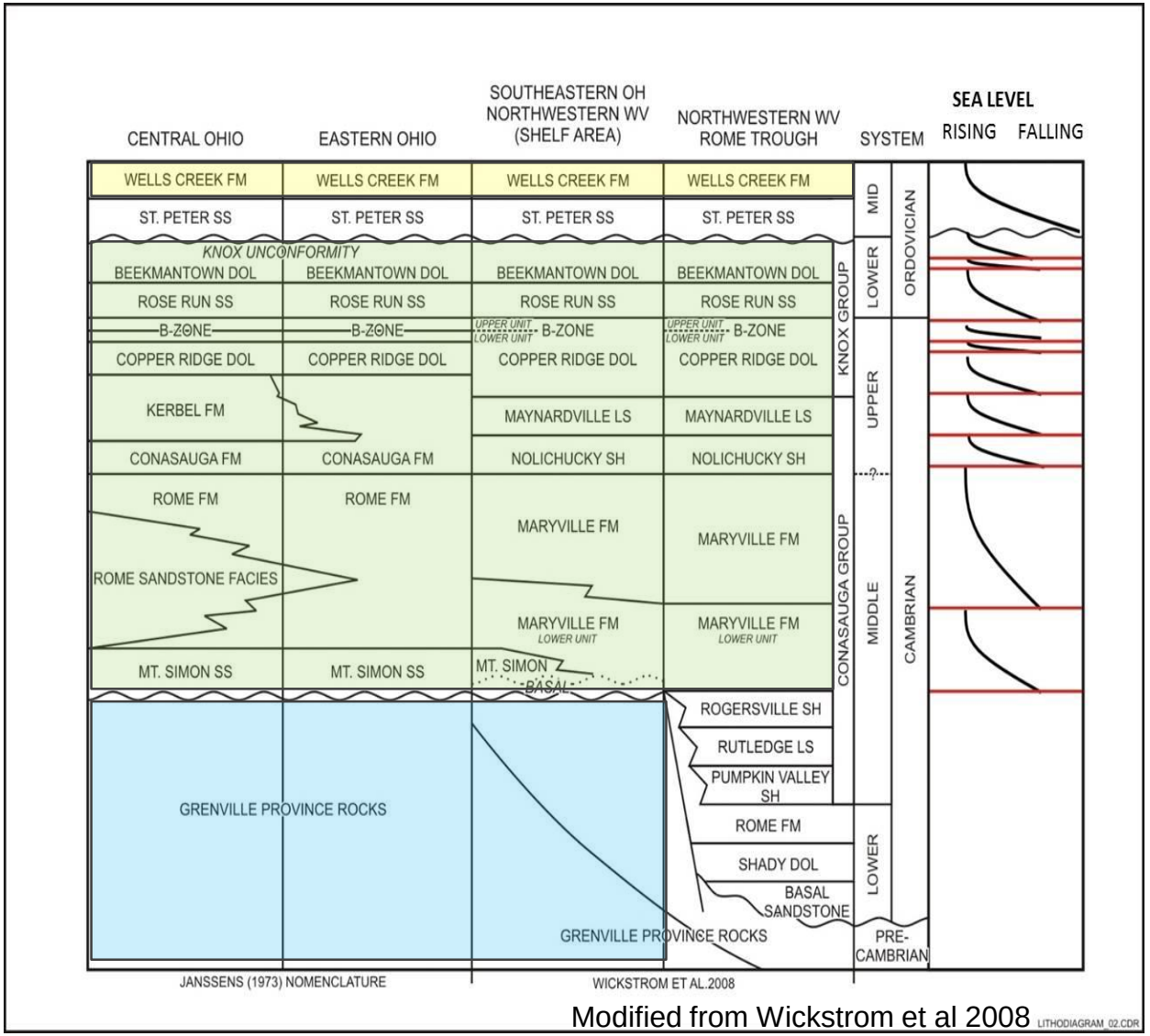


After Blakey 2010



Formations of Interest

- Black River Group
- Lower Chazy/Wells Creek
- **Beekmantown**
- **Rose Run**
- **Upper Copper Ridge**
- **Copper Ridge B**
- **Lower Copper Ridge**
- **Kerbel**
- **Conasauga**
- **Rome**
- **Basal Sands**
- *Precambrian Basement*



Modified from Wickstrom et al 2008

METHODS

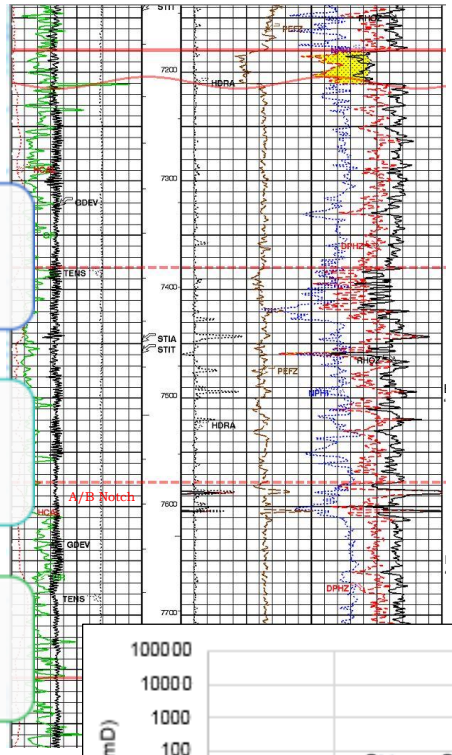
REGIONAL MAPPING, CROSS SECTIONS AND PETROPHYSICS

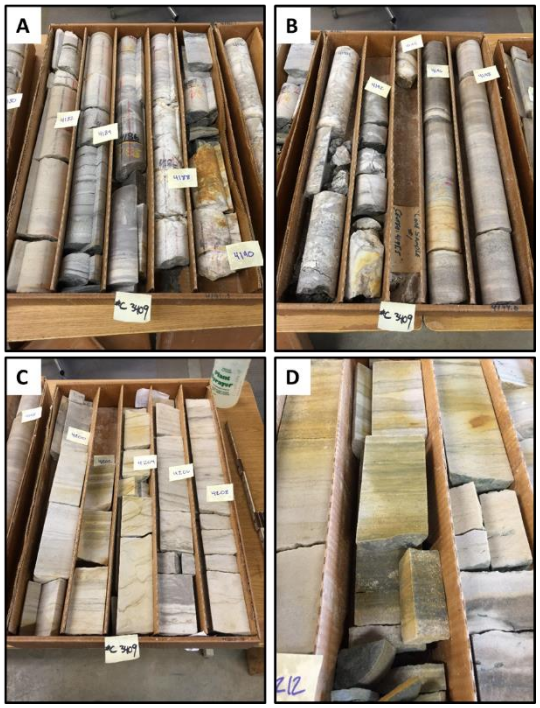
Geologic Workflow

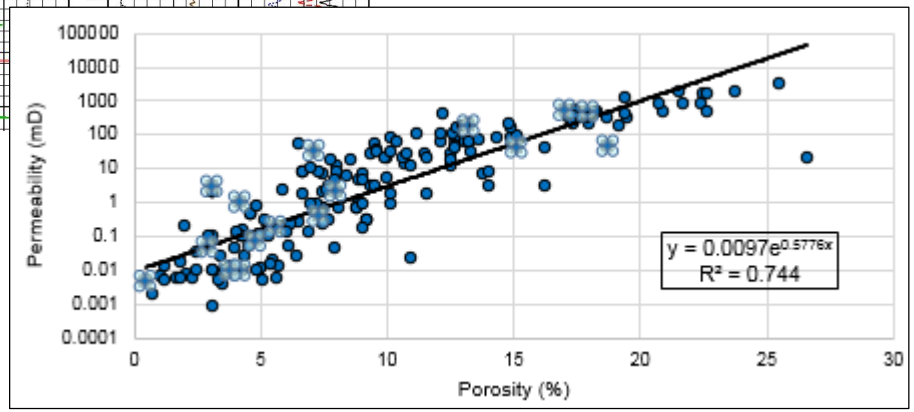
Data Acquisition
- Wireline Logs
- Core
- Literature Review
- Formation Tops
- Porosity and Permeability

Data Analysis
- Petrophysics
- Statistics
- Porosity-Permeability Transforms
- Property Indicators
- Seismic

Mapping
- Isopach
- Permeability
- Porosity
- Properties

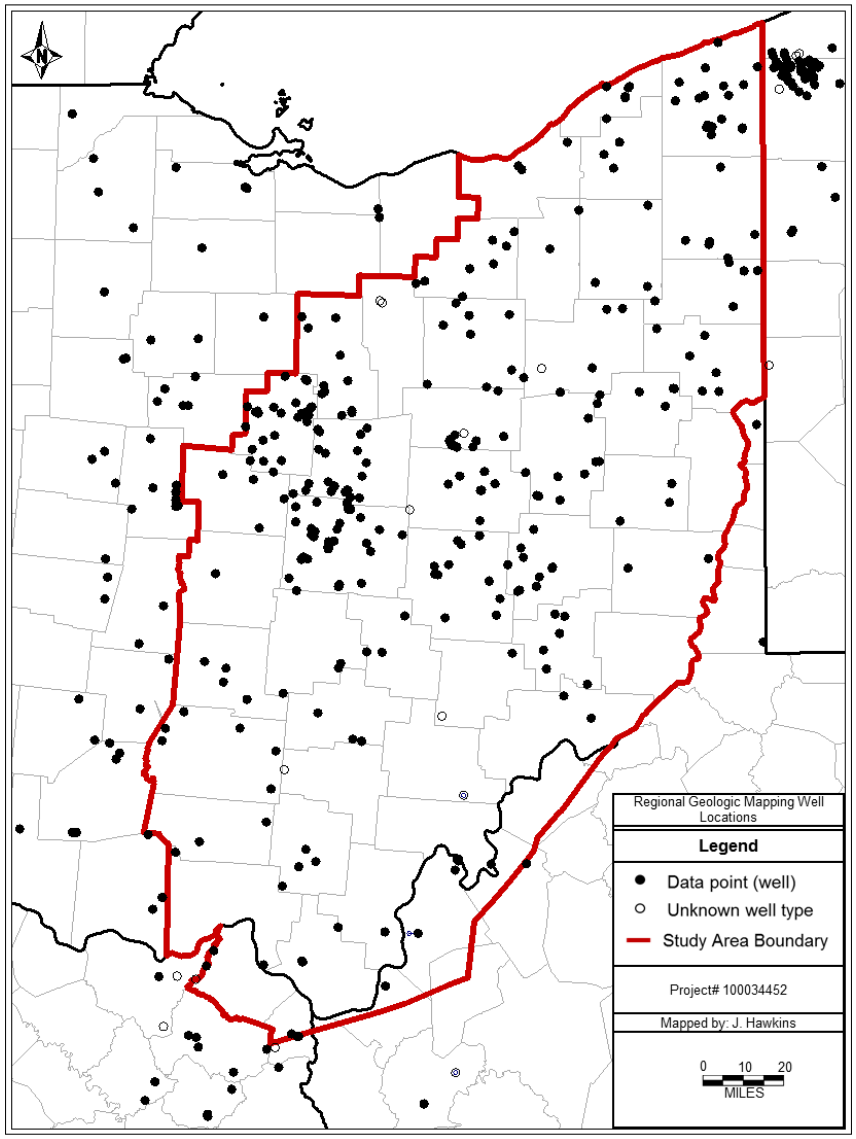


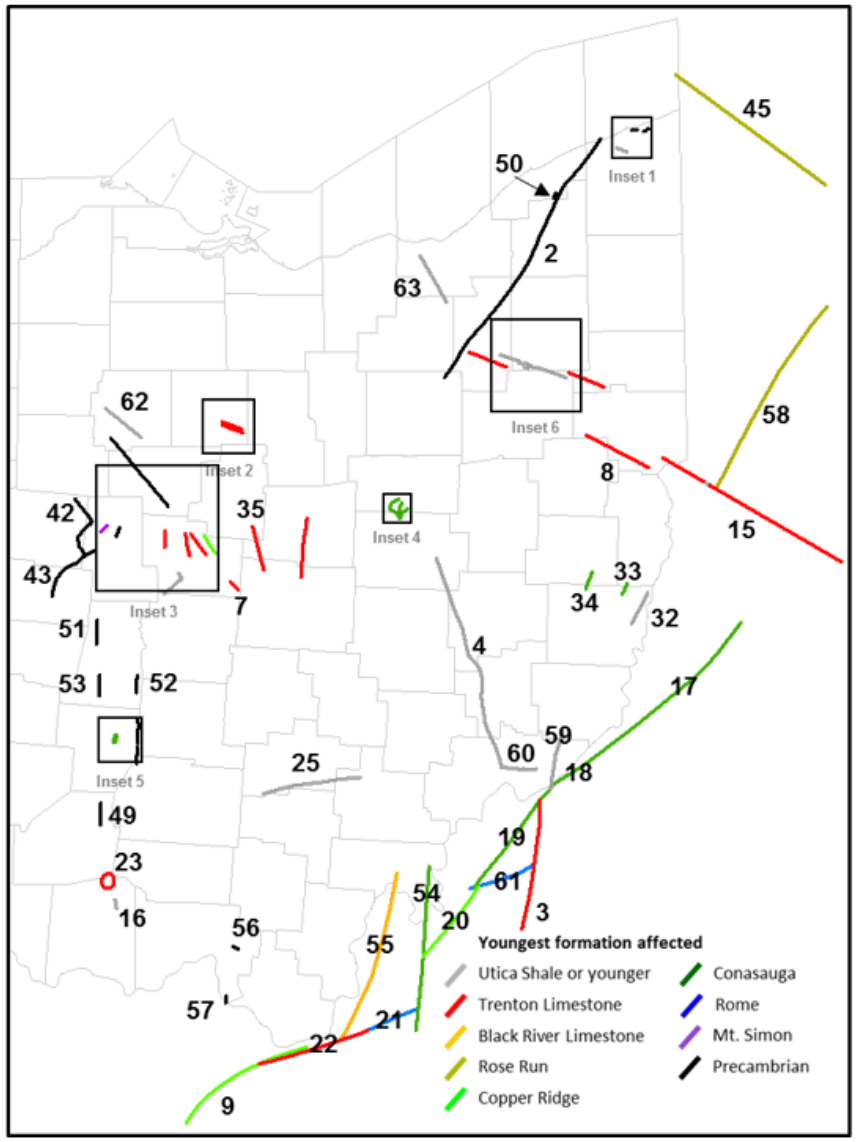




Regional Mapping

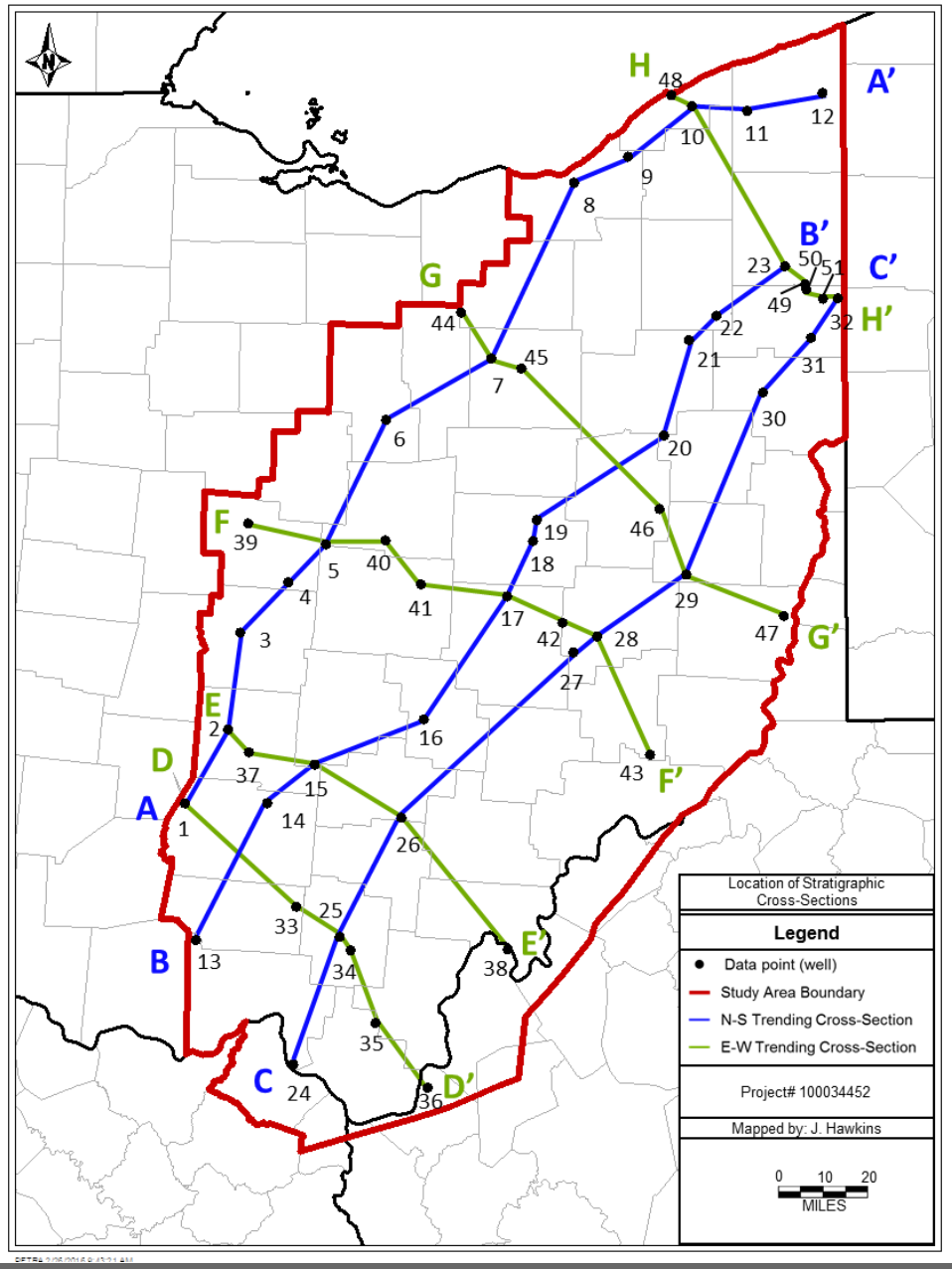
Baranoski 2013





Regional Cross Sections

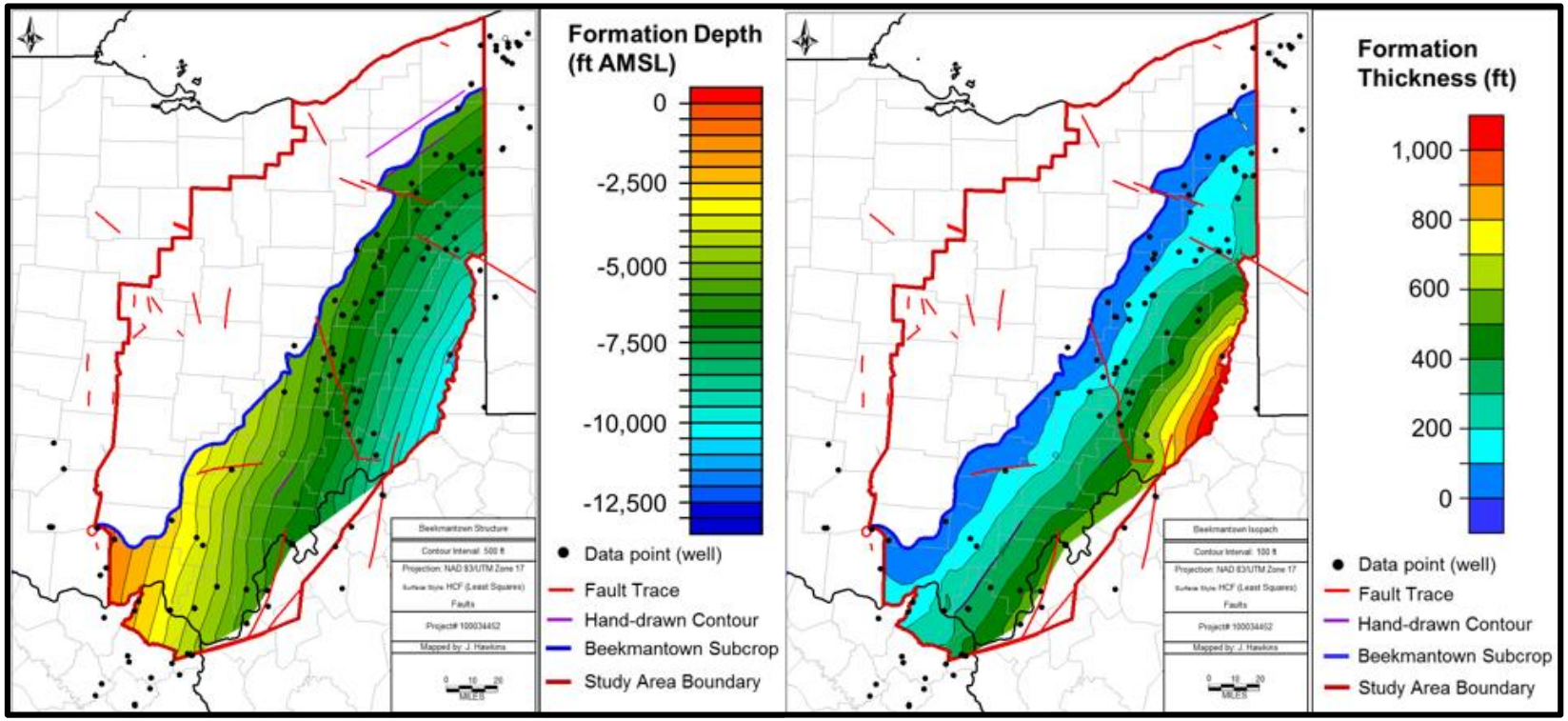
- **51 wells and 8 cross section lines used to construct stratigraphic cross sections of the Lower Ordovician-Cambrian formations in the study area.**



FORMATION RESULTS

Beekmantown

Structure and Isochore Maps



Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
30-937	146	19-933	206	0.1-1	0.97

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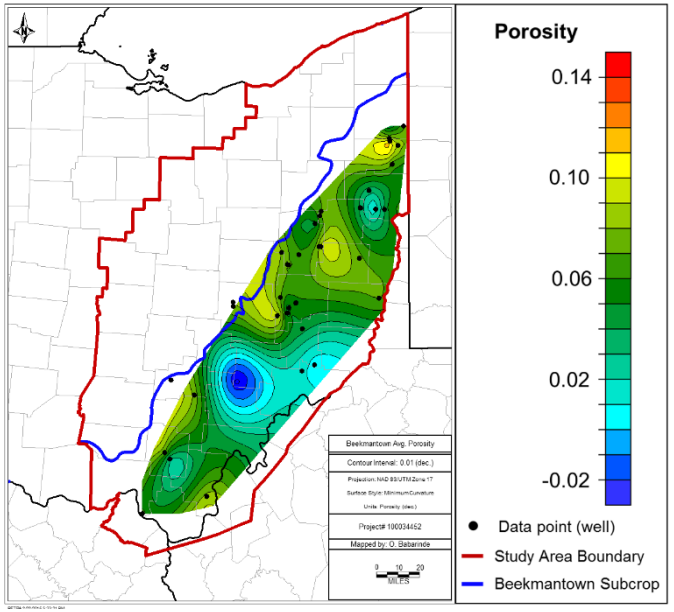
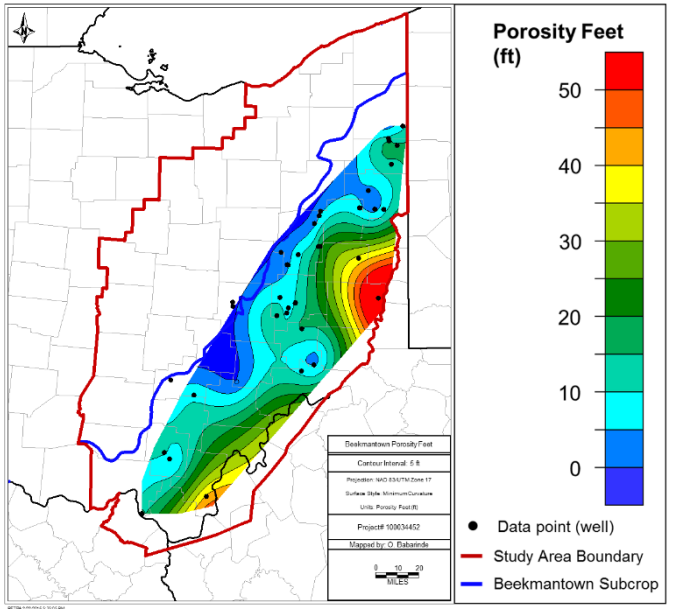
Beekmantown
Regional Analysis

- Available Digital Logs = 40
- Reservoir quality is irregularly distributed across the study area.
- Highest porosity potential is along the subcrop belt but this section is thin due to erosion

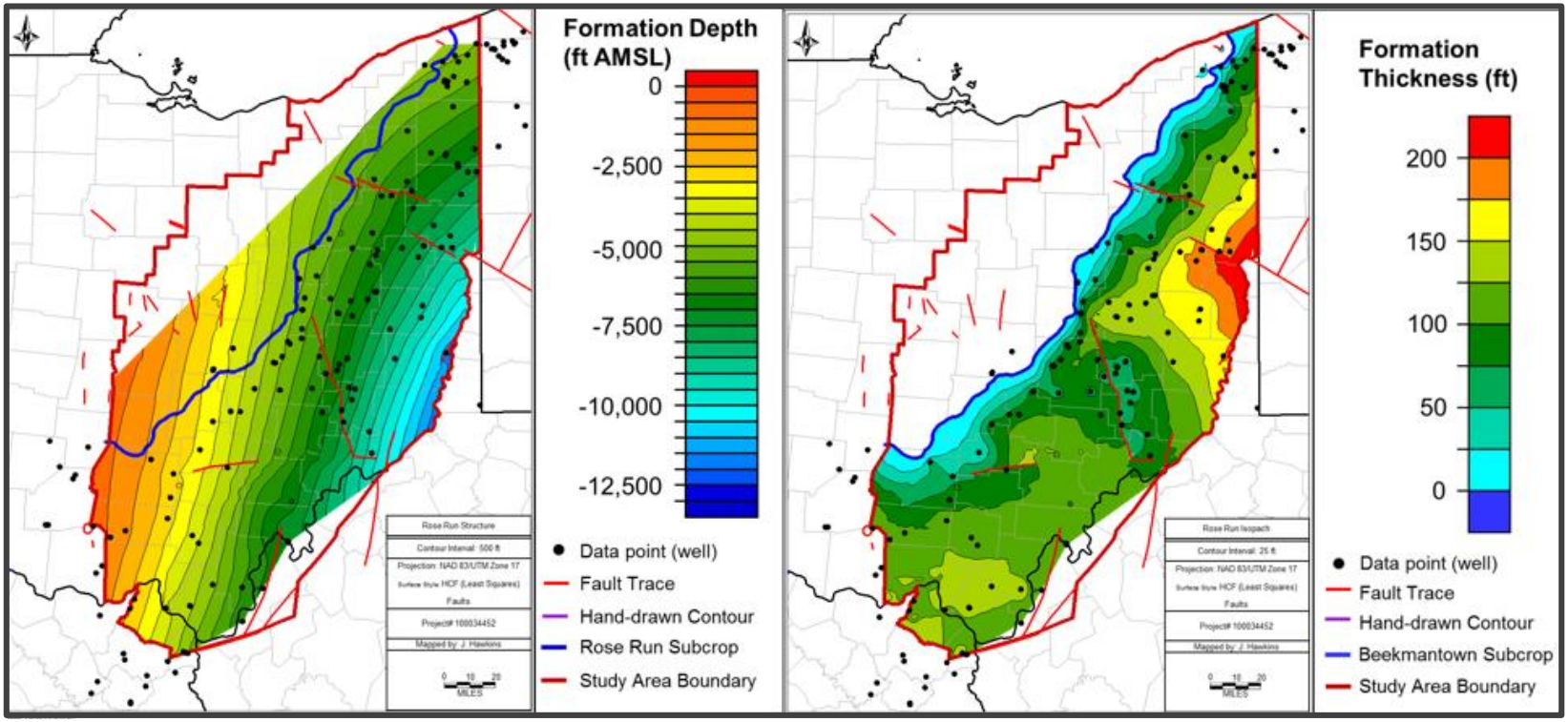




Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-12	6	0-67	12

Rose Run

Structure and Isochore Maps



Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
20-295	94	1-124	35	0-1	0.33

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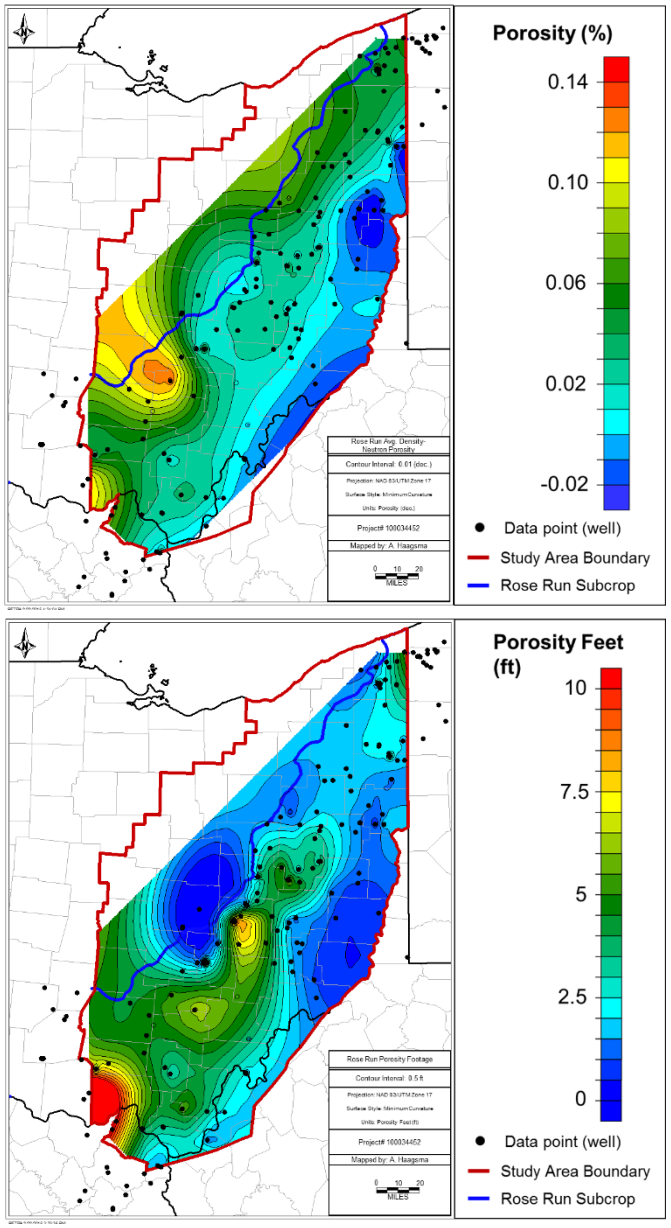
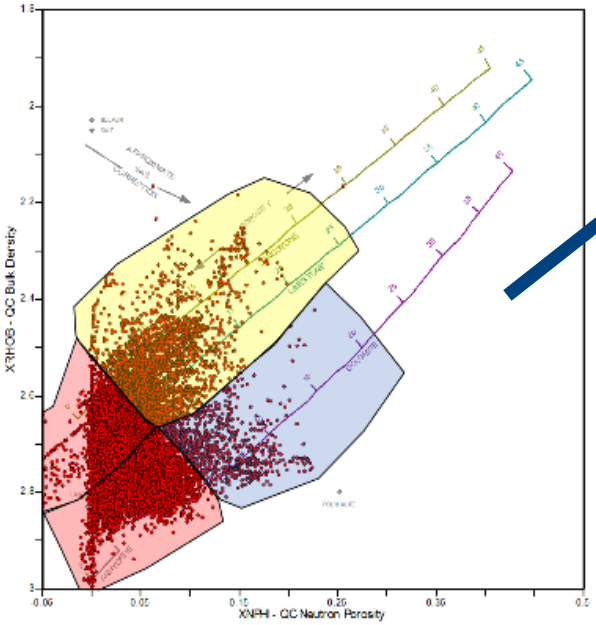
Rose Run
Regional Analysis

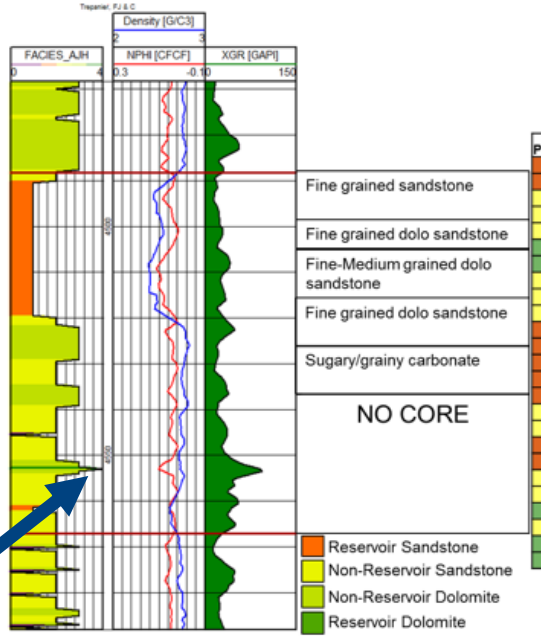
- Available Digital Logs = 139
- Property, petrophysical, and facies maps all showed a strong trend of reservoir sandstone running from south-central to northeastern Ohio, parallel to the Cambrian paleoshoreline.
- Key facies were based on core descriptions and core measurements.

Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-22	4	0.-18	3

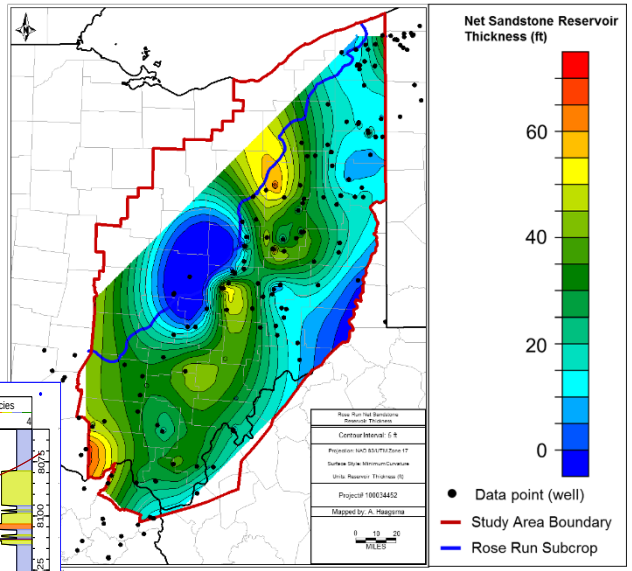


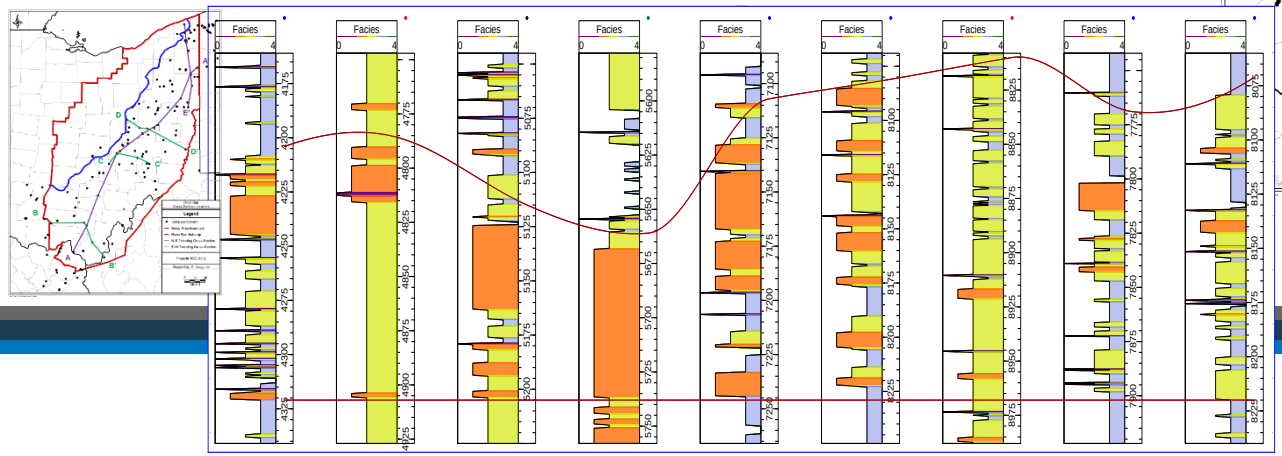
Rose Run
Facies Mapping





Permeability (mD)	Porosity (%)
0.1	1.5
3	3.1
17	7.8
33	9.6
26	11.5
156	12.8
60	10.4
17	8.6
6.3	8.4
6.7	9.1
3.5	7.7
0.3	5.2
0.1	2.9
0.1	5.3
0.2	5.6
8.6	8
8.1	7.3
3.5	9.5
0.9	9
20	11.6
18	12.5
159	14.9
28	10.8
63	13.2
71	13.6





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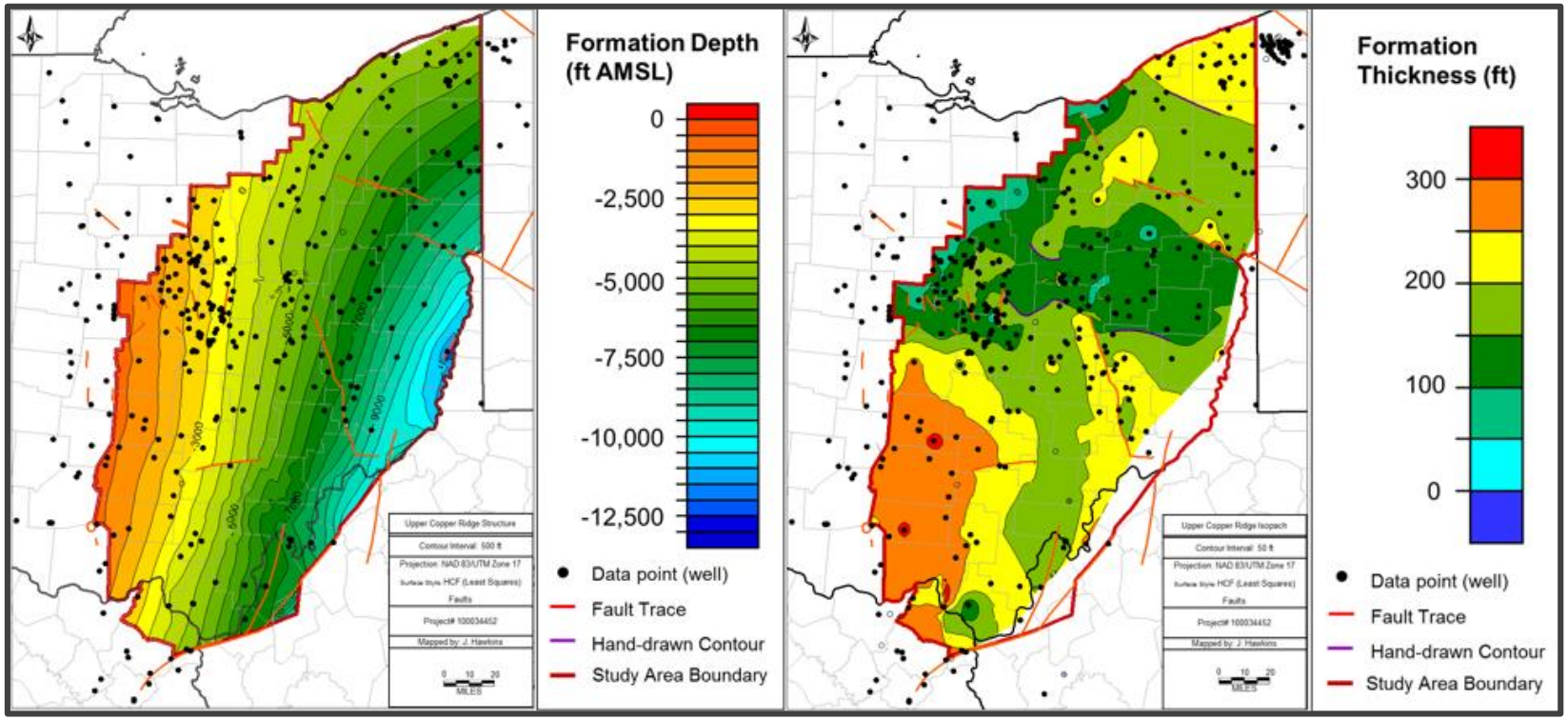
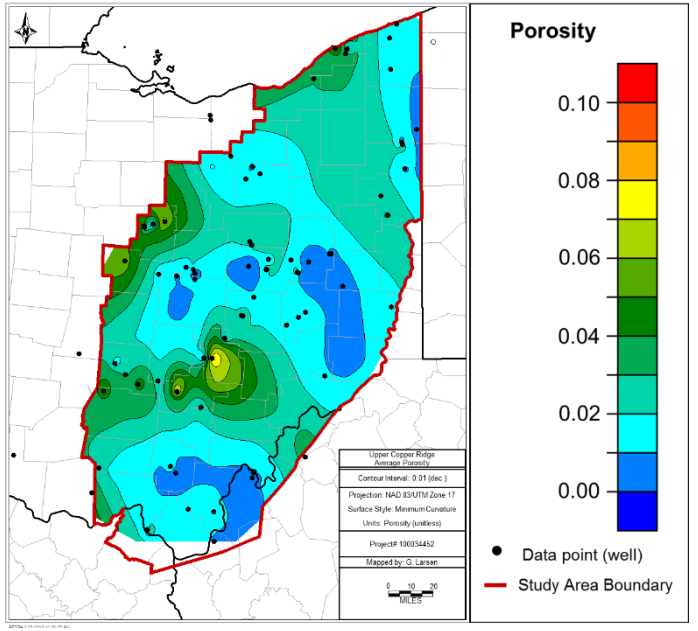
Upper Copper Ridge
Structure and Isochore Maps

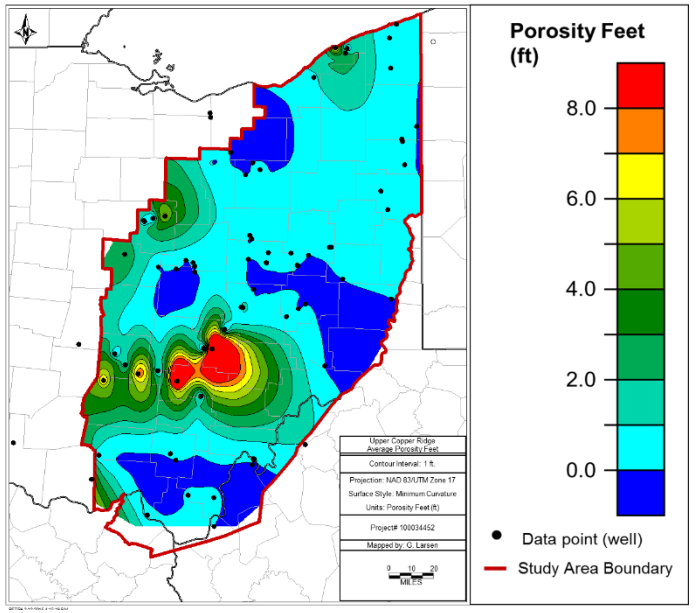


Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
25-336	174	0-230	25	0-0.86	0.13

Upper Copper Ridge
Regional Analysis

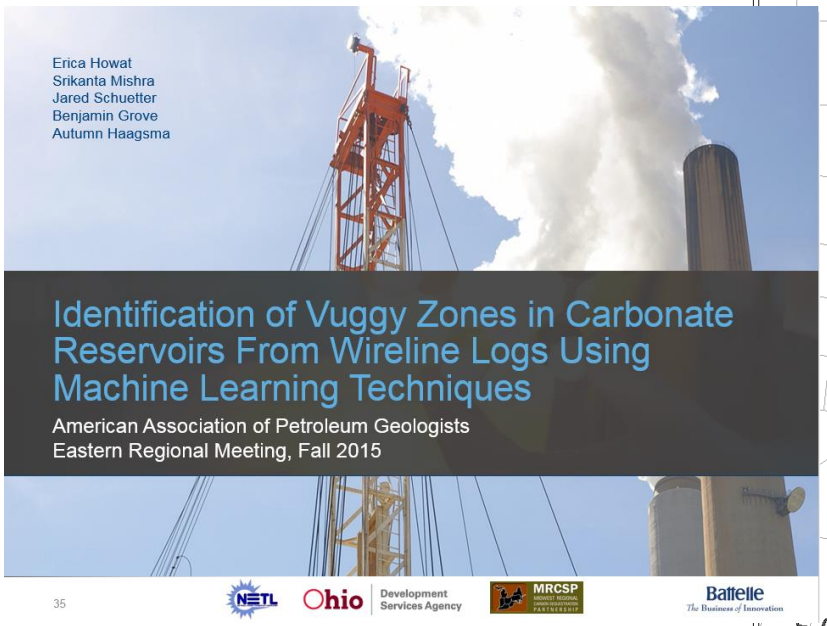
- Available Digital Logs = 252
- Highest porosities were found in the central to eastern region of Ohio
- Vug analysis model predicts development in discrete portions of the study area

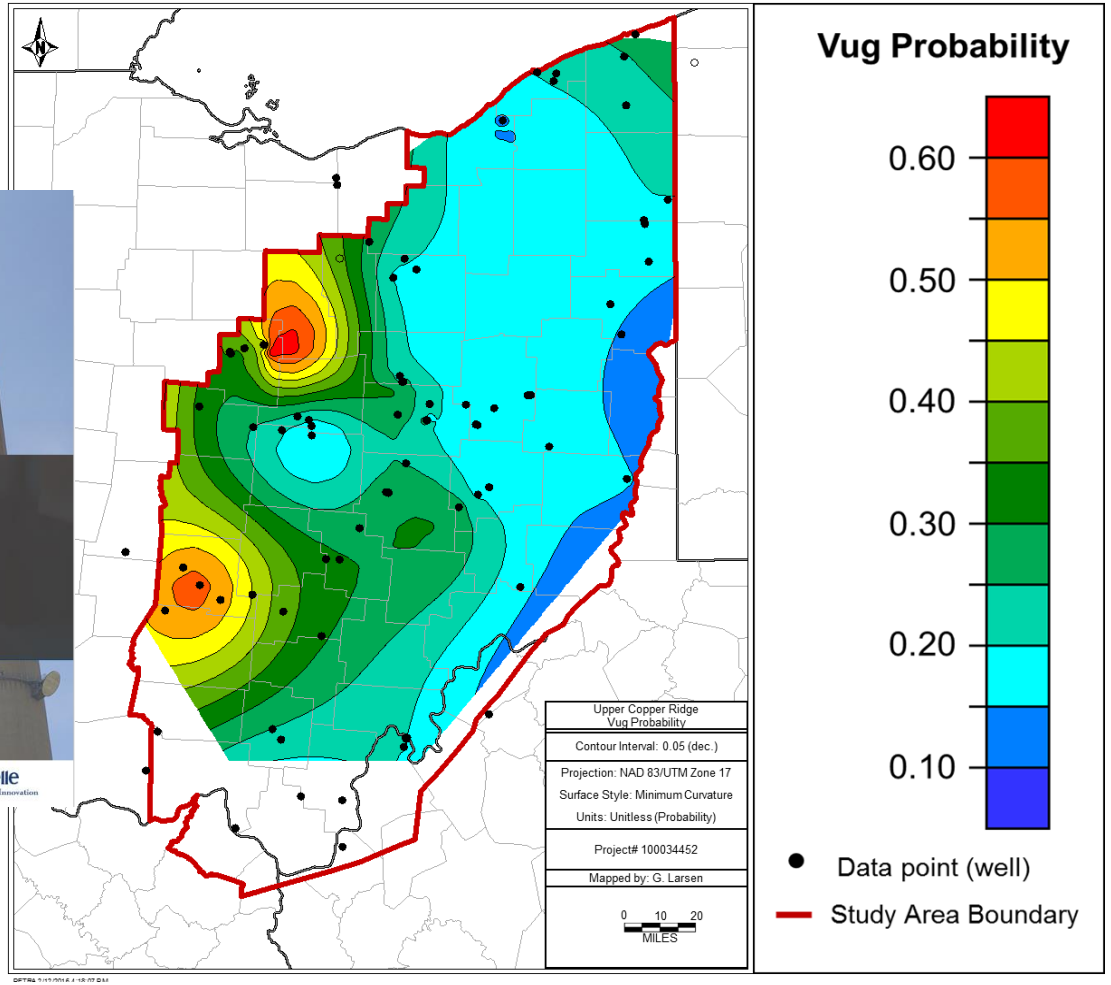




Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-8	2	0-20	2.5

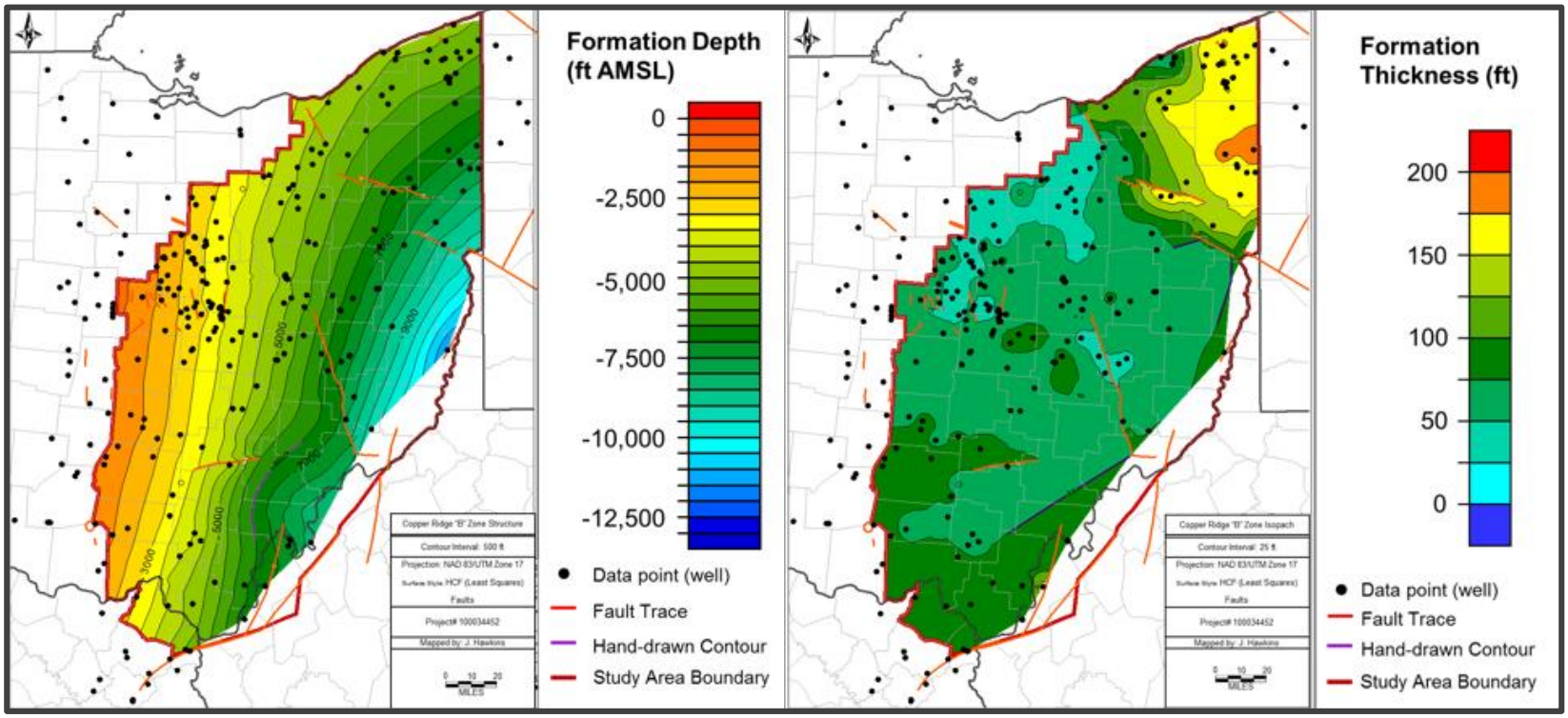
Upper Copper Ridge
Vug Analysis





Copper Ridge "B"

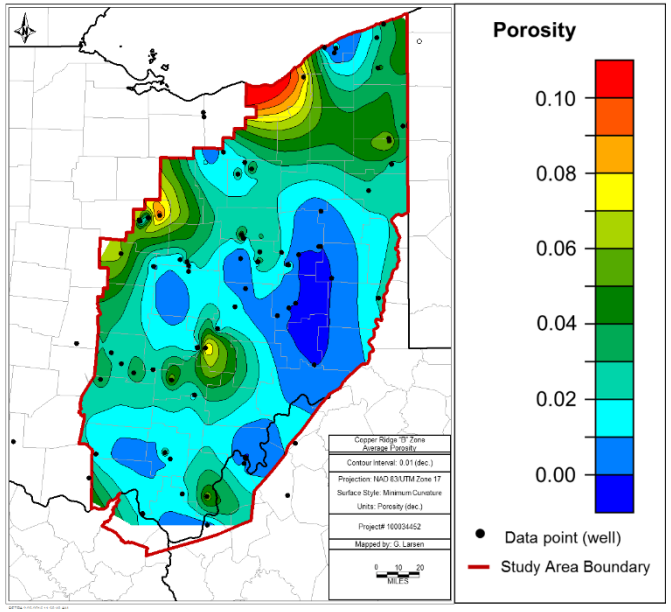
Structure and Isochore Maps

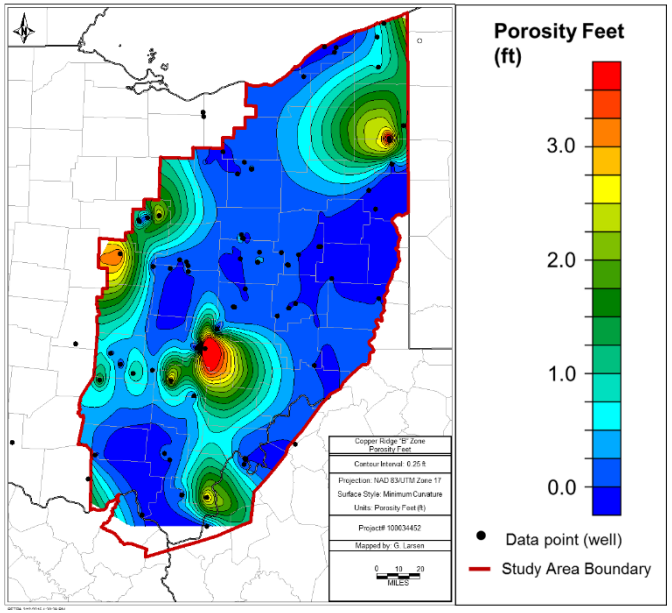


Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
30-200	68	0-65	14	0-0.97	0.16

Copper Ridge B
Regional Analysis

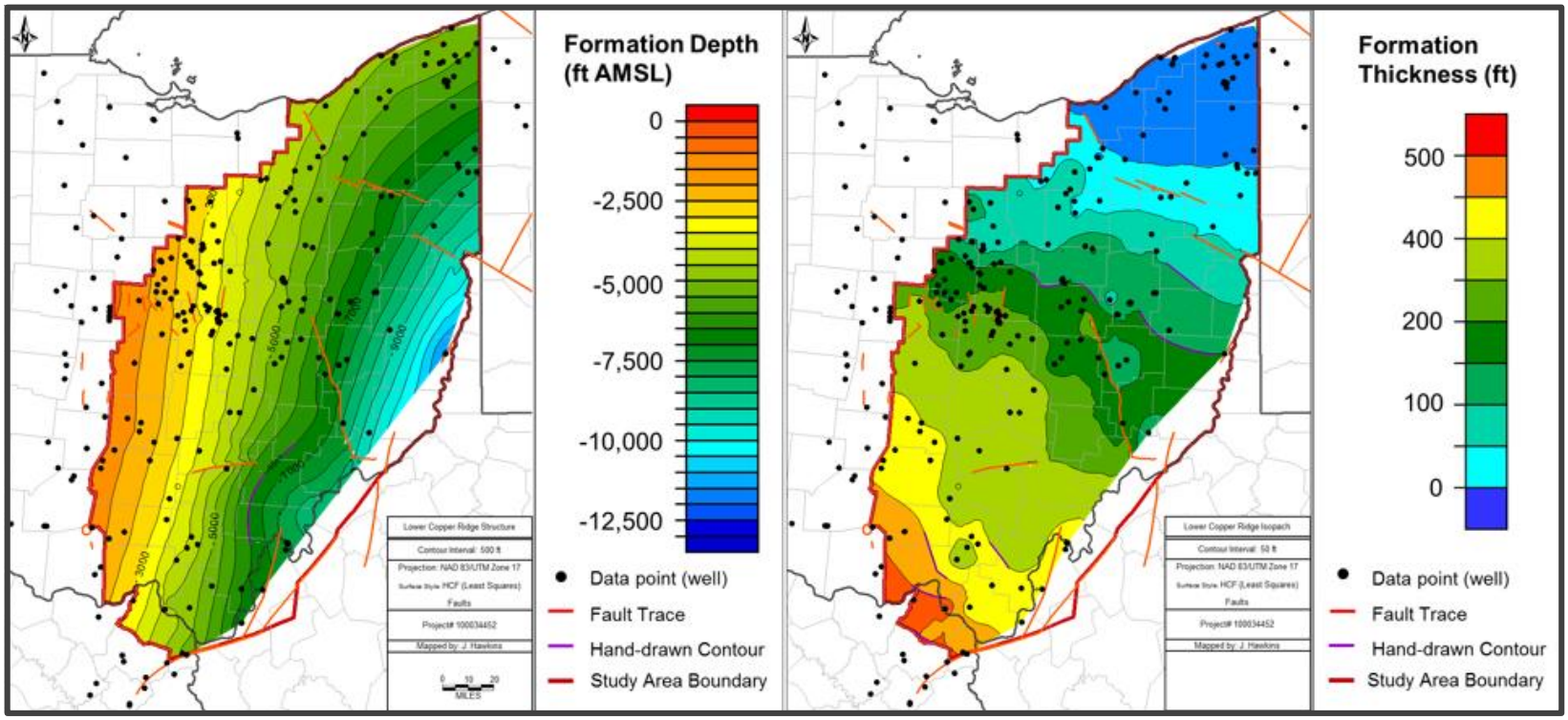
- Available Digital Logs = 216
- Whole core analysis revealed that a gradational contact exists between the upper Copper Ridge and “B” zone and that the B should be considered a facies of Upper Copper Ridge.





Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-12	3	0-5	1

Lower Copper Ridge
Structure and Isochore Maps



Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
14-462	219	10-186	26	0-0.7	0.36

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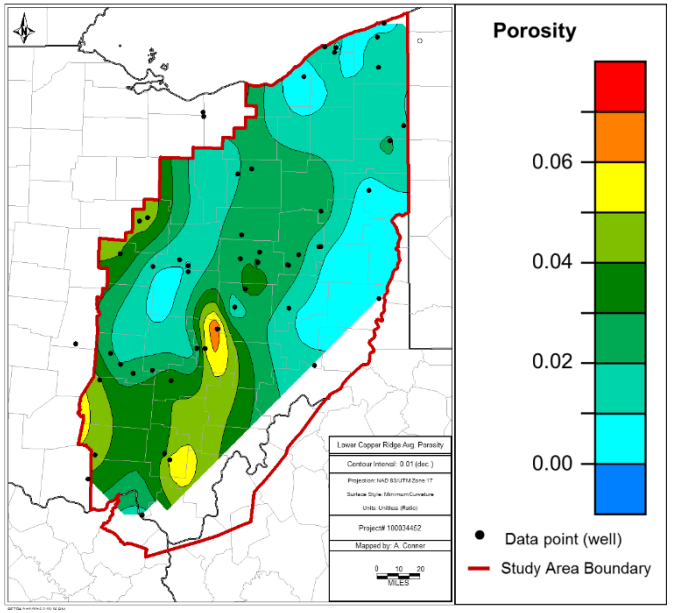
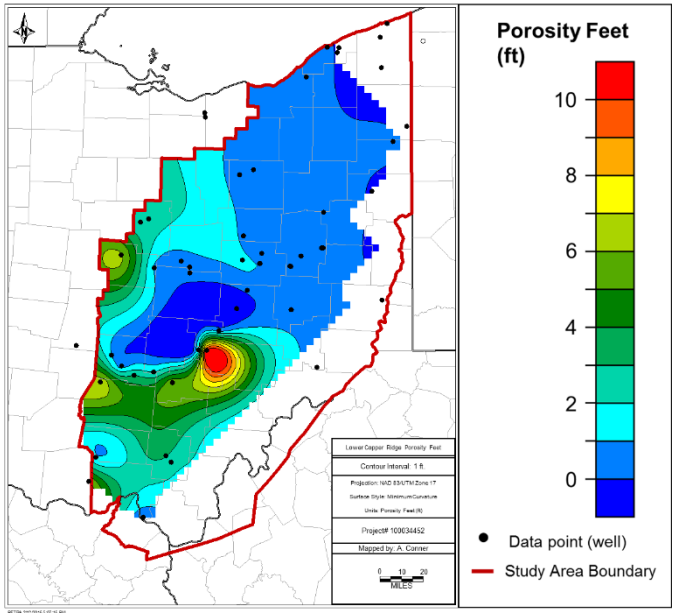
Lower Copper Ridge
Regional Analysis

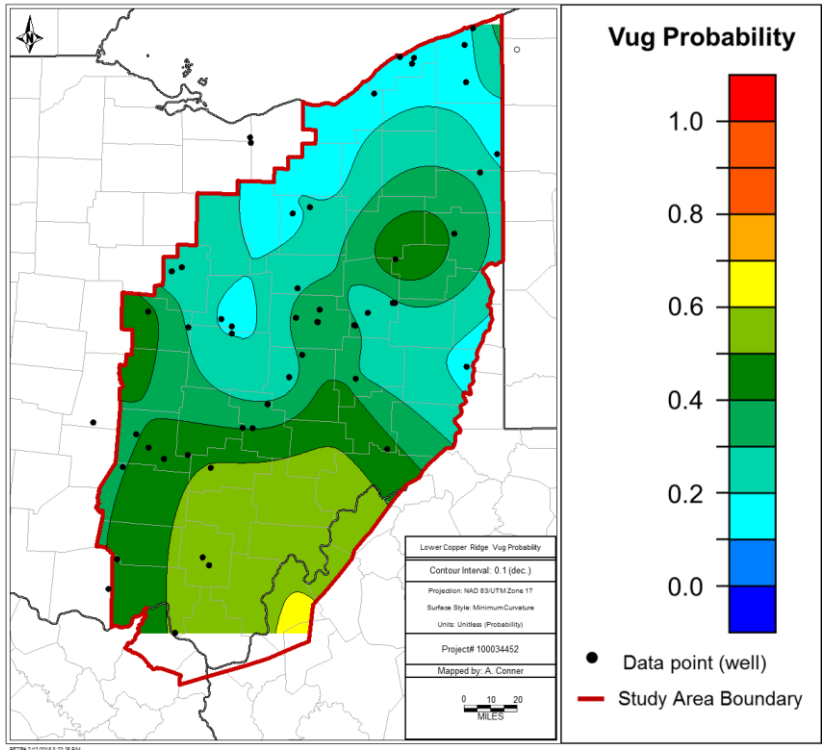
- Available Digital Logs = 202
- Vug model predicts high probability of vug development in southern portions of the state
- An arkosic sandstone facies identified at the base of the lower Copper Ridge was previously misidentified as a shale or tight carbonate due to high gamma ray signatures.

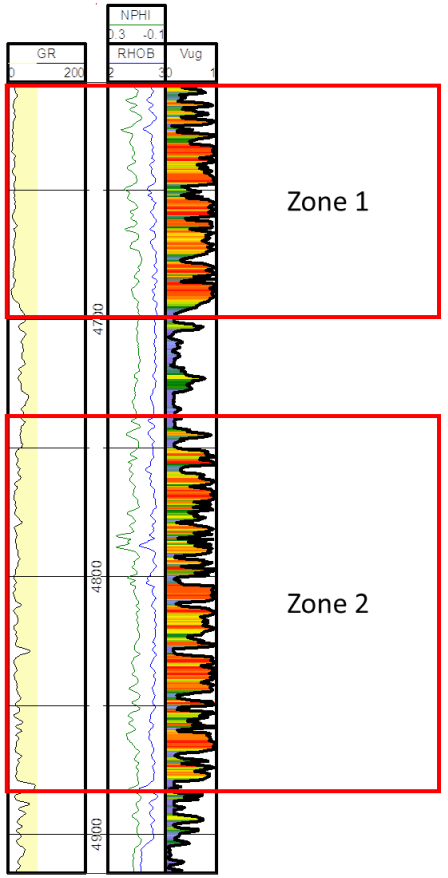




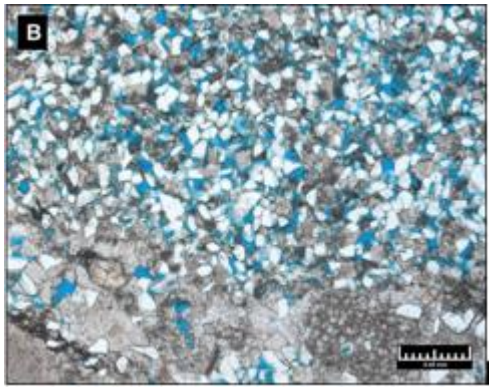
Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-8	5	0-15	2.5

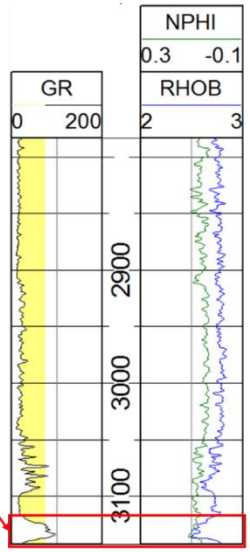
Lower Copper Ridge
Vug Model Predictions



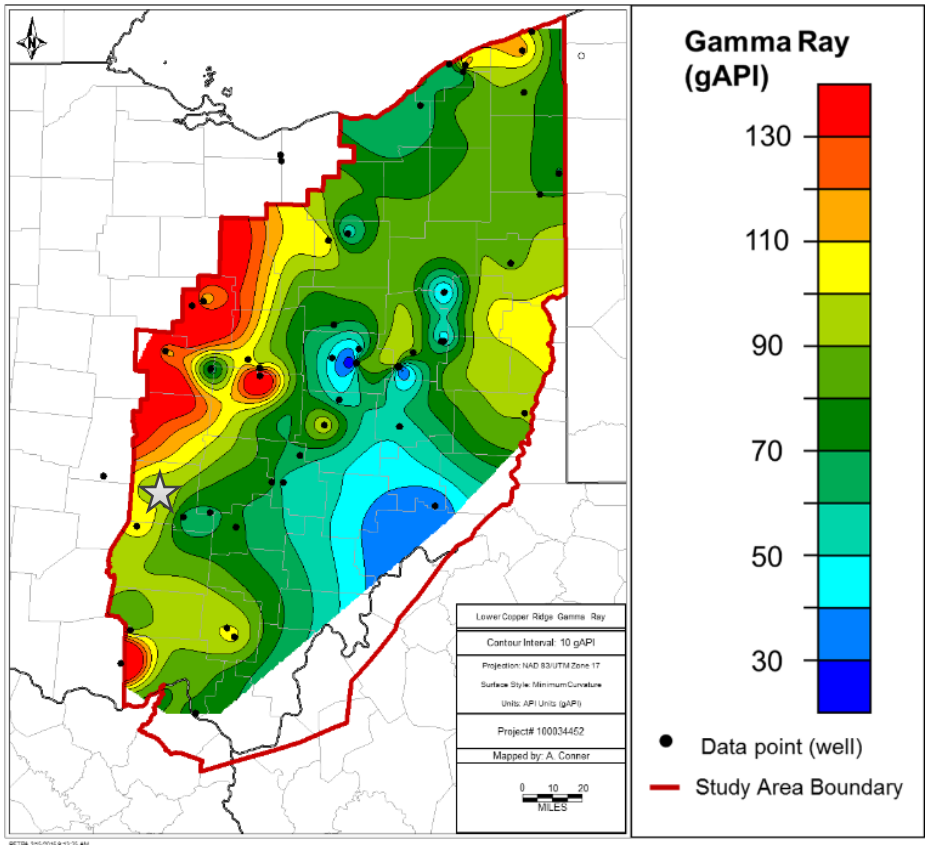


Lower Copper Ridge
Basal Sand Facies



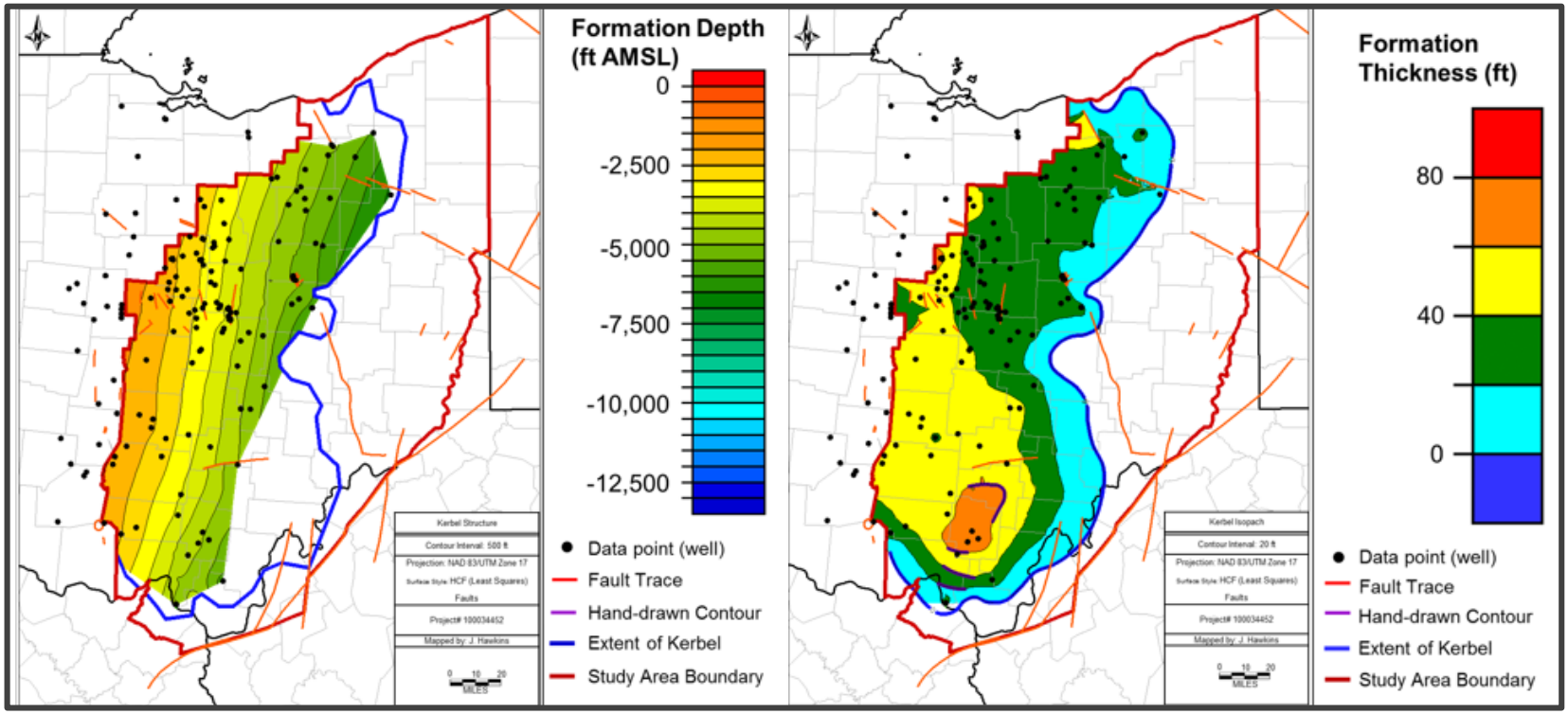


Sand Indicator



Kerbel

Structure and Isochore Maps

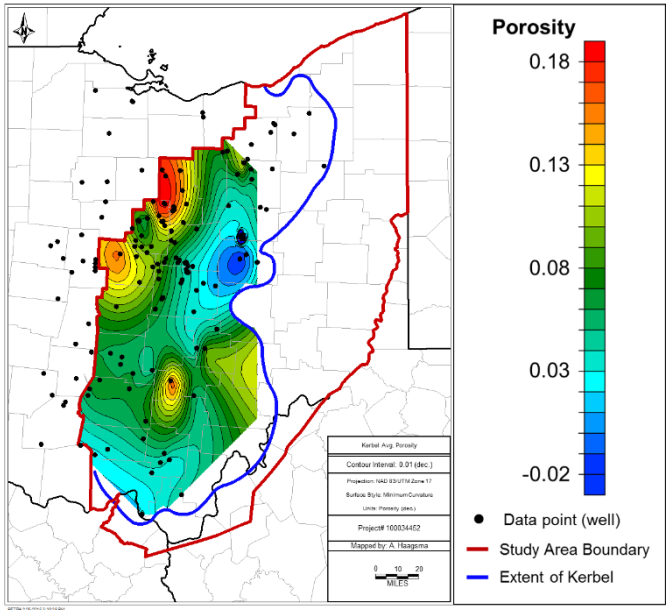


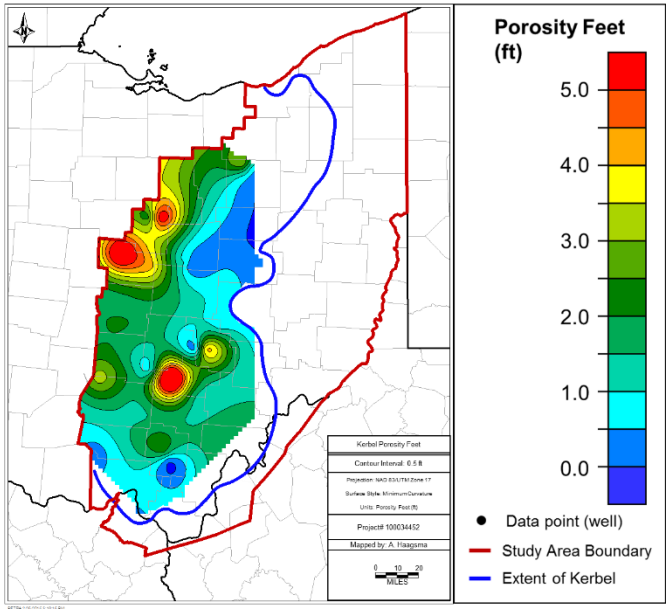
Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
0-75	36	1-47	22	0-1	0.53

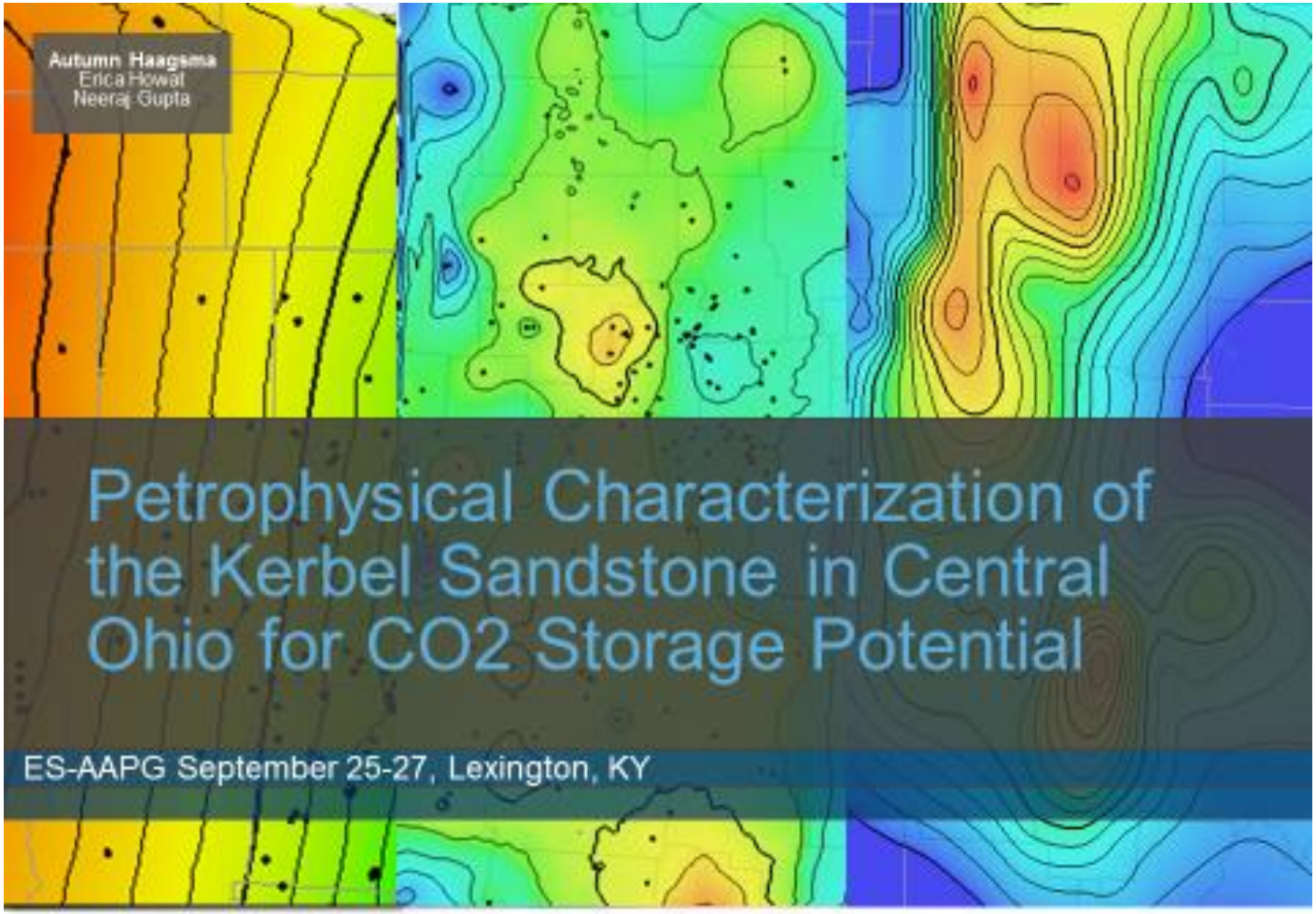
Kerbel
Regional Analysis

- Available Digital Logs = 141
- Initially interpreted as a delta deposit, but core descriptions indicate a barrier island to shallow marine environment.
- Log signatures indicate a facies change from northern to southern Ohio, beginning with clean sandstone, to dolomitic sandstone, to a dolomite/mudstone in southern Ohio.

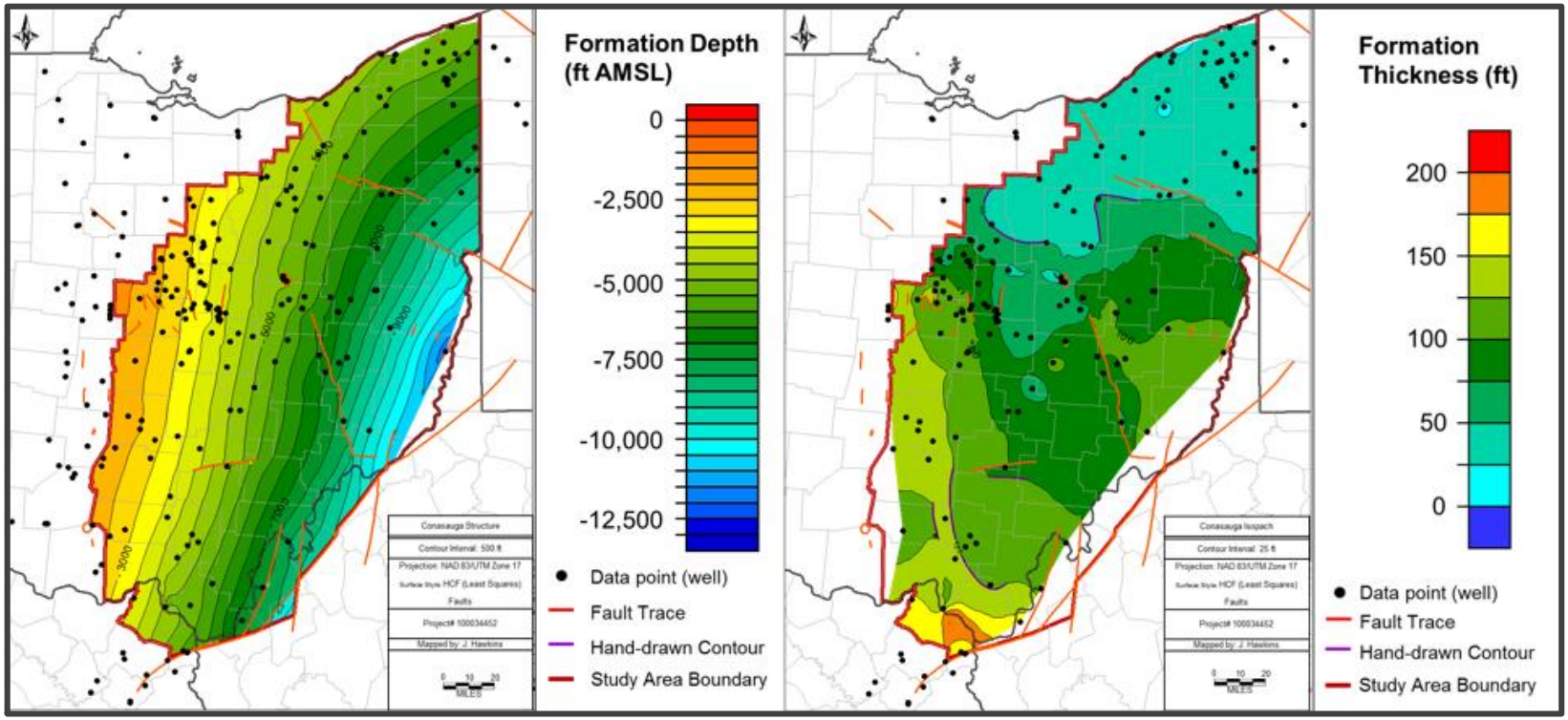
Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-18	6	0-8	2.4






Autumn Haagsma
Erica Howat
Neeraj Gupta
Petrophysical Characterization of the Kerbel Sandstone in Central Ohio for CO2 Storage Potential
ES-AAPG September 25-27, Lexington, KY
Battelle

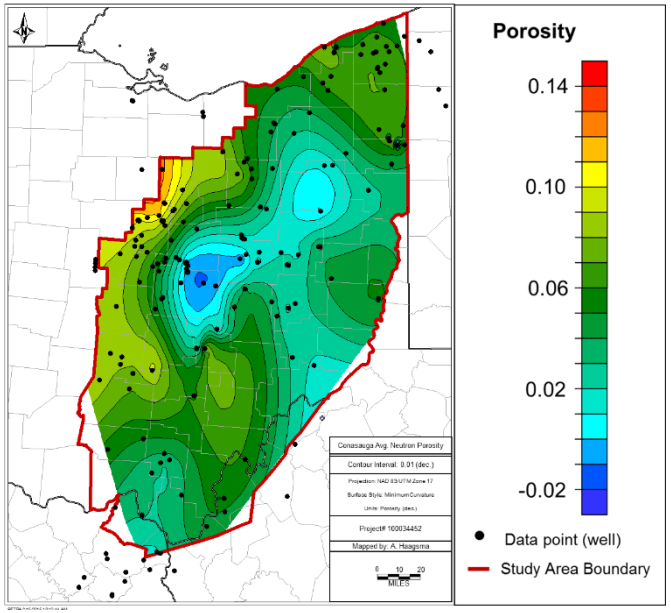
Conasauga
Structure and Isochore Maps

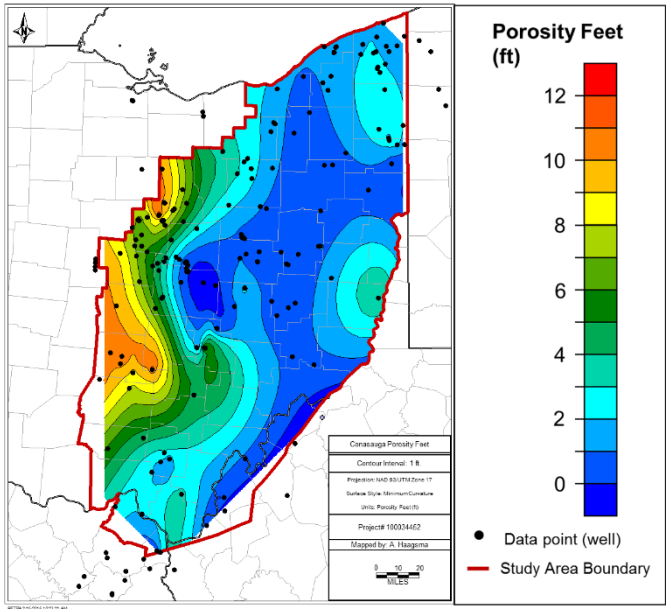


Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
16-482	73	1-114	34	0-1	0.42

Conasauga
Regional Analysis

- **Available Digital Logs = 159**
- **Piggyback well revealed presences of arkosic sand facies at base of formation**





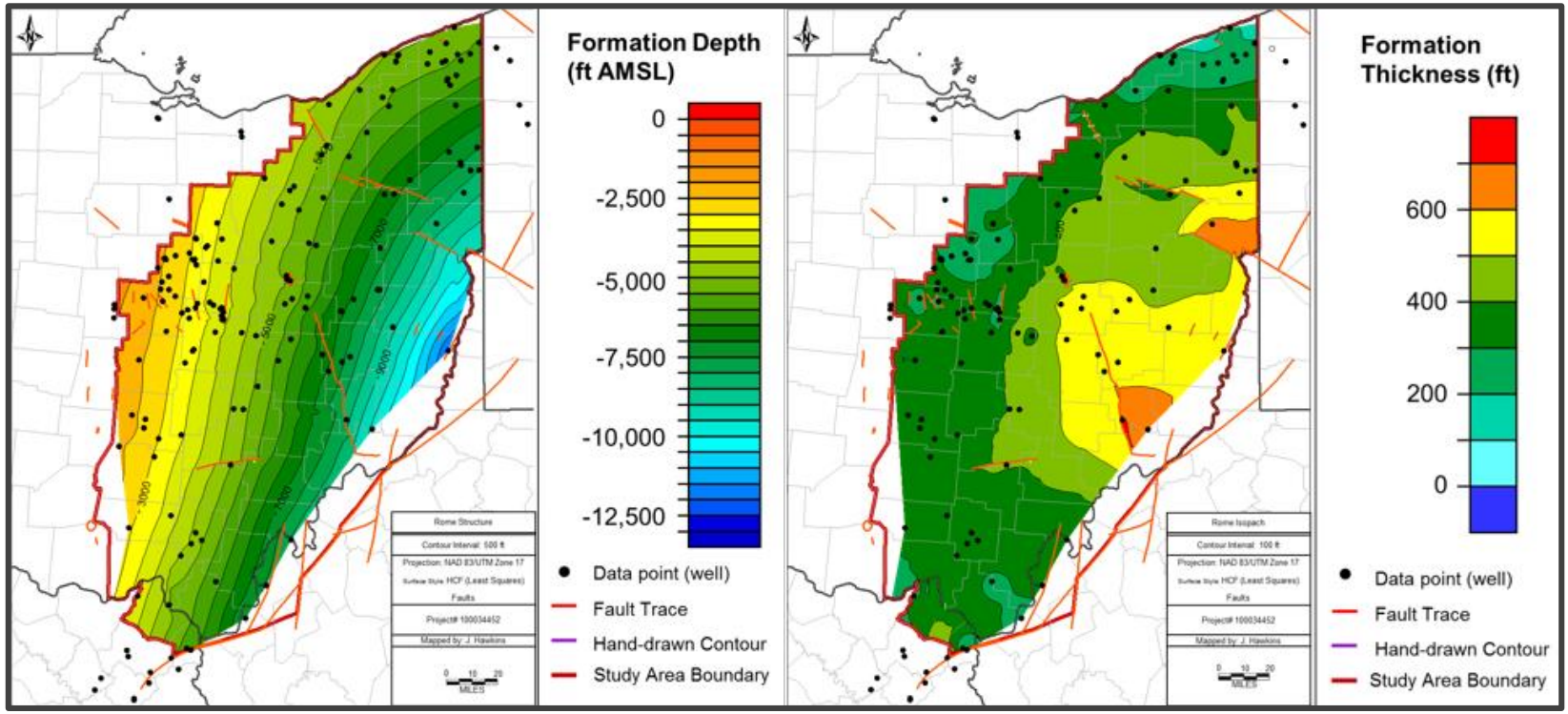
Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-15	5	0-16	3.1

Conasauga


Structural Impacts on the Deposition and Reservoir Development in the Conasauga Group in Ohio
Autumn Haagsma, Glenn Larsen, Erica Howat, and Charlotte Sullivan
1 AAPG Indianapolis 2015
Ohio Development Services Agency
MRCSP
Battelle

Rome

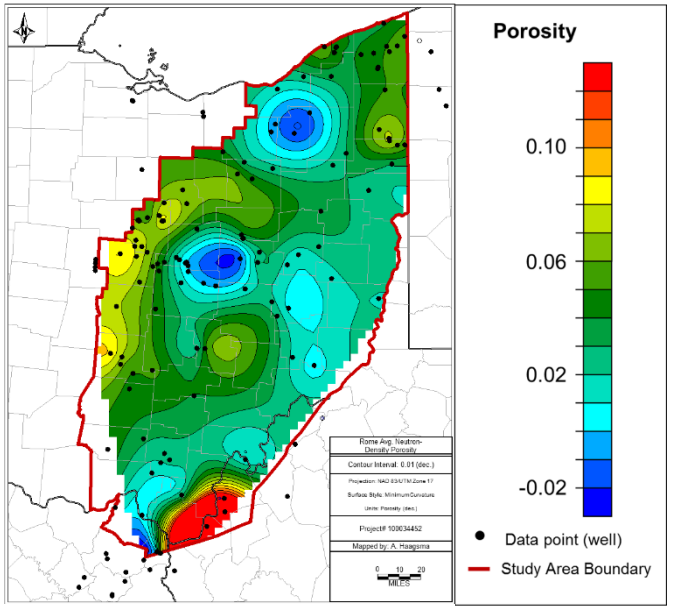
Structure and Isochore Maps

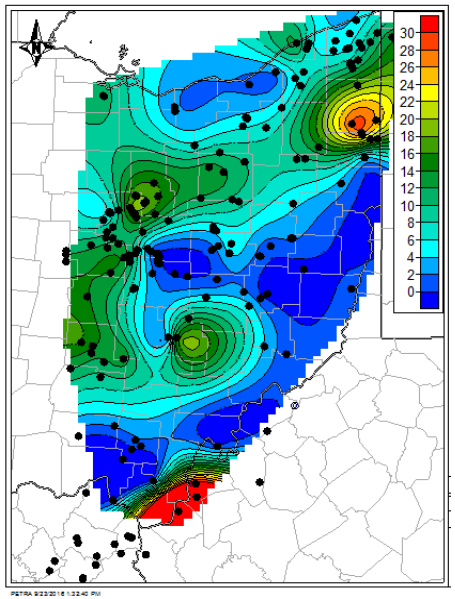


Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
150-707	344	1-388	100	0-1	0.32

Rome
Regional Analysis

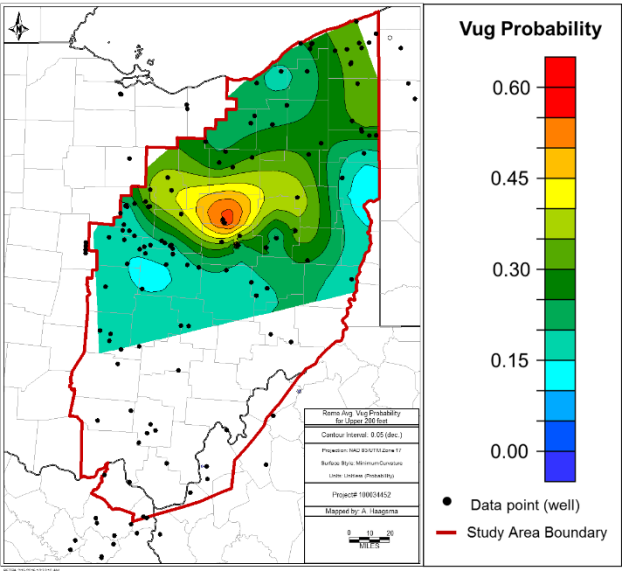
- **Available Digital Logs = 153**
- A zone of high vug probability occurred in the upper 100 to 150 feet in central to northern Ohio.
- Vugs strongly correlate to mixed carbonates

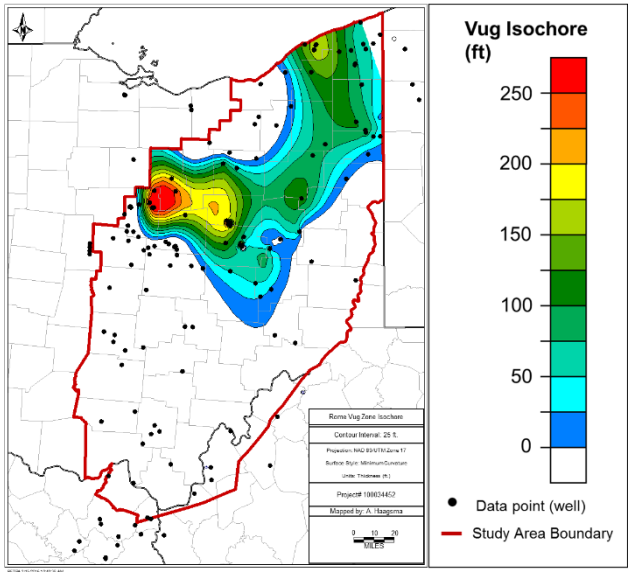


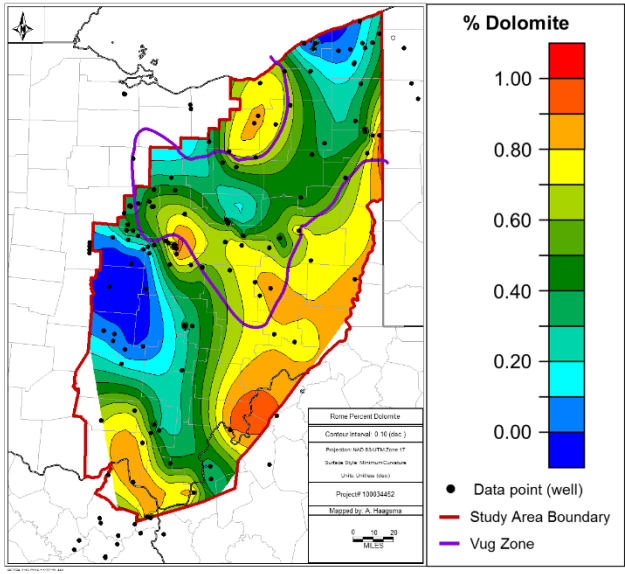


Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-11	4	0-66	7

Rome
Vug Probability

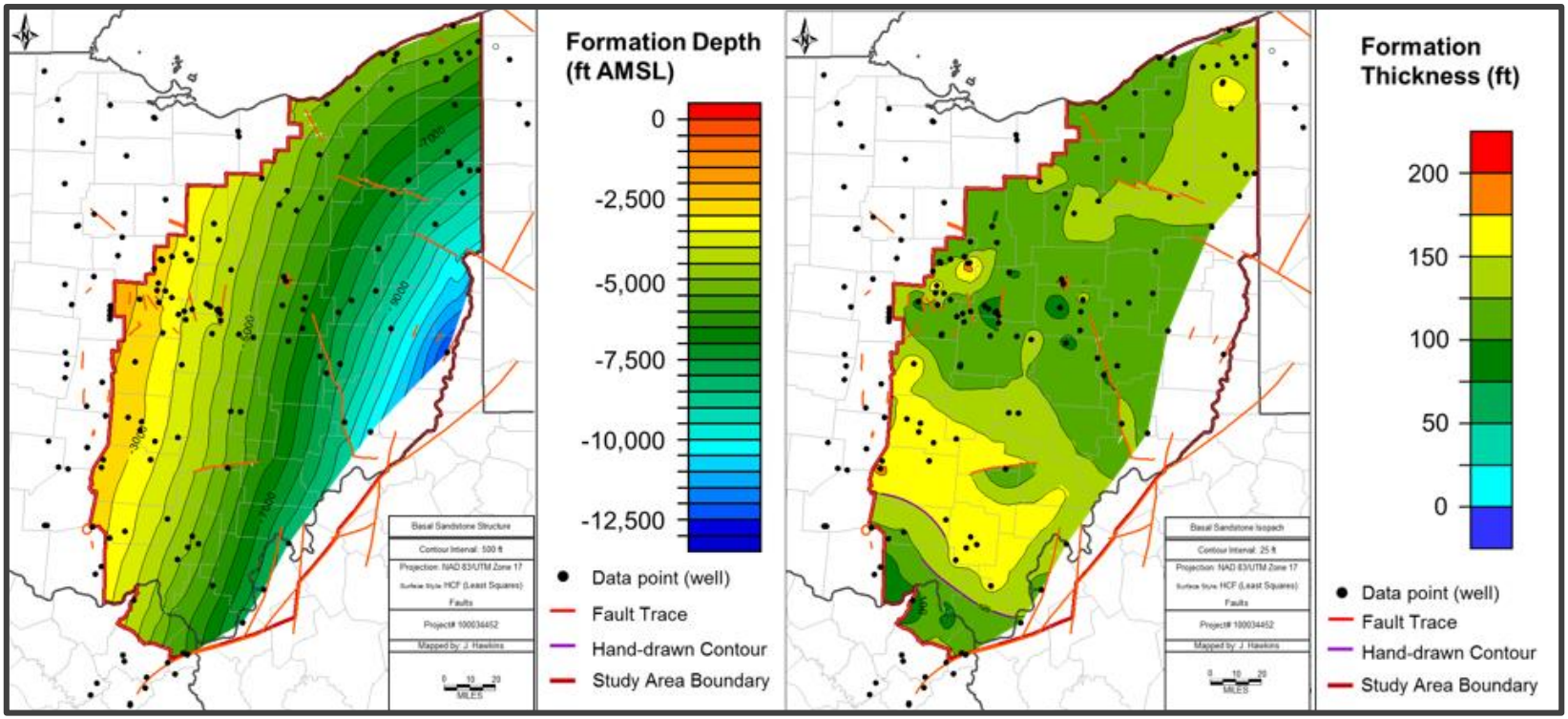






Basal Sands

Structure and Isochore Maps



Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
Range	Average	Range	Average	Range	Average
66-342	130	0-172	51	0-0.98	0.38

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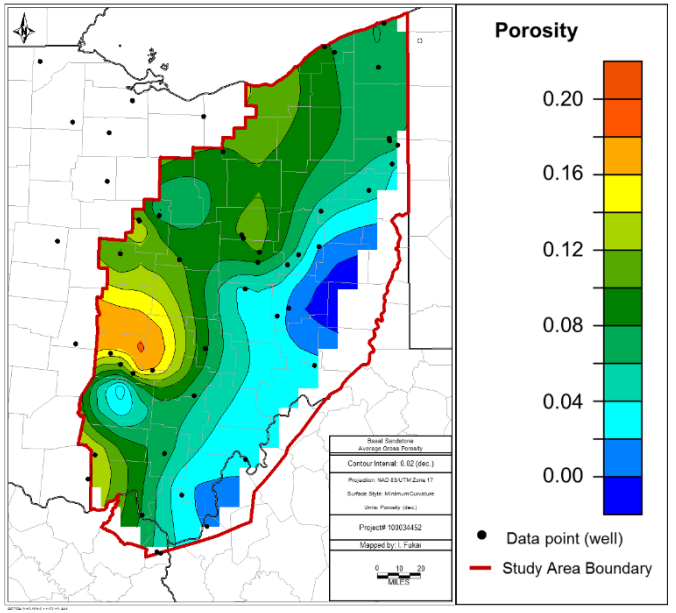
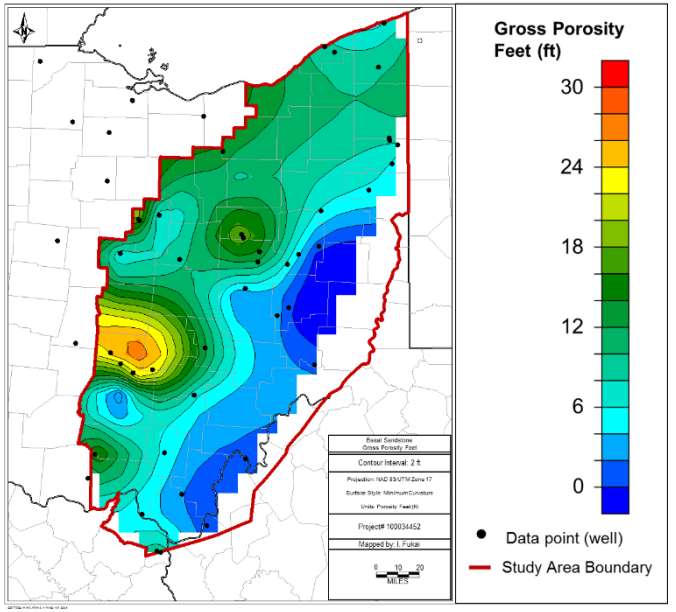
The Business of Innovation

Basal Sands
Regional Analysis

- Available Digital Logs = 53
- Mineralogy played an important role in porosity development of the basal sandstones. Sandstones with higher K-feldspar and quartz amounts were found along the western edge of the study area and had the highest reservoir potential. Toward the east, the basal sandstone became more dolomitic and had less porosity.

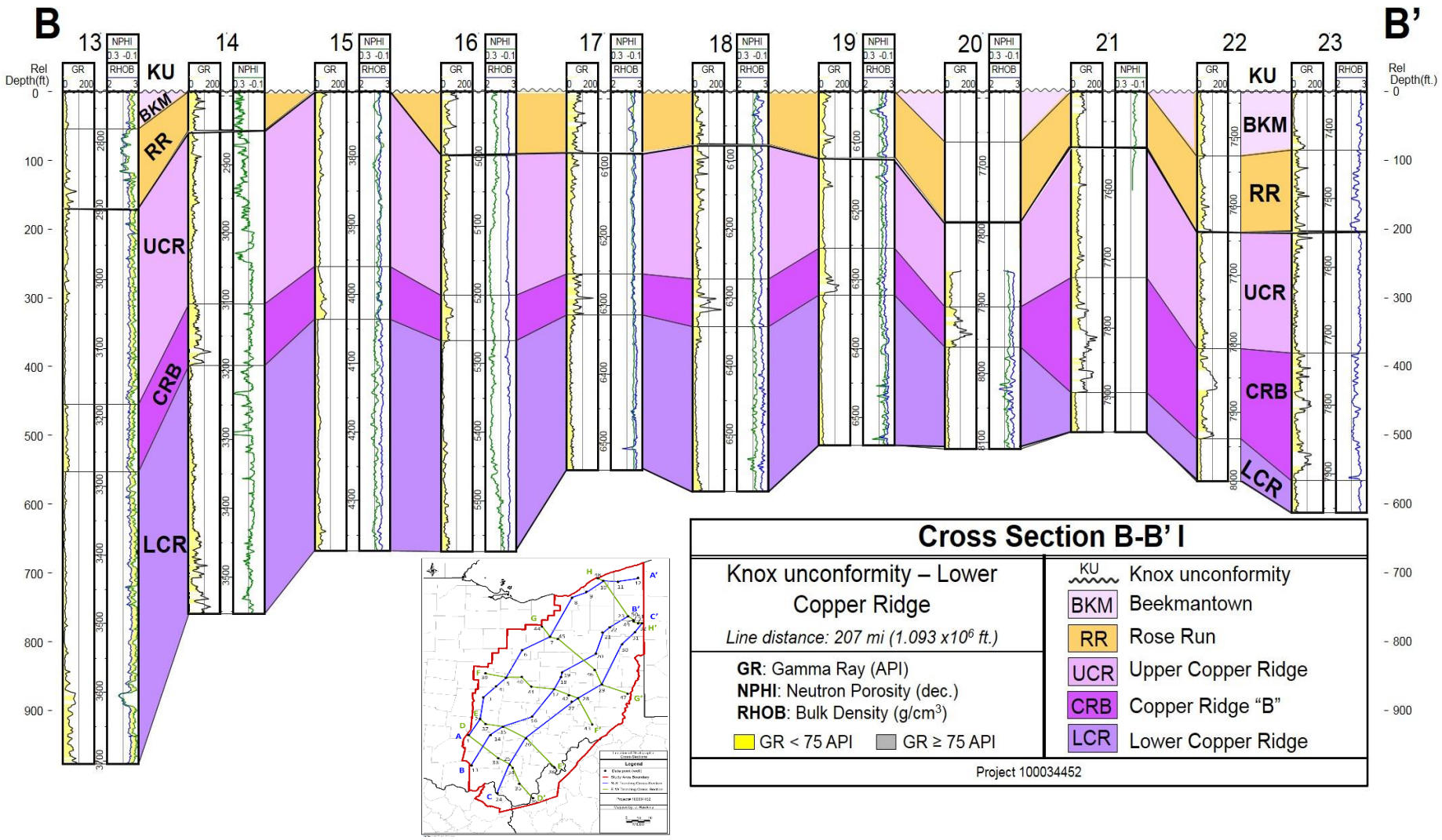




Porosity (%)		Porosity Feet	
Range	Average	Range	Average
0-22	9	0-28	8

REGIONAL CROSS SECTIONS

Upper Section Strike Section:
Beekmantown to Lower Copper Ridge



Cross Section B-B' I

Knox unconformity – Lower Copper Ridge

Line distance: 207 mi (1.093 x10^6 ft.)

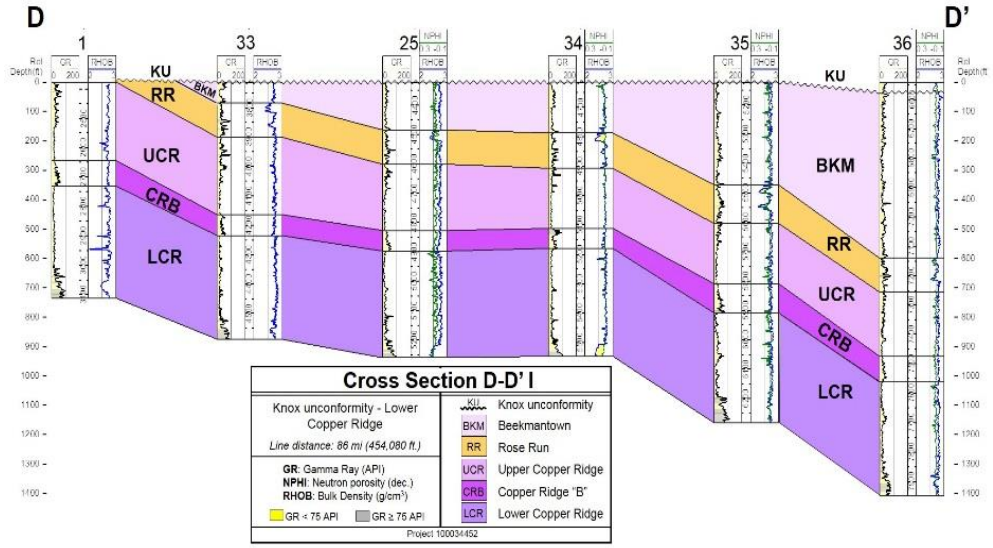
GR: Gamma Ray (API)
NPHI: Neutron Porosity (dec.)
RHOB: Bulk Density (g/cm^3)

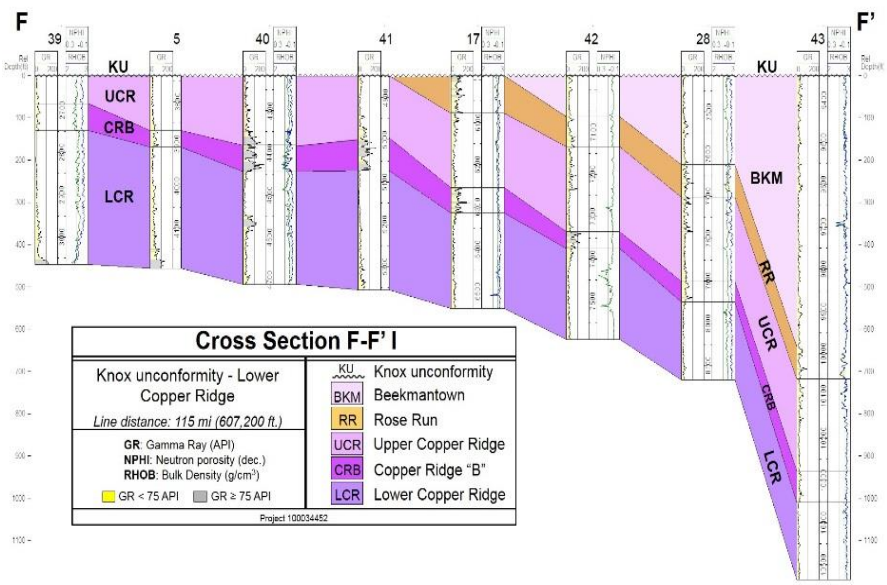
GR < 75 API GR ≥ 75 API

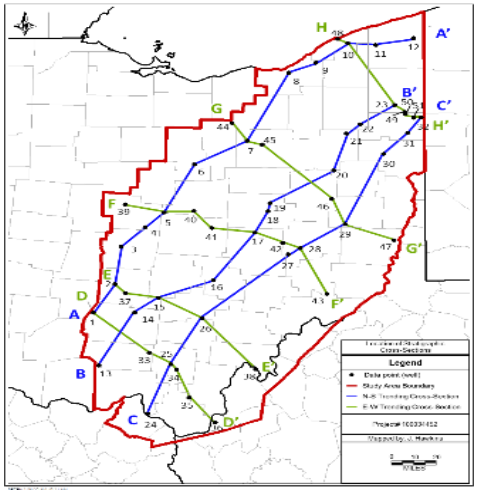
KU	Knox unconformity
BKM	Beekmantown
RR	Rose Run
UCR	Upper Copper Ridge
CRB	Copper Ridge "B"
LCR	Lower Copper Ridge

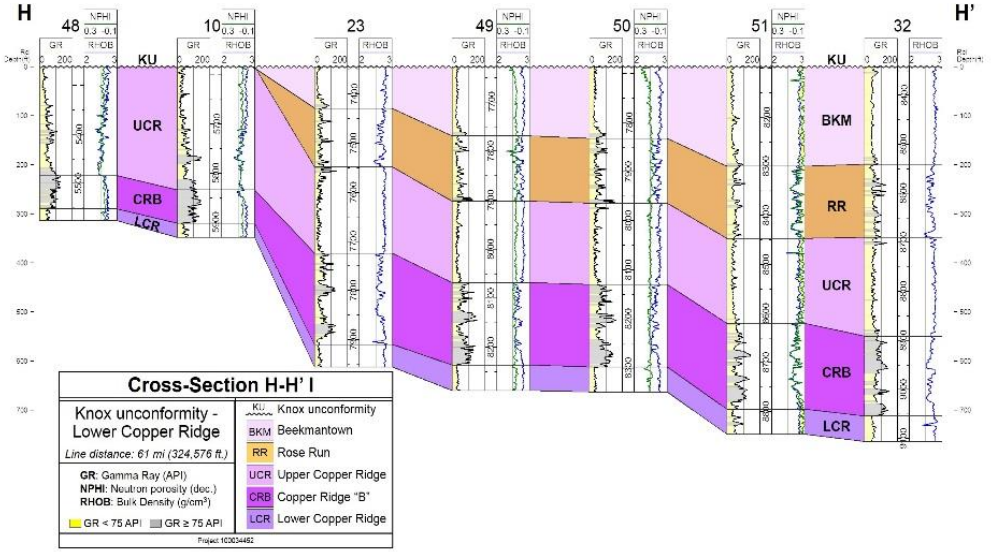
Project 100034452

Upper Section Dip Sections:
Beekmantown to Lowe Copper Ridge



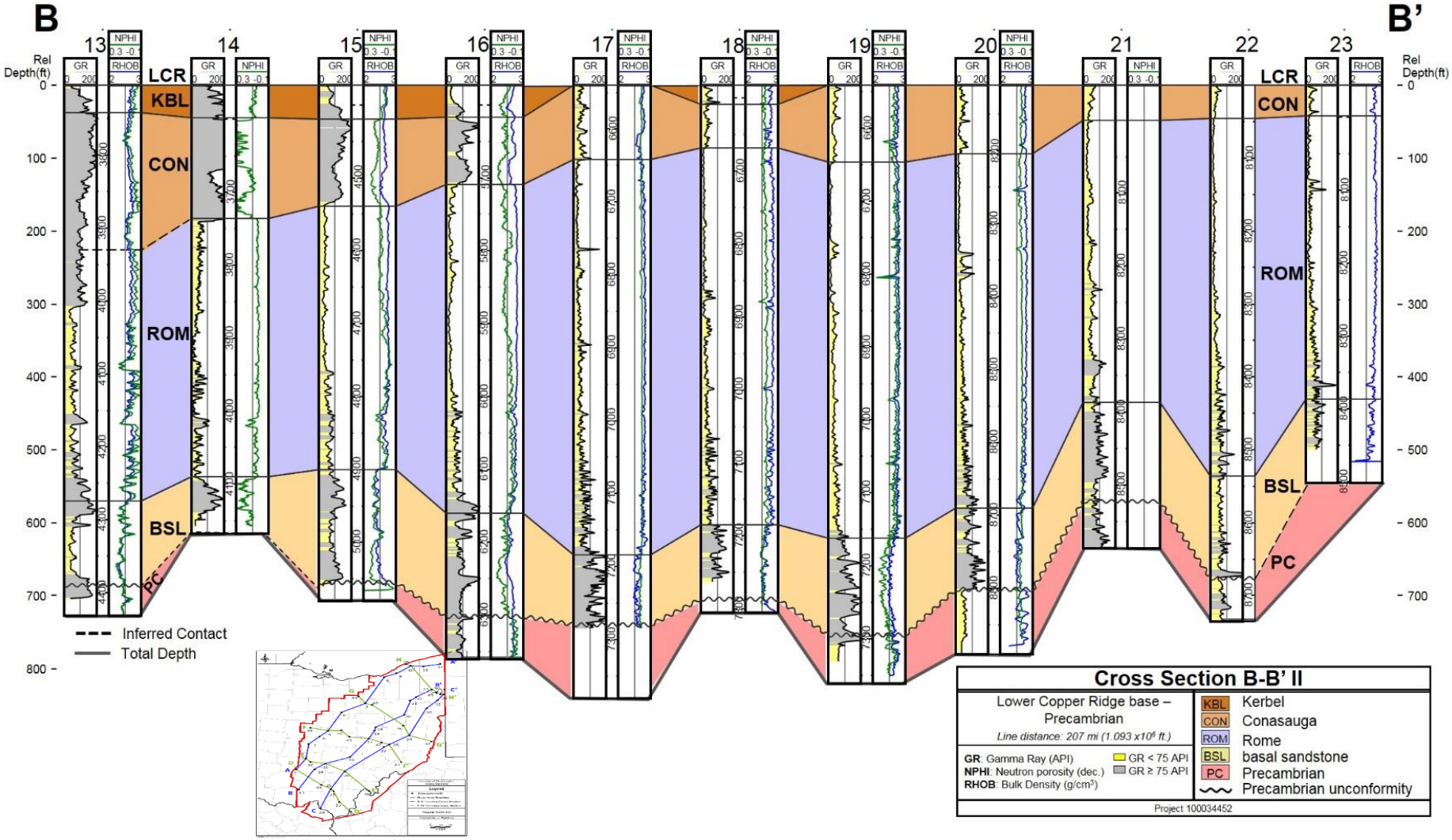






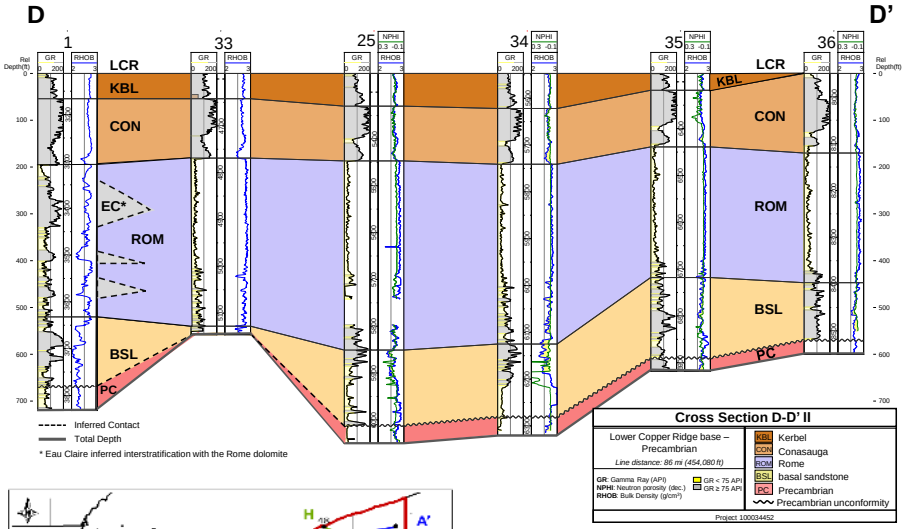
Lower Section Strike Section:

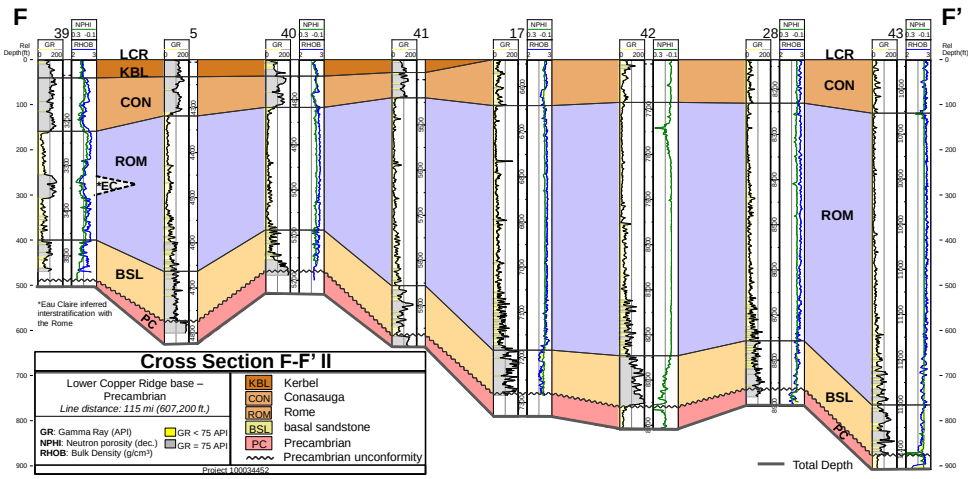
Kerbel to Precambrian Basement

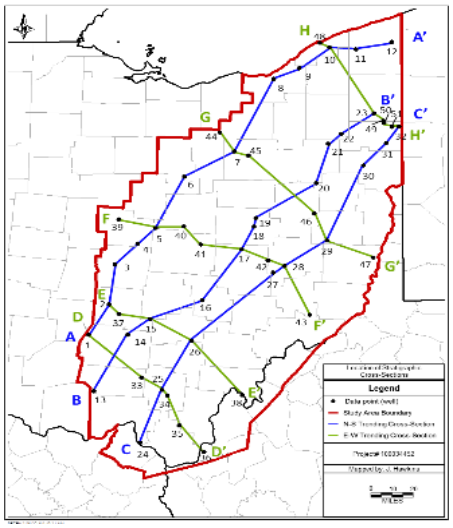


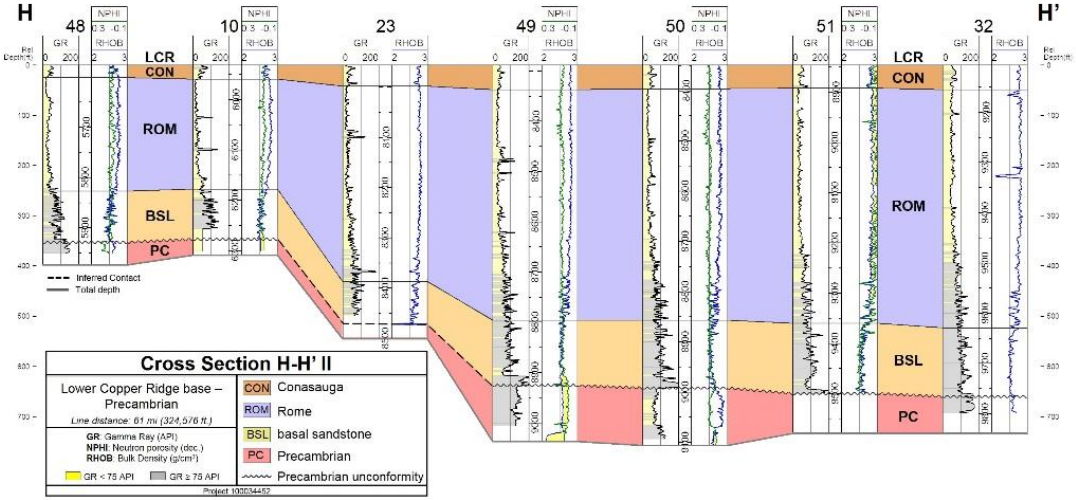
Lower Section Dip Sections:

Kerbel to Precambrian Basement



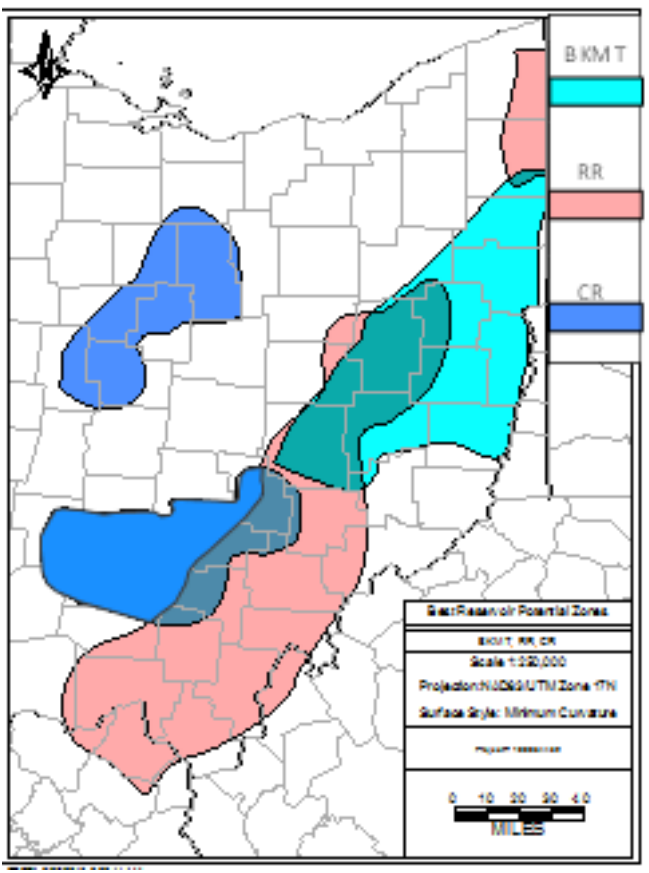


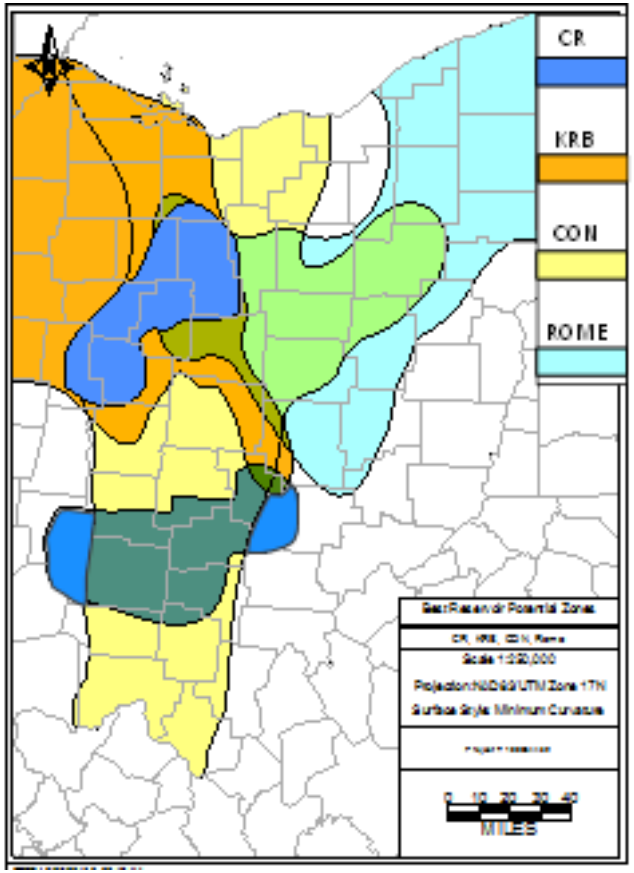


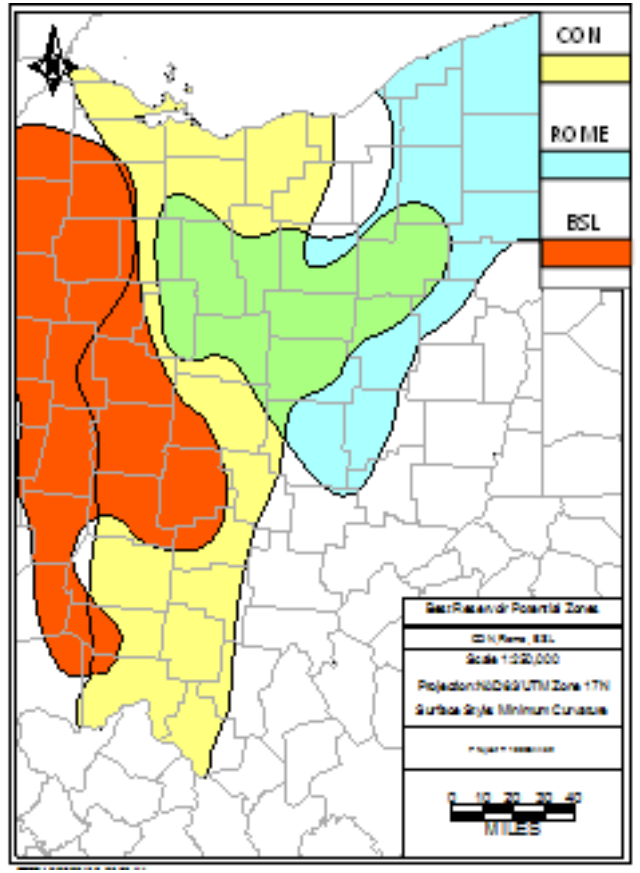


REGIONAL CONCLUSIONS

Potential Reservoir Zone Overlap







ACKNOWLEDGMENTS

OHIO COAL DEVELOPMENT OFFICE (ODCO)

MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP (MRCSP)

OHIO DIVISION OF NATURAL RESOURCES (ODNR)

BATTELLE ENERGY TEAM

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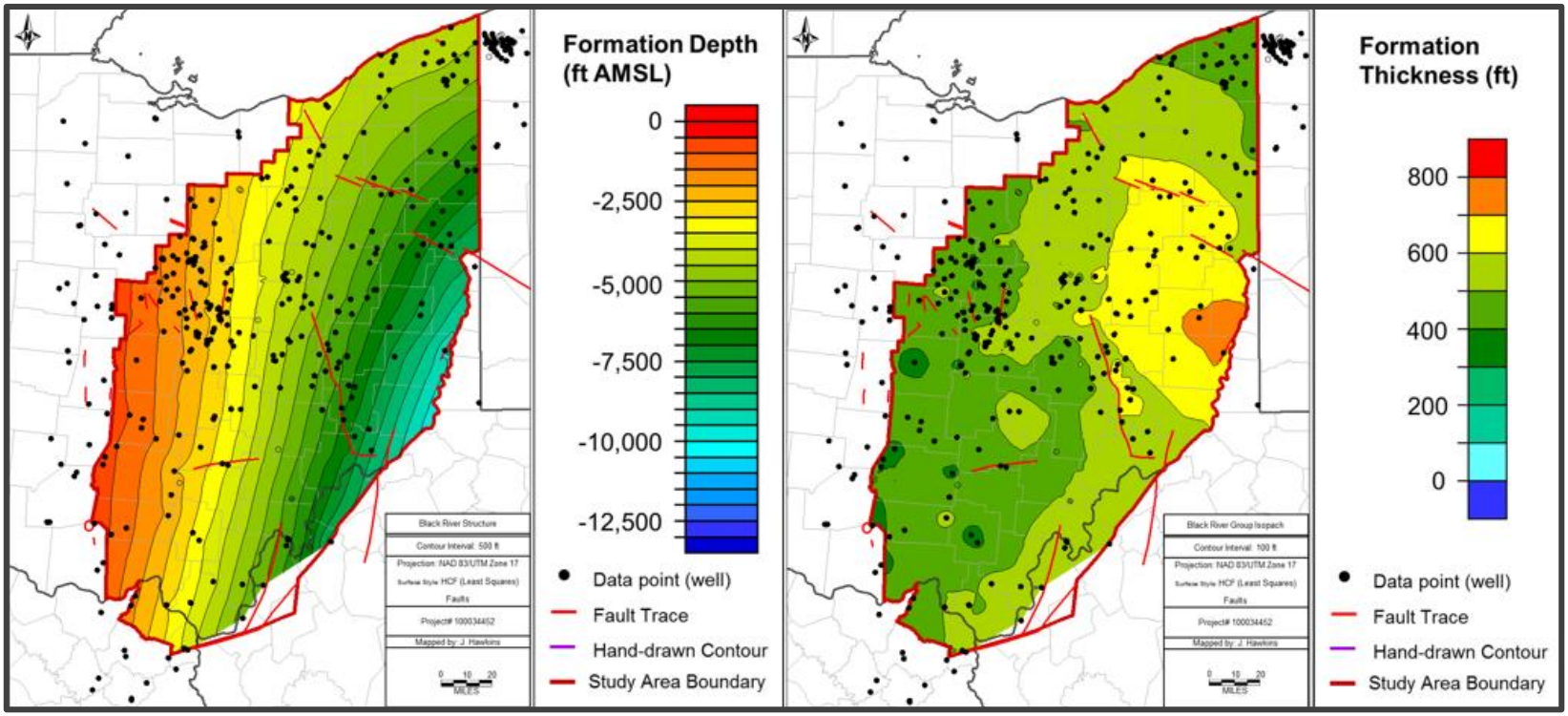
Battelle

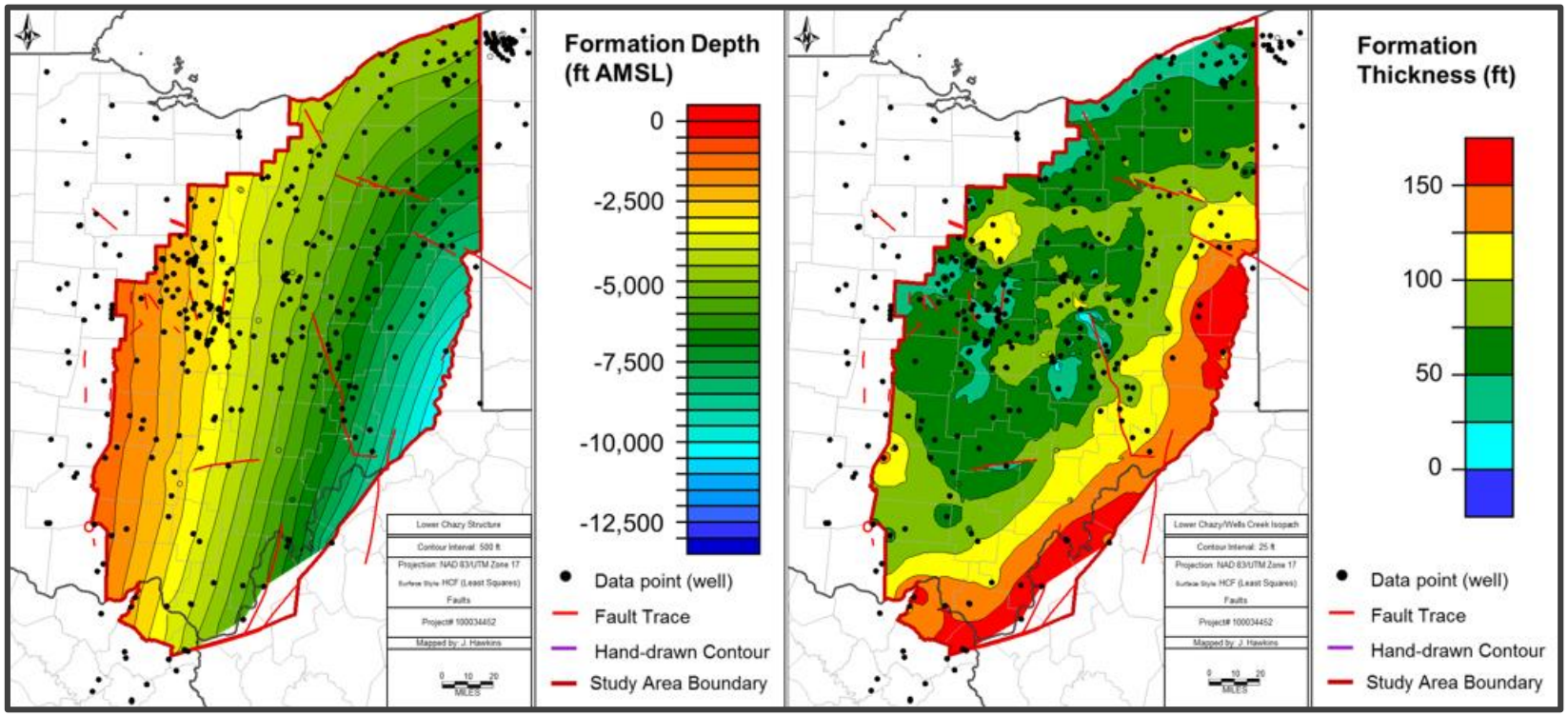
The Business *of* Innovation

Black River

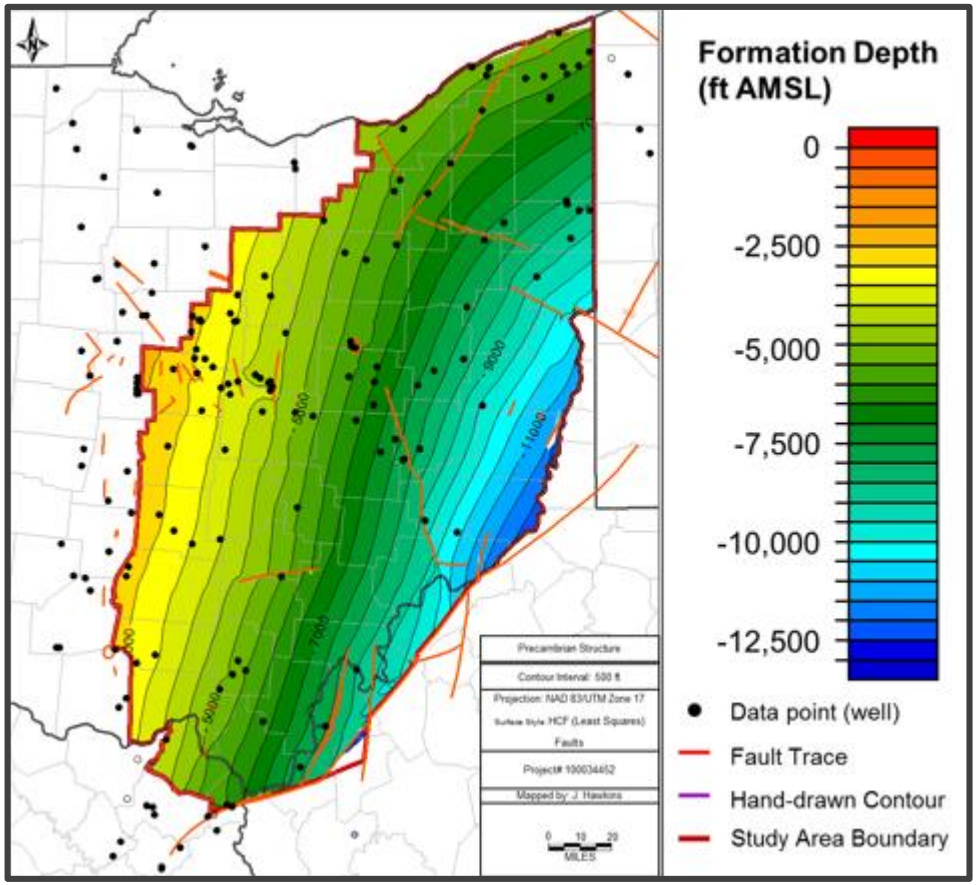
Structure and Isochore Maps



Lower Chazy/Wells Creek
Structure and Isochore Maps



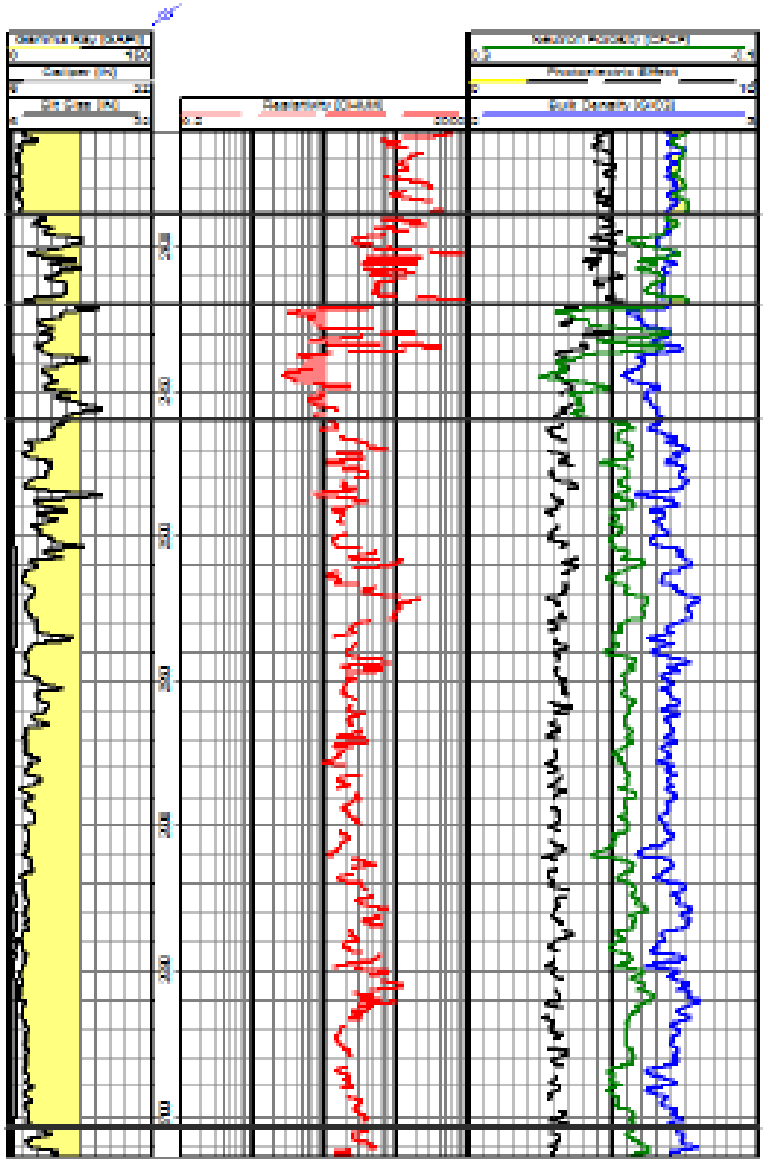
Precambrian
Structure Map



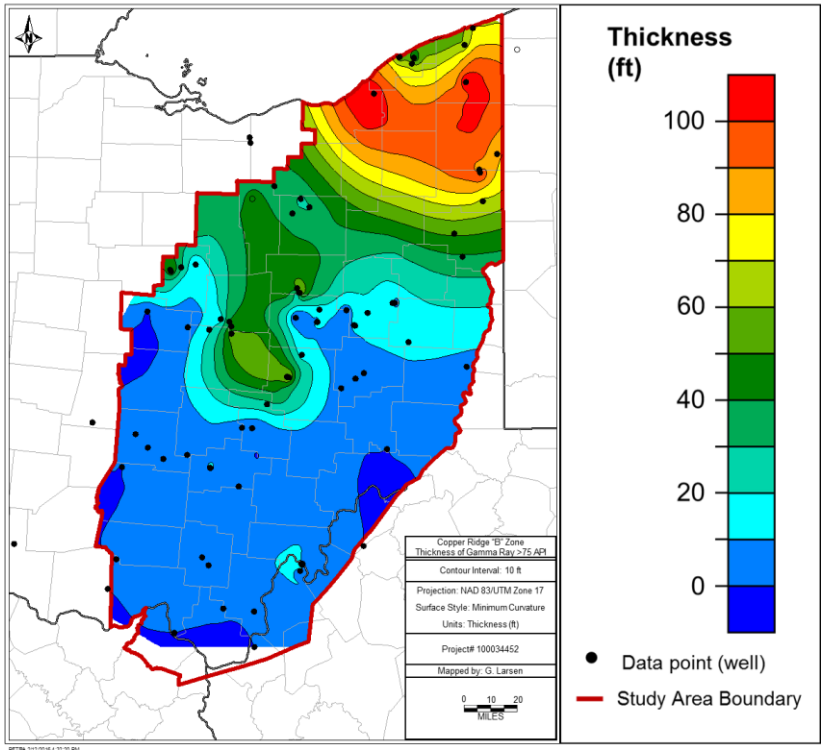
Tops Selections

Rose Run Base/ Upper Copper Ridge Top

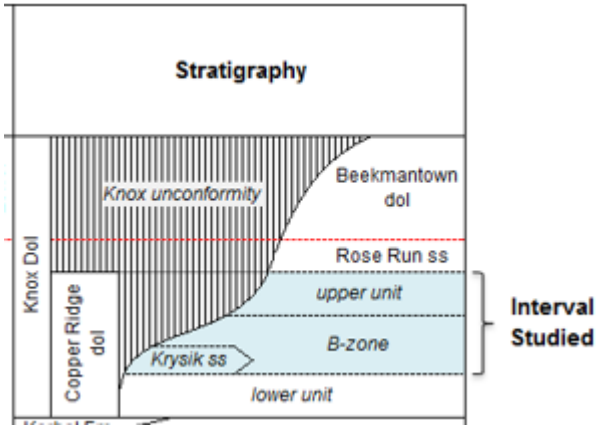
- Selection differs from ODNR/common usage
- Based off of flow units
- Last identifiable sand



Relationship between Copper Ridge B and Krysik Sandstone



The Krysik was described as arkosic sandstone, so gamma ray maps were generated to better understand the extent of sand development..



Petrophysics Overview
Thickness

	Gross Thickness (ft)		Net Thickness (ft)		Net/Gross Ratio	
	Range	Average	Range	Average	Range	Average
Beekmantown	30-937	146	19-933	206	0.1-1	0.97
Rose Run	20-295	94	1-124	35	0-1	0.33
Upper Copper Ridge	25-336	174	0-230	25	0-0.86	0.13
Copper Ridge "B"	30-200	68	0-65	14	0-0.97	0.16
Lower Copper Ridge	14-462	219	10-186	26	0-0.7	0.36
Kerbel	0-75	36	1-47	22	0-1	0.53
Conasauga	16-482	73	1-114	34	0-1	0.42
Rome	150-707	344	1-388	100	0-1	0.32
Basal Sand	66-342	130	0-172	51	0-0.98	0.38

Petrophysics Overview
Porosity

	Porosity (%)		Porosity Feet	
	Range	Average	Range	Average
Beekmantown	0-12	6	0-67	12
Rose Run	0-22	4	0.-18	3
Upper Copper Ridge	0-8	2	0-20	2.5
Copper Ridge "B"	0-12	3	0-5	1
Lower Copper Ridge	0-8	5	0-15	2.5
Kerbel	0-18	6	0-8	2.4
Conasauga	0-15	5	0-16	3.1
Rome	0-11	4	0-66	7
Basal Sand	0-22	9	0-28	8