Battelle
The Business of Innovation

"Managing Climate Change and Securing a Future for the Midwest's Industrial Base"

Phase I Results

David Ball
Battelle
Rattan Lal
The Ohio State University
Larry Wickstrom
Ohio Geological Survey

DOE Annual Review Meeting
Pittsburgh, Pennsylvania
October 12, 2005
DOE Cooperative Agreement No. DE-FC26-03NT41981

Outline

- Makeup of the MRCSP
- Regional Characterization and CO_2 Source Analysis
- Terrestrial Characterization
  - 145 Million Tonnes CO_2/yr (20% offset of CO_2 from large point sources)*
- Geologic Characterization
  - 400-500 Billion Tonnes CO_2 (centuries of storage for large point sources)*
- Capture Technologies Review
- Regulatory Analysis
- Public Outreach
- Economic Modeling

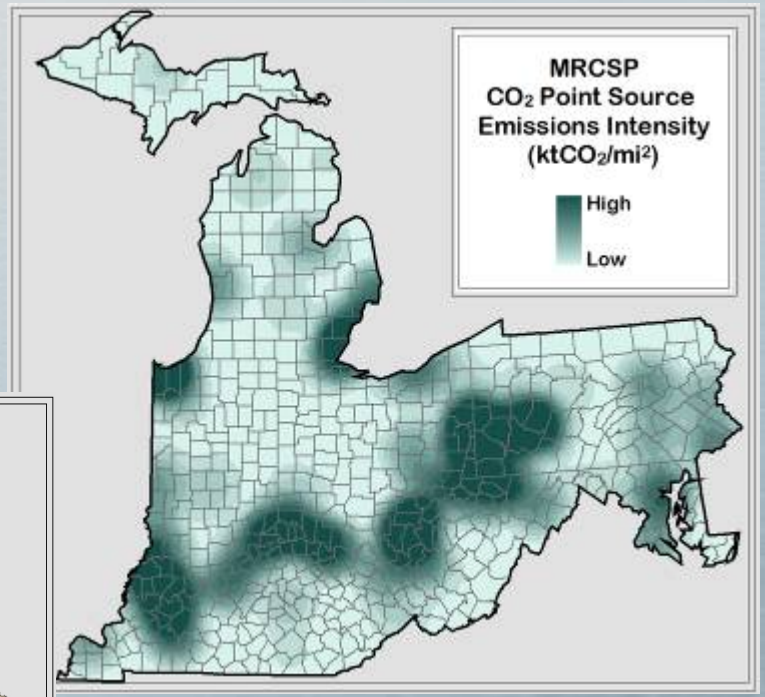
(*) These are preliminary estimates of sequestration potential

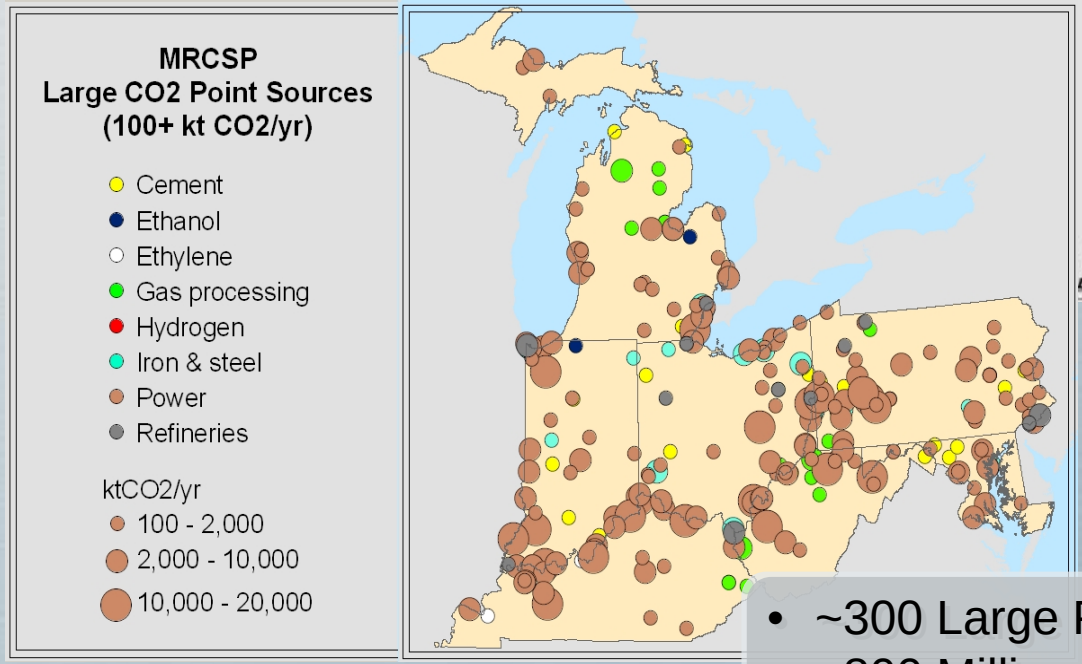
MRCSP Phase I Partners

U.S. Department of Energy/NETL

The MRCSP Region: The Nation's Engine Room

- One in six Americans
- 1/6 of U.S. Economy
- 1/5 of U.S. Electricity Generated
  - ¾ From Coal





- ~300 Large Point Sources (>100,000 tonnes/year)
- ~800 Million tonnes CO_2/year

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Multiple layers of information on over 600 individual CO_2 sources

Facility Type	Number of Facilities	Percent of CO2 Emissions
Ammonia	1	0.0
Cement	29	1.9
Ethanol	4	0.1
Ethylene	3	0.1
Ethylene Oxide	1	0.0
Gas Processing	33	1.8
Hydrogen	9	0.1
Iron and Steel	64	9.0
Refineries	18	2.6
Power Generation	455	84.4
Totals	**617**	**100.0**

Bituminous coal fired power generation is clearly a major source in our region

Unit Type	Number of Units	Average Capacity	Average Vintage
Coal			
Bituminous	340	315	1964
Subbituminous	14	305	1973
Other	18	80	1987
IGCC	1	192	1995
Gas			
Combined Cycle	16	86	1991
Gas Turbine	4	51	1978
Steam Turbine	15	265	1969
Oil	10	368	1973

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Terrestrial Research Team and Roles

- Non-eroded Cropland (Terrestrial Team Lead)
  - The Ohio State University: Rattan Lal
- Eroded Cropland
  - Purdue University: William McFee and Larry Biehl
- Marginal Land
  - Pennsylvania State University: Sjoerd Duiker
- Mineland
  - West Virginia University: Mark Sperow
- Wetland and Marshland
  - University of Maryland: Brian Needelman
- Modeling (all land classifications)
  - Michigan State University: Peter Grace

MRCSP Land-use, Area, and Preliminary Estimates of Potential C Storage

Land-Use	Area (Mha)	C Storage (MMTC yr^{-1})
Non-Eroded Cropland	10.7	3.7
Eroded Cropland	1.6	3.1
Marginal Land	6.5	26.9
Mineland	0.6	1.5
Wetland/Peatland	3.4	3.9
Total	22.8	39.1

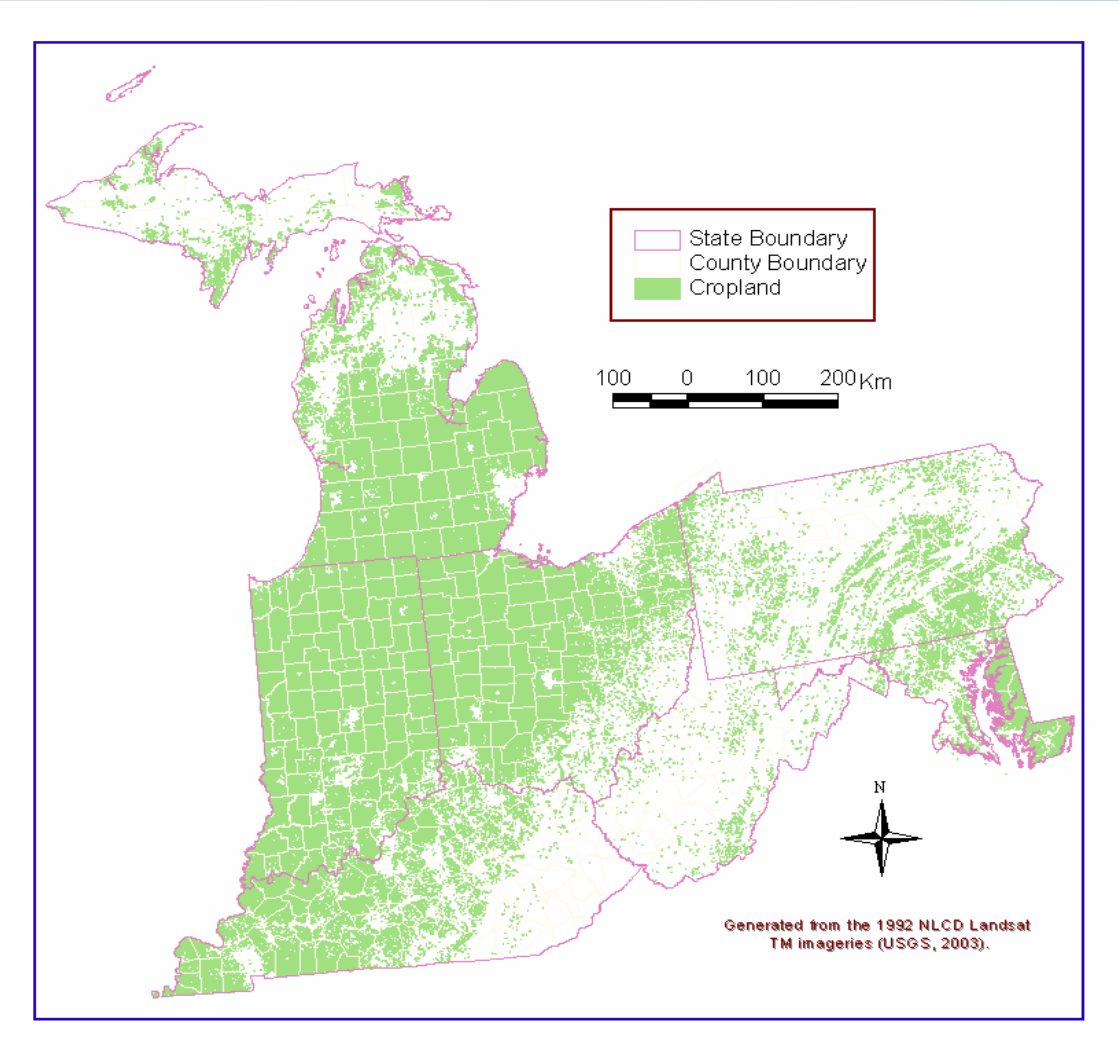
MRCSP CO_2 Emissions[1]
715 MMT **(195** MMTCE[2]**)**

MRCSP CO_2 Offset Potential
20% of Emissions

[1] Emissions include only large sources (>100 Kt CO_2).

[2] MMTCE = Million Metric Tons of Carbon Equivalent

Distribution of Non-eroded Cropland



Potential SOC Sequestration Over 20 Years and Annually for Non-eroded Croplands*

Scenario	IN	KY	MD	MI	OH	PA	WV	**MRCSP**	Stdev
Area (Tha)	5,137	1,412	355	3,603	4,085	118	117	15,285	
	----------Million Metric Tons ----------								
100% NT[1]	23.5	5.2	1.5	19.7	21.4	2.3	0.2	73.9	23.7
75% NT	17.7	3.9	1.1	14.8	16.1	1.7	0.2	55.4	17.7
	---------- Million Metric Tons yr^{-1} ----------								
Annual Potential	1.2	0.3	0.08	1.0	1.1	0.1	0.01	3.7	

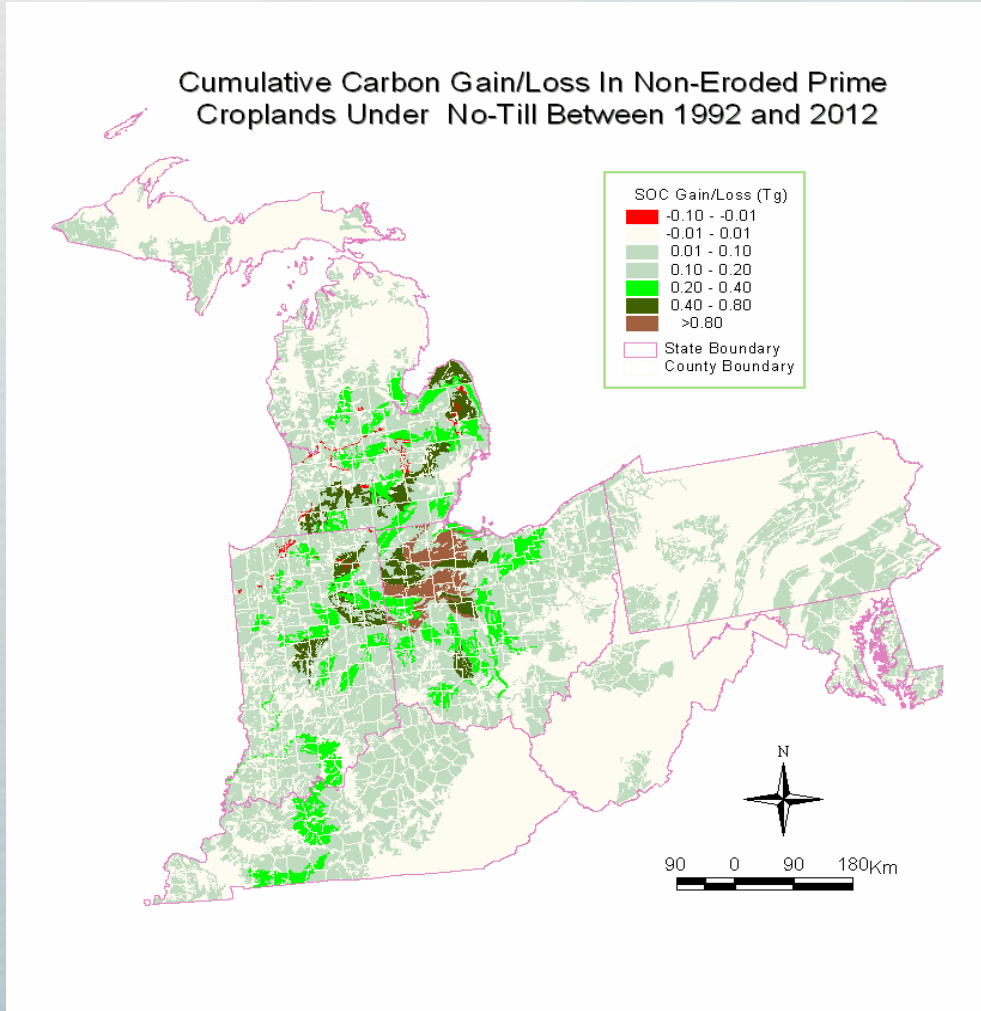
[1] NT = No Till

(*) These are preliminary estimates of sequestration potential

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

C Sequestration Potential on non-eroded Cropland in 20 Years*



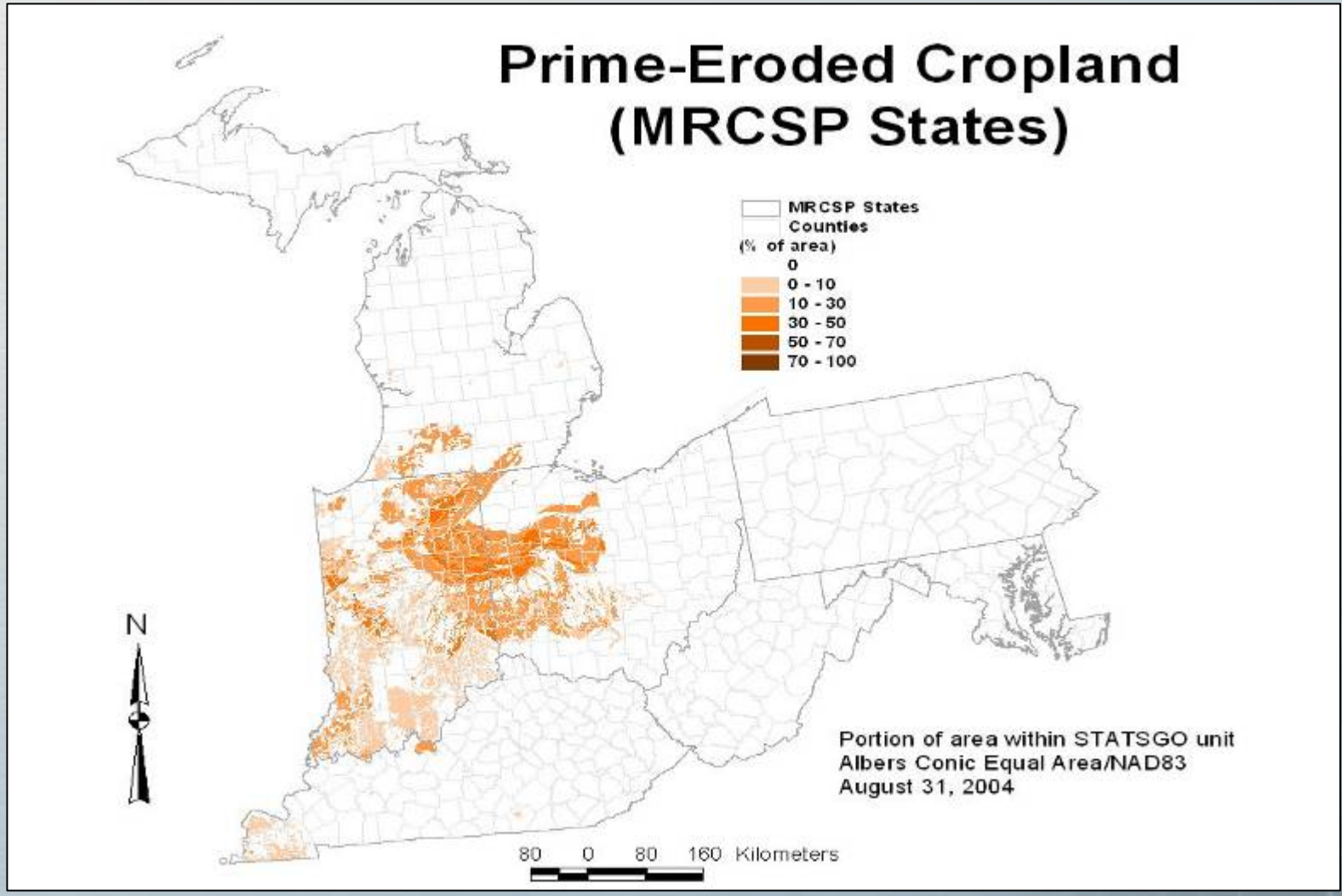
Area	15.3 Mha
Total C	74 MMT

(*) These are preliminary estimates of sequestration potential

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Area of Prime-Eroded Cropland



Prime Eroded Cropland*

State	IN	KY	MD	MI	OH	PA	WV	MRCSP
Area (Tha)	933	39	0	80	513	0	0	1,565
	Cumulative C Sequestered (Million Metric Tons)							
Scenario 1	7.2	0.2		0.6	4.3			12.3
Scenario 2	36.1	1.1		3.2	21.4			61.8
	---------- Million Metric Tons yr^{-1} ----------							
Annual Potential	1.8	0.06		0.2	1.1			3.1

(*) These are preliminary estimates of sequestration potential

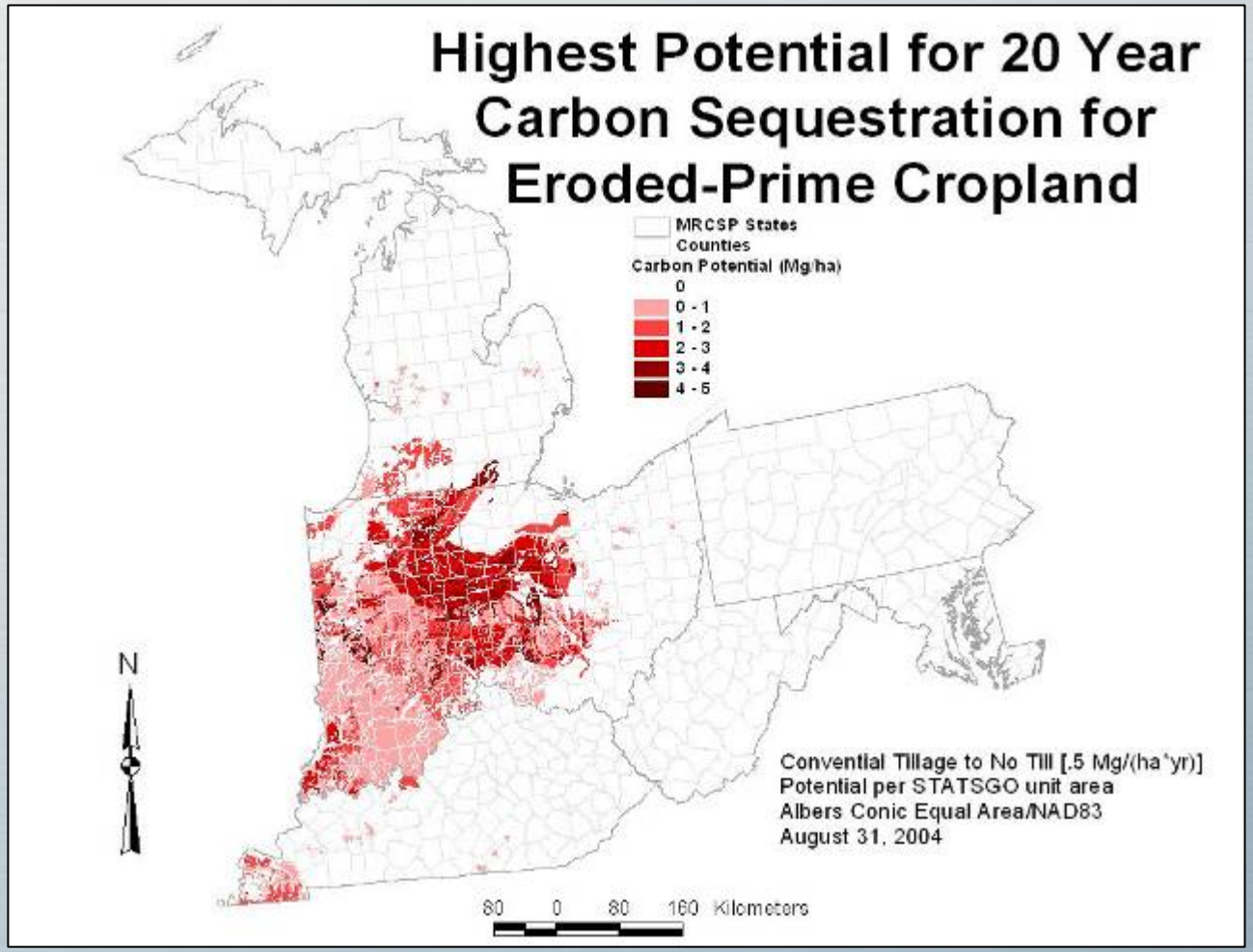
Scenario 1: SOC may be restored to 60% of native with shift to conservation practices

Scenario 2: All SOC may be recovered under good management or set-aside (return to grass/legume)

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

C Sequestration Potential on Eroded Cropland in 20 Years*



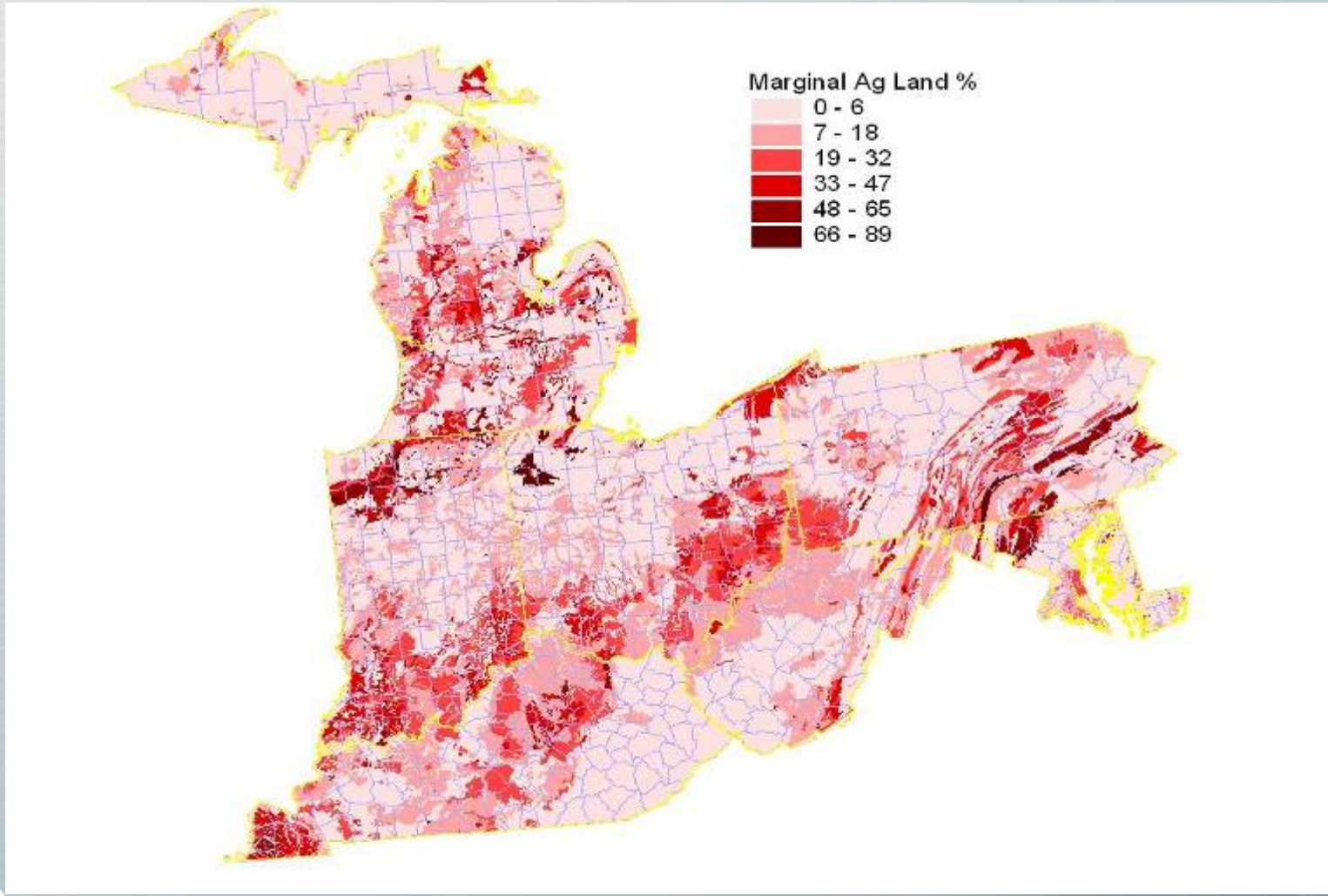
Area	1.6 Mha
Total C	62 MMT

(*) These are preliminary estimates of sequestration potential

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Distribution of Marginal Land



Potential C Accumulation Over 20 Years and Annually on Marginal Land from Afforestation*

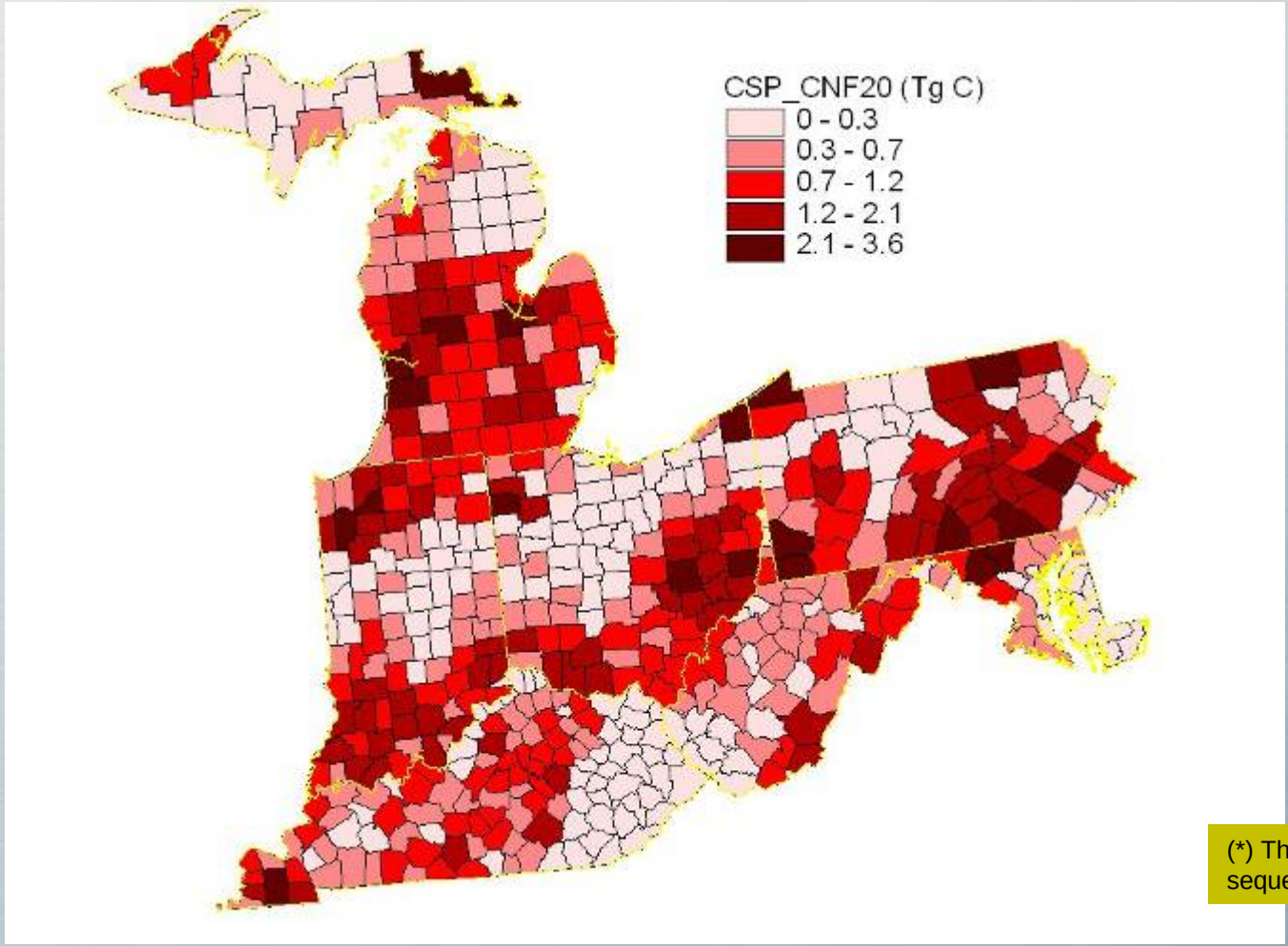
State	IN	KY	MD	MI	OH	PA	WV	MRCSP
Area (Tha)	1,238	1,012	246	1,230	1,156	1,181	481	6,543
	---------- Million Metric Tons ----------							
	105.3	91.6	20.8	87.9	95.3	96.8	41.5	529.2
	---------- Million Metric Tons yr^{-1} ----------							
Annual Potential	5.3	4.6	1.0	4.4	4.8	4.8	2.1	26.9

(*) These are preliminary estimates of sequestration potential

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

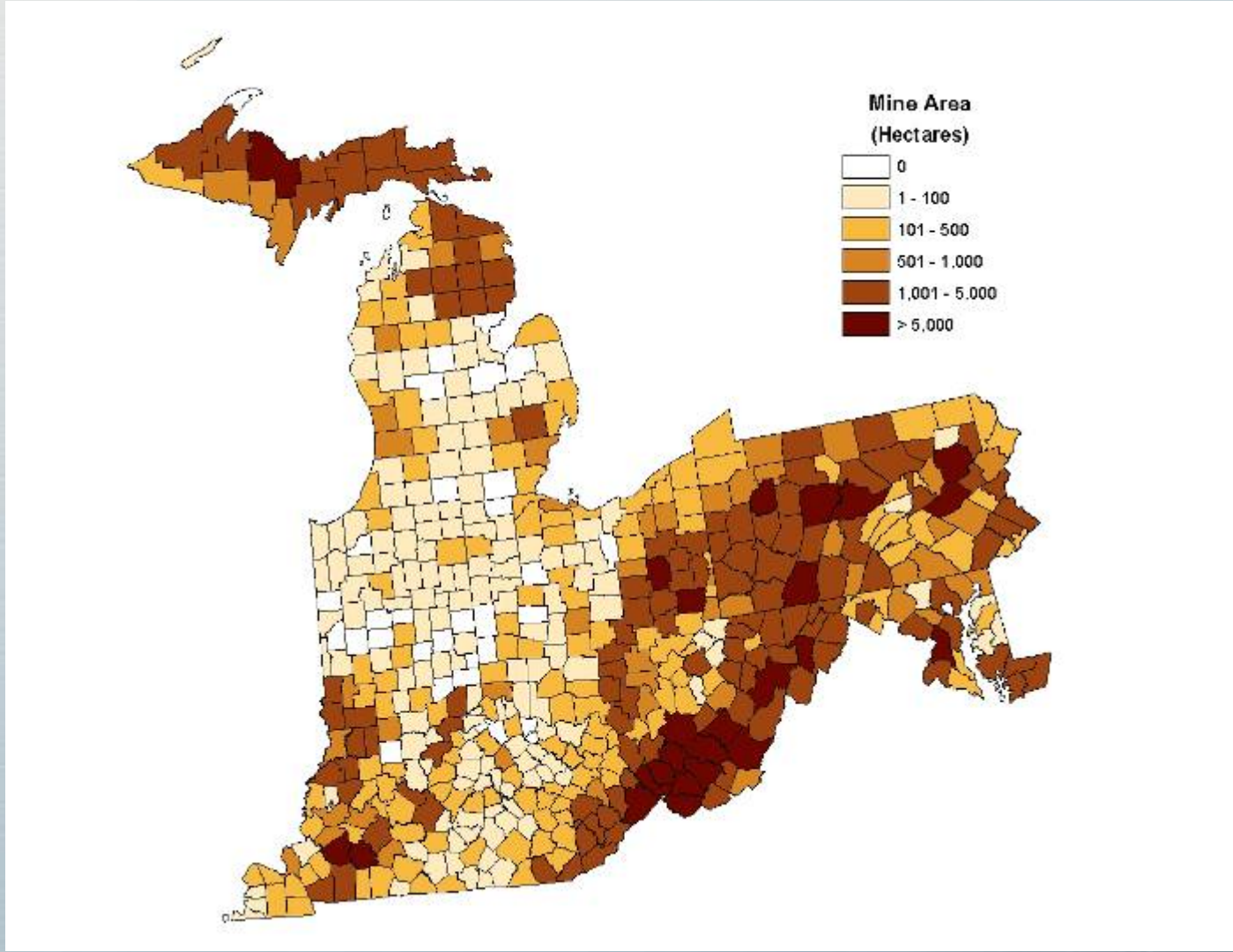
20 Year C Potential on Marginal Lands from Coniferous Forest*



Area	6.5 Mha
Total C	529 MMT

(*) These are preliminary estimates of sequestration potential

Area of Mineland

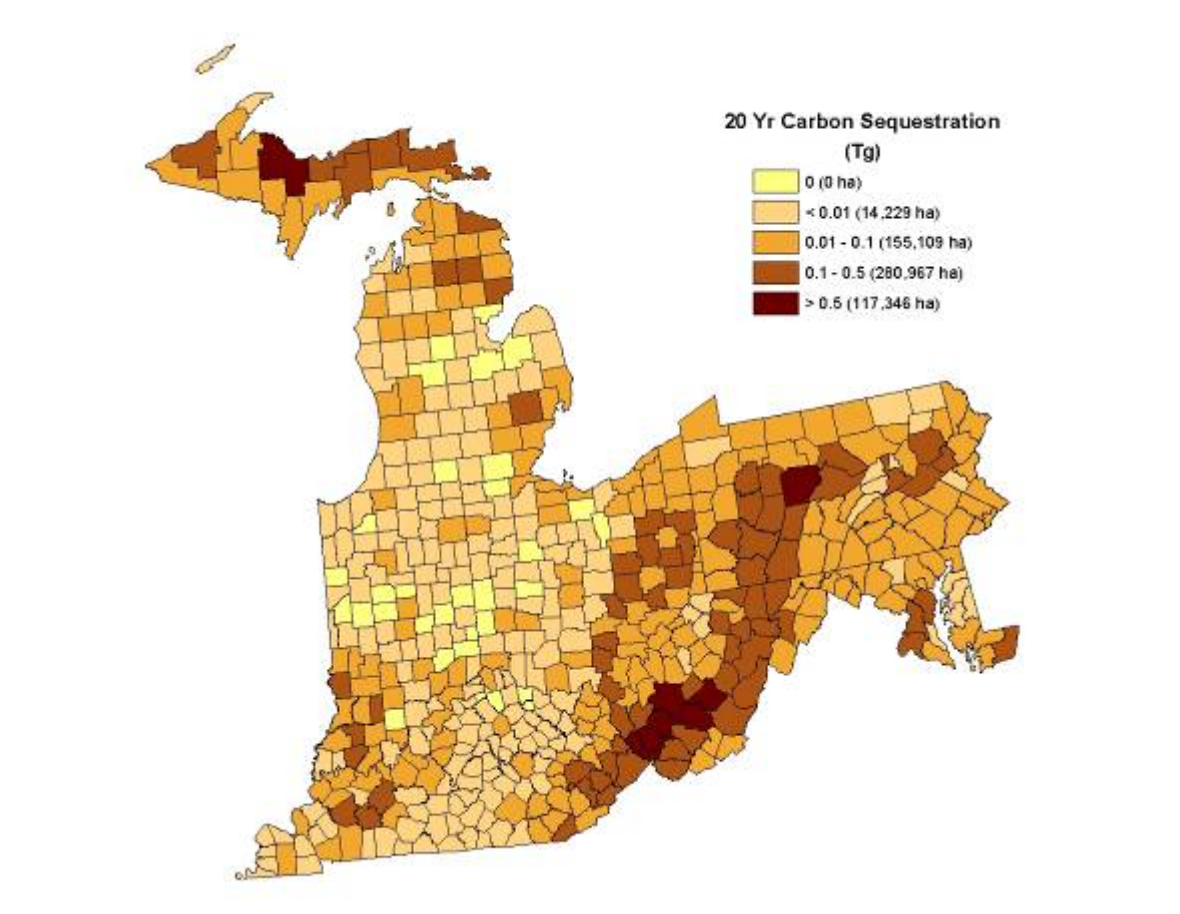


Potential C Accumulation over 20 Years and Annually on Reclaimed Minelands*

	IN	KY	MD	MI	OH	PA	WV	Total
Area (Tha)	30.2	67.8	29.1	68.3	125.4	63.4	183.5	567.7
	---------- Million Metric Tons ----------							MMT
Total Forest	1.6	3.5	1.4	3.6	3.6	5.1	10.74	29.5
Forest Biomass	0.9	2.1	0.5	1.6	2.0	2.8	6.70	16.6
Forest Litter	0.1	0.2	0.1	0.3	0.2	-0.3	0.36	0.9
Forest Soil	0.6	1.3	0.7	1.7	1.4	2.6	3.69	12.0
Pasture Soil	0.8	1.8	0.8	1.9	1.7	3.4	4.83	15.1
Cropland Soil	0.6	1.8	0.3	1.4	2.3	3.7	1.0	10.9
	---------- Million Metric Tons yr^{-1} ----------							
Annual Potential	0.08	0.2	0.1	0.2	0.2	0.3	0.5	1.6

(*) These are preliminary estimates of sequestration potential

C Accumulation on Minelands over 20 Years*



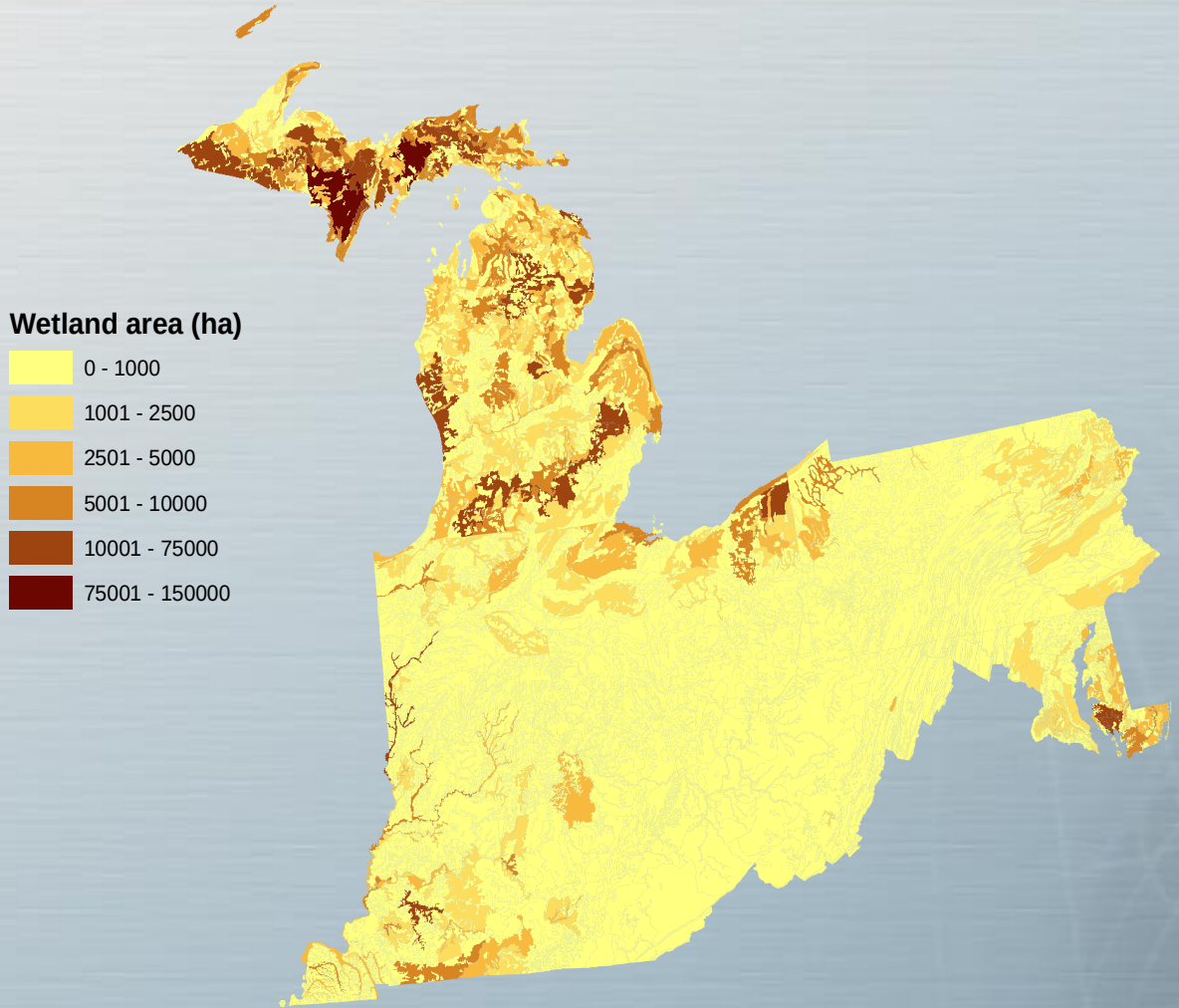
Area	0.6 Mha
Total C	29.5 MMT

(*) These are preliminary estimates of sequestration potential

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Area of Wetlands



Wetland C Sequestration Potential Over 20 Years and Annually*

Land use	Tidal Marshes	Peatlands	Crop to wetland	Total
Area (THa)	82	196	100 to 435	378 to 713
	---------- Million Metric Tons ----------			
Total Potential	4.1 – 9.3	0.9 – 1.4	16 - 68	5 – 10.7[1] 21 – 78.7[2]
	---------- Million Metric Tons yr^{-1} ----------			
Annual Potential	0.2 - 0.5	0.05 - 0.07	0.8 to 3.4	0.26 to 0.53[1] 1.1 to 3.9[2]

1 Without cropland conversion to wetland
2 With cropland conversion to wetland

(*) These are preliminary estimates of sequestration potential

Note: Current wetland carbon pool is estimated to be **656** MMT on 3.4 Mha.

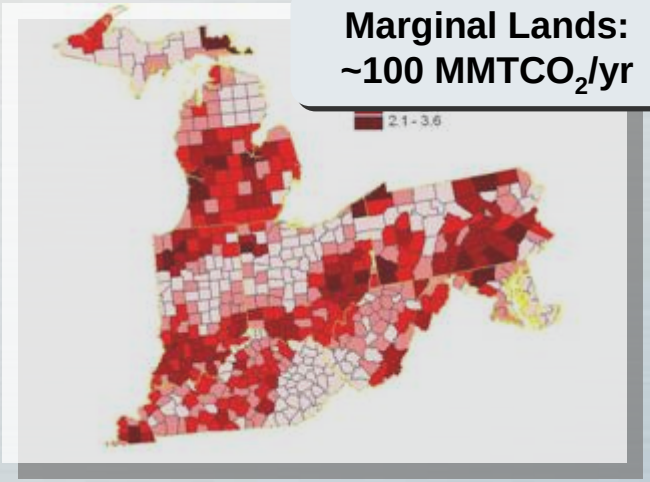
Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

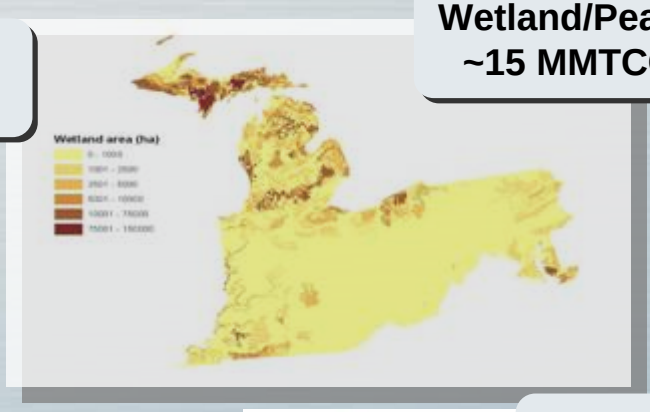
SOCRATES Modeling Results – Annual Potential C Sequestration

Category	IN	KY	MD	MI	OH	PA	WV	Total
	----------Million Metric Tons yr^{-1}----------							
Cropland	2.5	0.8	0.2	1.7	2.3	0.27	0.04	7.8
Eroded Cropland	0.27	0.05	0.00	0.02	0.1	0.00	0.00	0.45
Marginal Cropland	2.98	2.4	0.61	0.94	2.8	2.6	1.1	13.5
Marginal Pasture	3.2	1.8	0.3	3.4	2.1	0.9	0.3	12.0
Mineland	0.15	0.37	0.19	0.27	0.16	0.70	0.42	2.3
Total	9.1	5.4	1.3	6.3	7.5	4.5	1.9	36.0

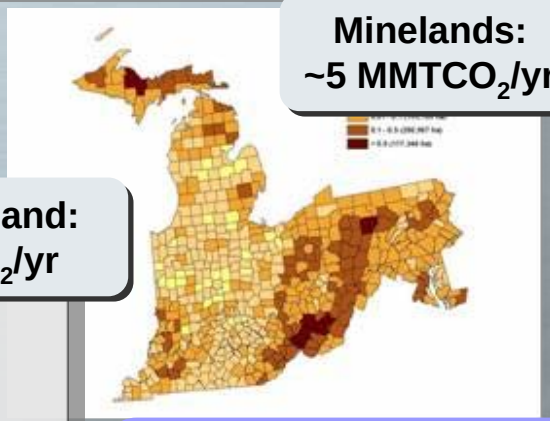
The terrestrial sequestration potential in the region is also large*



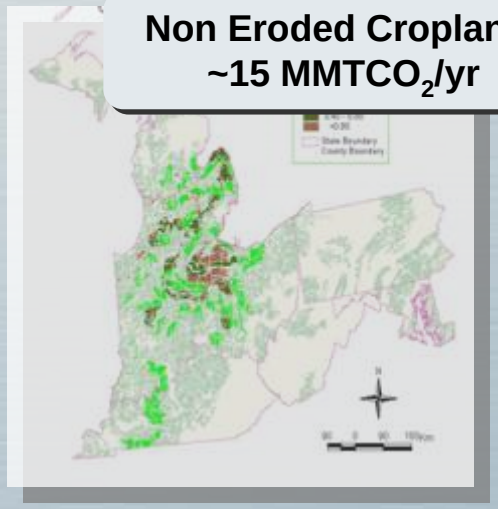
Marginal Lands: ~100 $MMTCO_2$/yr



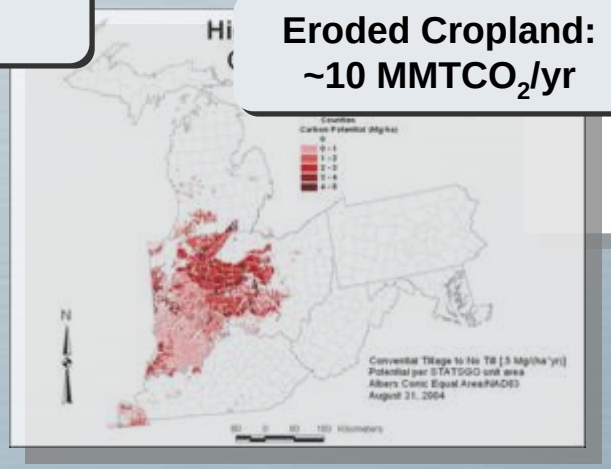
Wetland/Peatland: ~15 $MMTCO_2$/yr



Minelands: ~5 $MMTCO_2$/yr



Non Eroded Cropland: ~15 $MMTCO_2$/yr



Eroded Cropland: ~10 $MMTCO_2$/yr

Together these represent up to 20% of the CO_2 emissions from the region's large point sources.

(*) These are preliminary estimates of sequestration potential

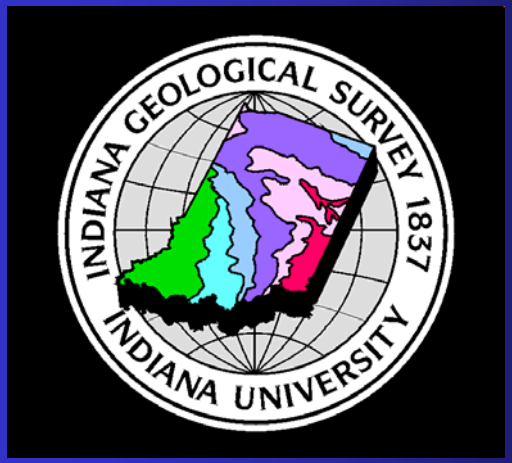
Terrestrial economics

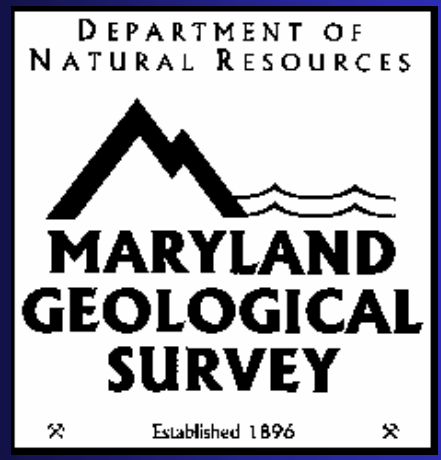
- Hierarchy of costs to increase C through activities addressed
  - 1. Non-Eroded Cropland – tillage intensity change
  - 2. Mineland – afforestation (additional costs incurred)
  - 3. Marginal Land – afforestation
  - 4. Eroded Cropland – grass/legumes yield highest C
  - 5. Wetland – restoration of cropland to wetland
- Refined analyses required to define actual costs to compare to benefits

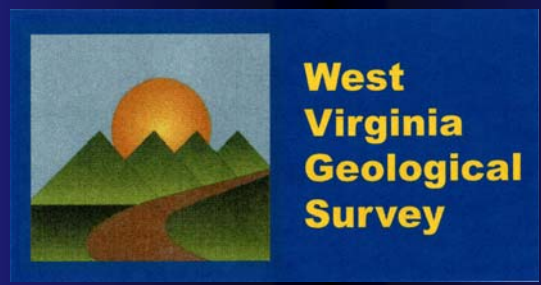
Geological Characterization

- Larry Wickstrom, Ohio Geological Survey

Team Partners are the Major Geologic Data Sources in this Region







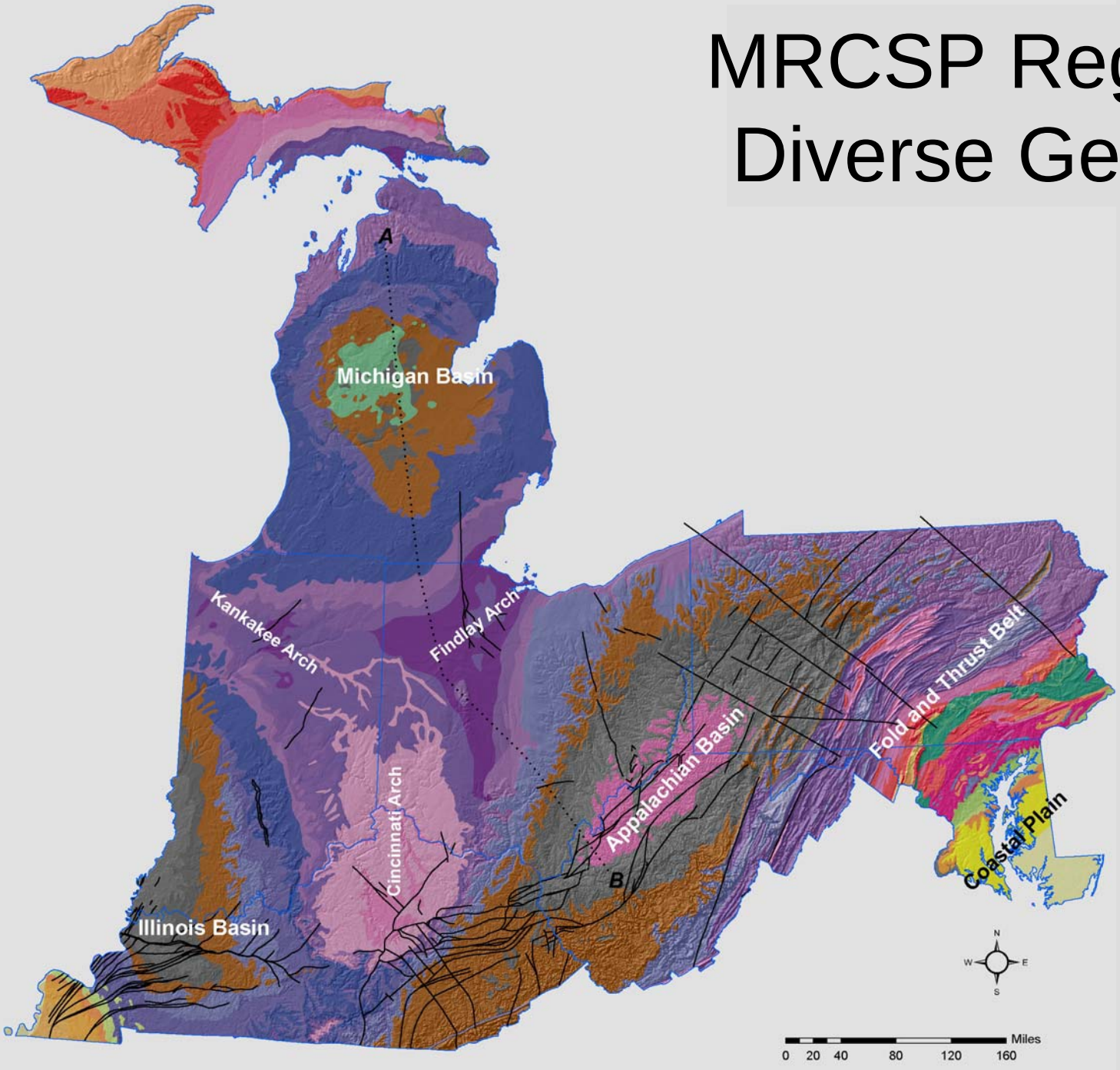
A partnership of regional expertise

MRCSP Geologic Characterization

- **Preliminary estimates of potential CO2 storage capacities:**
  - **Saline Aquifers: > 450 Billion Metric Tonnes**
  - **Oil and Gas Reservoirs: > 2 Billion Metric Tonnes**
  - **Coal: > 250 Million Metric Tonnes**
  - **Organic Shales: >45 Million Metric Tonnes**

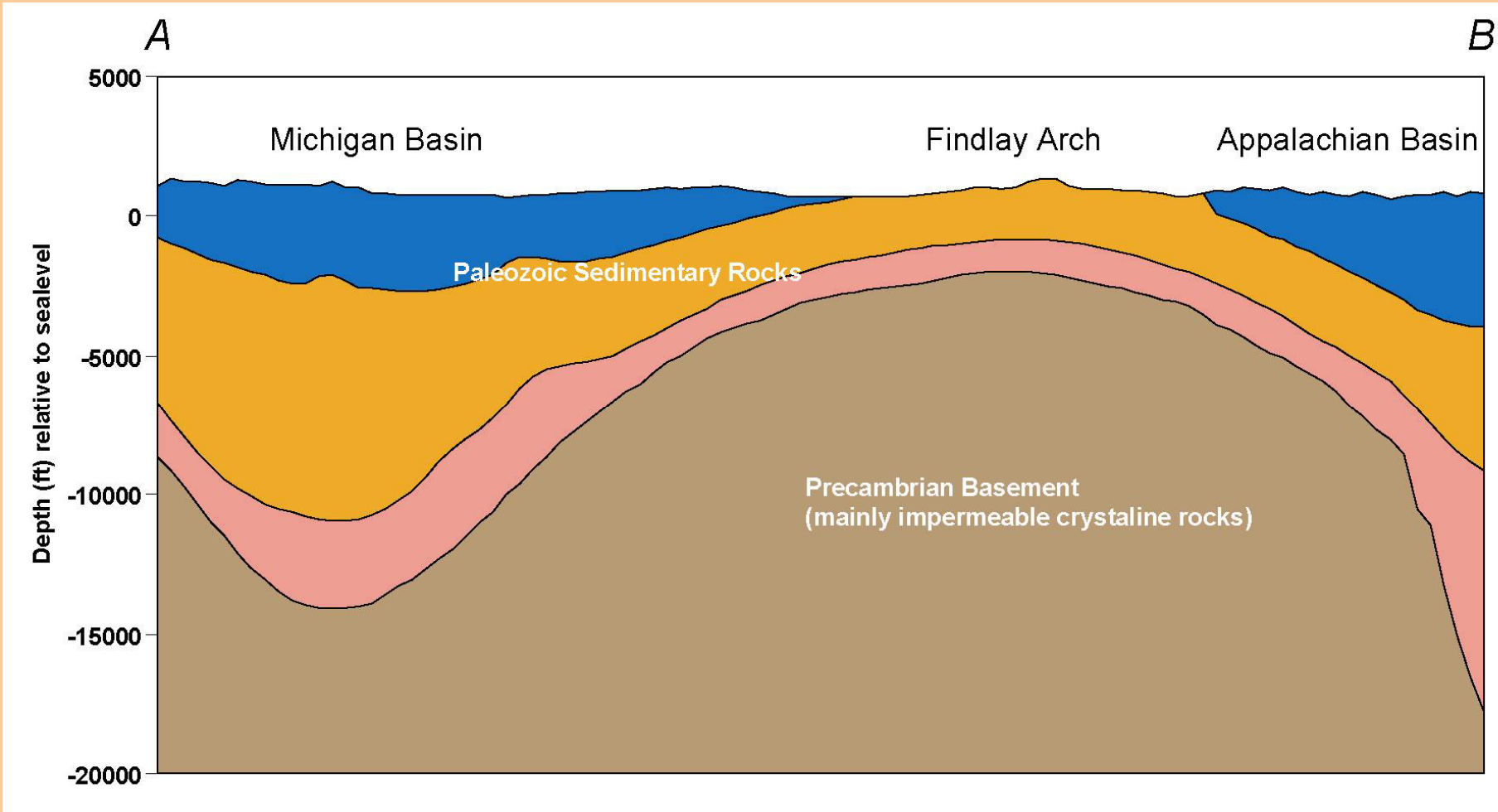
Enough geologic sequestration capacity to last the region over 600 years!

MRCSP Region's Diverse Geology



Modified from

King, et al, 1974



Illustrative cross section – location shown on previous slide. Geologic units thicken and become deeper in basins, thinner and shallower on arches.

- Onondaga to Surface
- Knox to Onondaga
- pC to Top Knox
- Precambrian

MRCSP Regional Correlation Chart – Deepest Geologic Units

- Geologic Heterogeneity -

Local sequestration target

Sequestration target

Confining unit

Organic shale

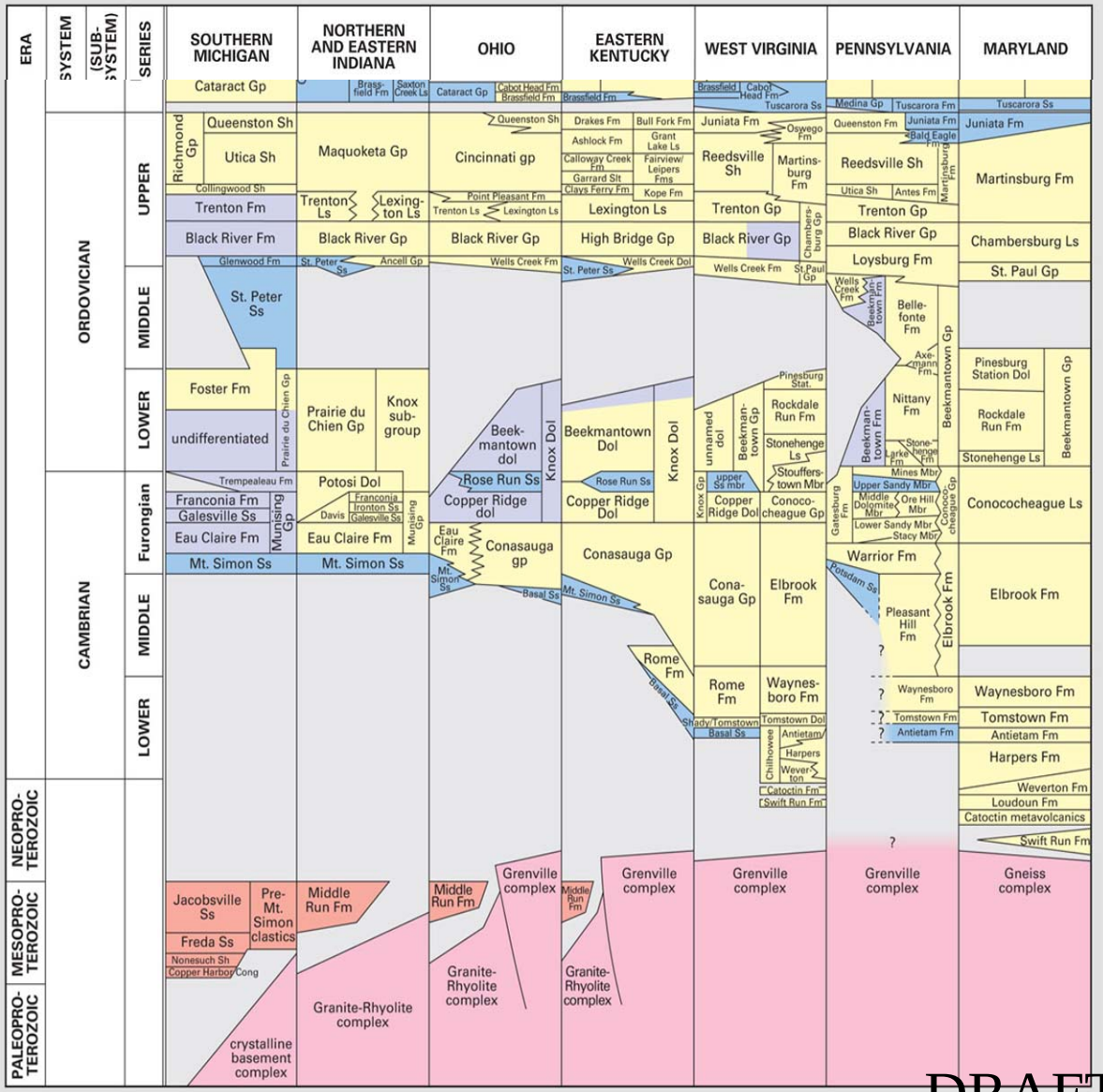
Coal-bearing interval

Basal confining units

Sedimentary rocks

Igneous and metamorphic rocks

Unconformity

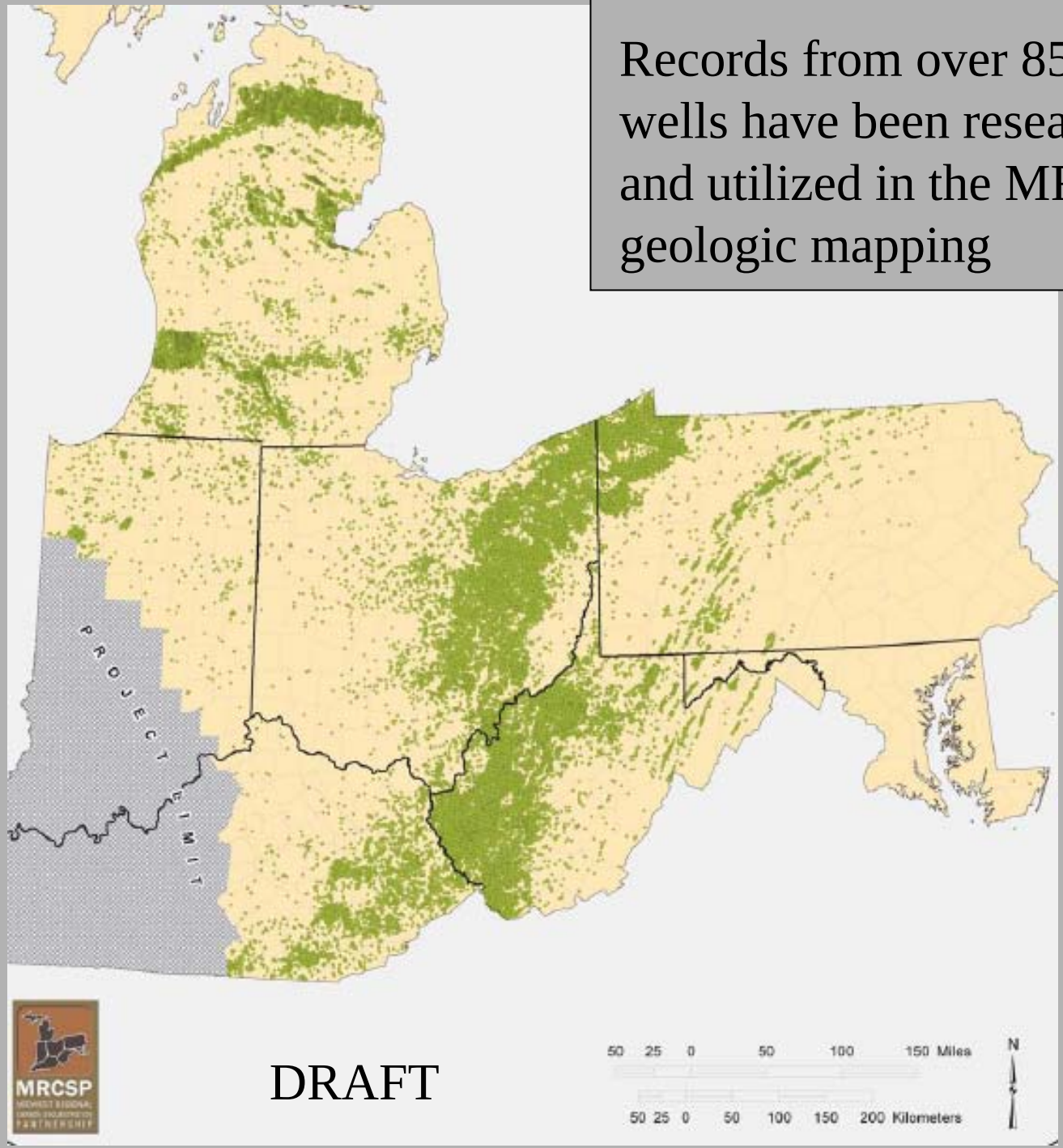


DRAFT

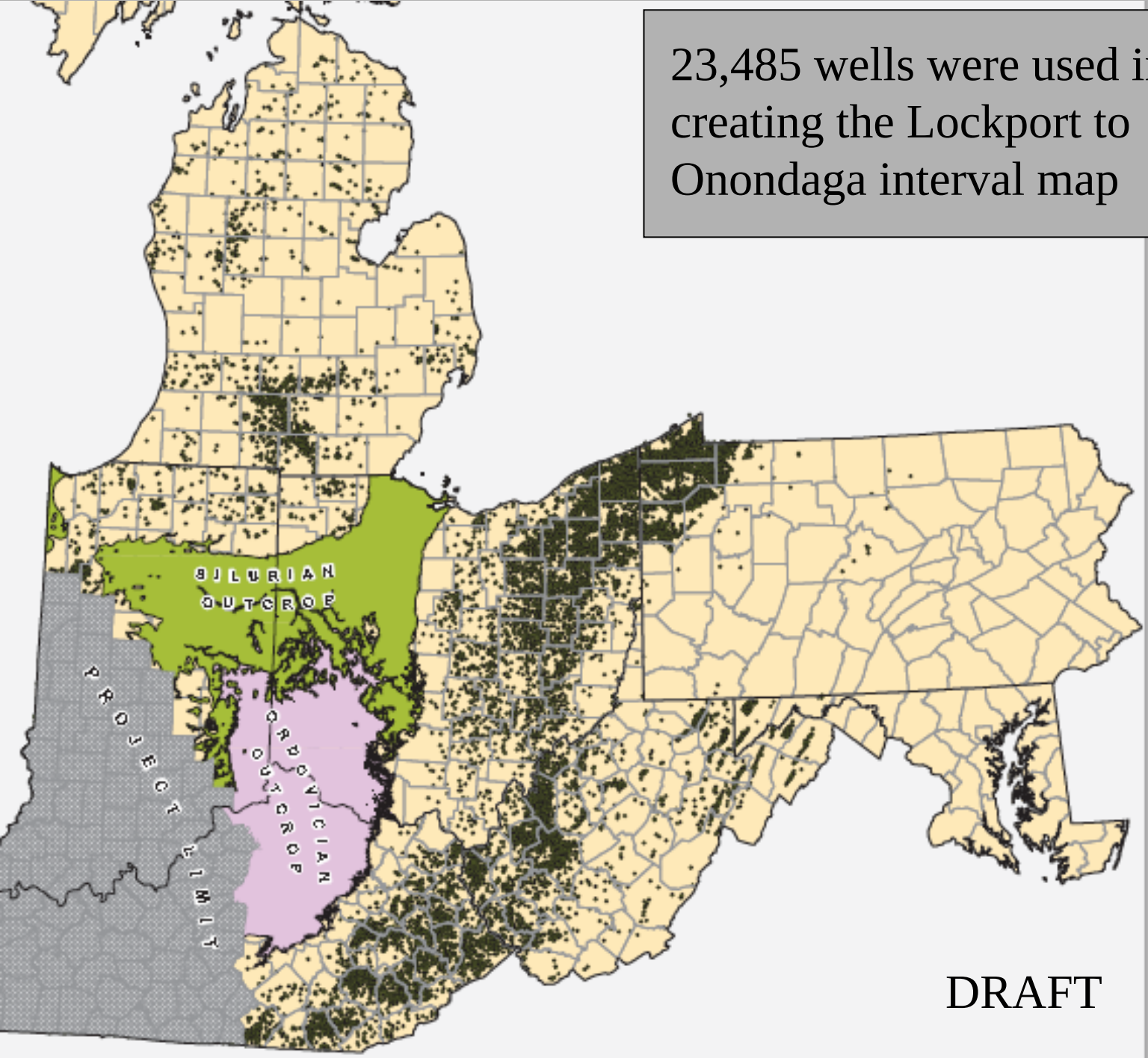
MRCSP Map & Data Collection:

- **Structure (depth) and thickness maps**
- **Porosity, salinity, temperature data – grids**
- **Oil and gas field locations, production data**
- **Coal – Thickness, depth, and number of beds**

- **In total, the geologic team produced:**
  - **30 original depth and thickness maps, 9 regional thematic maps, and 14 derivative capacity maps**

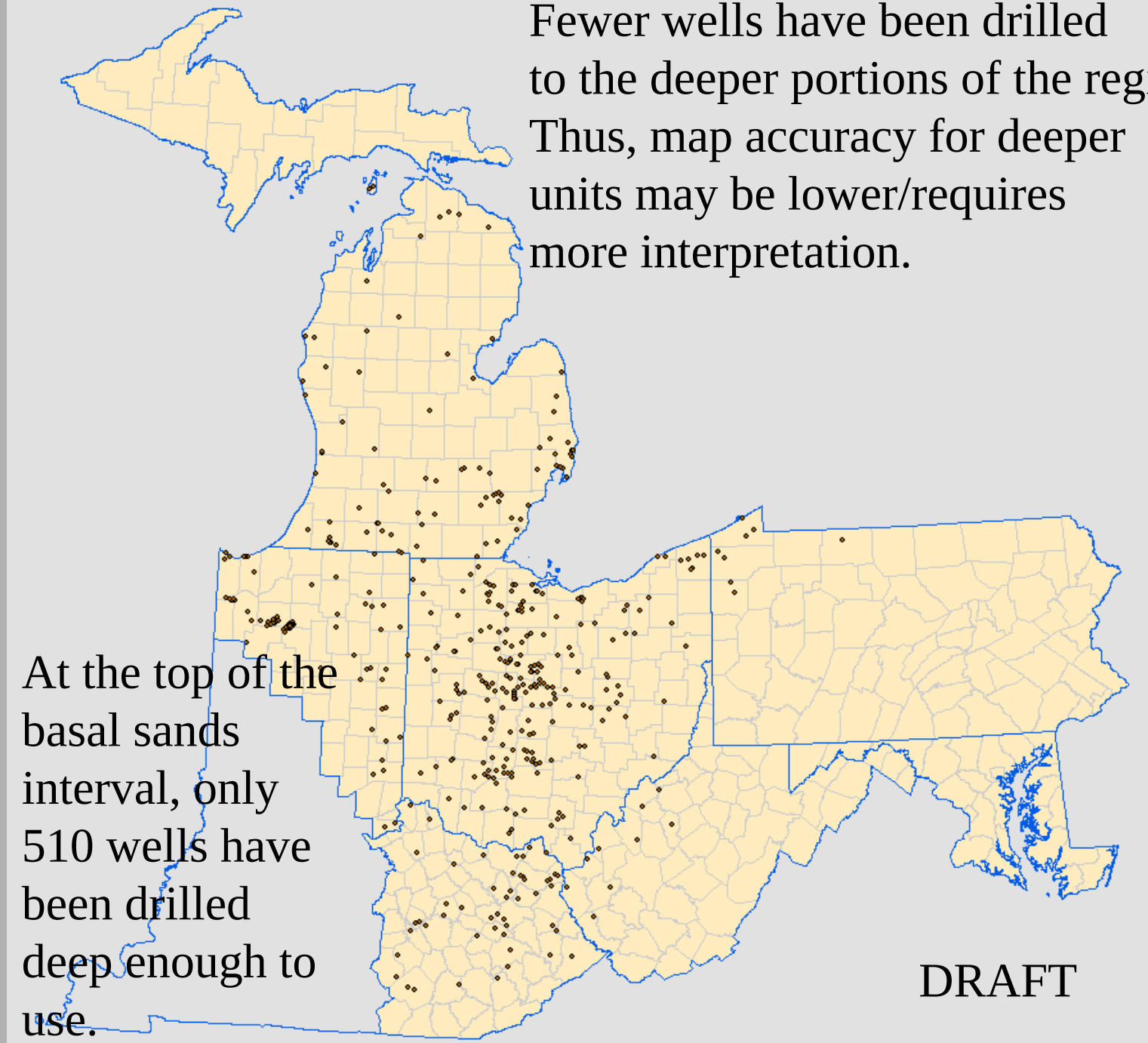


Records from over 85,000 wells have been researched and utilized in the MRCSP geologic mapping



23,485 wells were used in creating the Lockport to Onondaga interval map

DRAFT



Fewer wells have been drilled to the deeper portions of the region. Thus, map accuracy for deeper units may be lower/requires more interpretation.

At the top of the basal sands interval, only 510 wells have been drilled deep enough to use.

DRAFT

MRCSP Geology Team Firsts!

First “detailed” regional mapping effort to combine this group of states. First such consortium to tackle more than one basin.

First “detailed” regional Oil and Gas Fields map, and it is digital!

First ever digital compilation at the state level for:

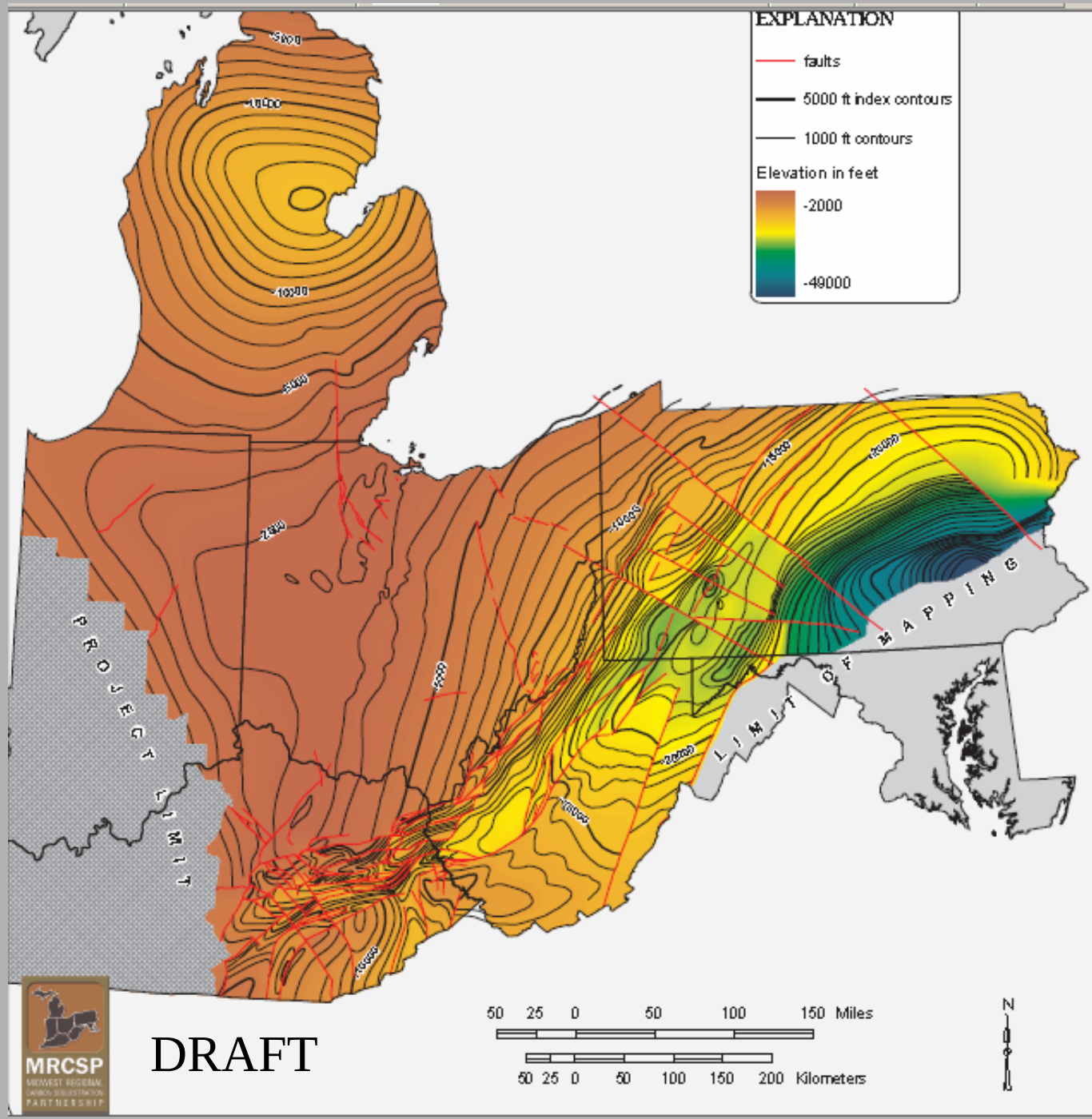
PA, MI, WVA, MD

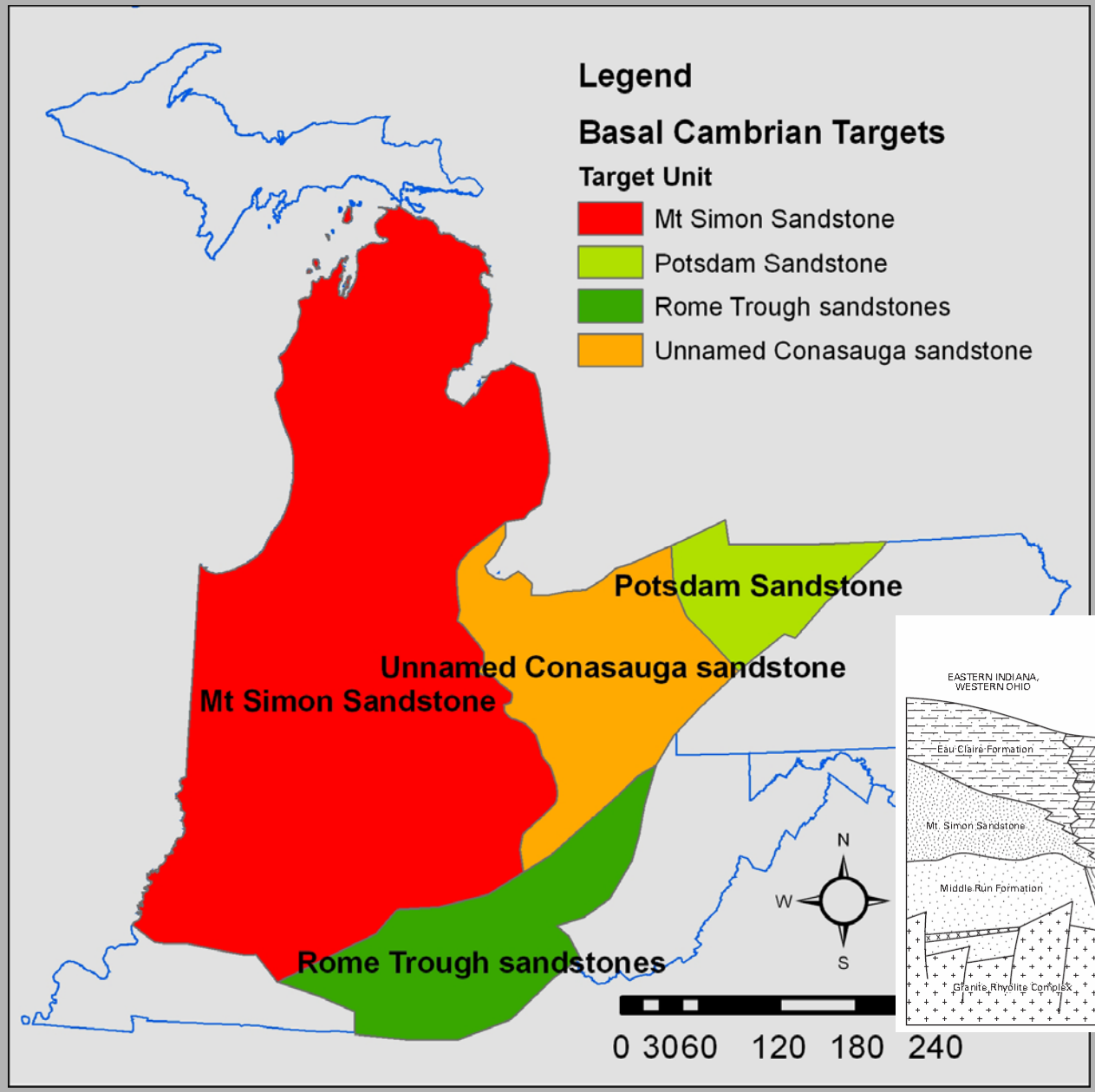
First mapping of CO2 Sequestration potential, ever, in MI, MD, PA, WVA.

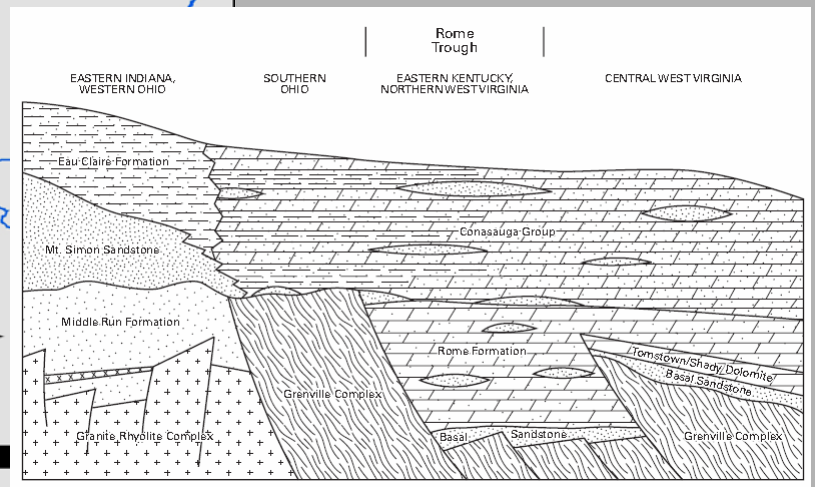
First regional database compilation for mapping formations, salinity, geothermal gradient.

First time MD data put into digital format; first time that state has been included in regional mapping of subsurface units.

Structure map drawn on the top of the Precambrian unconformity

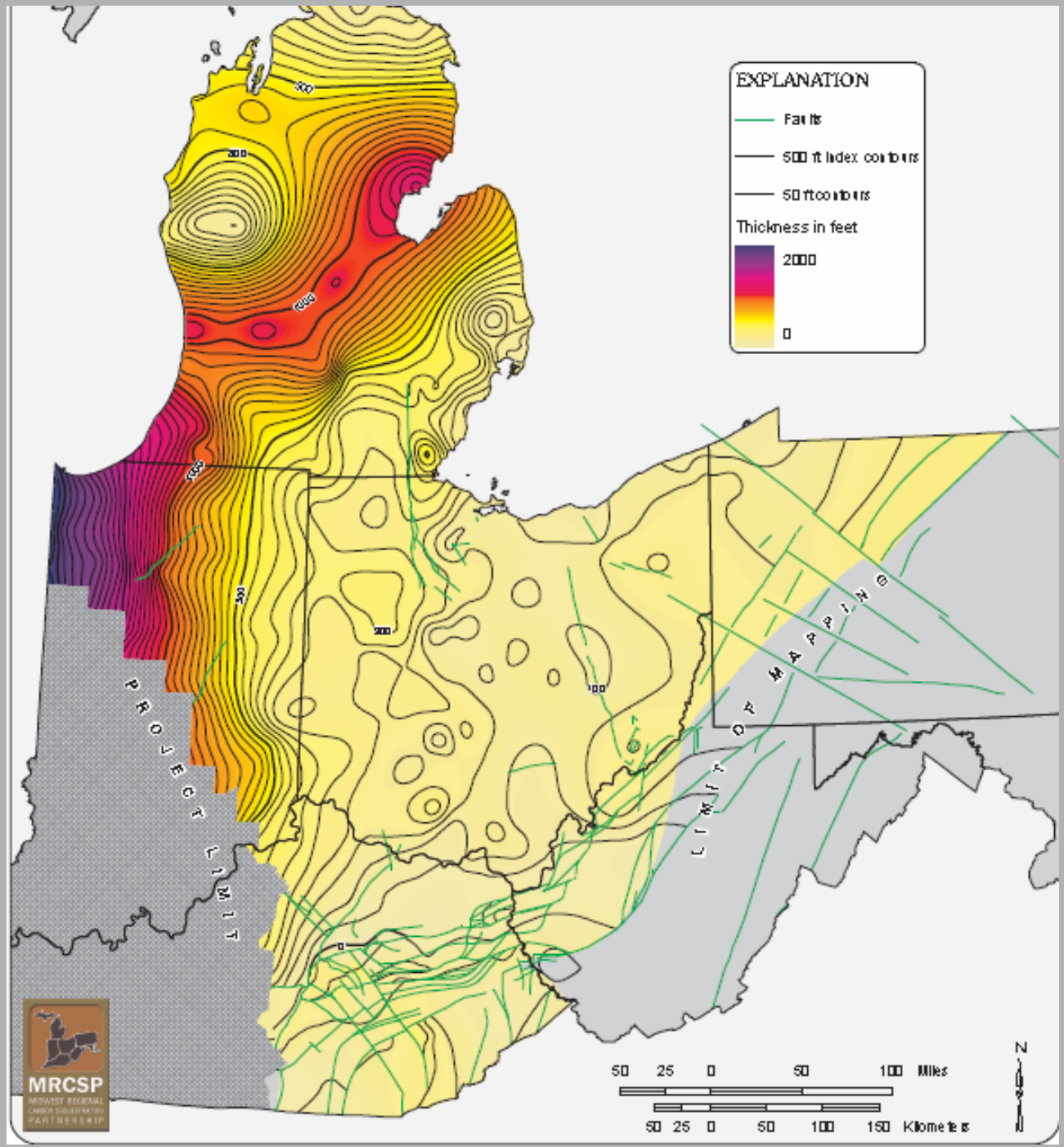



Legend
Basal Cambrian Targets
Target Unit
Mt Simon Sandstone
Potsdam Sandstone
Rome Trough sandstones
Unnamed Conasauga sandstone
Potsdam Sandstone
Unnamed Conasauga sandstone
Mt Simon Sandstone
Rome Trough sandstones
N
W
S
0 3060 120 180 240


Rome Trough
EASTERN INDIANA, WESTERN OHIO
SOUTHERN OHIO
EASTERN KENTUCKY, NORTHERN WEST VIRGINIA
CENTRAL WEST VIRGINIA
Eau Claire Formation
Mt. Simon Sandstone
Conasauga Group
Middle Run Formation
Rome Formation
Tomstown/Shady Dolomite/
Basal Sandstone
Grenville Complex
Granite Rhyolite Complex
Basal
Sandstone
Grenville Complex

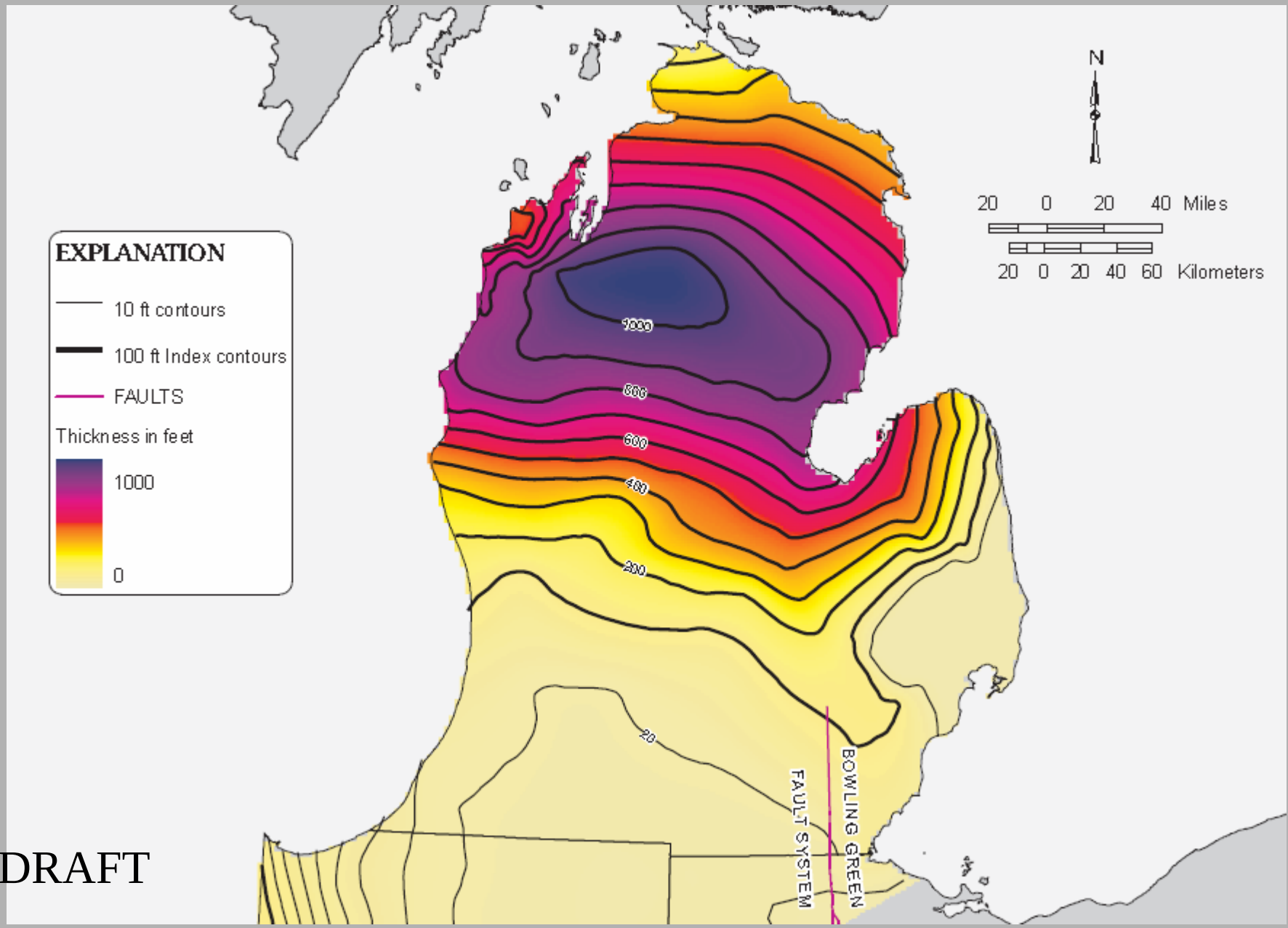
DRAFT

Map showing the thickness of the basal Cambrian sands interval.



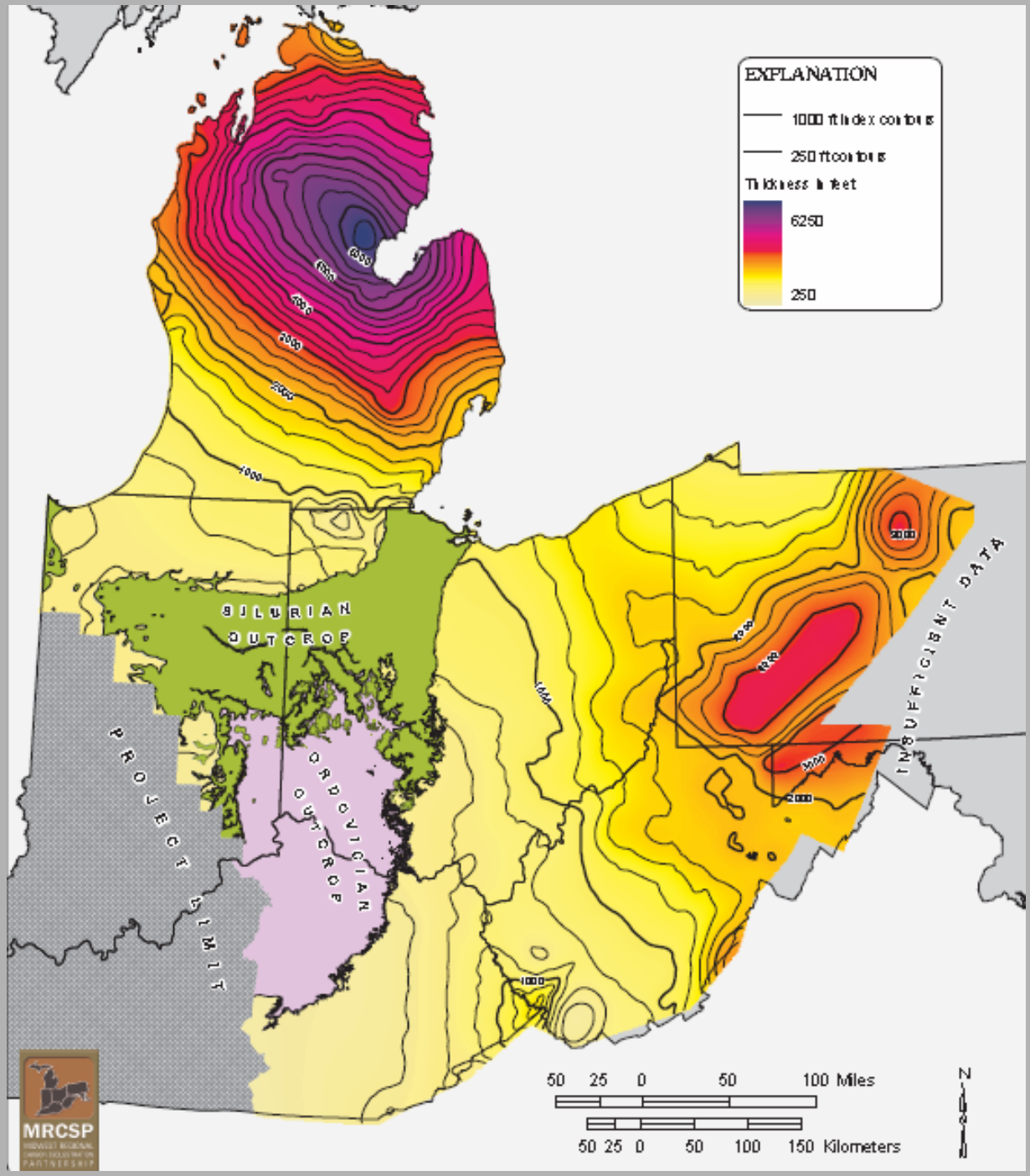
DRAFT

Map showing the thickness of the St. Peter Sandstone

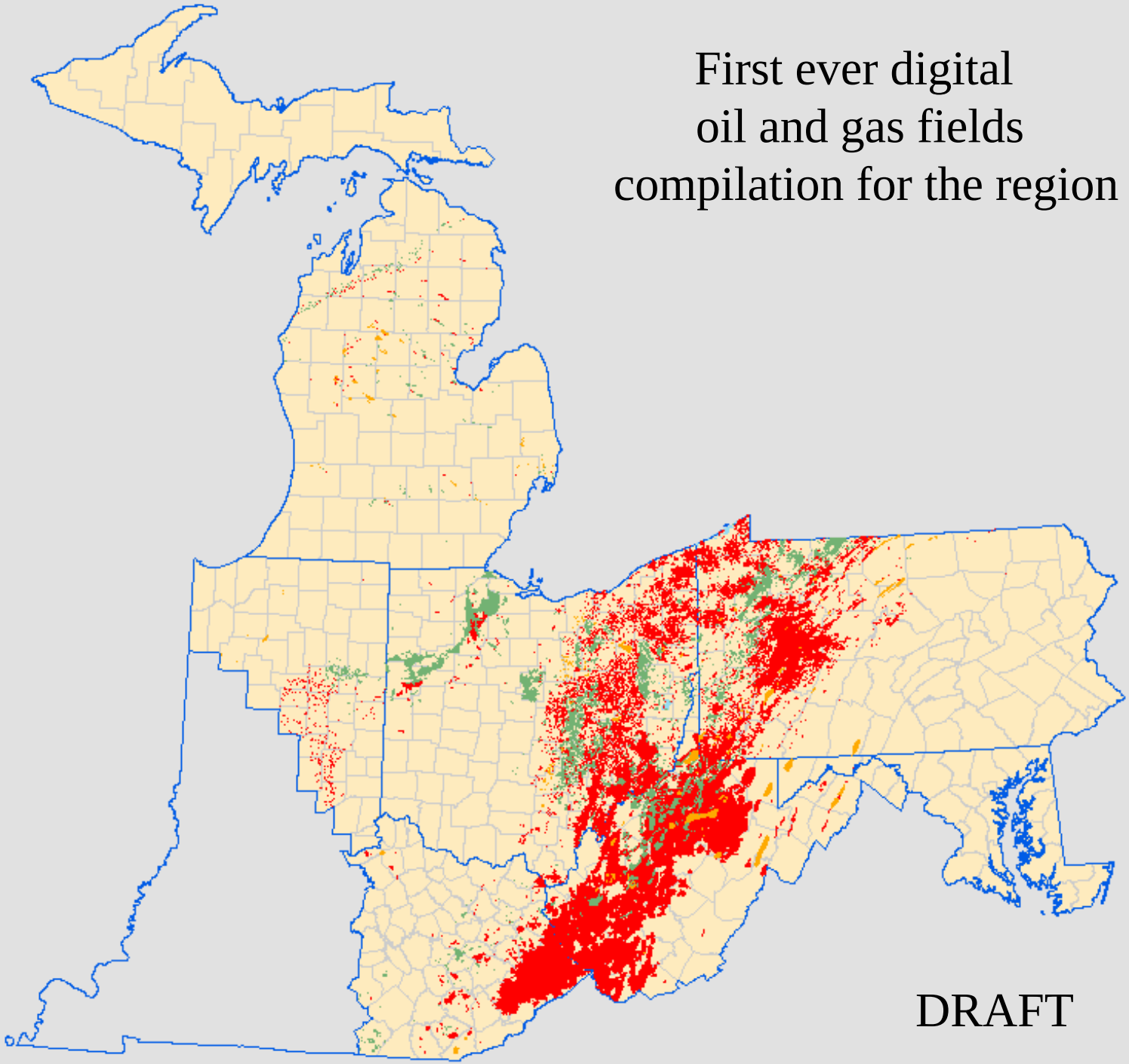


DRAFT

Map showing the thickness of the Niagaran to Onondaga Limestone interval.



DRAFT

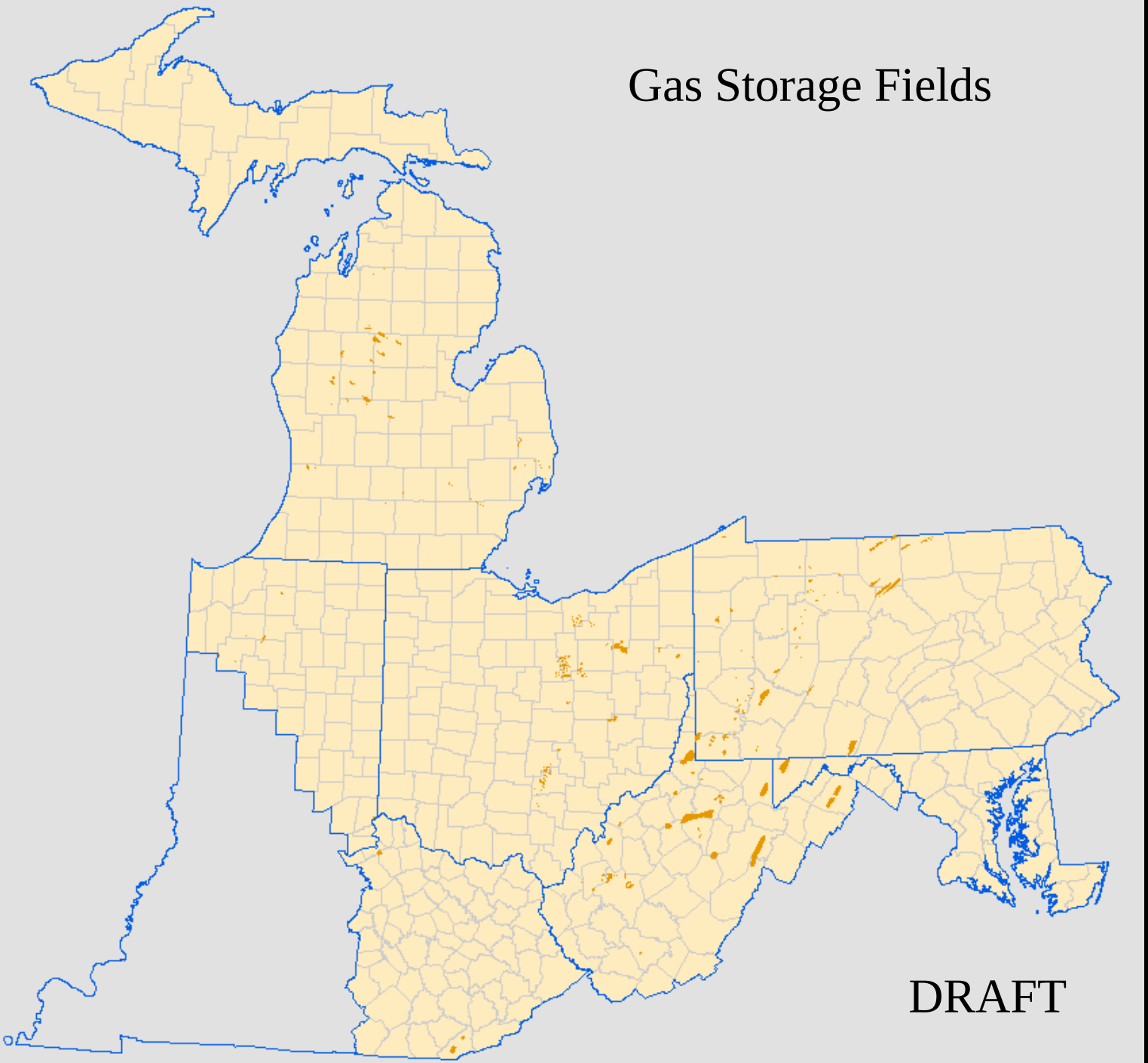


First ever digital
oil and gas fields
compilation for the region

DRAFT

MRCSP, 2005

Gas Storage Fields



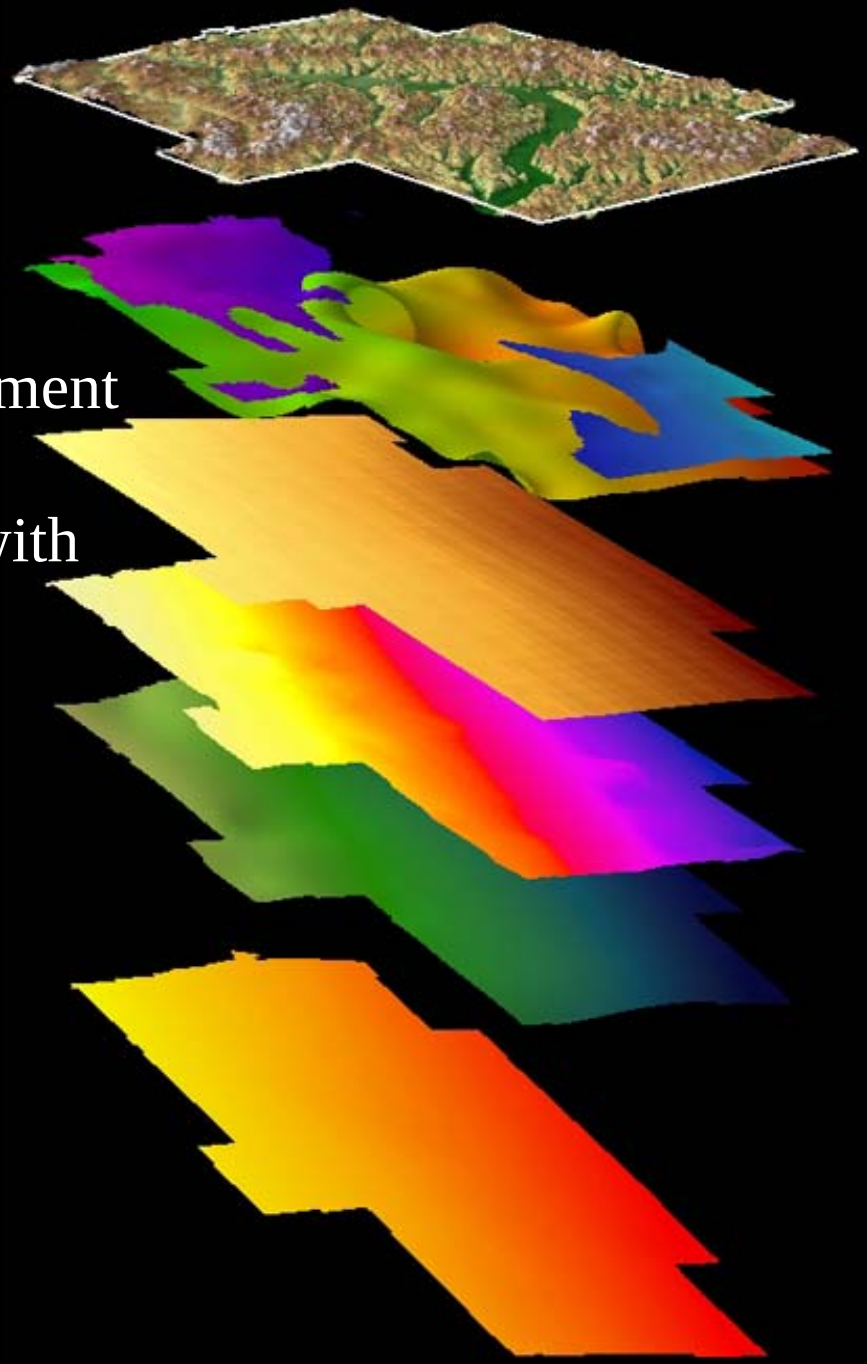
DRAFT

The MRCSP has the largest aggregate natural gas storage potential of any region in the U.S. (2002)

Data Source: Natural Gas Monthly, May 2002

DRAFT

Having all maps/data within a GIS environment allows us to easily combine any layers with any others – intelligently



Surface topography

Oriskany Sandstone

Bass Islands Dolomite

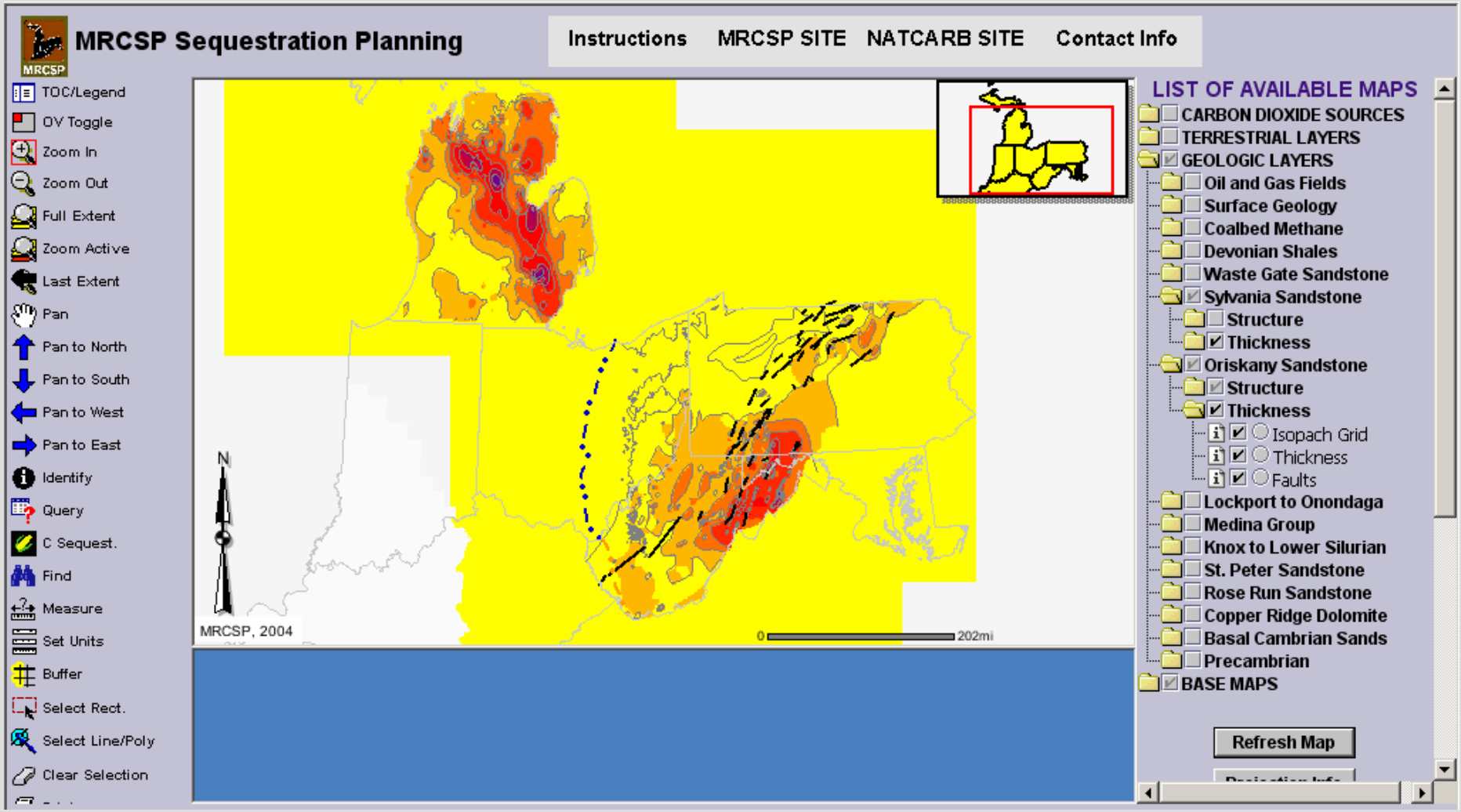
Clinton Sandstone (oil & gas)

Rose Run Sandstone

Copper Ridge Dolomit

Cambrian sands?

DRAFT



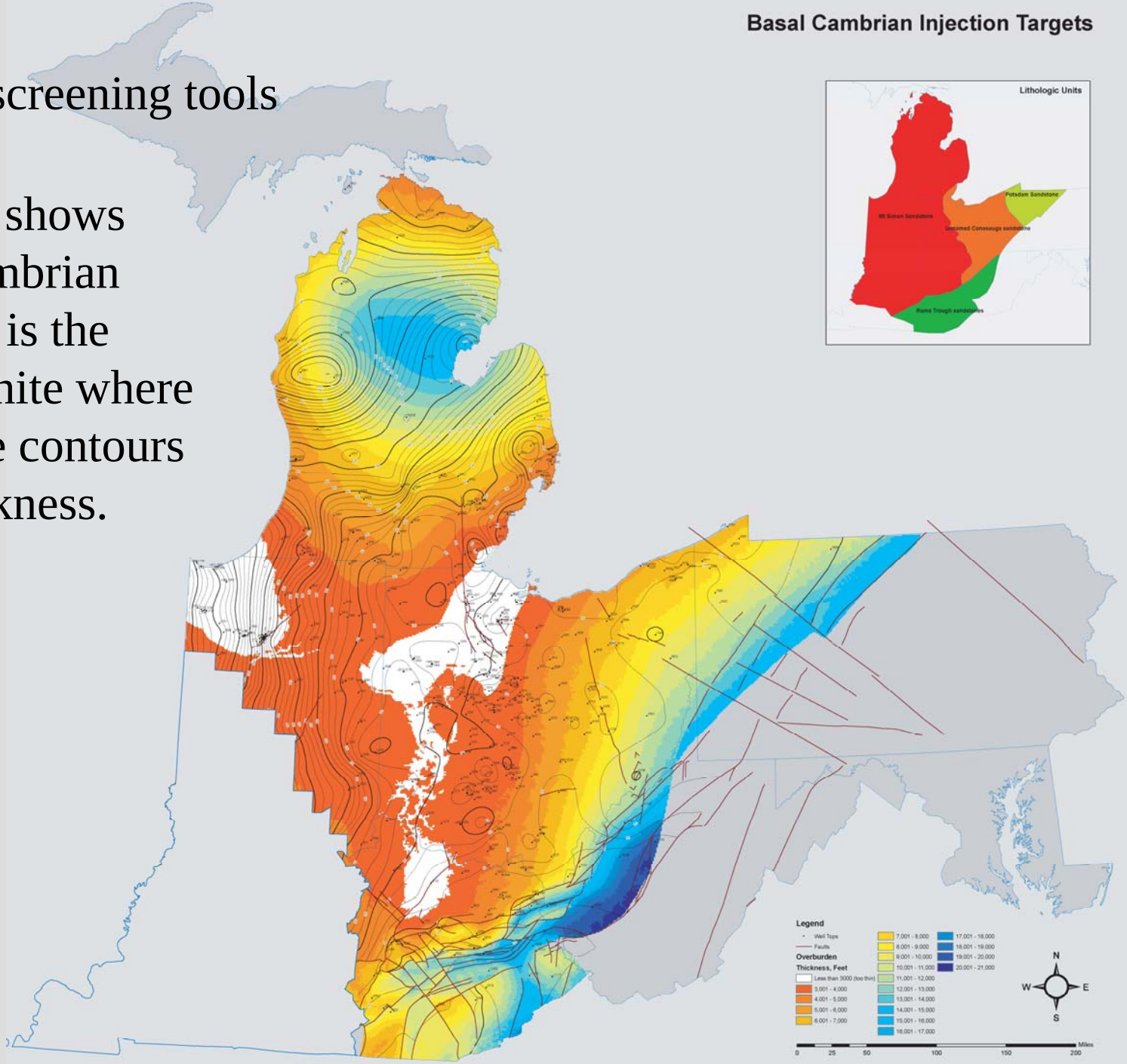
DRAFT

Visualizing the data

Basal Cambrian Injection Targets

Potential screening tools

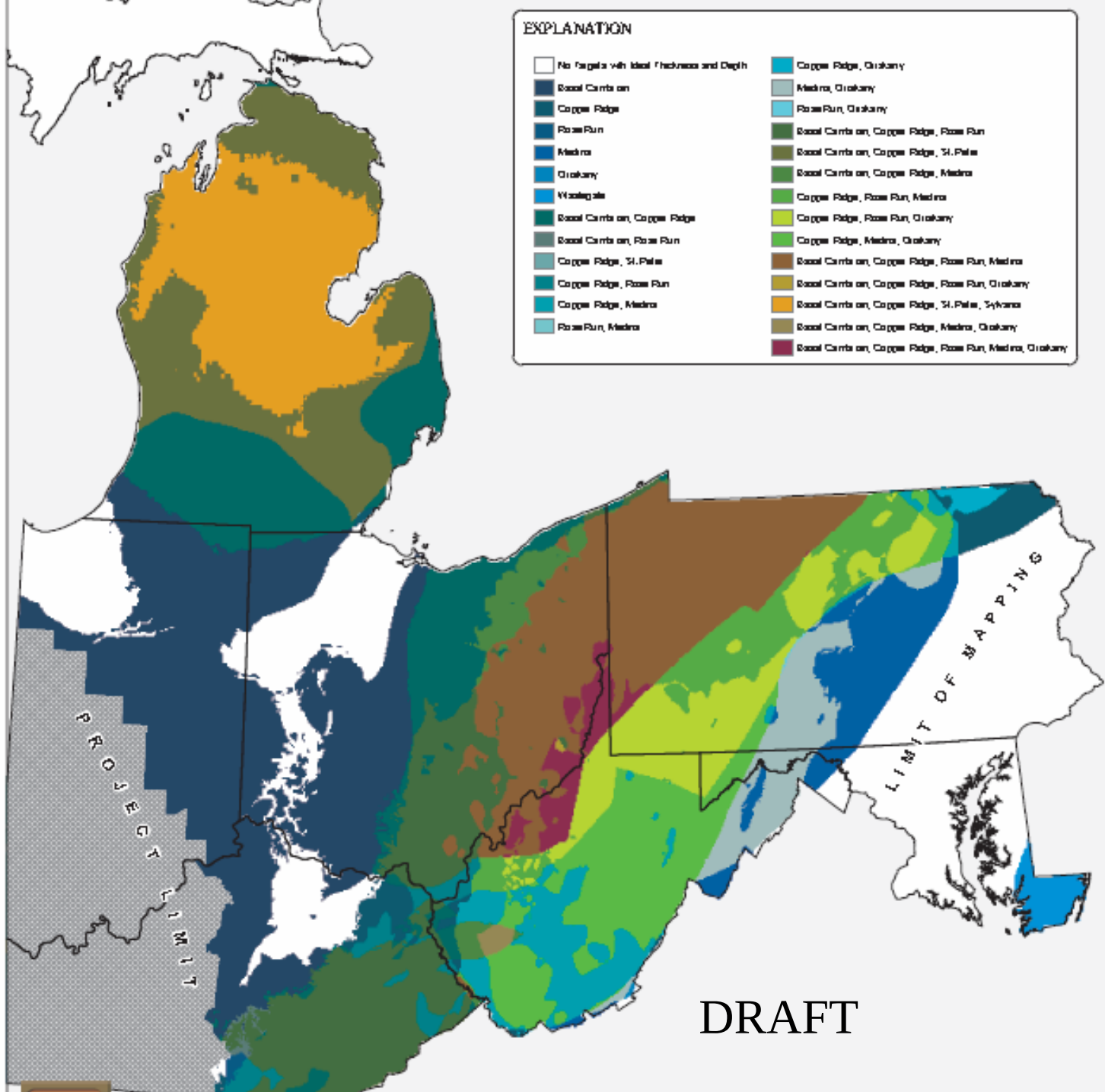
This example shows The basal Cambrian sands – depth is the color grid –white where < 3,000’. The contours show the thickness.

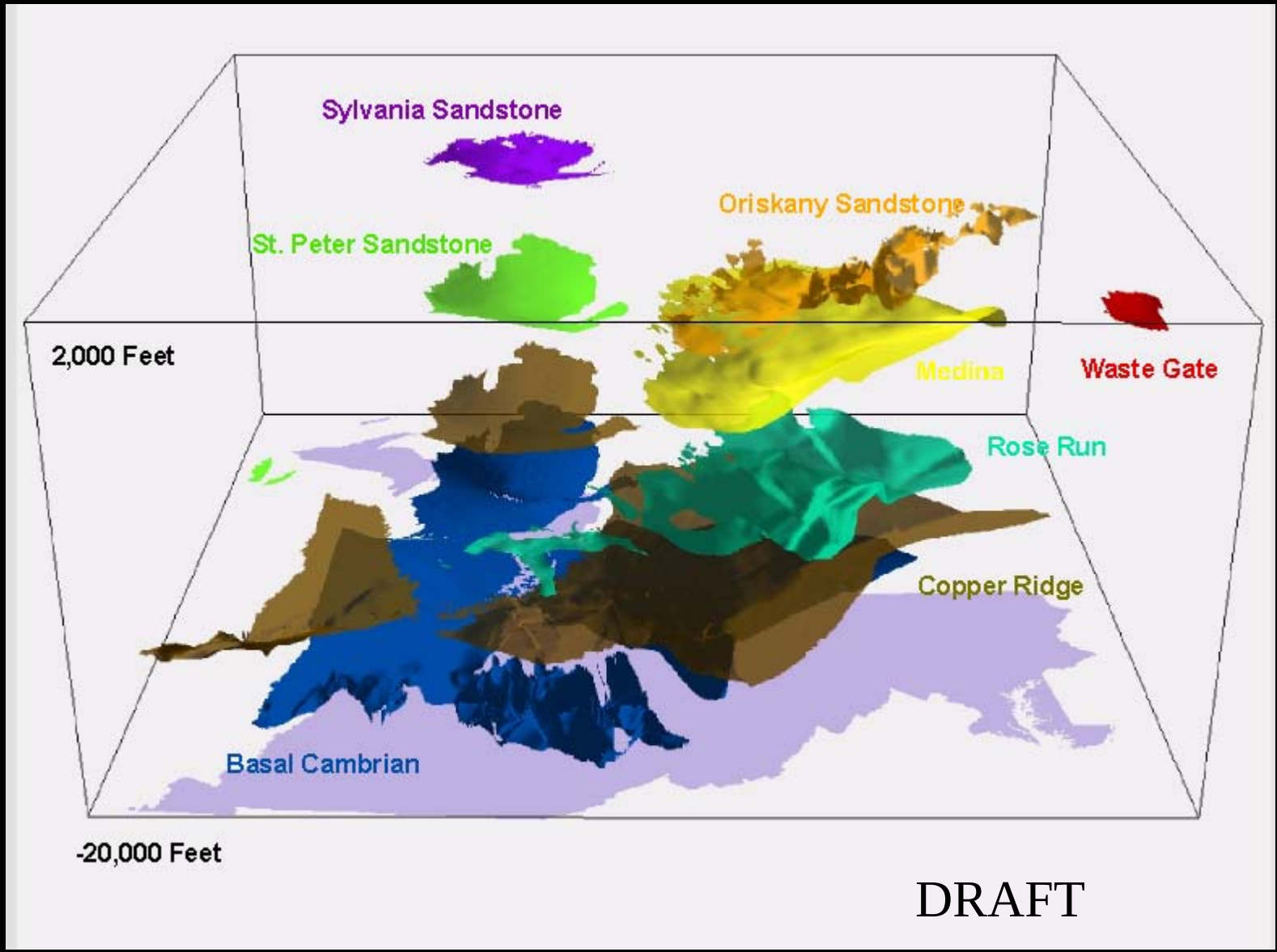


DRAFT

Another example synthesis map.

This shows the number and names of saline formations present At any location that meet the criteria of 3,000 feet or greater depth and at least 50 feet thick.





3-D View of the same screening map.

- Saline formations that meet the criteria of 3,000 feet or greater depth and at least 50 feet thick.

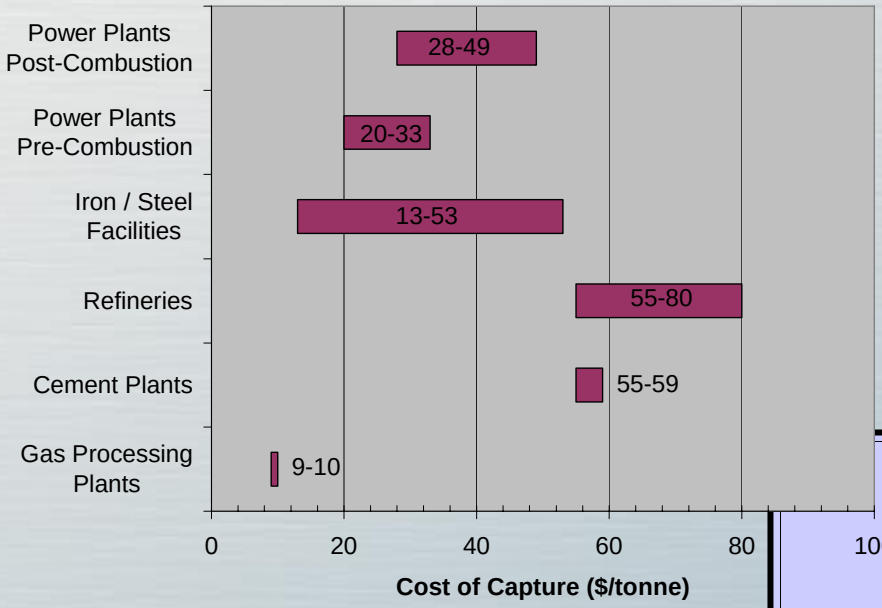
CONSOL has completed a detailed analysis of capture technologies for MRCSP

Technologies Considered

- Amine Scrubbing
- Alkaline Salt Scrubbing
- Ammonia Scrubbing
- Physical Absorption
- Gas Separation Membrane
- Gas Absorption Membrane
- Physical Adsorption
- Solid Chemical Absorption
- Cryogenic
- Hydrate Formation
- Electrochemical Separation
- Biochemical Separation
- Oxyfuel
- Chemical Looping Combustion

An Amine Capture Plant on a Gas Processing Plant
Photo provided by CONSOL Energy

Capture Analysis



Cost of capture is in the range of $20 to $50 per tonne of CO_2 for most MRCSP sources

Capture technologies were ranked as:

- **"L" Likely,**
- **"A" Attractive, and**
- **"S" Speculative**

Source Type	Point of Capture	Amine Scrubbing	Ammonia Scrubbing	Physical Absorption	Gas Separation Membrane	Gas Absorption Membrane	Oxyfuel + Drying/Compression	Simple Drying/Compression
Power Plants Post-Combustion	Flue Gas	L	A	--	A	A	A	--
Power Plants Pre-Combustion	Shifted Syngas	--	--	L	A	--	--	--
Iron / Steel Facilities	Blast Furnace Gas (~60-70% of total CO_2)	L	--	L	A	S	--	--
Refineries	Heater/Boiler Flue Gas (~65-85% of total CO_2)	L	S	--	A	S	A	--
Cement Plants	Kiln Flue Gas	L	S	--	S	S	S	--
Gas Processing Plants	Vented CO_2	--	--	--	--	--	--	L

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Regulatory Analysis

- Contacts made in all states. Copies of pertinent regulations obtained and analyzed.
- Meetings held at state level
  - public utility commissions, EPA, and other stakeholders
- Analysis includes:
  - Regulations for fluid injection and analogues such as gas storage
  - Discussion of selected case law related to subsurface injection
  - Review of rights of way/mineral rights issues for subsurface reservoirs
  - Review of pipeline rights of way procedures and precedents
  - Assessment of eminent domain issues
  - Assessment of credit mechanisms for terrestrial storage
  - International accords related to carbon mitigation
  - Carbon trading status in the USA
  - Identification of regulatory jurisdiction in all seven states

Status of UIC Regulation Primacy in MRCSP States

- **Indiana**:
  - EPA Region 5 regulates all classes of well except Class 2. The Indiana Department of Natural Resources, Division of Oil and Gas is responsible for Class 2 wells.
- **Kentucky**:
  - EPA Region 4 regulates all classes of wells.
- **Maryland**:
  - The Maryland Department of the Environment has primacy over all classes of wells.
- **Michigan**:
  - EPA Region 5 oversees all classes of wells.
- **Ohio**:
  - The Ohio EPA Division of Ground and Drinking Water regulates Class 1, 3, and 5 wells. The Ohio Department of Natural Resources Division of Mineral Resources Management Office of Oil and Gas handles Class 2 wells.
- **Pennsylvania**:
  - EPA Region 3 regulates all classes of wells.
- **West Virginia**:
  - The West Virginia Department of Environmental Protection regulates all wells. Its Division of Water Resources Groundwater UIC oversees Class 5 wells (there are not class 1 wells); the Office of Oil and Gas handles Class 2 wells.

Regulatory Findings

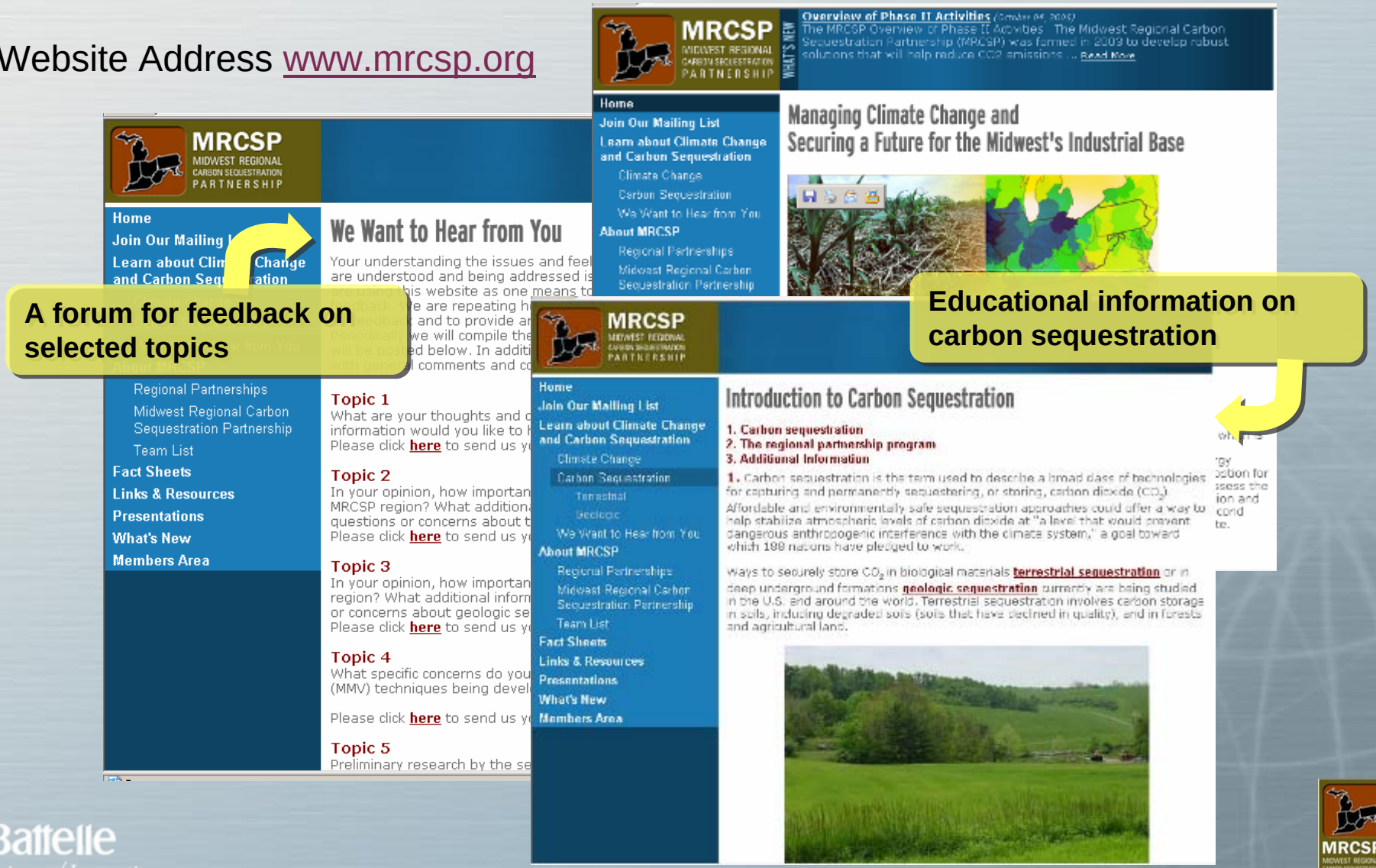
- Terrestrial sequestration
  - Few constraints to implementation.
    - Jurisdiction is dispersed over various agencies e.g. DNR for forests, minelands, and wetlands; Agriculture for croplands and conservation
  - Monitoring and verification protocols need further refinement.
- Geologic sequestration
  - Uncertain how to handle long term liability
  - UIC program for drinking water will apply in the absence of other specific statutes
  - State regulators confirm that pilot projects will be permitted under the UIC
- Need for interagency coordination
  - Little dialogue between various state agencies on sequestration so far
  - Knowledge and awareness of sequestration technologies is lacking
  - It's clear that an integrated siting and permitting process is lacking.

Outreach

- Confirmed previous studies which show limited public awareness of carbon sequestration:
  - regulatory and other state officials reported sequestration is a new and relatively unknown topic
  - limited public feedback provided to questions posed on MRCSP website, despite increased site visitation
  - environmental group members appeared more knowledgeable but noted their limited resources and higher priority of other issues
- Laid a foundation for Phase II
  - developed a stakeholder database to use in networking to others
  - made initial state contacts and became aware of differing state contexts and regulatory issues
  - visited candidate geologic field sites and established a basis for future collaboration

Interactive Website

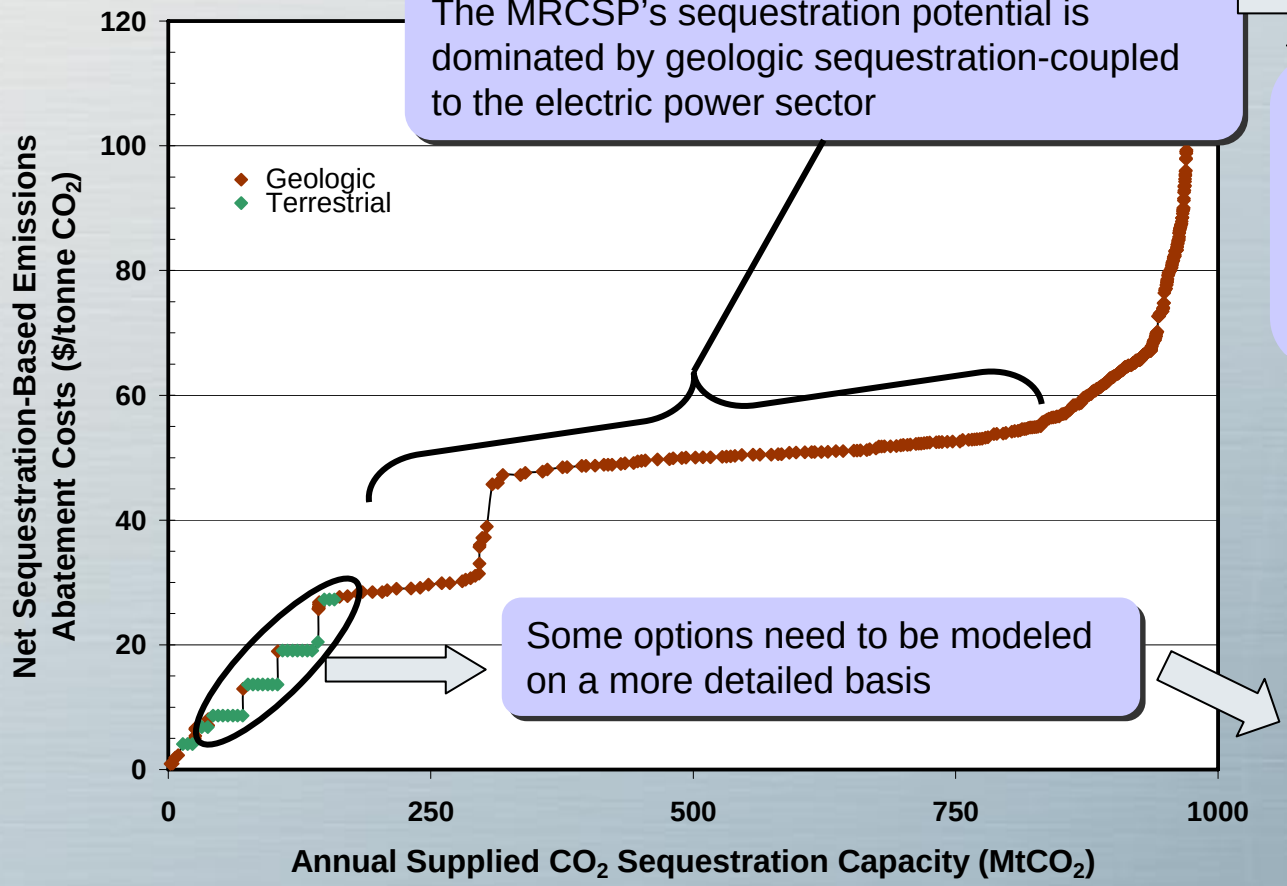
Website Address www.mrcsp.org



Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

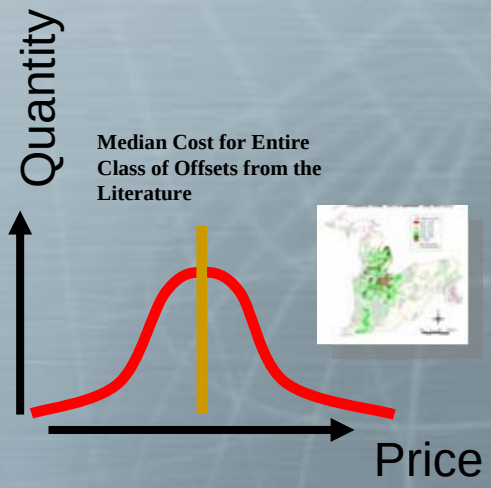
We have begun to integrate our knowledge into a first ever supply curve for the region



The MRCSP's sequestration potential is dominated by geologic sequestration-coupled to the electric power sector

Some options need to be modeled on a more detailed basis

Thus, lowering the cost of CO_2 capture could shift this cost curve down, thus delivering significant cost savings to the region's economy.



Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP


MRCSP
MIDWEST REGIONAL
CARBON SEQUESTRATION
PARTNERSHIP