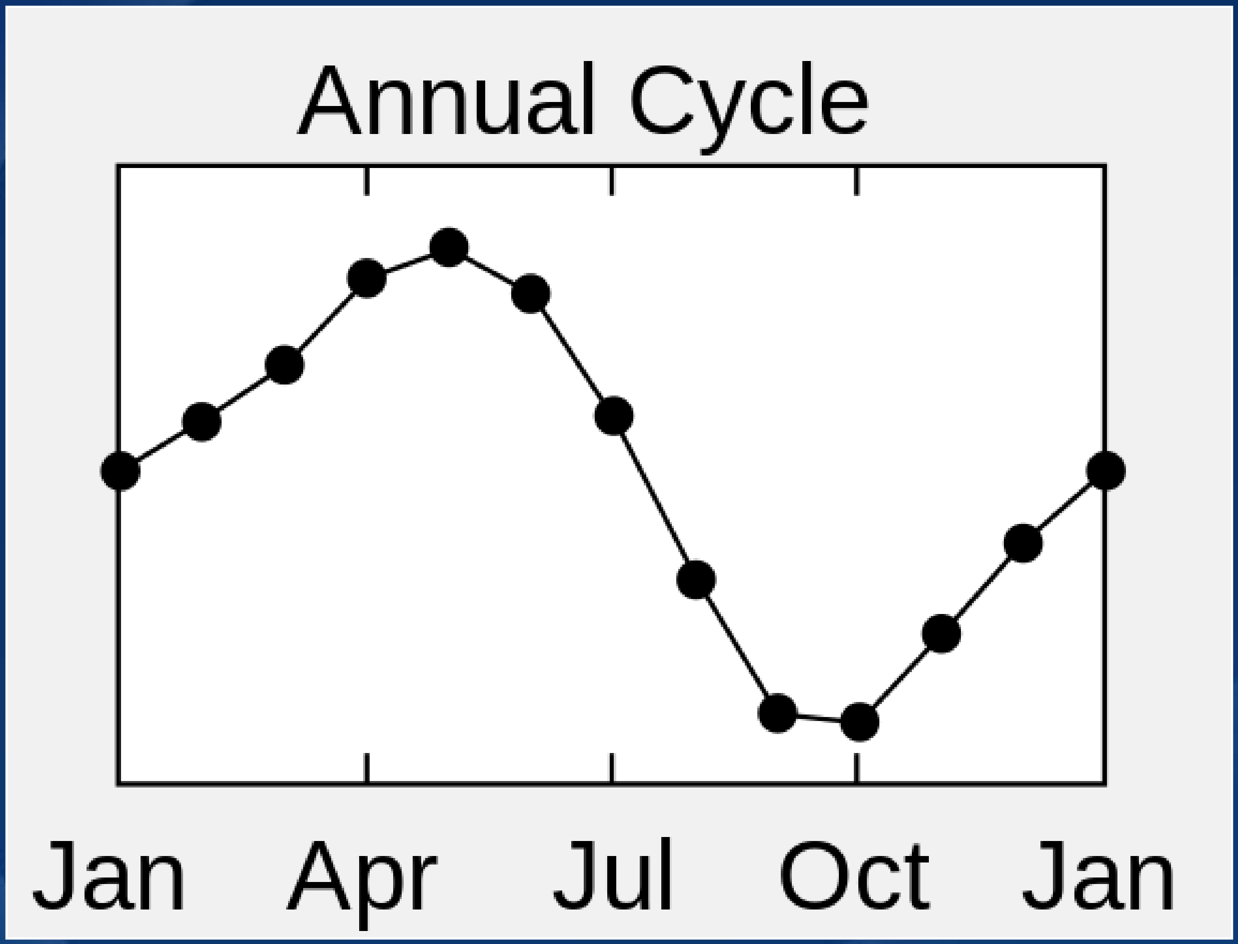
Carbon Sequestration In New York State: A Decade of Research

Brian Slater
4/30/2014

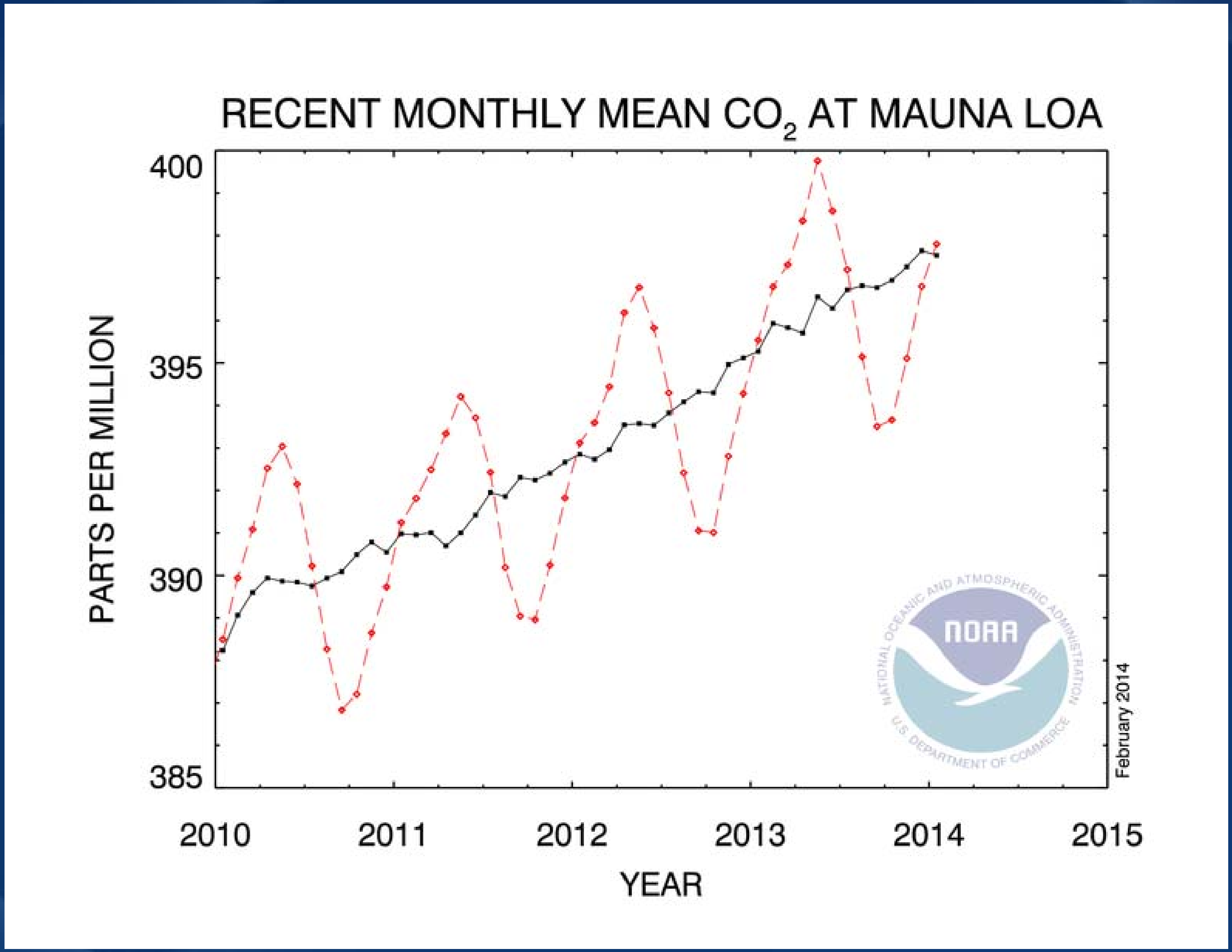
Presentation Layout

- **WHY?** Carbon Dioxide (CO_2) in the atmosphere
- **HOW?** Basics of carbon sequestration
- **WHERE?** A look at projects across New York
  - Jamestown Project
  - AES Cayuga Project
  - Trenton-Black River Potential
  - TriCarb Project
  - MRCSP – Offshore Research

CO_2 in the atmosphere



Historical Concentration of Atmospheric CO_2



Keeling Curve

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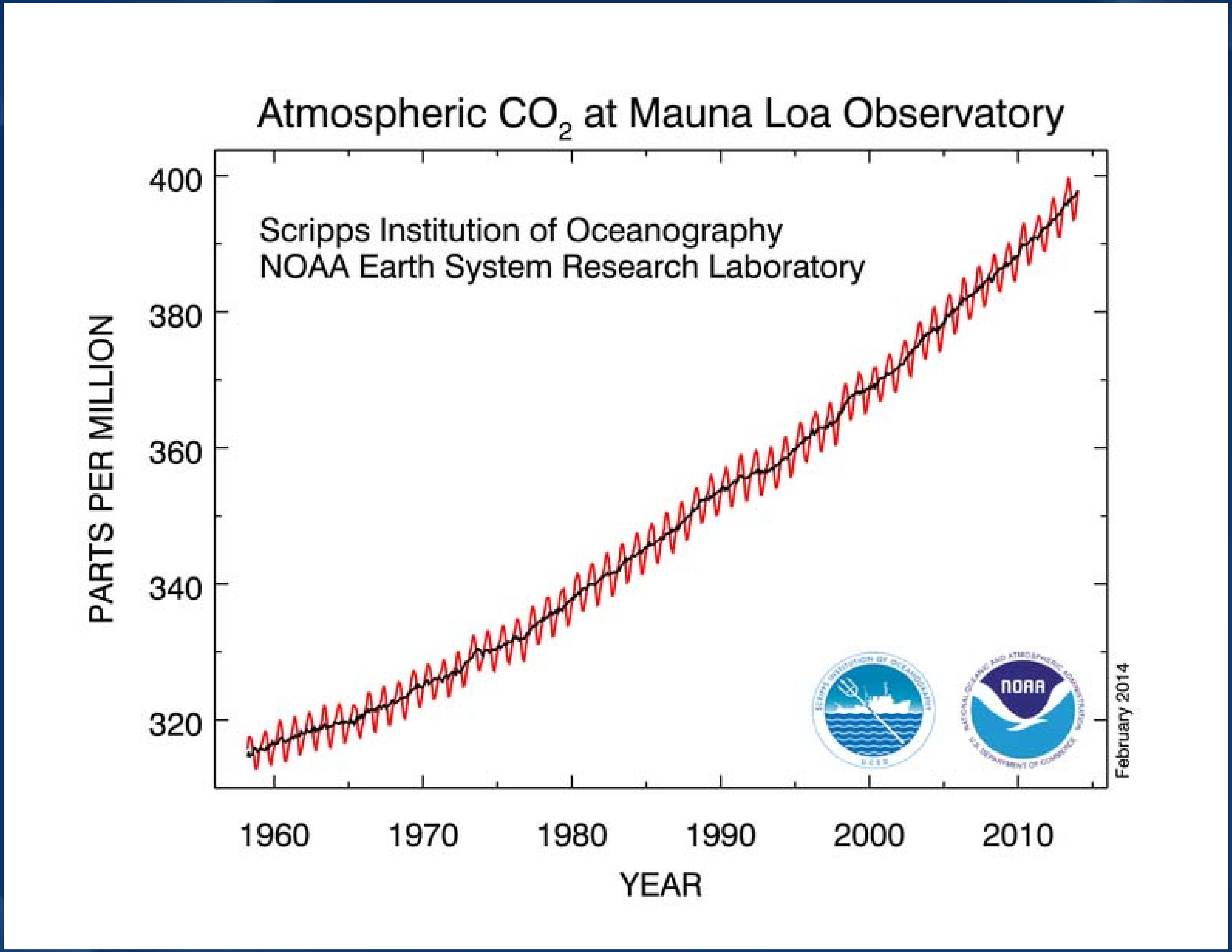

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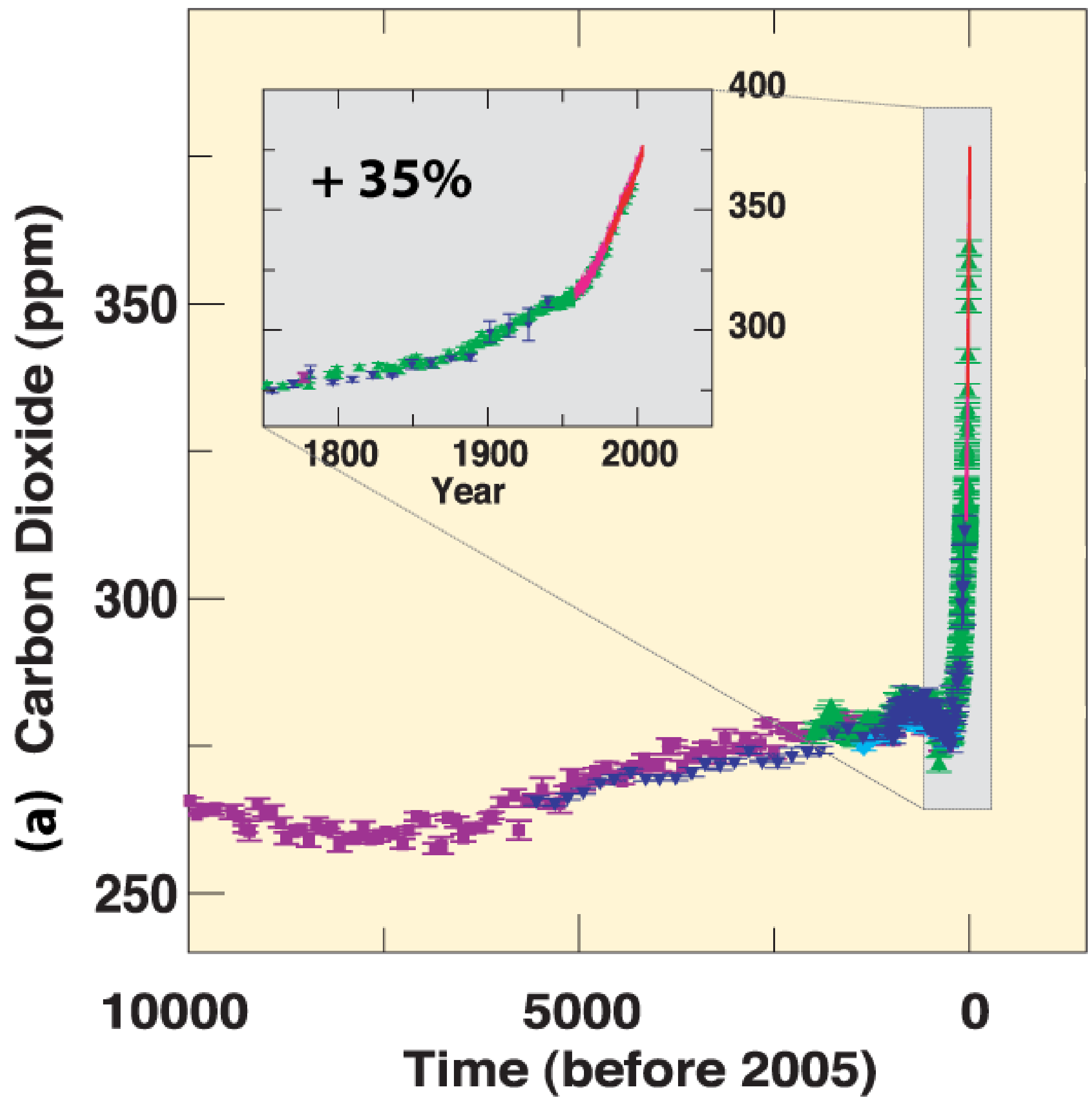

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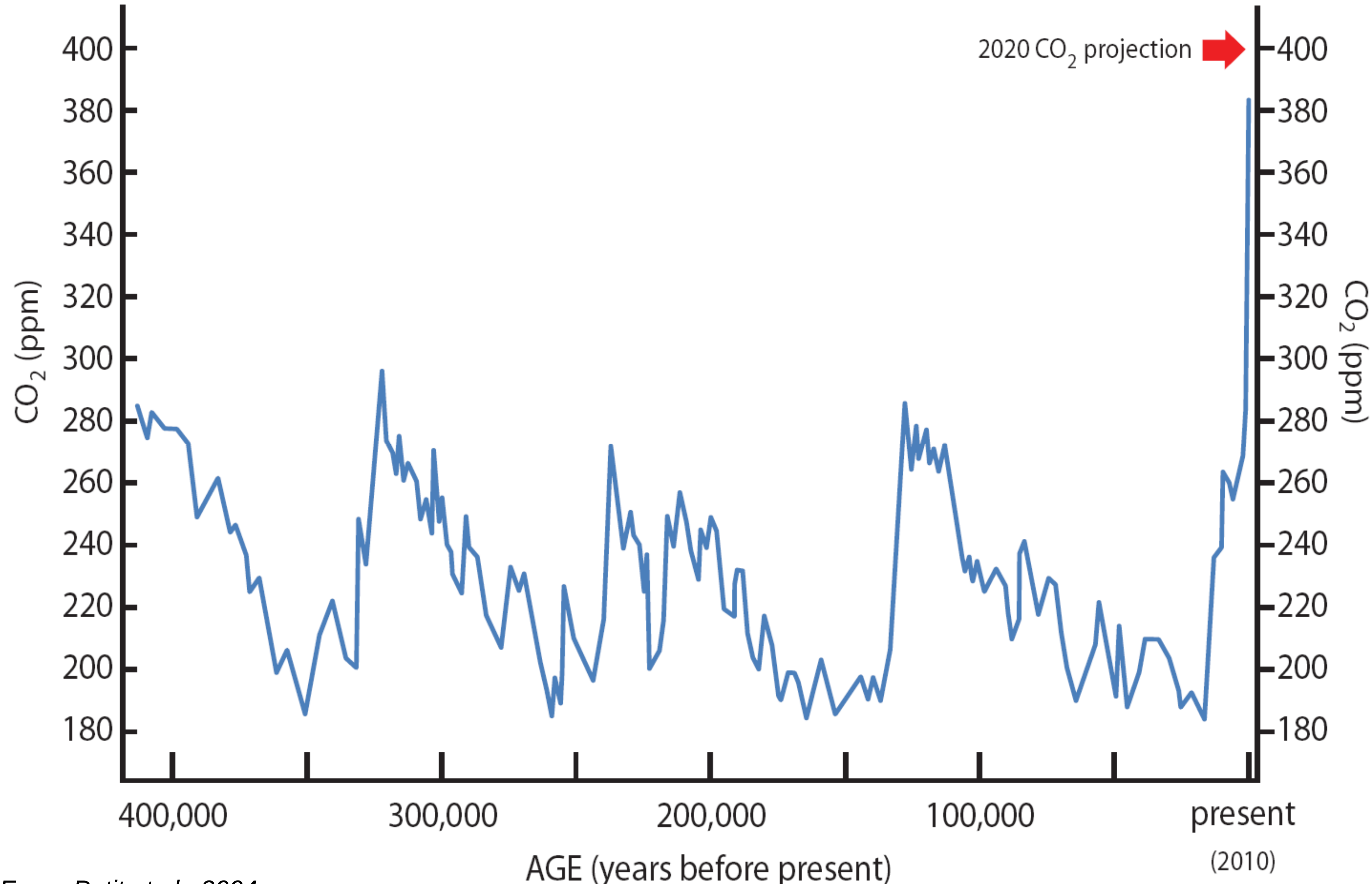

From: Petit et al., 2004

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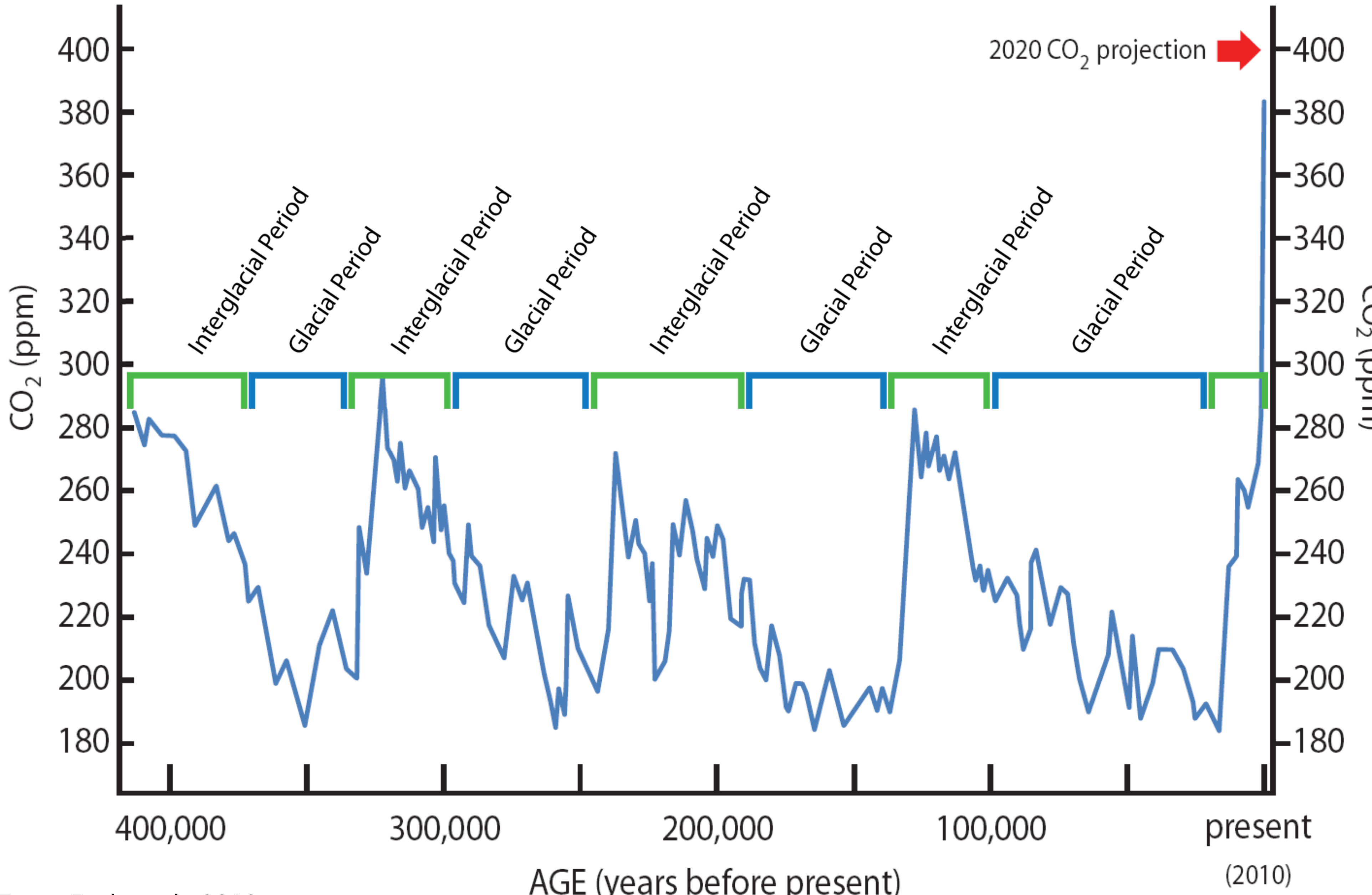

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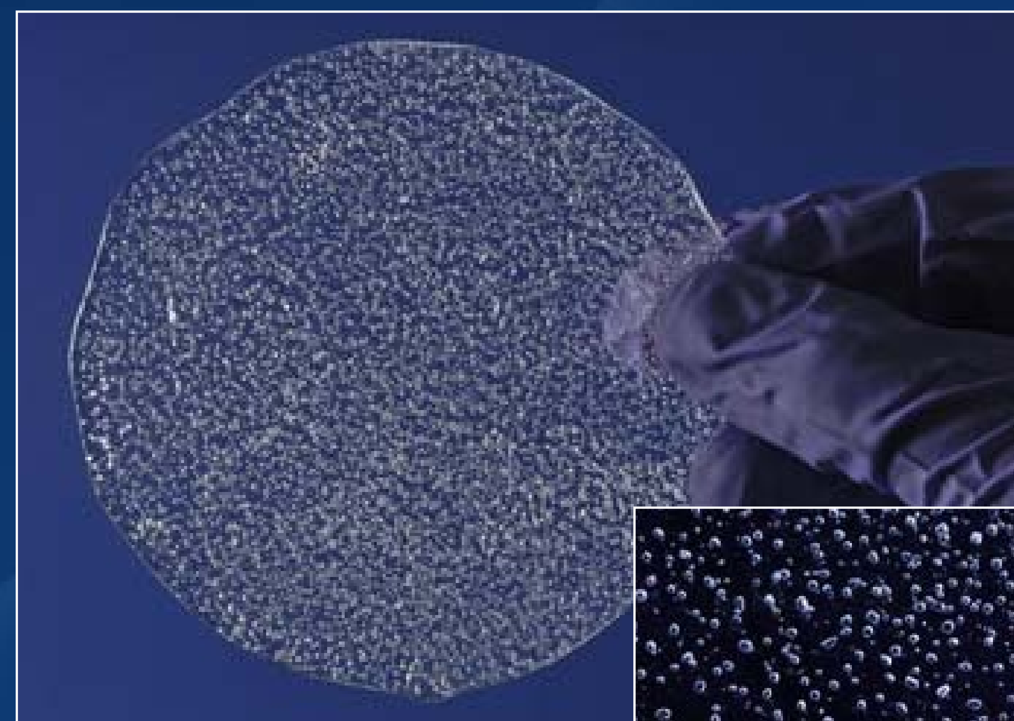
CO_2 in ice cores



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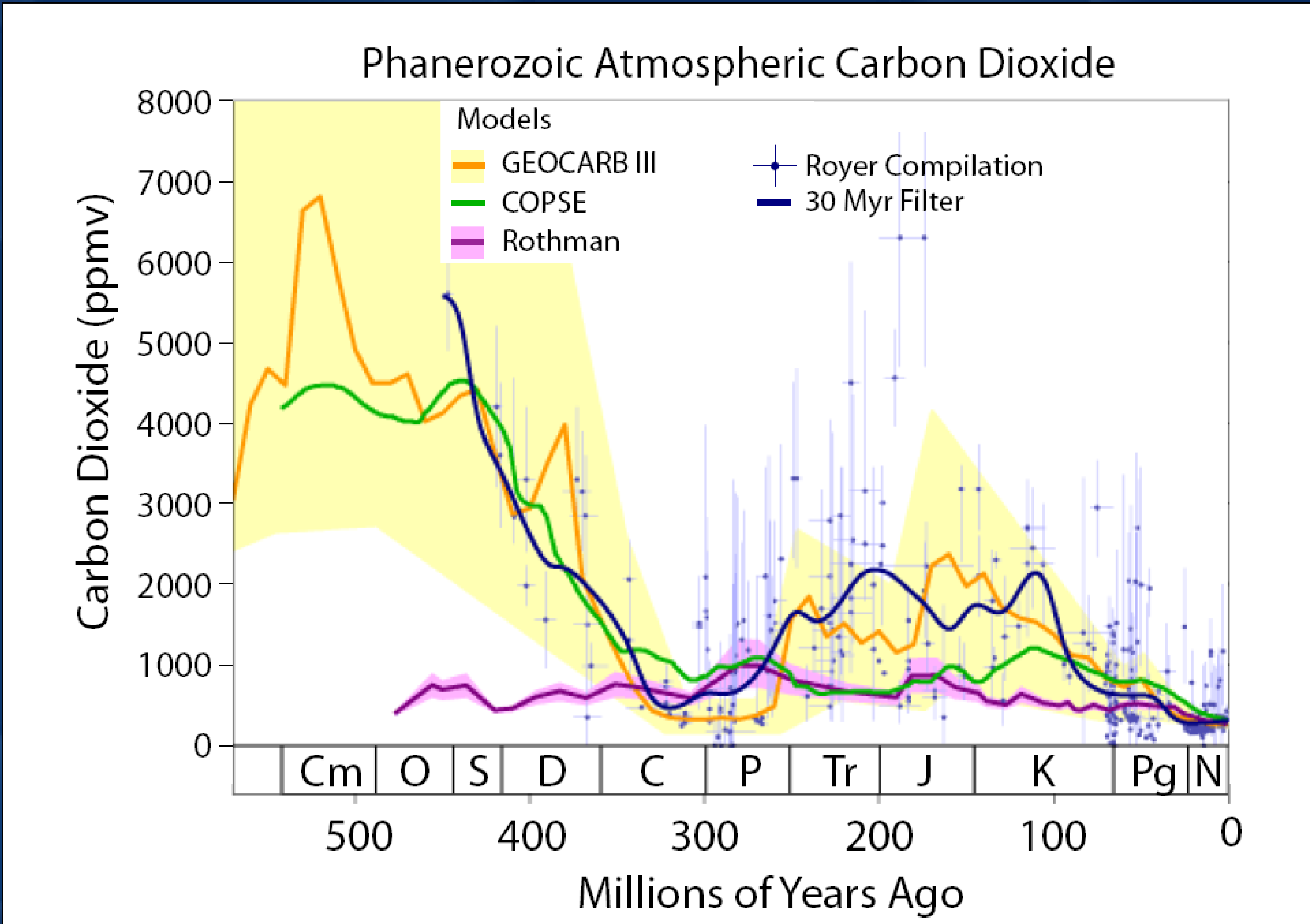

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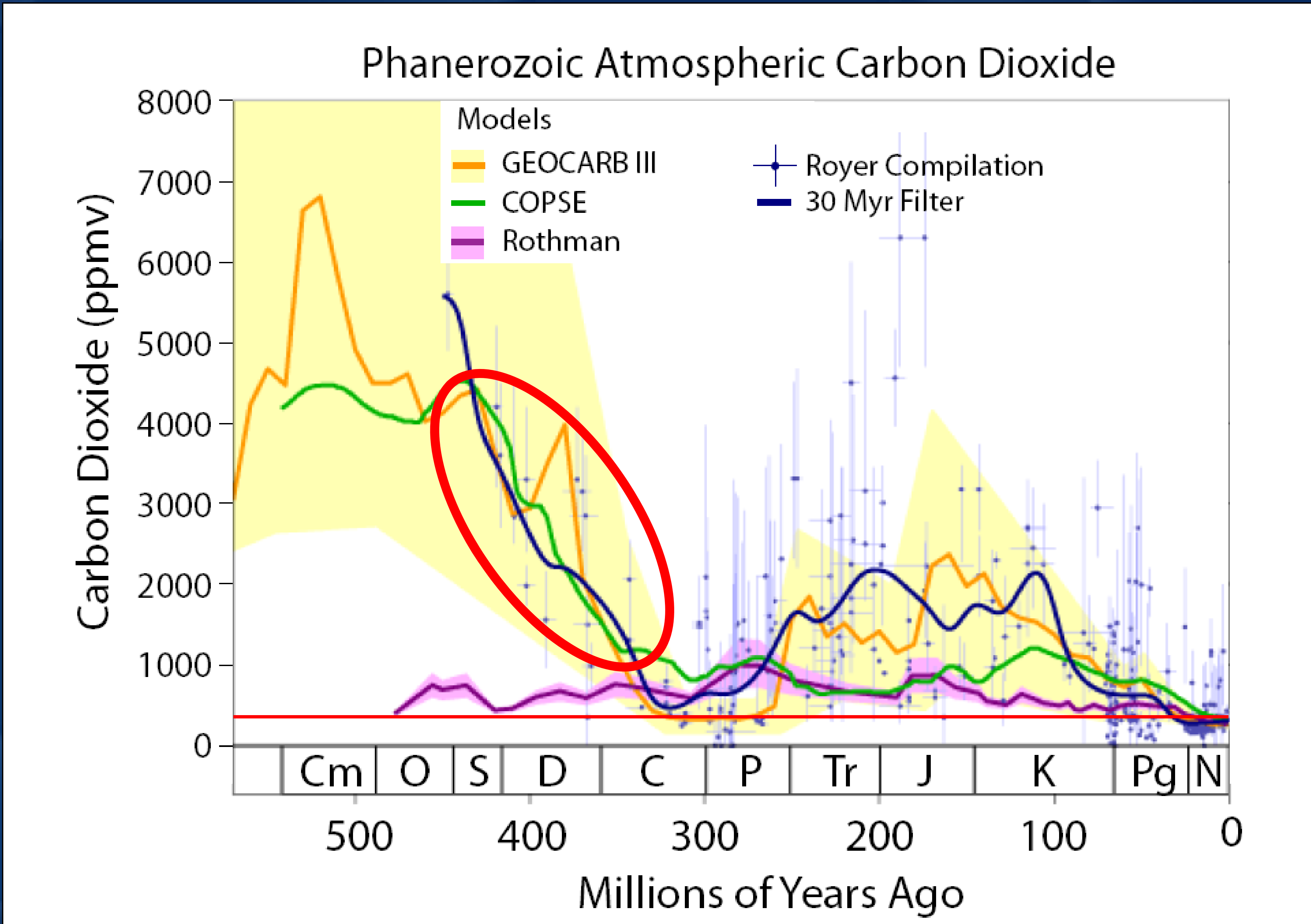
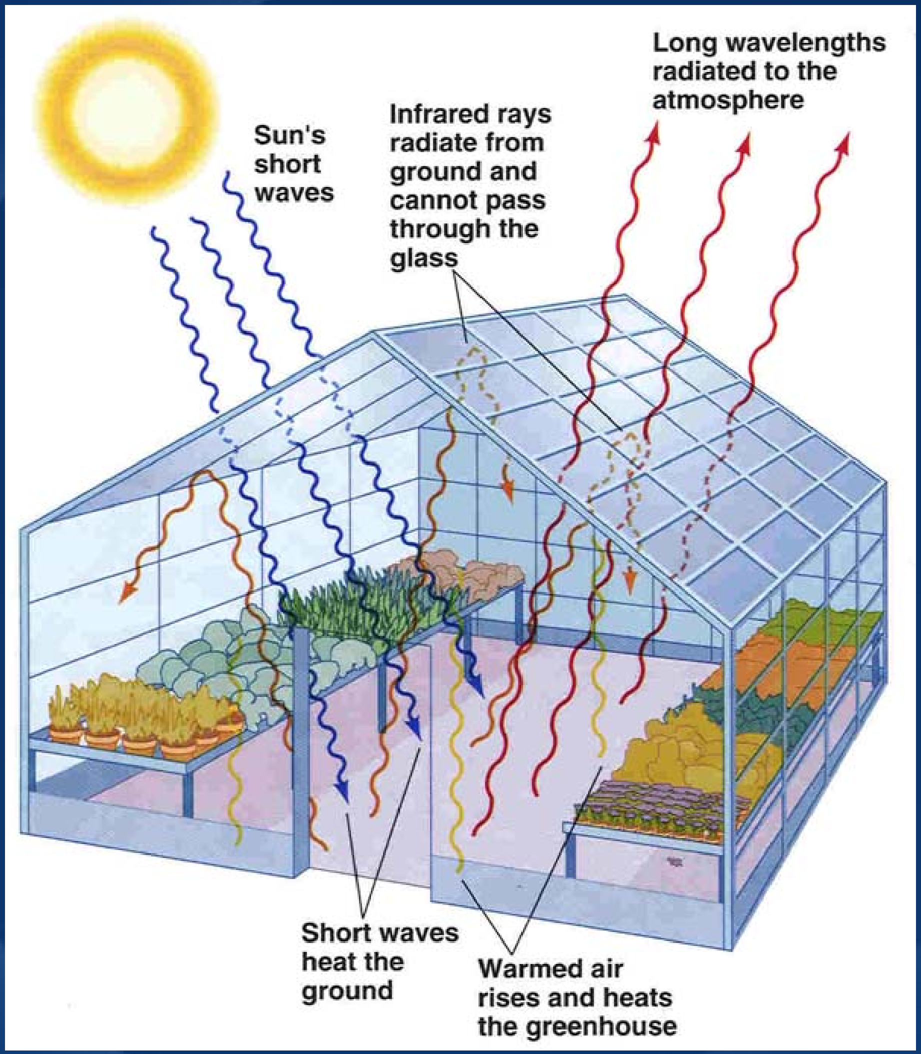
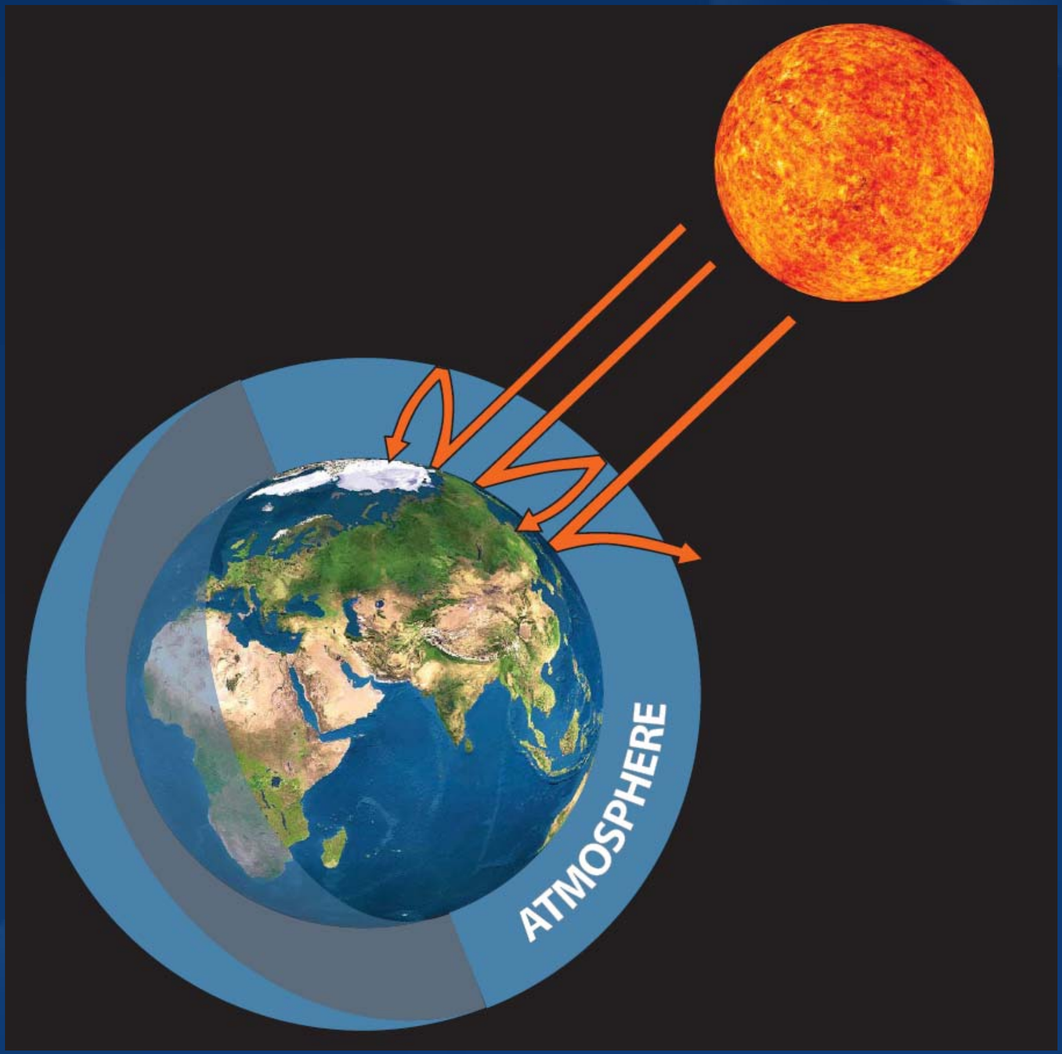
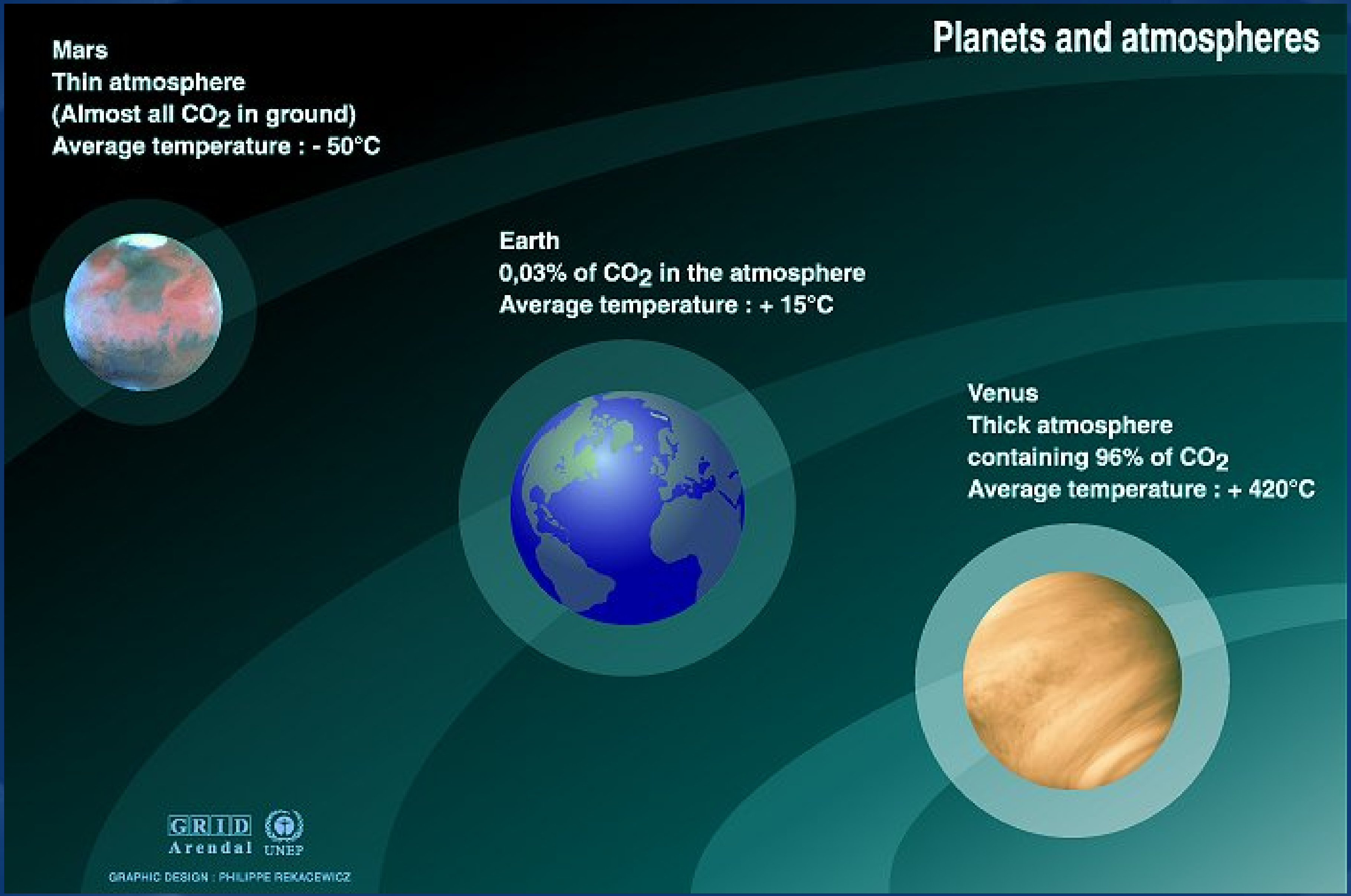


The Greenhouse Effect





Greenhouse Gases in the Atmosphere



Greenhouse Gases in the Atmosphere

Greenhouse Gases	Chemical Formula	Atmospheric Concentration
Carbon dioxide	CO_2	392600 ppbv
Methane	CH_4	1874.00 ppbv
Nitrous oxide	N_2O	324.000 ppbv
CFC-12	CCl_2F_2	0.53100 ppbv
CFC-11	CCl_3F	0.23800 ppbv
HCFC-22	$CHClF_2$	0.10500 ppbv
All Other	----	0.28900 ppbv

CDIAC
Carbon Dioxide Information Analysis Center

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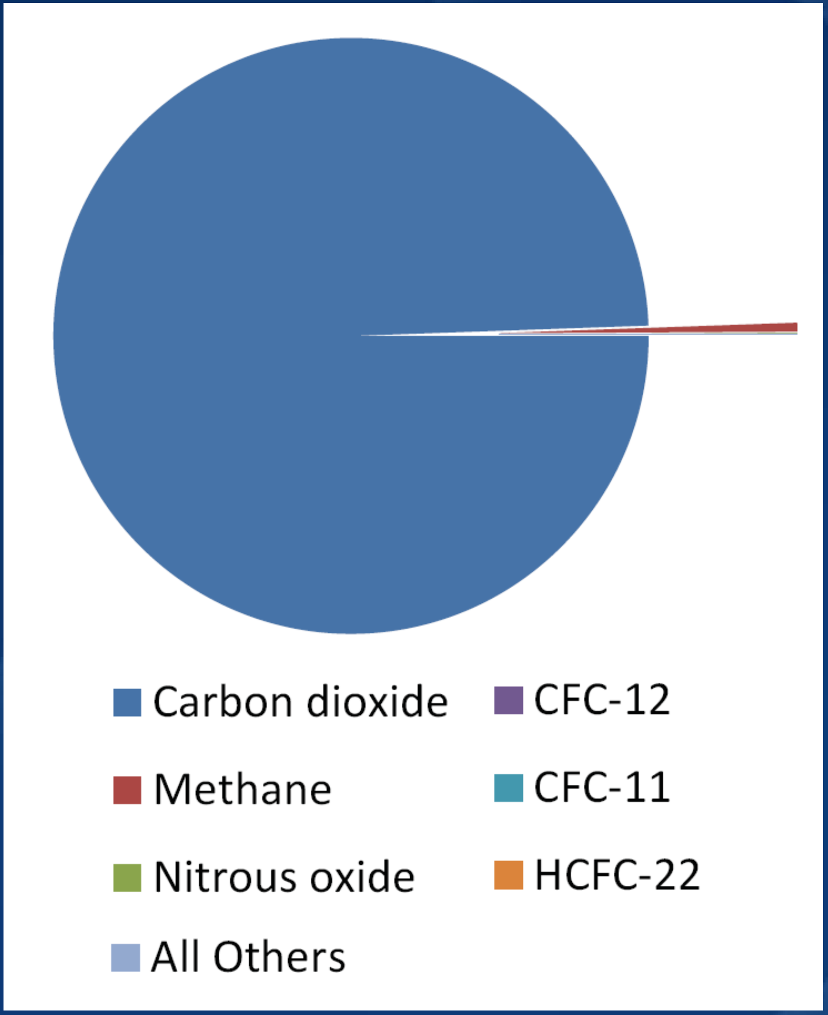

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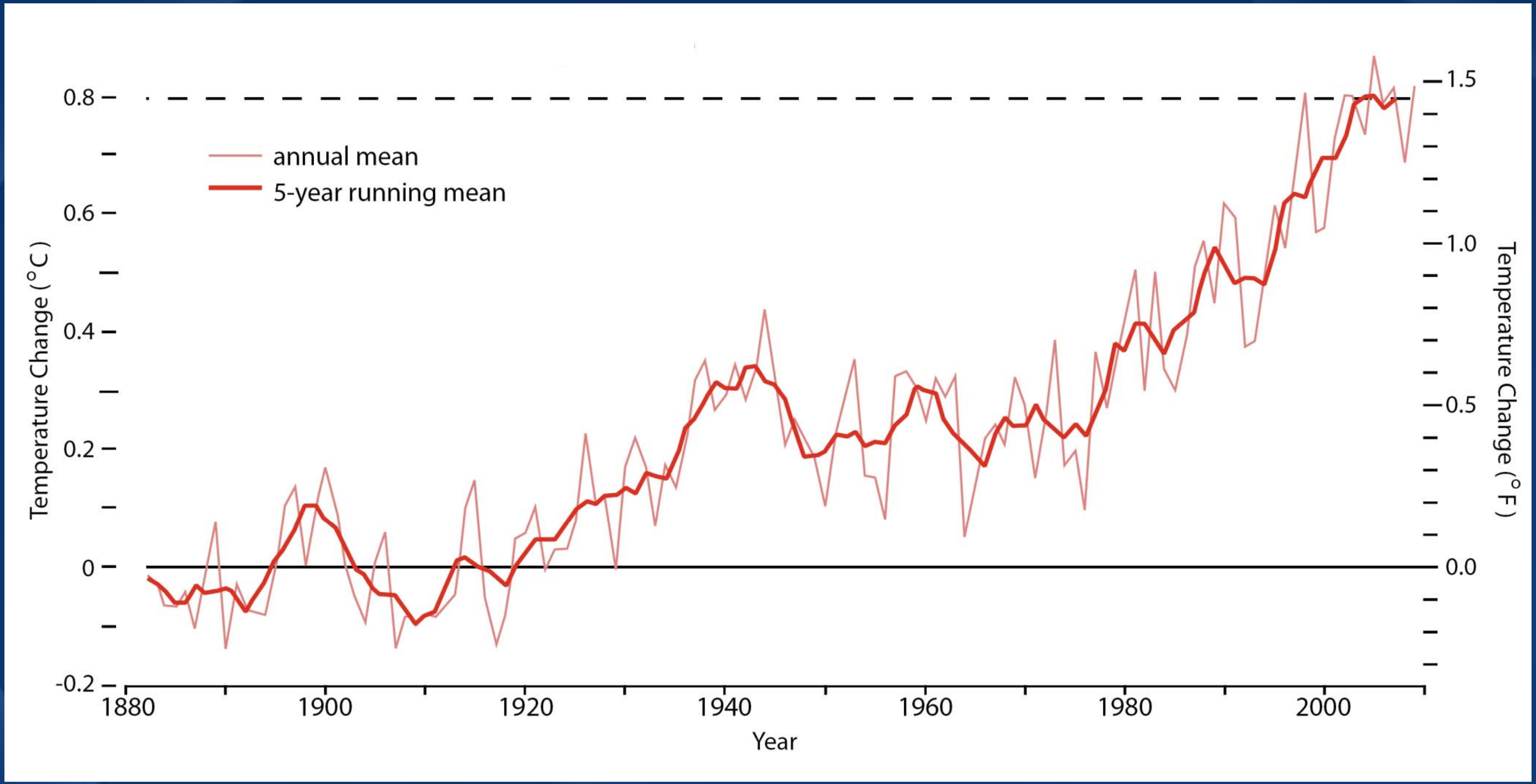
Average Global Surface Temperature

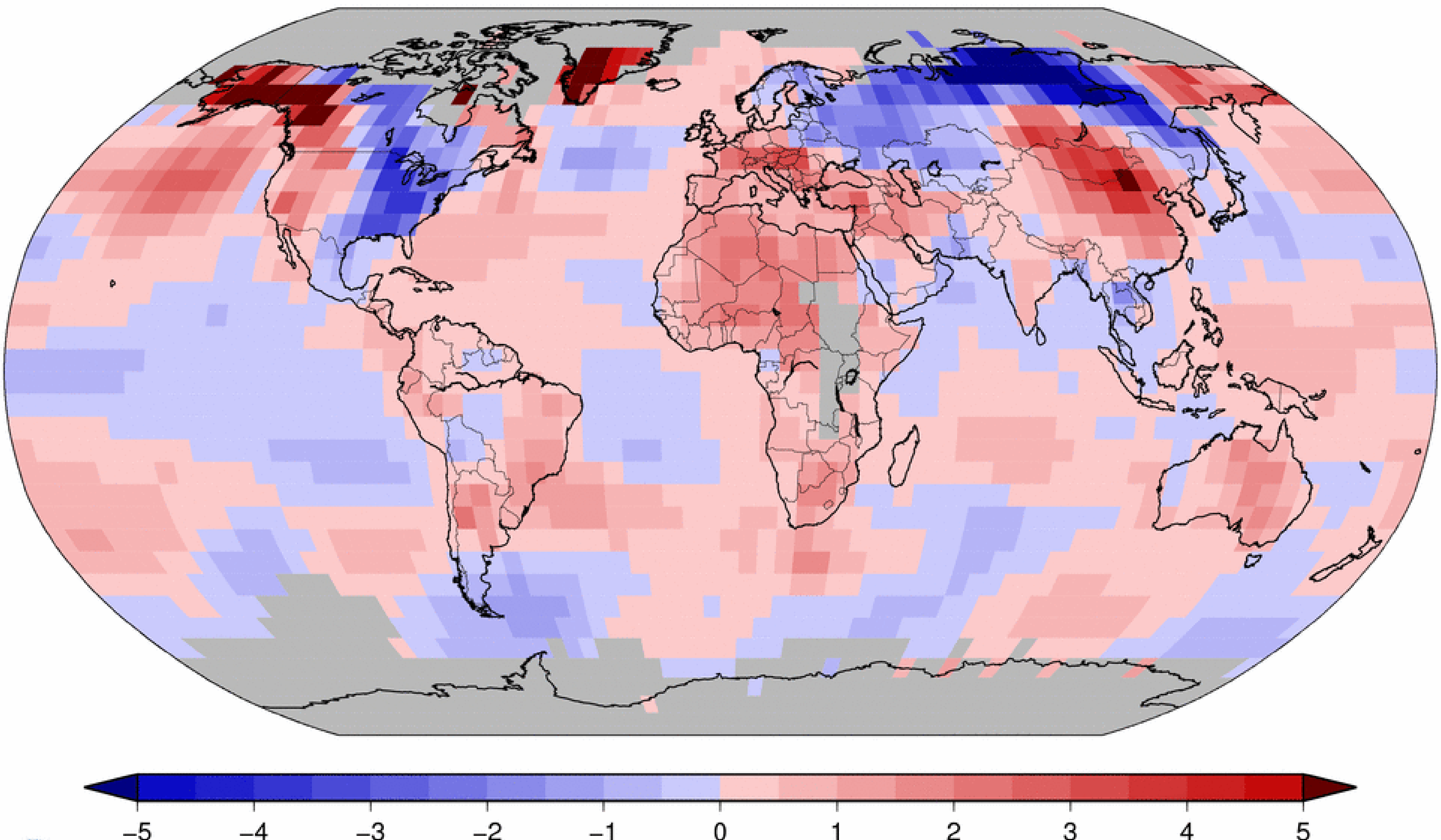


EARTH OBSERVATORY
Where every day is Earth Day

Land & Ocean Temperature Departure from Average Jan 2014

(with respect to a 1981–2010 base period)

Data Source: GHCN–M version 3.2.2 & ERSST version 3b

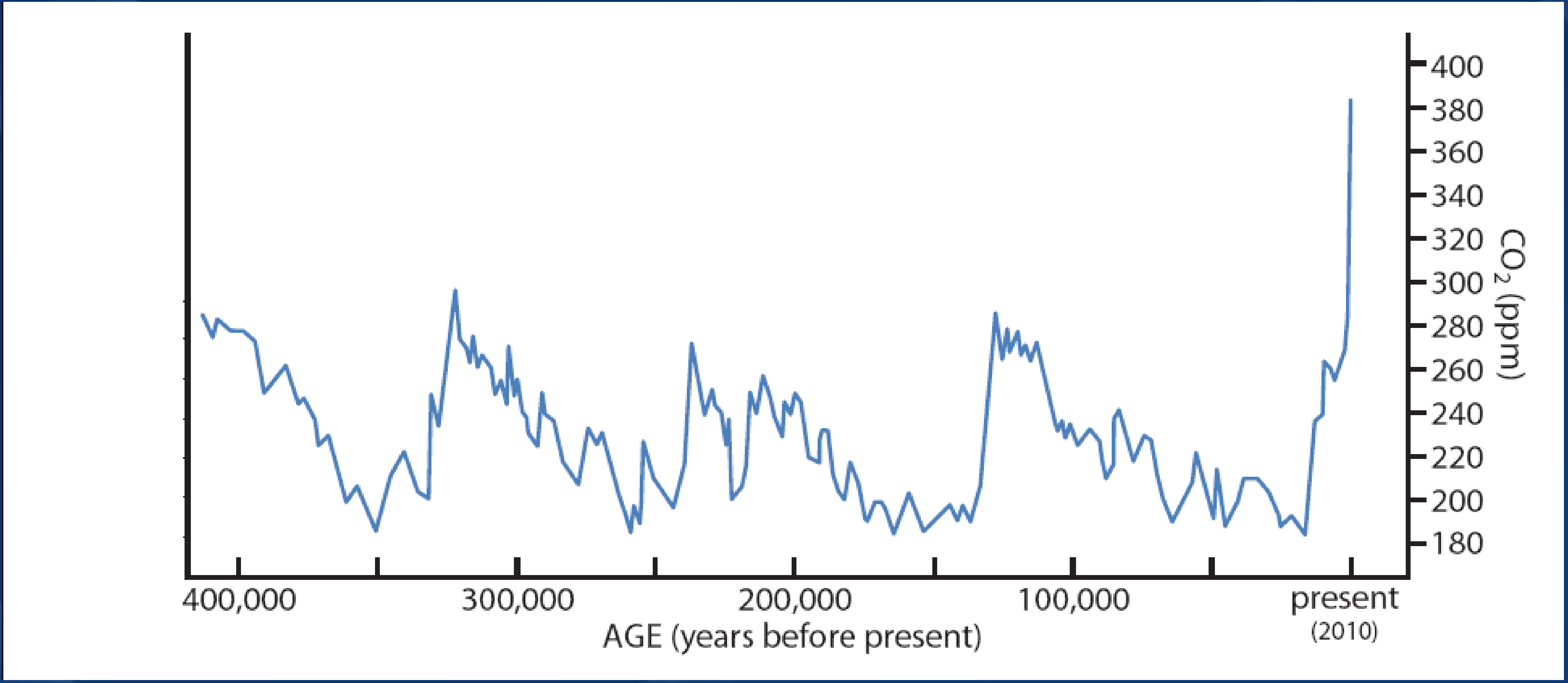


Degrees Celsius

NOAA's National Climatic Data Center
Wed Feb 12 07:43:21 EST 2014

Please Note: Gray areas represent missing data
Map Projection: Robinson

CO_2 and Temperature



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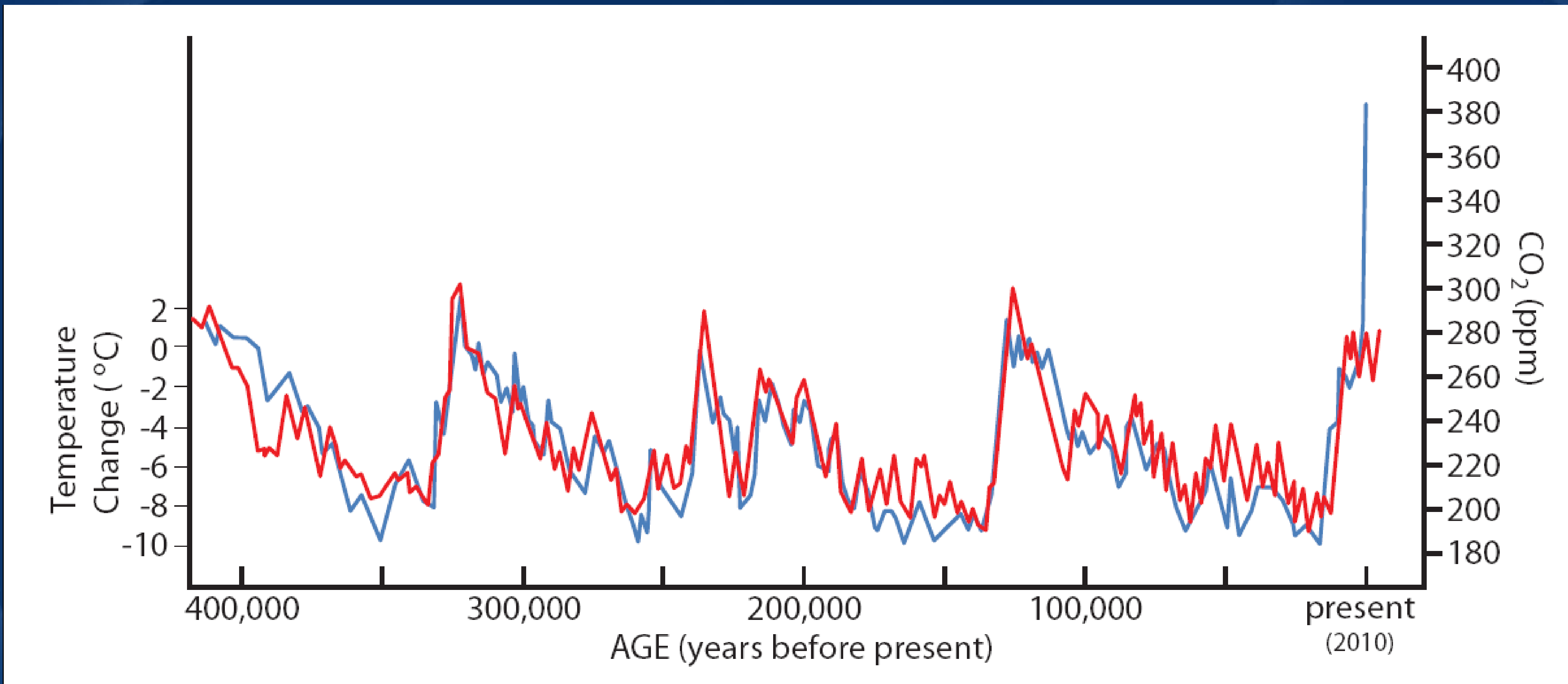

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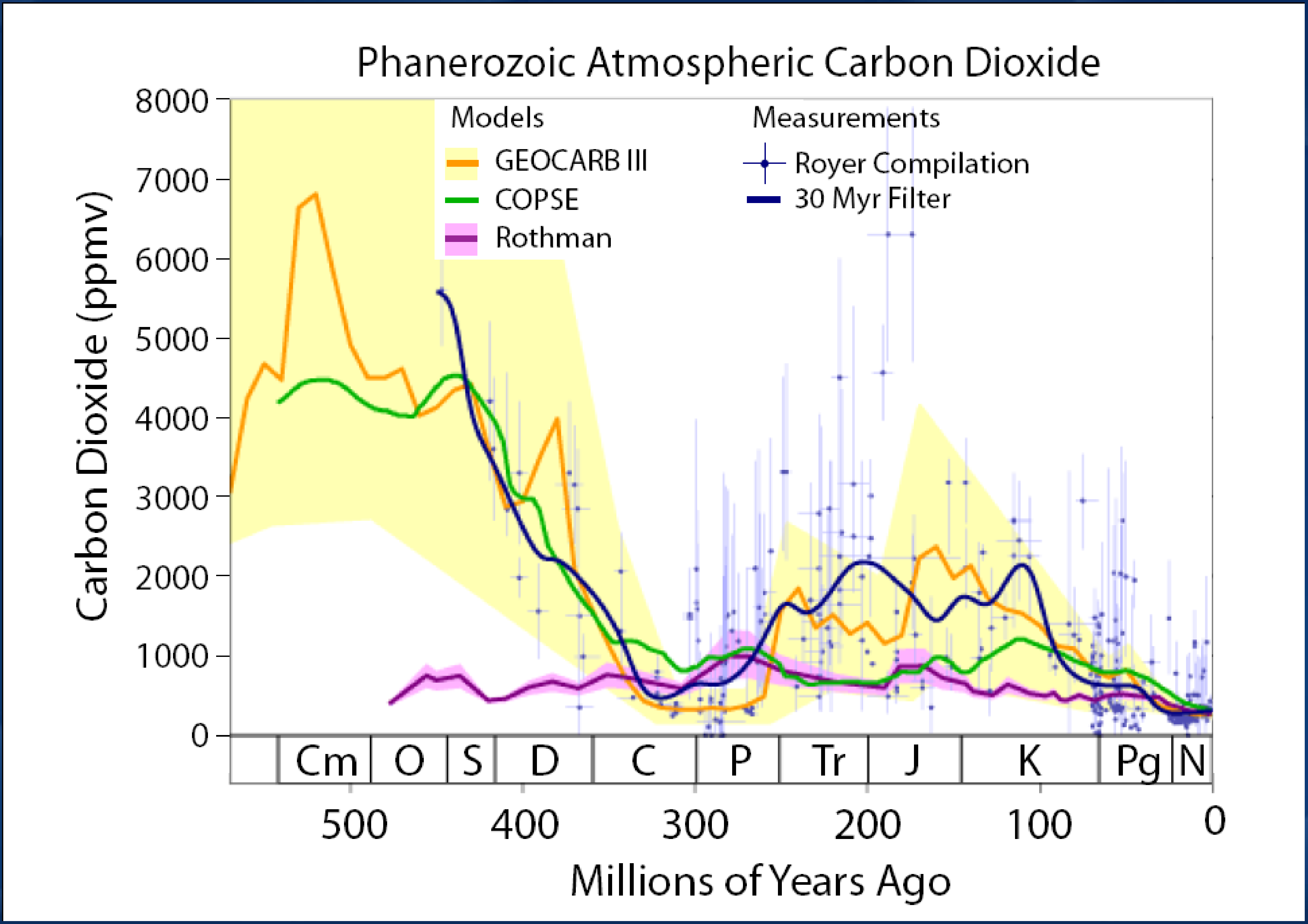

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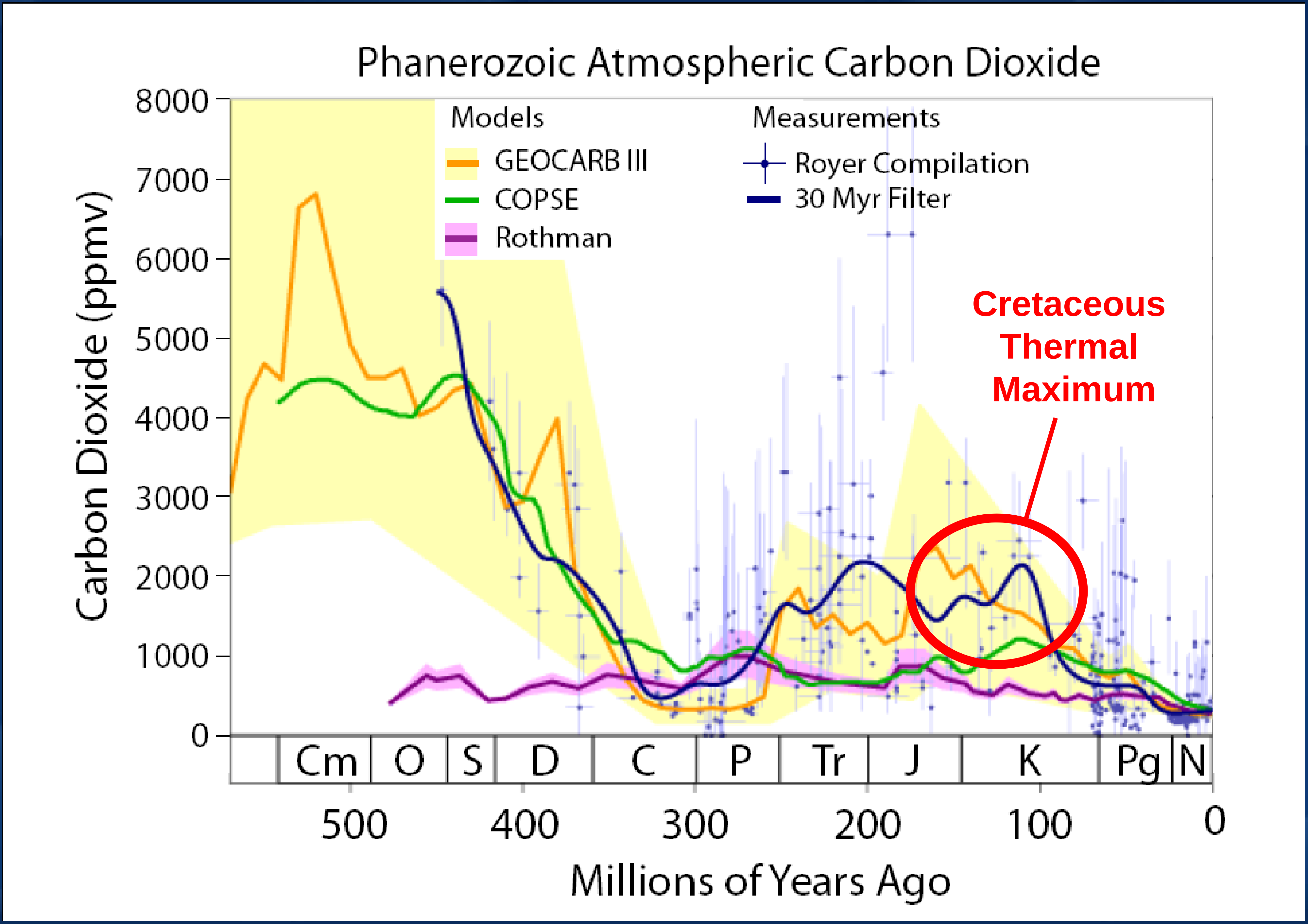
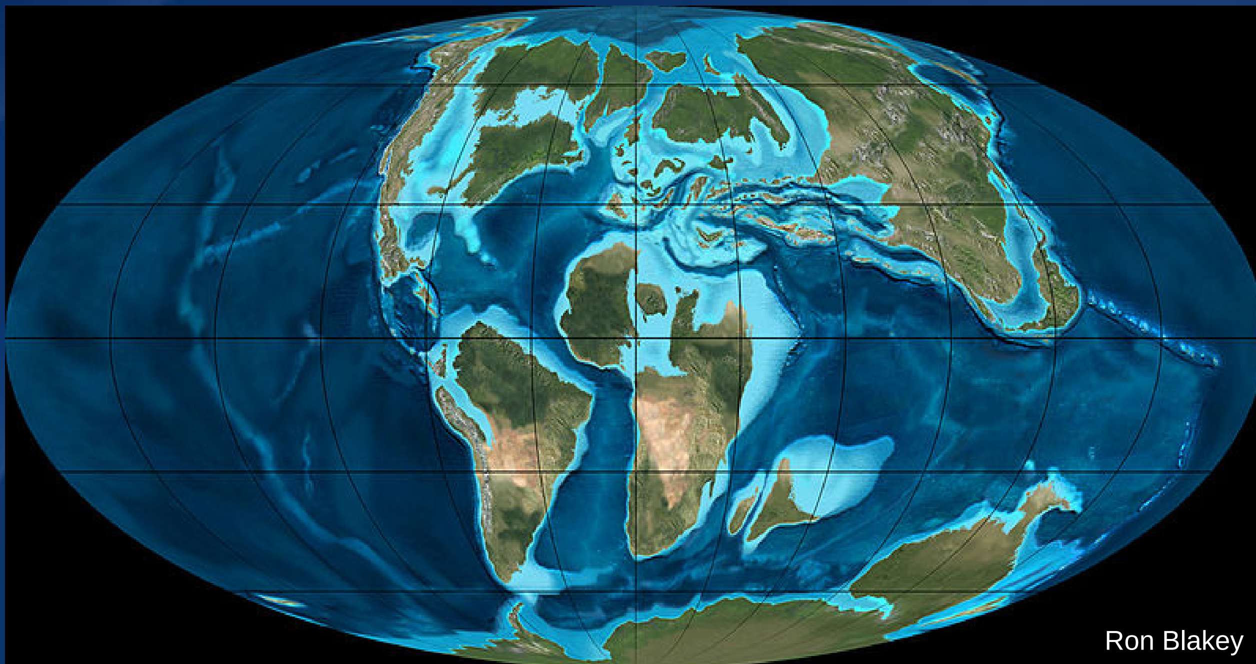
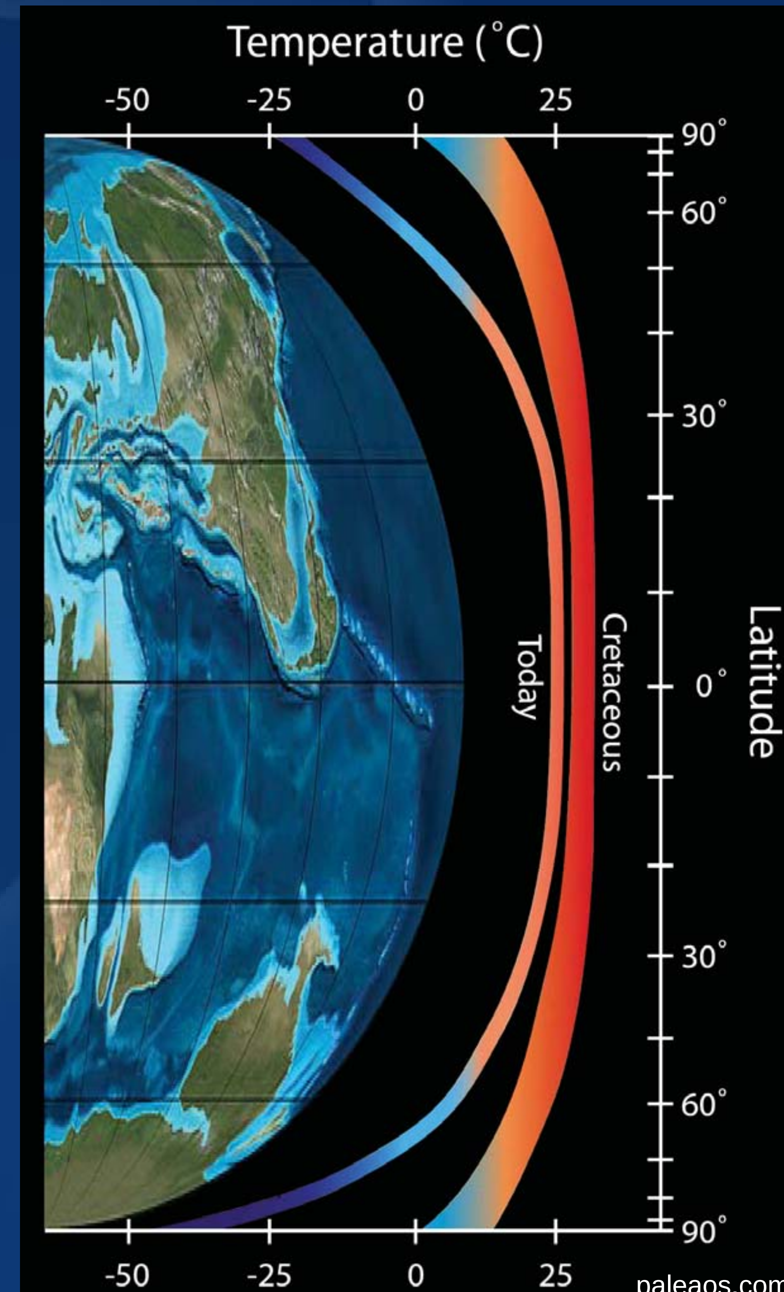


The Cretaceous Thermal Maximum (Greenhouse Earth)



- CO_2 levels greater than 1000ppm
- Equatorial temps were 3°- 5°C degrees higher
- Polar temps were 20°- 30°C higher
- Polar forests: evolution of conifers and ferns
- Tropical waters as far away as 40° from the equator



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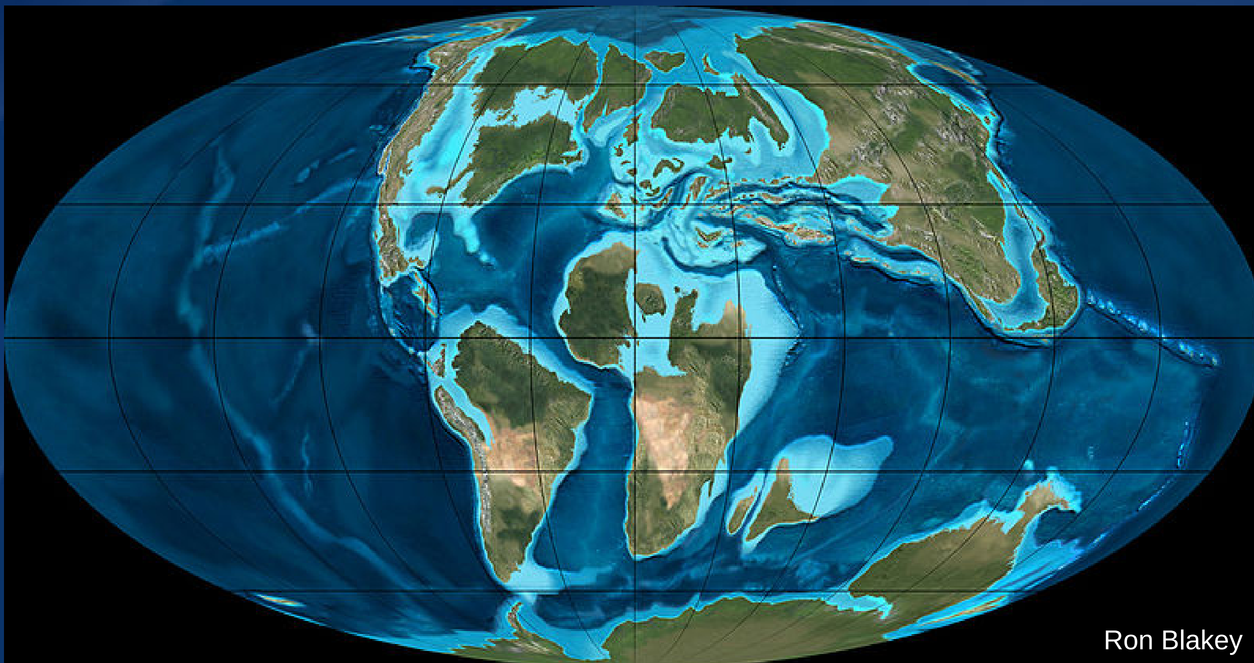

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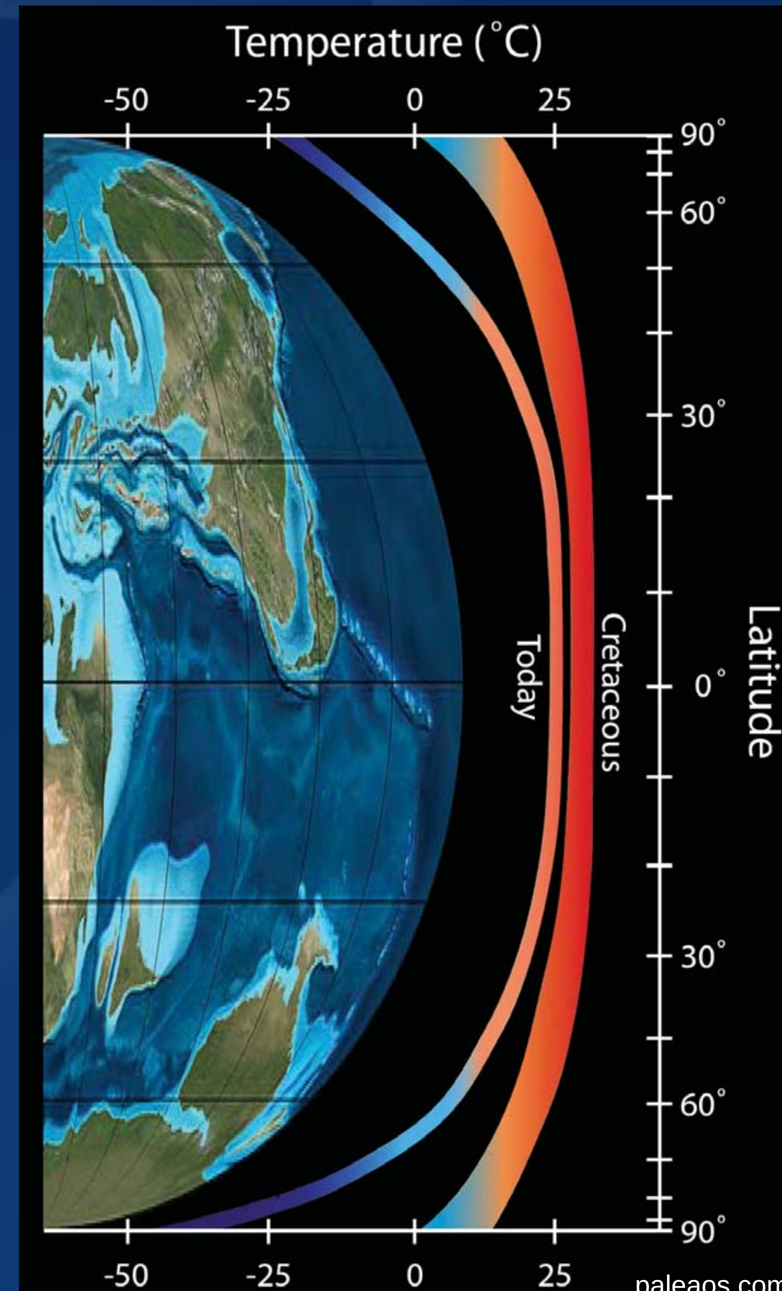
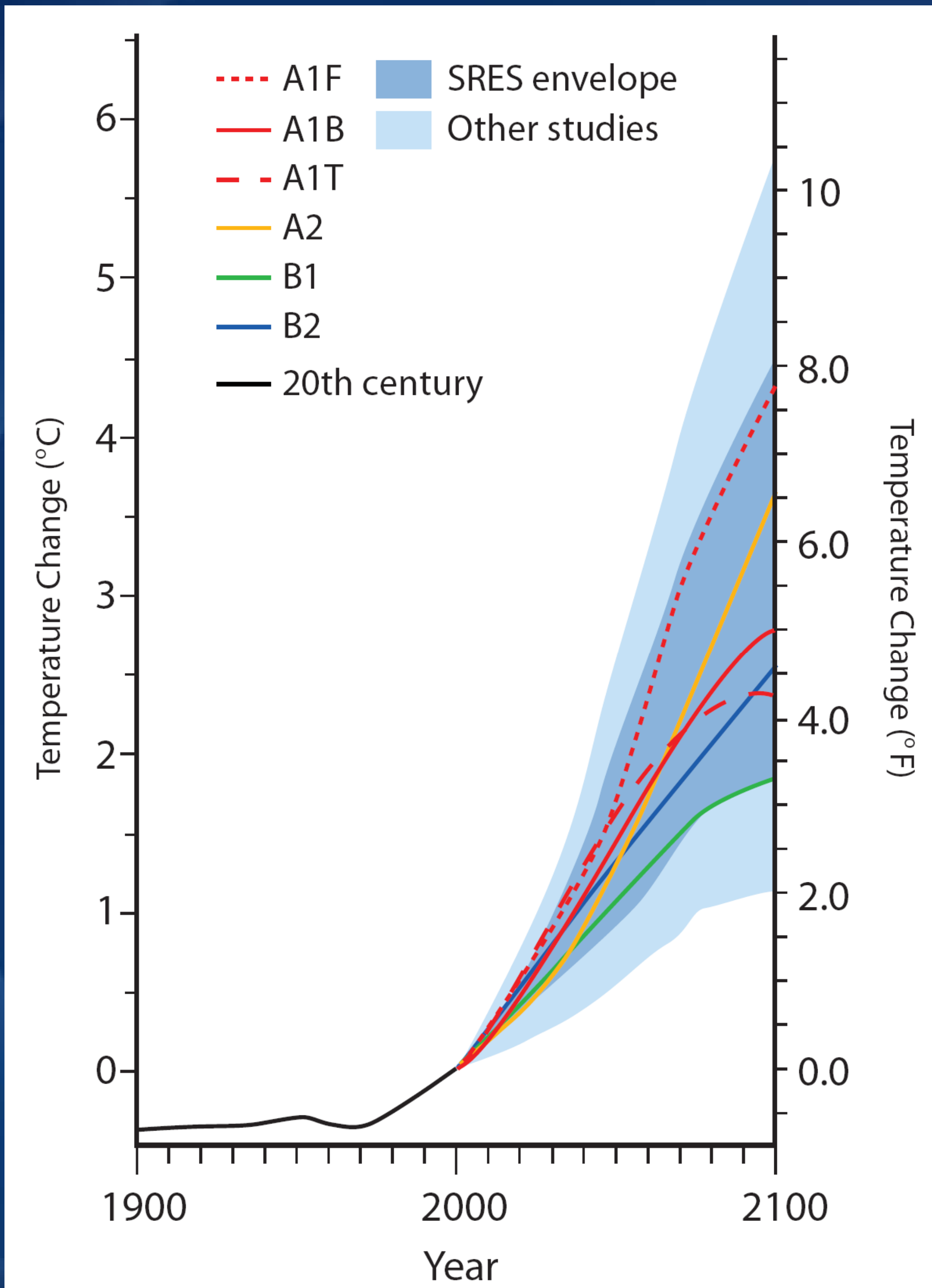
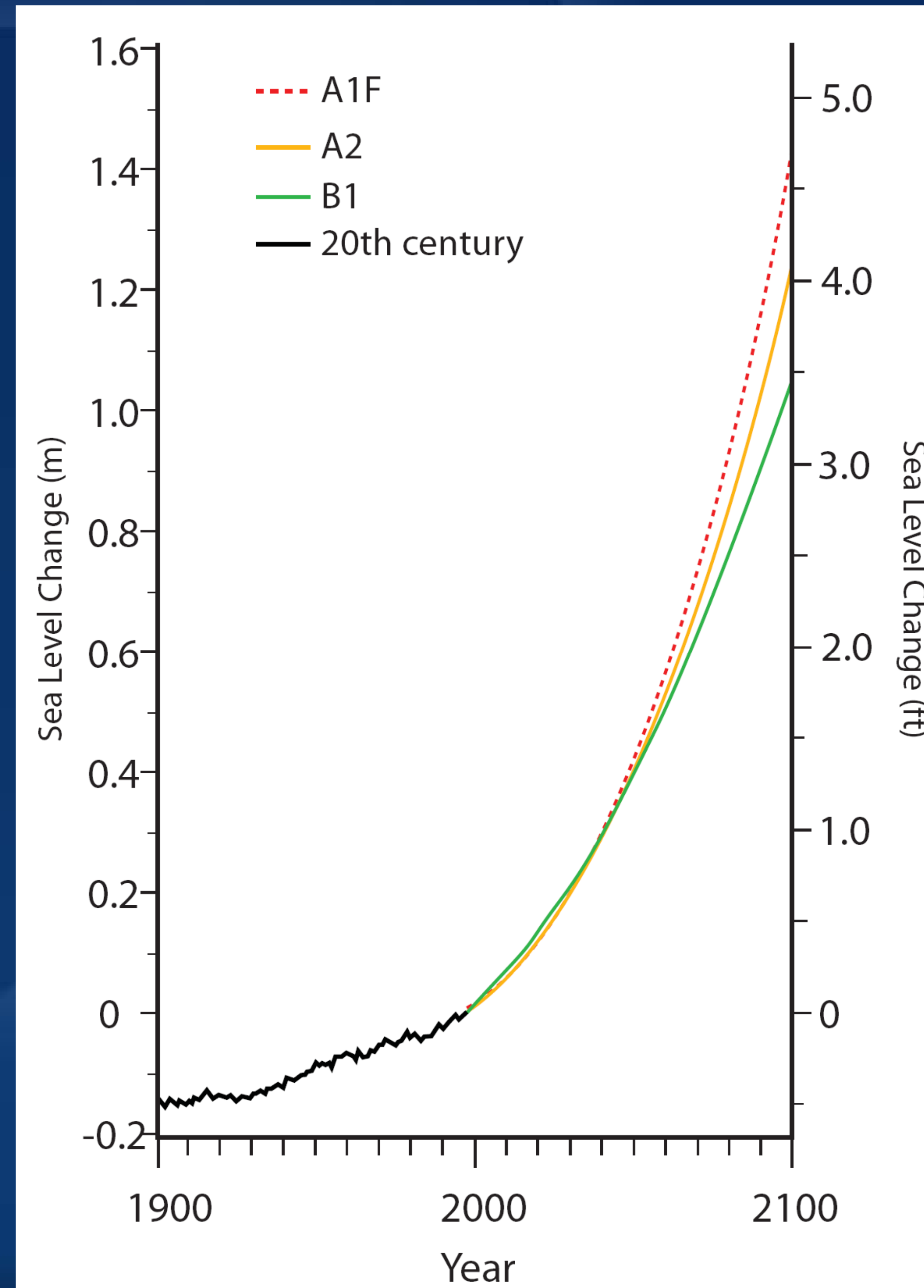
- **"Relatively" Rapid sea level rise: widespread shallow seas**



Temperature



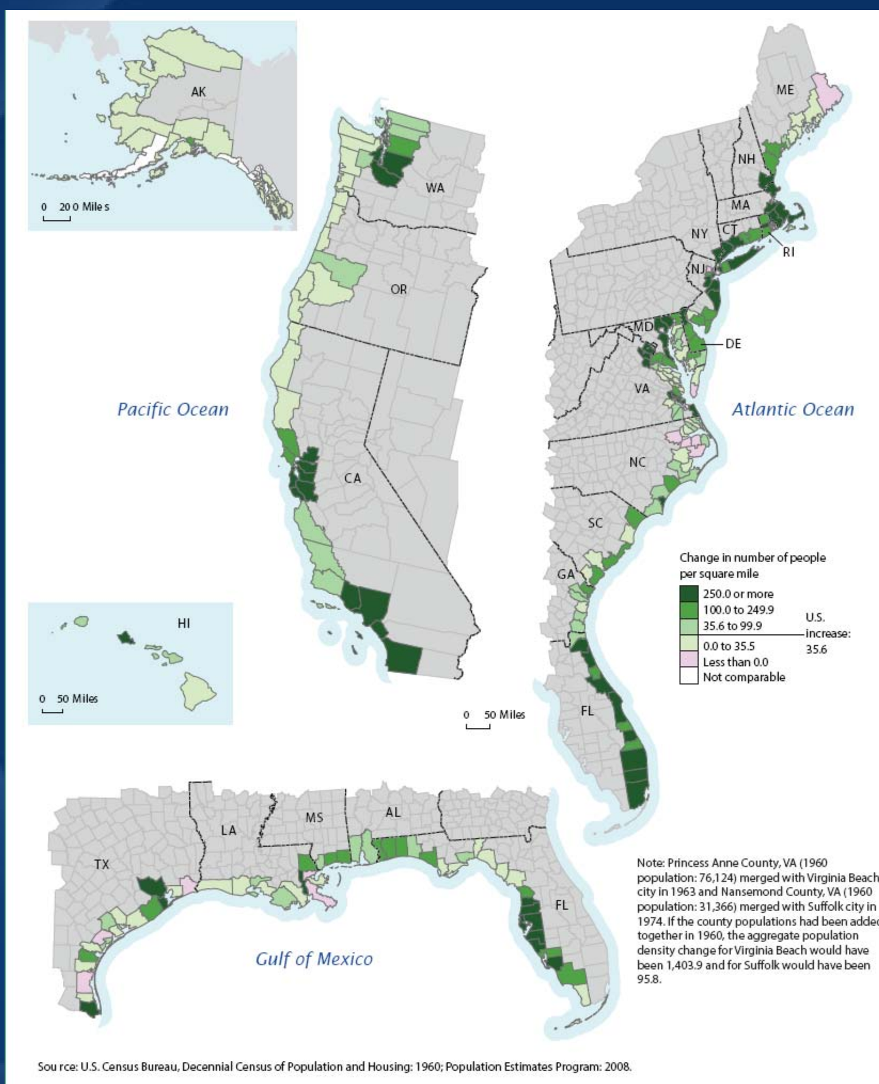
Sea Level



Coastal Population

- 123.3 million people (39%) of the US population lives in Coastal Shoreline Counties

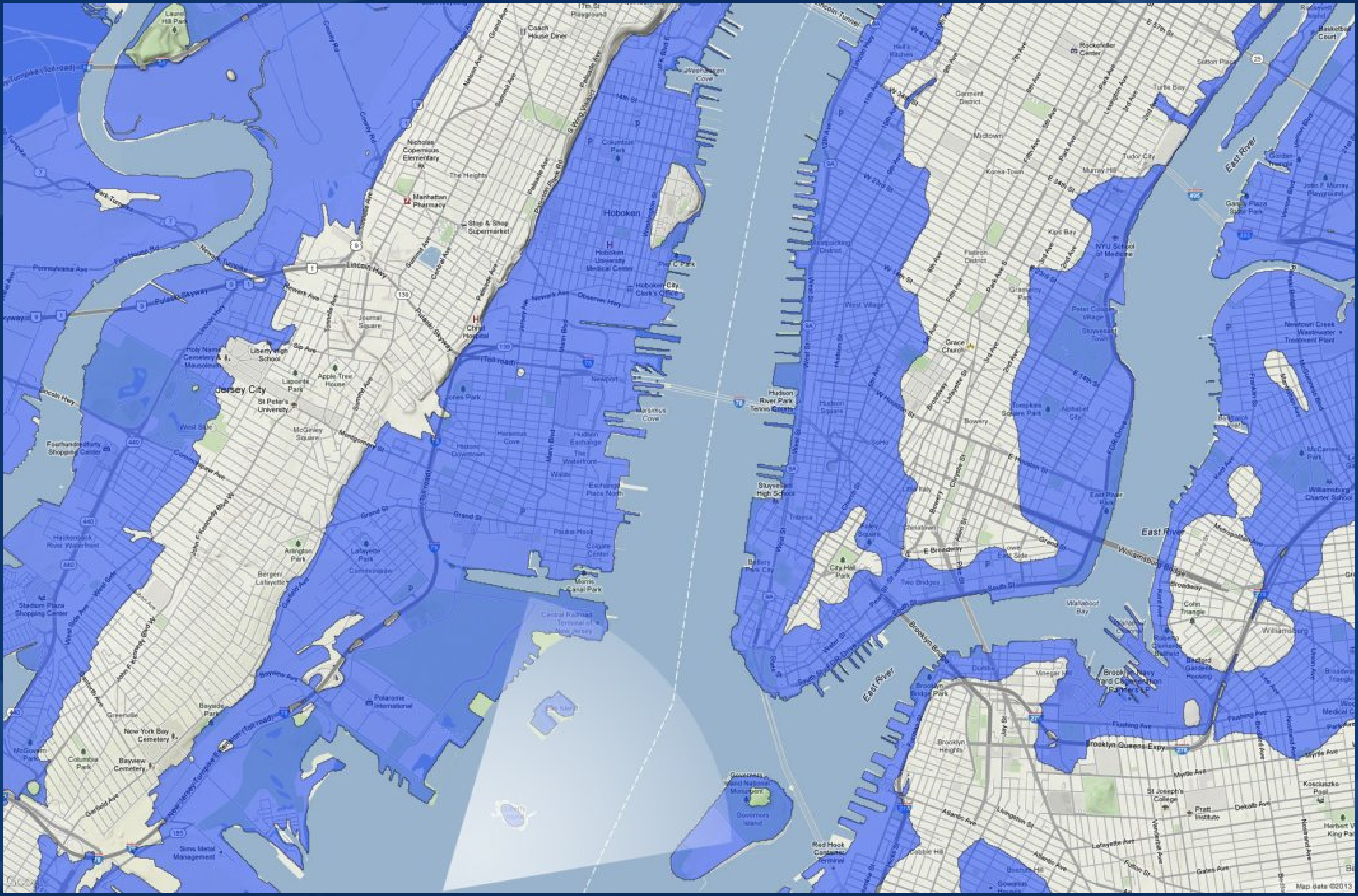
- As of 2010, ~2.9 billion people, >40% of the world lives within 100km (60mi) of the coast.



New York City with 5 foot sea level rise

New York City with 12 foot sea level rise

New York City with 25 foot sea level rise



Boston Harbor Today

Boston Harbor with
5 foot sea level rise

Boston Harbor with 12 foot sea level rise

Boston Harbor with 25 foot sea level rise

Back Bay, New York City Today

Back Bay, New York City with 5 foot sea level rise

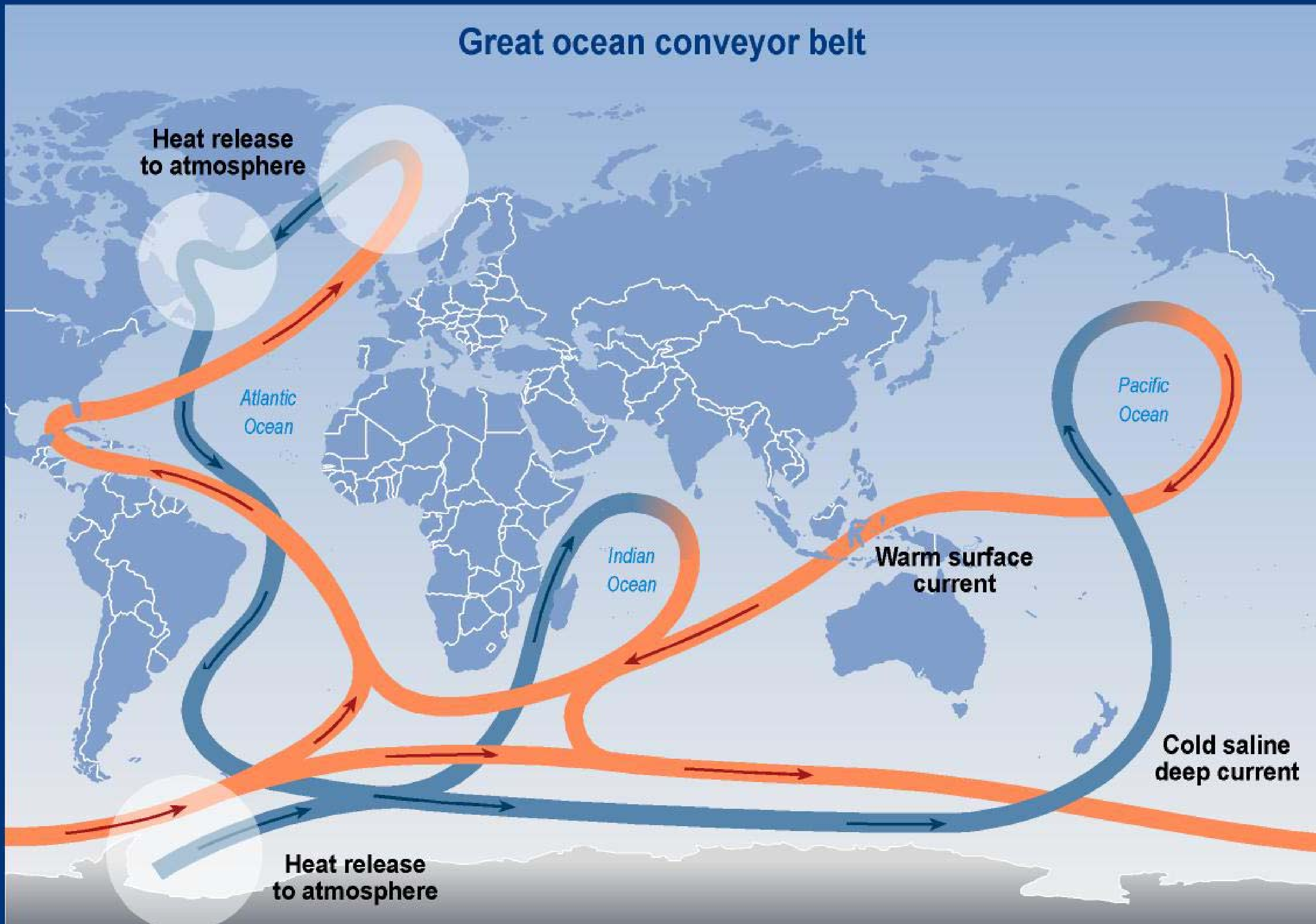
Back Bay, New York City with 12 foot sea level rise

Back Bay, New York City with 25 foot sea level rise

Harvard Campus with 12 foot sea level rise

Jefferson Memorial with 25 foot sea level rise

Thermo-haline Circulation



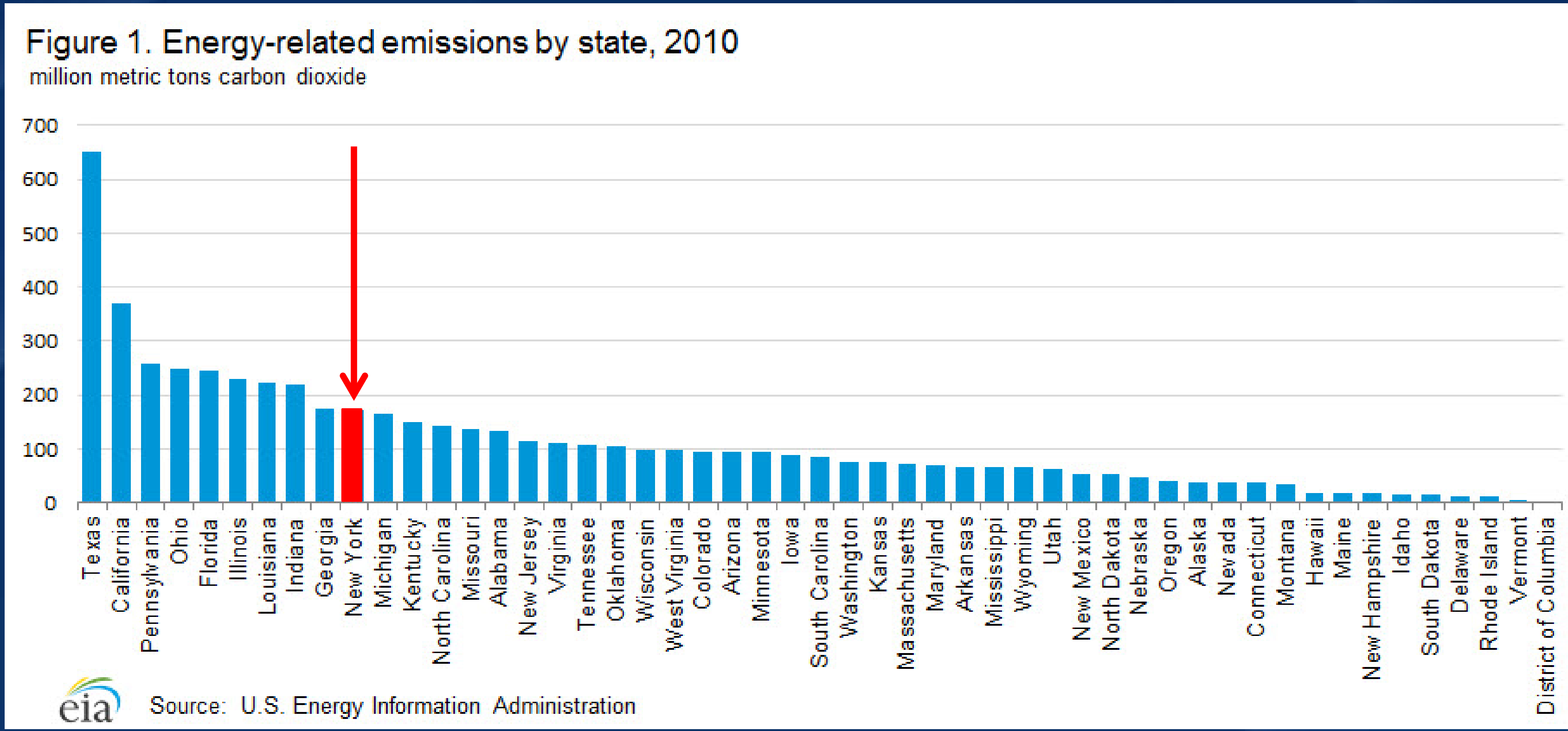


Figure 1. Energy-related emissions by state, 2010
million metric tons carbon dioxide
700
600
500
400
300
200
100
0
Texas
California
Pennsylvania
Ohio
Florida
Illinois
Louisiana
Indiana
Georgia
New York
Michigan
Kentucky
North Carolina
Missouri
Alabama
New Jersey
Virginia
Tennessee
Oklahoma
Wisconsin
West Virginia
Colorado
Arizona
Minnesota
Iowa
South Carolina
Washington
Kansas
Massachusetts
Maryland
Arkansas
Mississippi
Wyoming
Utah
New Mexico
North Dakota
Nebraska
Oregon
Alaska
Nevada
Connecticut
Montana
Hawaii
Maine
New Hampshire
Idaho
South Dakota
Delaware
Rhode Island
Vermont
District of Columbia
eia
Source: U.S. Energy Information Administration

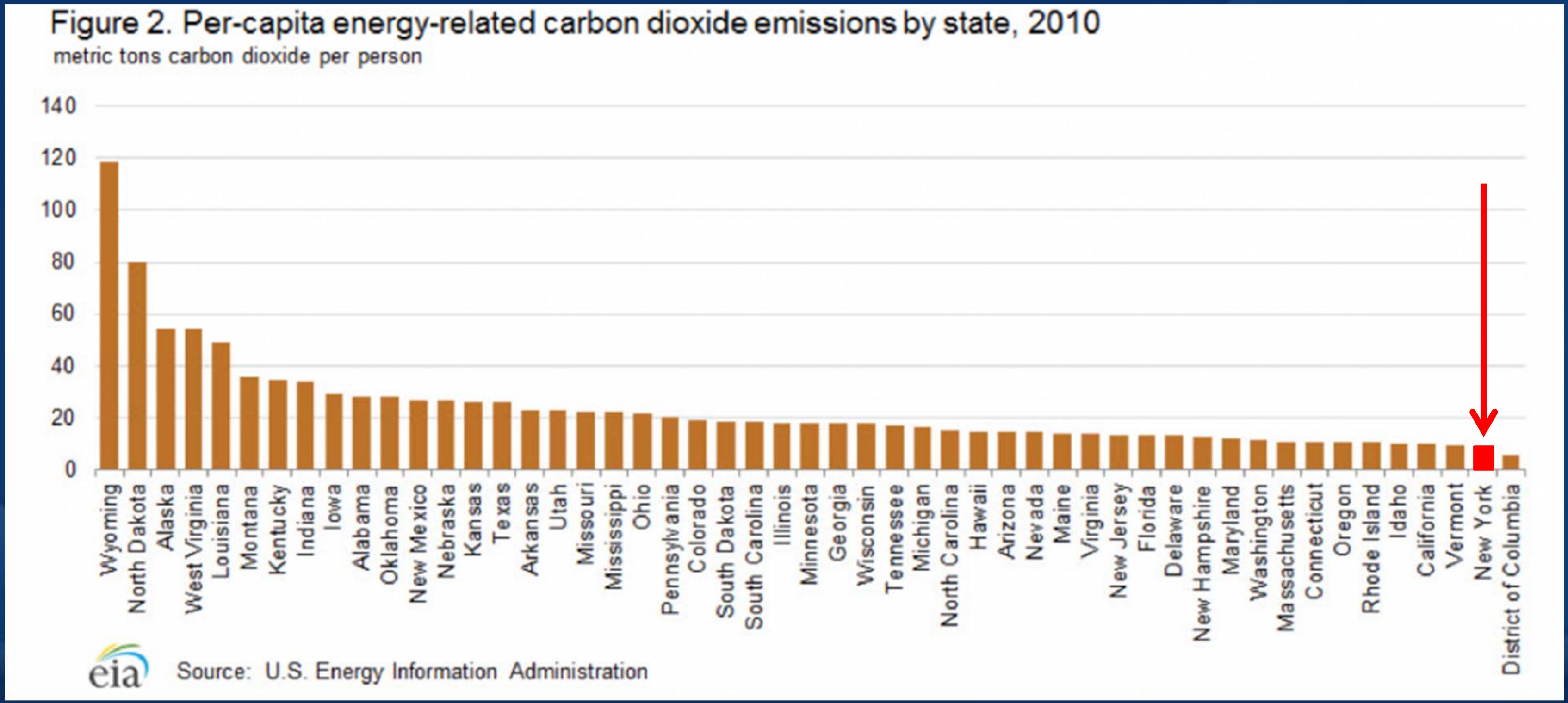
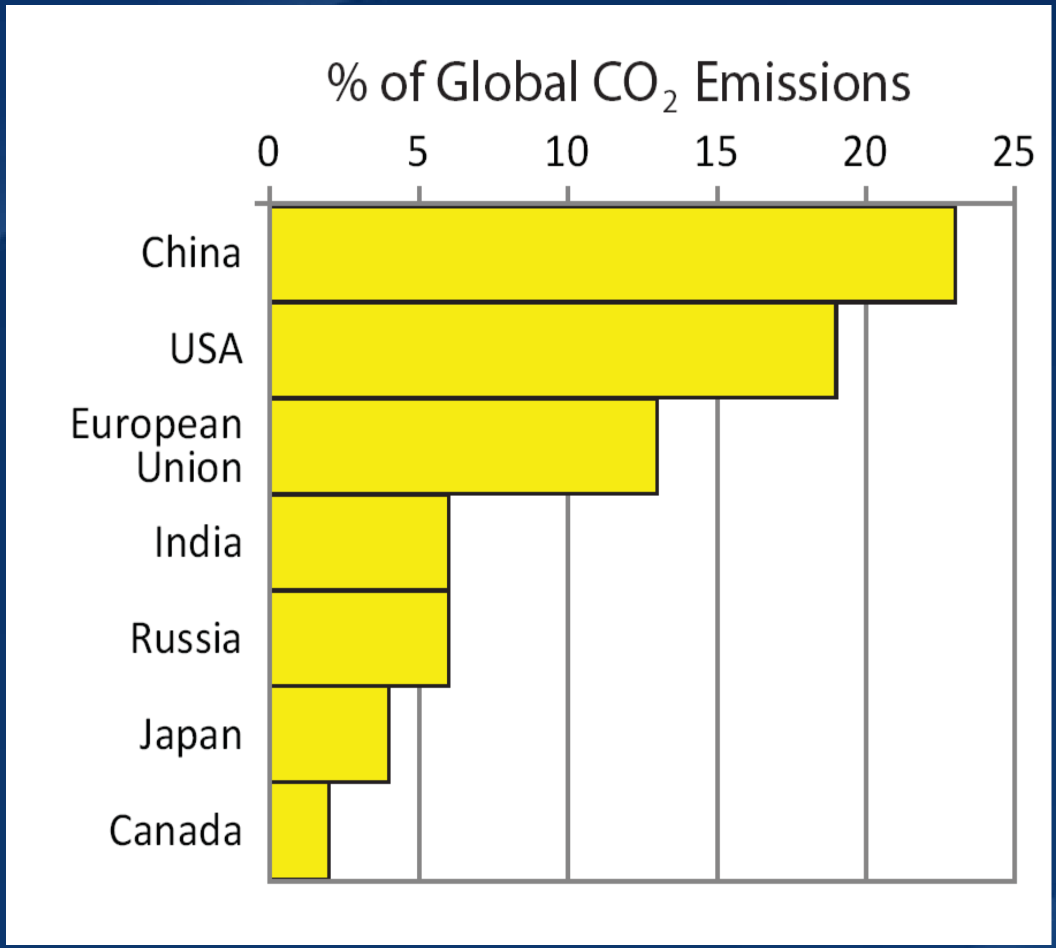
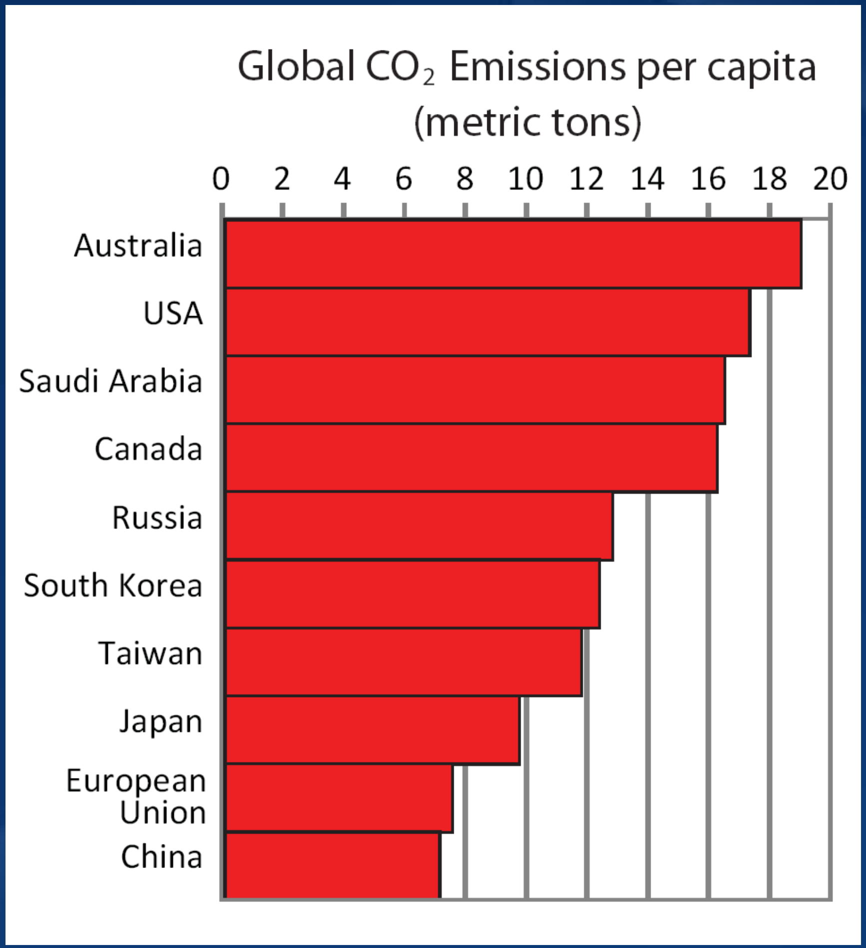


Figure 2. Per-capita energy-related carbon dioxide emissions by state, 2010
metric tons carbon dioxide per person
140
120
100
80
60
40
20
0
Wyoming
North Dakota
Alaska
West Virginia
Louisiana
Montana
Kentucky
Indiana
Iowa
Alabama
Oklahoma
New Mexico
Nebraska
Kansas
Texas
Arkansas
Utah
Missouri
Mississippi
Ohio
Pennsylvania
Colorado
South Dakota
South Carolina
Illinois
Minnesota
Georgia
Wisconsin
Tennessee
Michigan
North Carolina
Hawaii
Arizona
Nevada
Maine
Virginia
New Jersey
Florida
Delaware
New Hampshire
Maryland
Washington
Massachusetts
Connecticut
Oregon
Rhode Island
Idaho
California
Vermont
New York
District of Columbia
eia
Source: U.S. Energy Information Administration

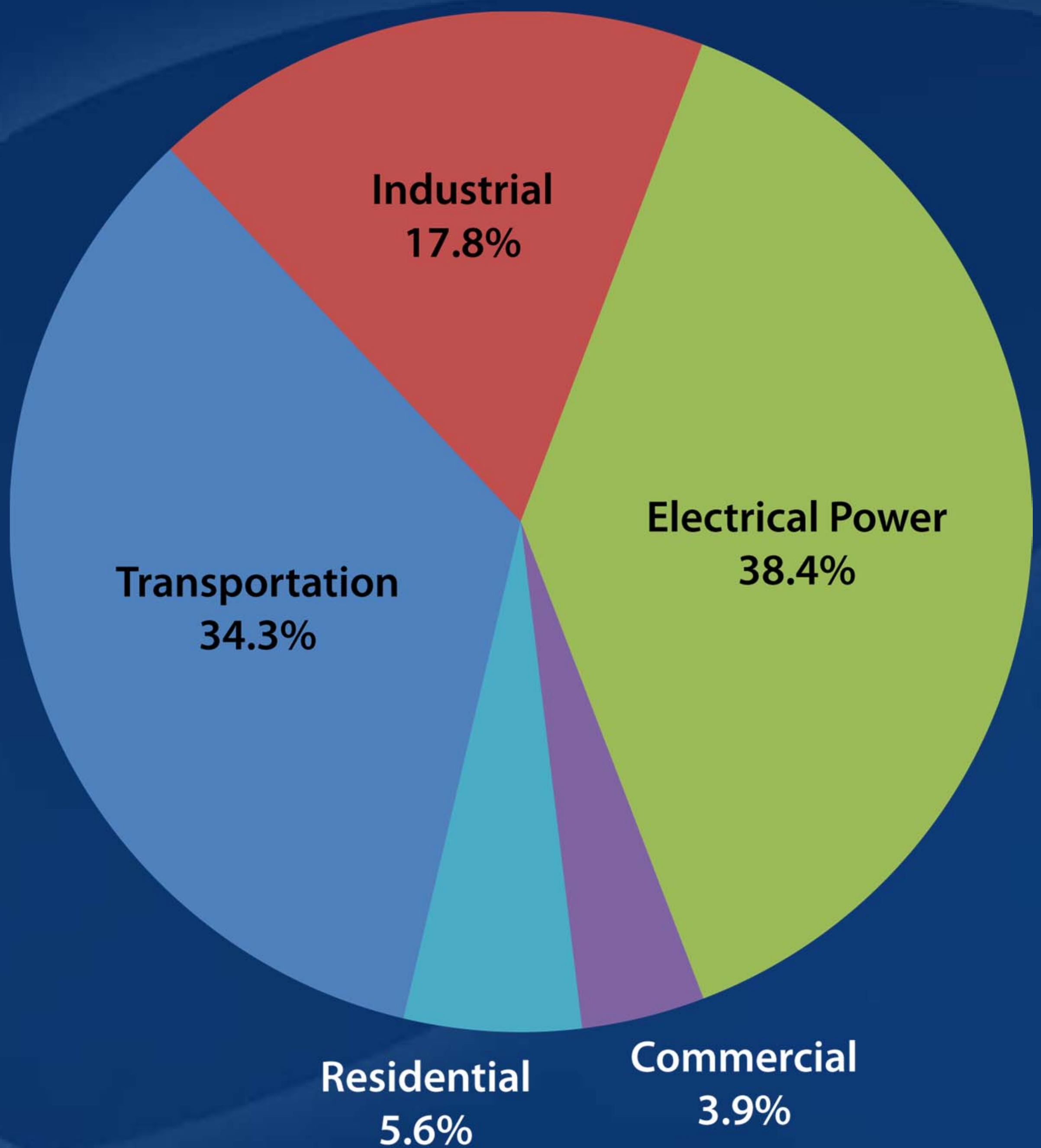
US 2012 CO_2 Emissions





Source: Energy Information Administration

US 2012 CO_2 Emissions



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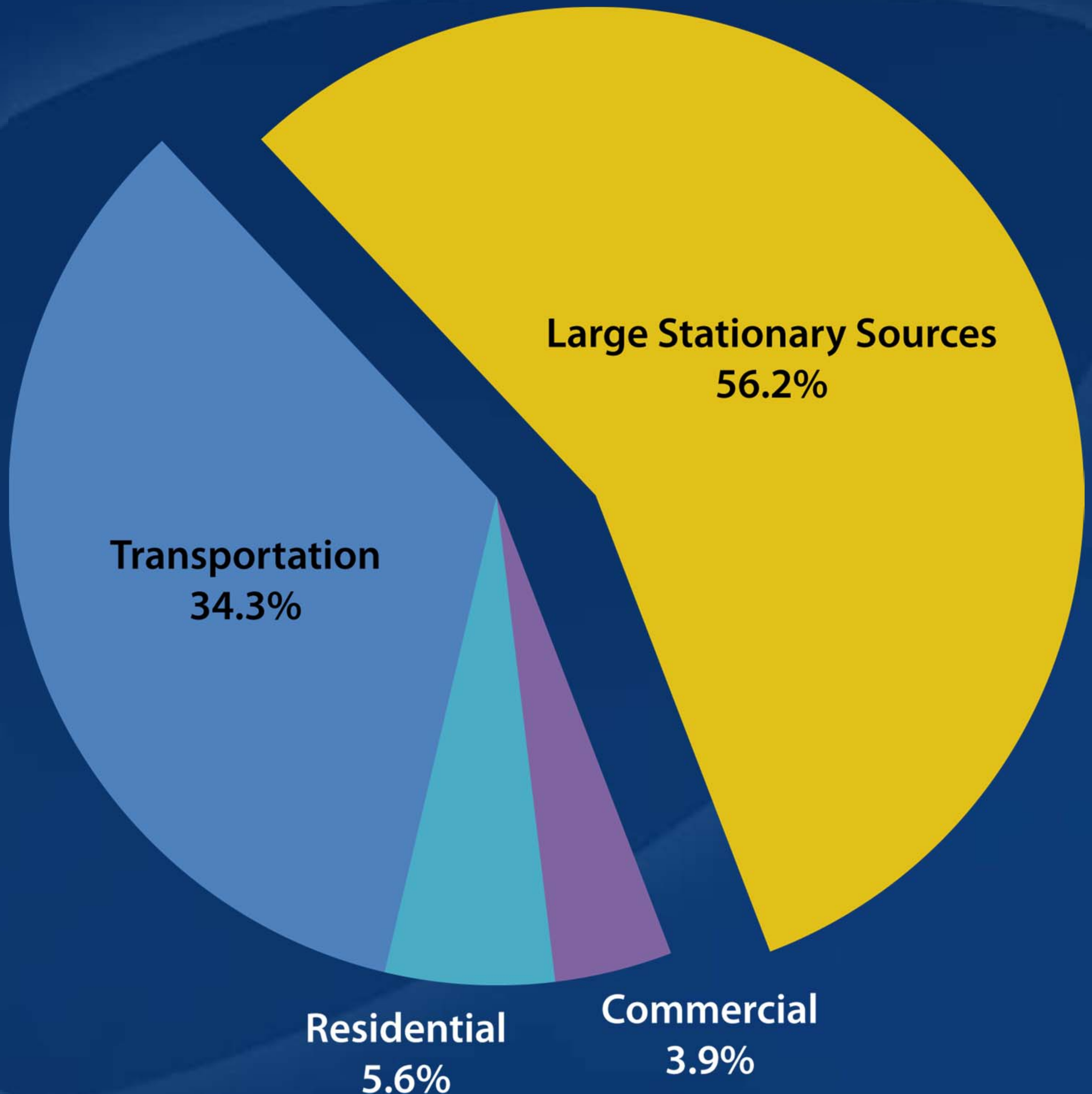
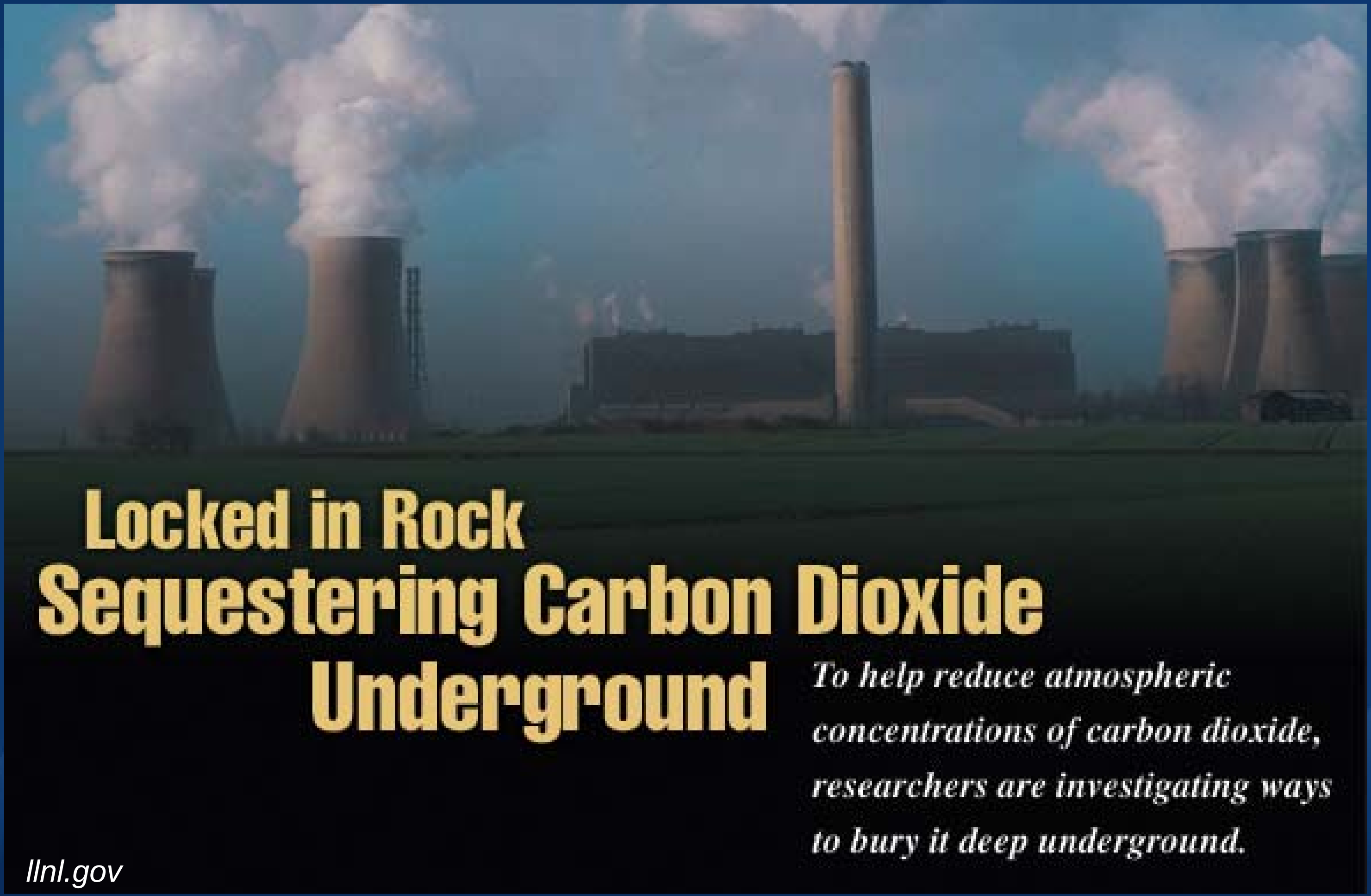


Source: Energy Information Administration

Geologic Carbon Sequestration aka Carbon Capture & Storage (CCS)

The use of porous and permeable rock formations to store carbon dioxide that would otherwise be emitted into the atmosphere.

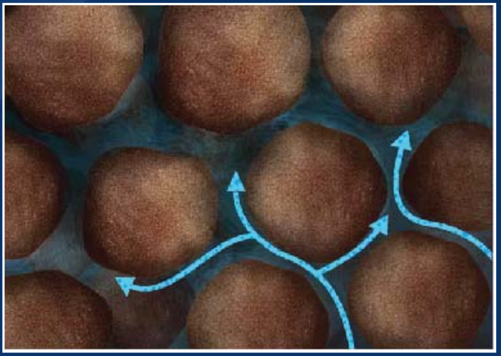
geoart.com



llnl.gov

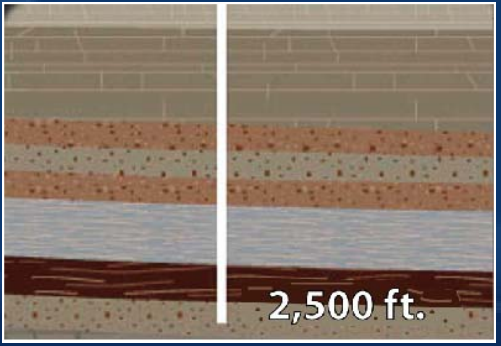
Reservoir Characteristics

Porosity - CO_2 is stored in the pore space between the grains of a given rock unit.



Permeability – the pores of a sequestration reservoir must be interconnected so that CO_2 can flow away from the injection point.

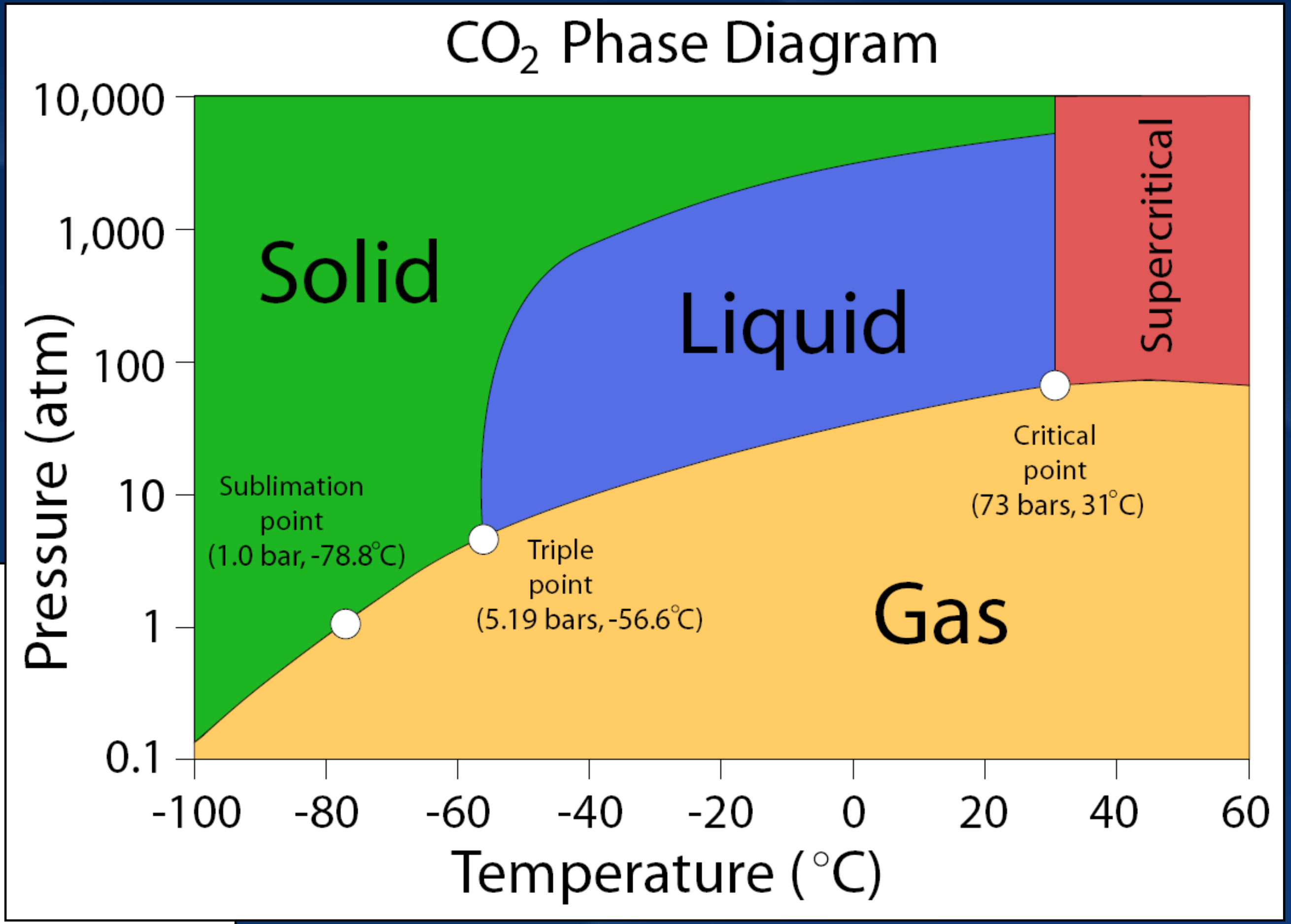
Cap Rock – There must be one or more confining layers (impermeable rock) overlying the reservoir to prevent upward leakage.

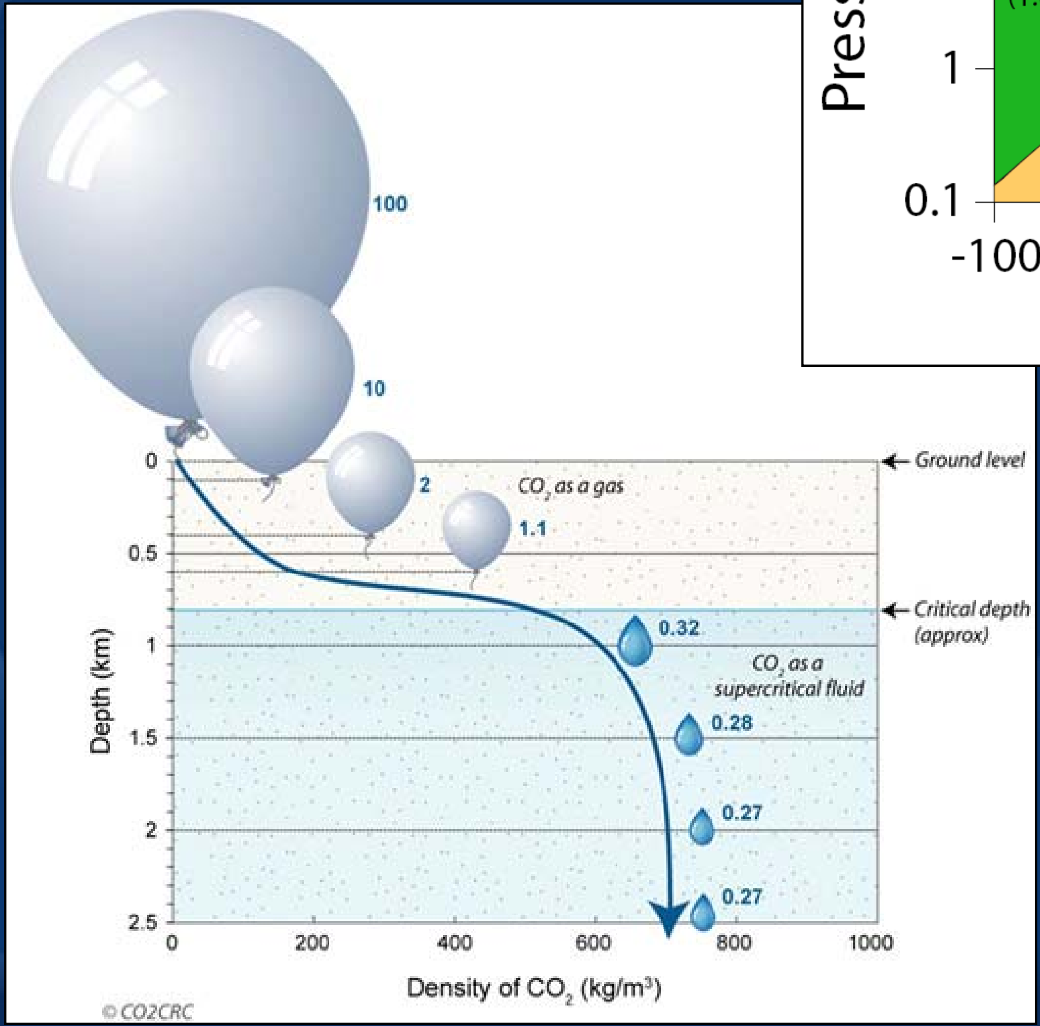


Depth – Deeper formations have higher temperatures and pressures which allow CO_2 sequestered as a supercritical fluid thereby allowing more to be stored.

Supercritical CO_2

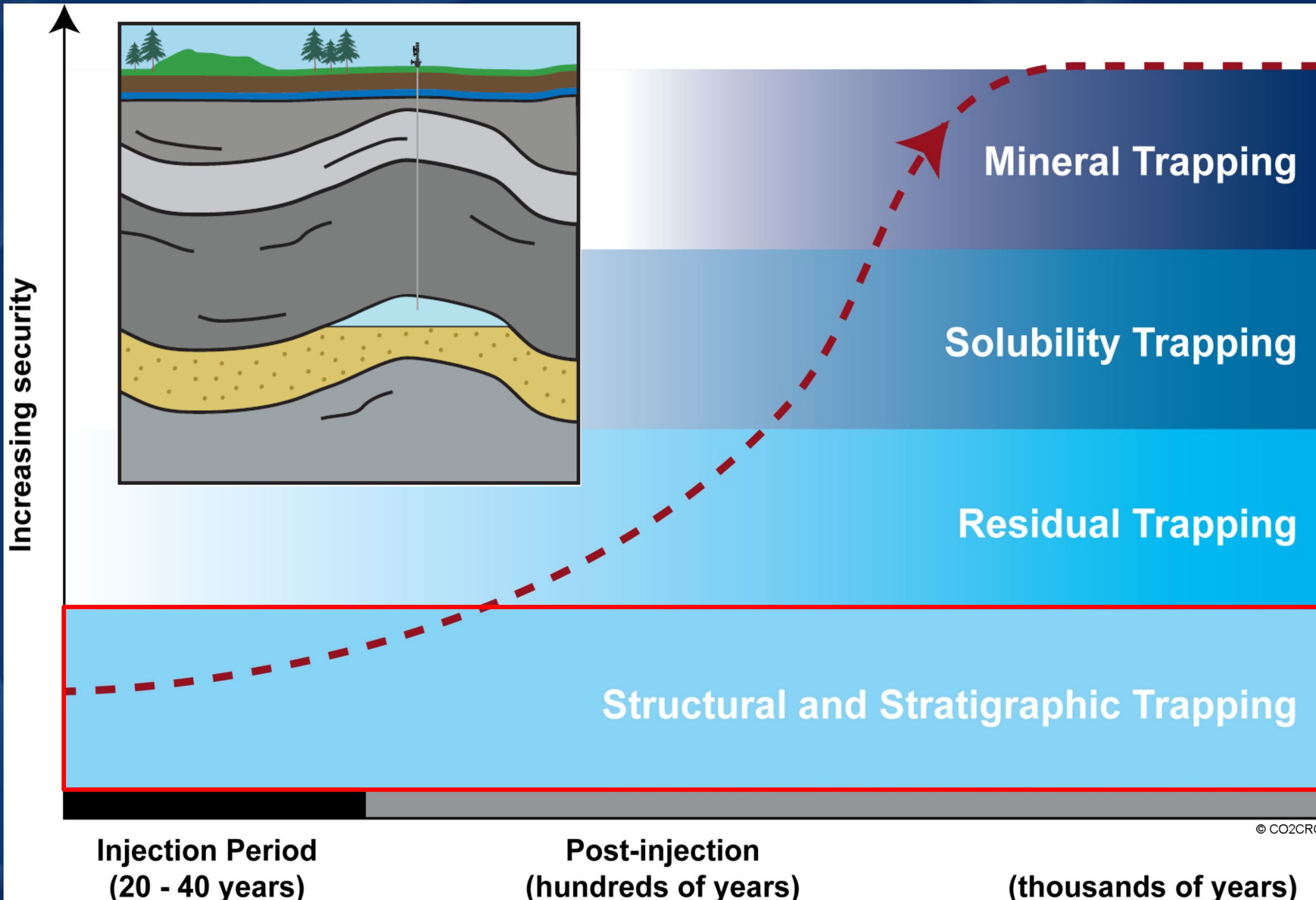
At 31°C and 73 bars, CO_2 is stable in a supercritical state.





Supercritical CO_2 is over 300 times more dense than gaseous CO_2 at the surface.

Phases of CO_2 Trapping



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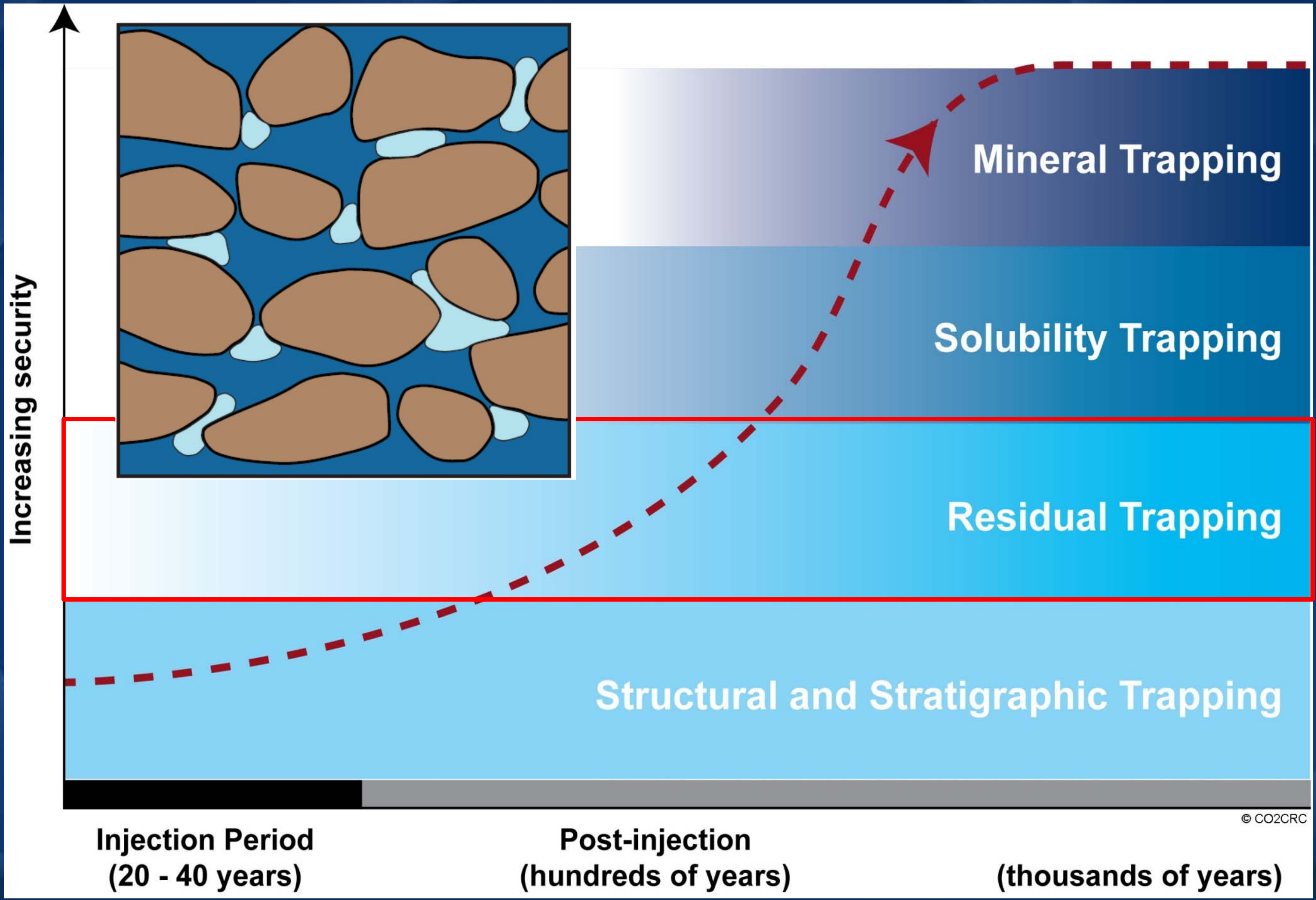

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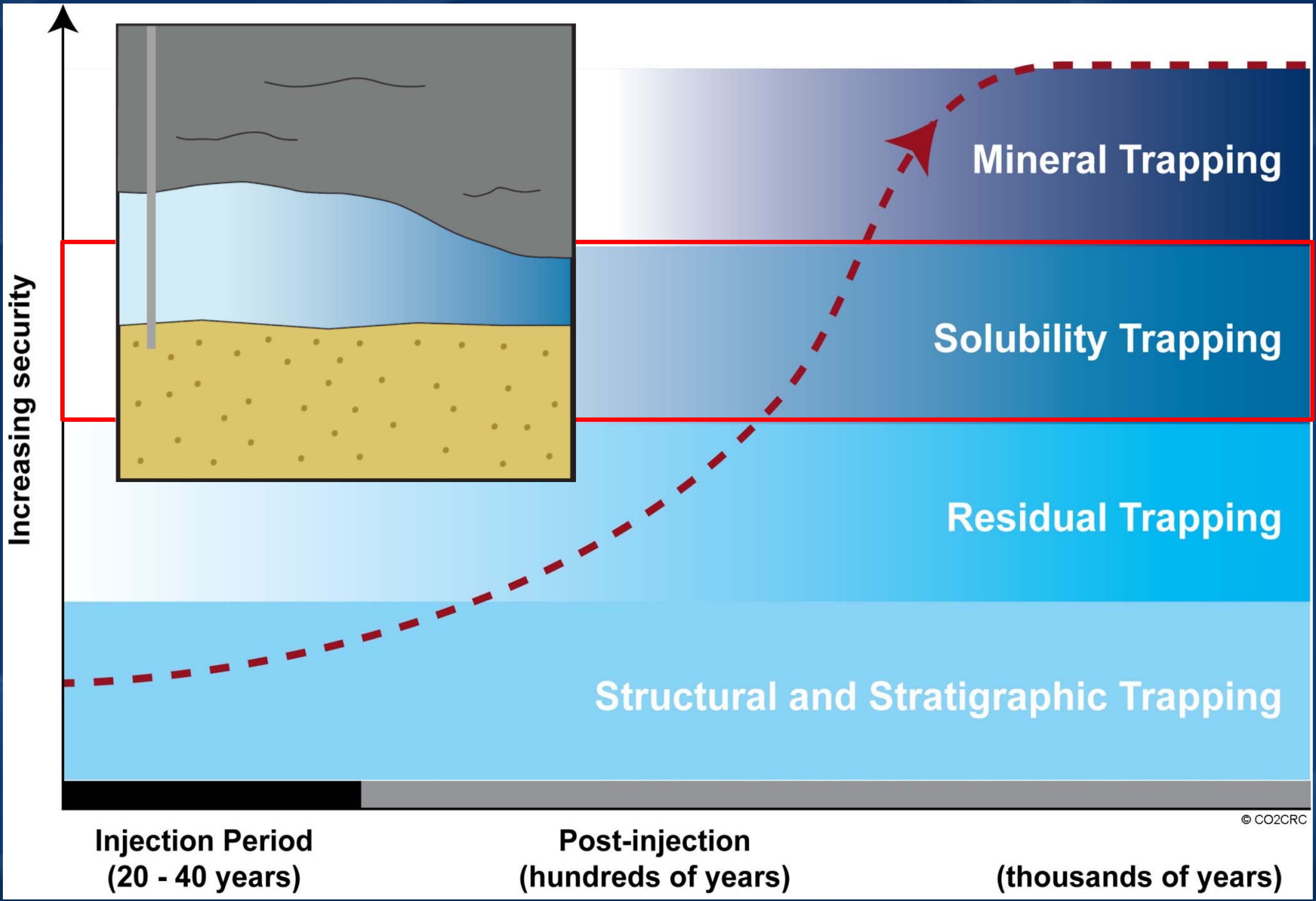

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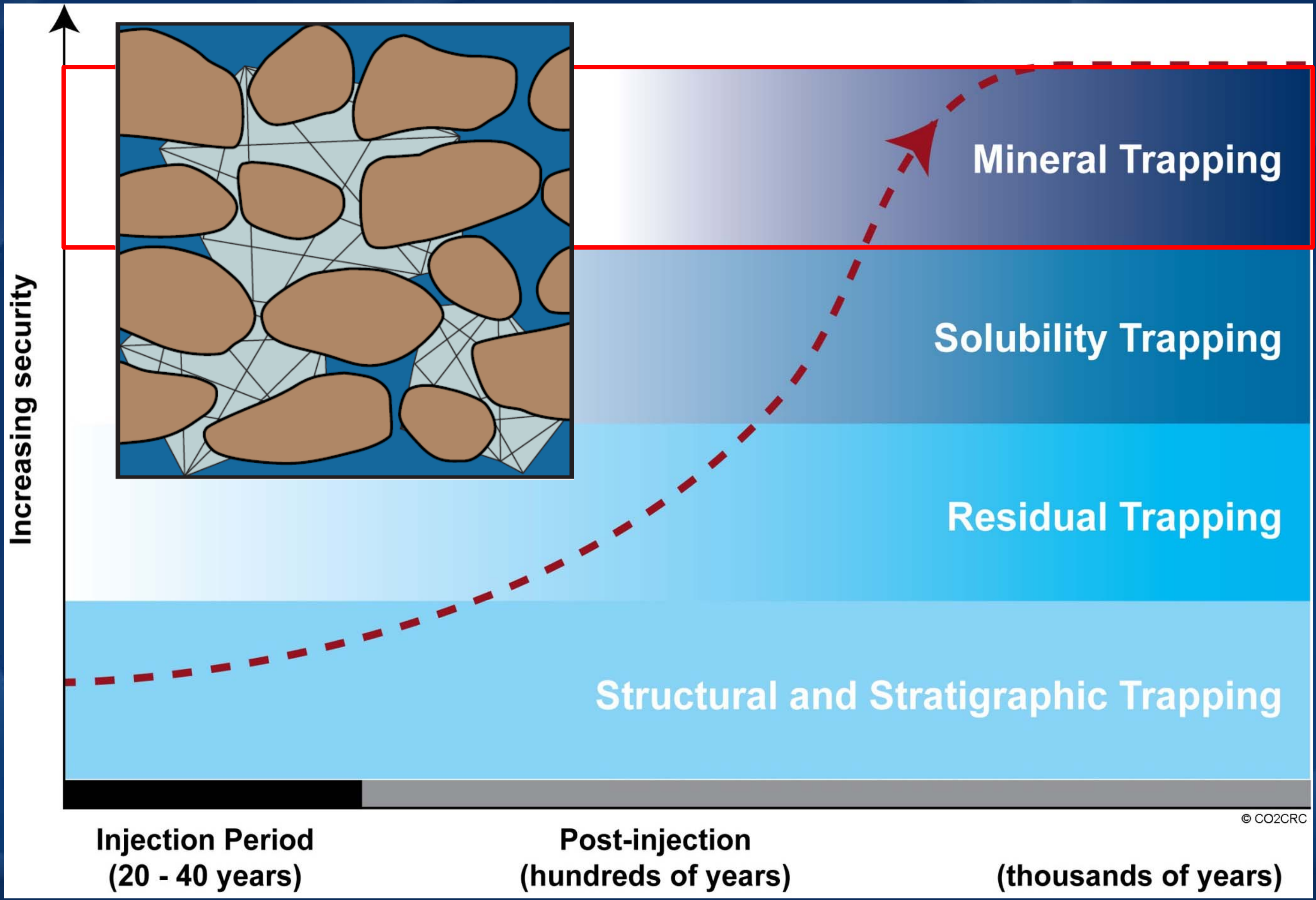
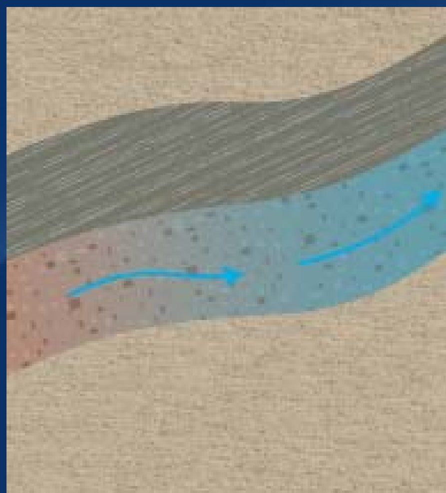
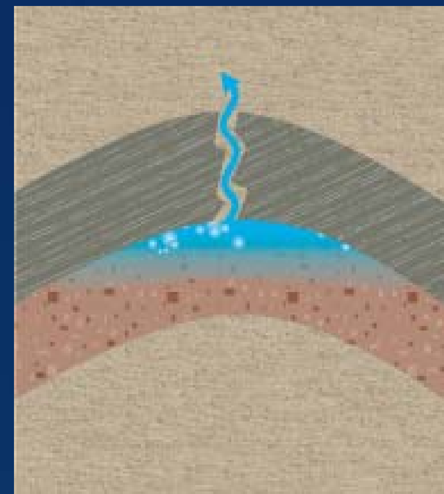


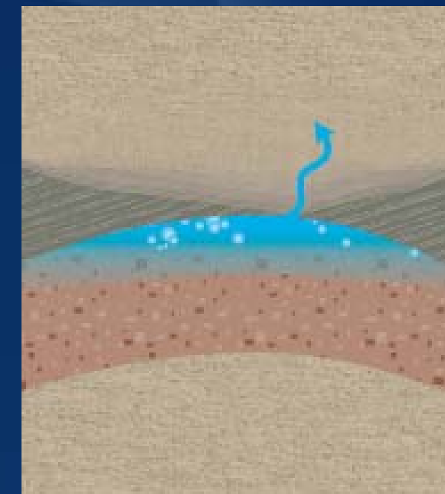
Possible Leakage



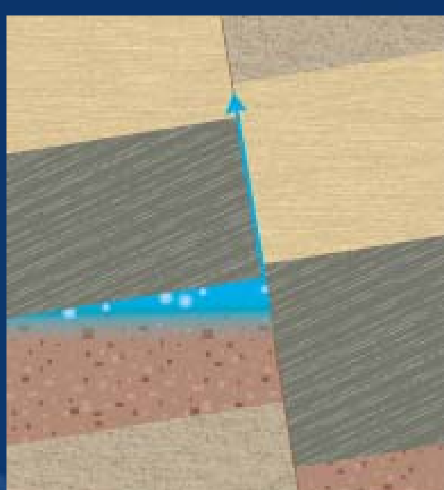
CO_2 migrates up dip to shallower depths



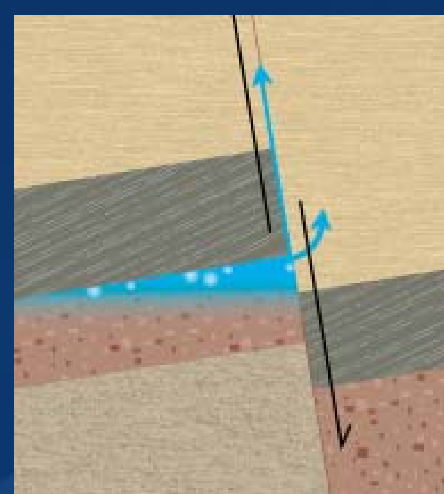
CO_2 pressure fractures the seal



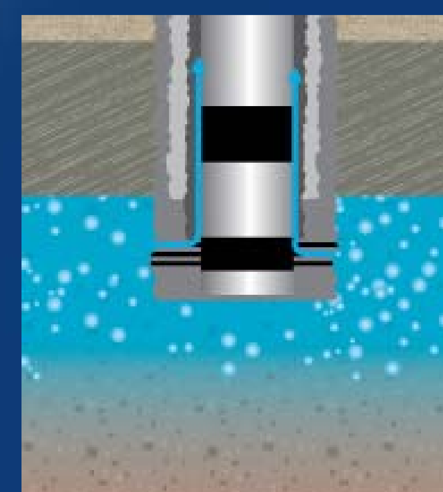
CO_2 escapes through a gap in the seal



CO_2 migrates up an open fault



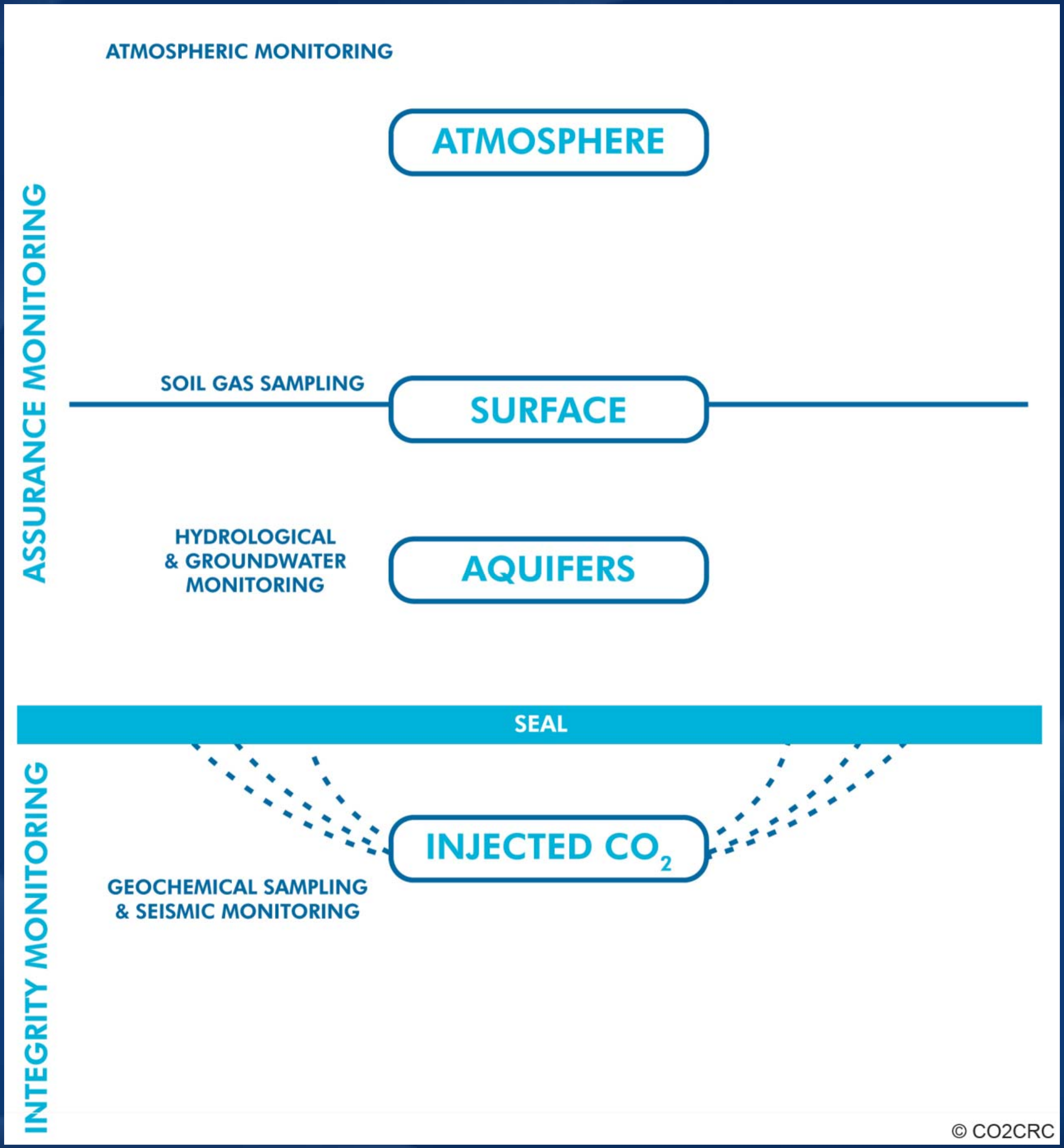
CO_2 pressure opens a fault or pathway



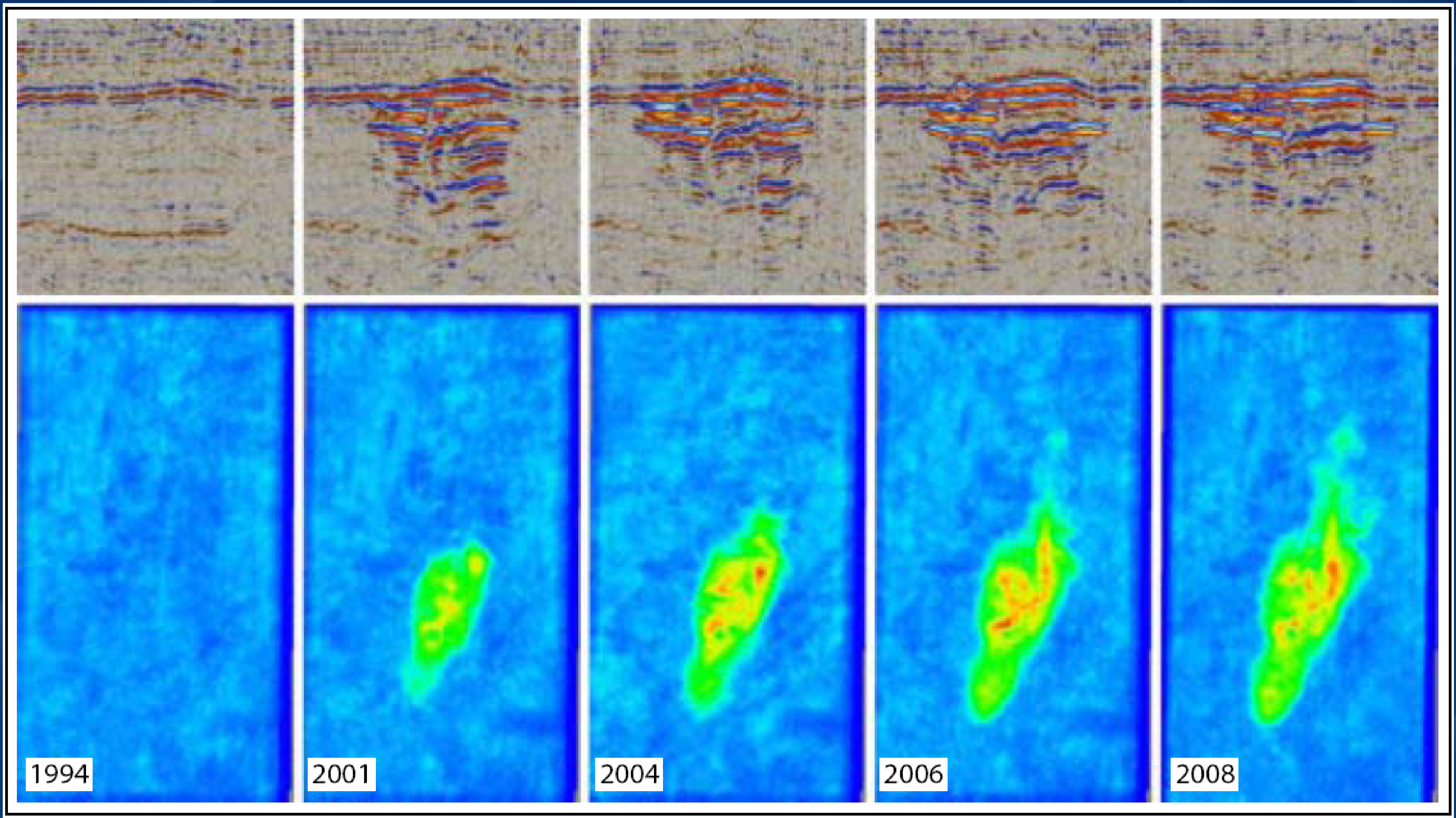
CO_2 escapes via a poorly abandoned well

CO2CRC

Leakage Detection



Seismic Monitoring of Injected CO_2



Worst Case Scenario

Lake Nyos: Camaroon, West Africa

- Deep crater lake on the flank of an inactive volcano
- Pocket of magma beneath the lake leaks CO_2 in the water
- August 21, 1986, a nearby landslide caused the lake to suddenly emit a large cloud of CO_2
- Because CO_2 is more dense than air, the cloud flowed down the hillside and into a town where it suffocated 1,700 people and 3,500 livestock

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Scientists at the University of Edinburgh, UK, collected data from 286 naturally occurring CO_2 seeps across Italy and Sicily. They then calculated the risk of death from CO_2 poisoning for the 20 million people living near those sites. All the seeps were associated with natural underground CO_2 reservoirs, volcanoes or aquifers that were leaking between 10 and 100 tons of CO_2 per day.

They found that in the last two decades 11 people died at the seeps, making the risk of death around 2.8×10^{-8} or 1 in 36 million. By comparison, the risk of being struck by lightning is around 1 in 43,000. 'It was a surprise to us,' said Roberts. 'We weren't really expecting to find values that were quite so low.'

What's more, their estimate represents a worst case scenario. Although CO_2 might leak in a similar way from a CCS site, models suggest the leakage rate would be lower than from natural stores. Perhaps more importantly, CCS sites would be subject to scrupulous monitoring, unlike the Italian sites. 'You'd be able to predict a leakage well before the CO_2 got to the surface," – ***Hayley Birch***

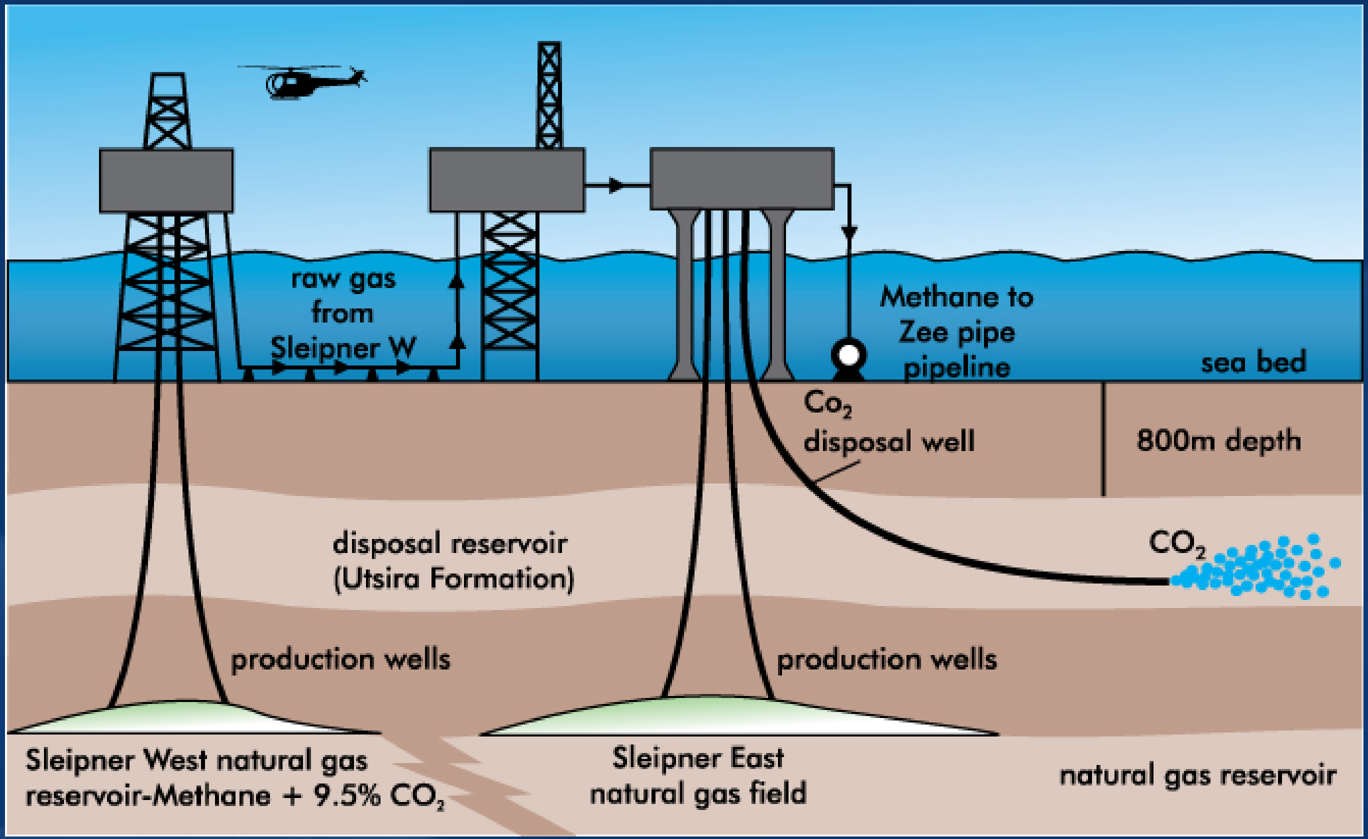
Current Carbon Sequestration Projects Around the World

Current Carbon Sequestration Projects Around the World

From CO2CRC

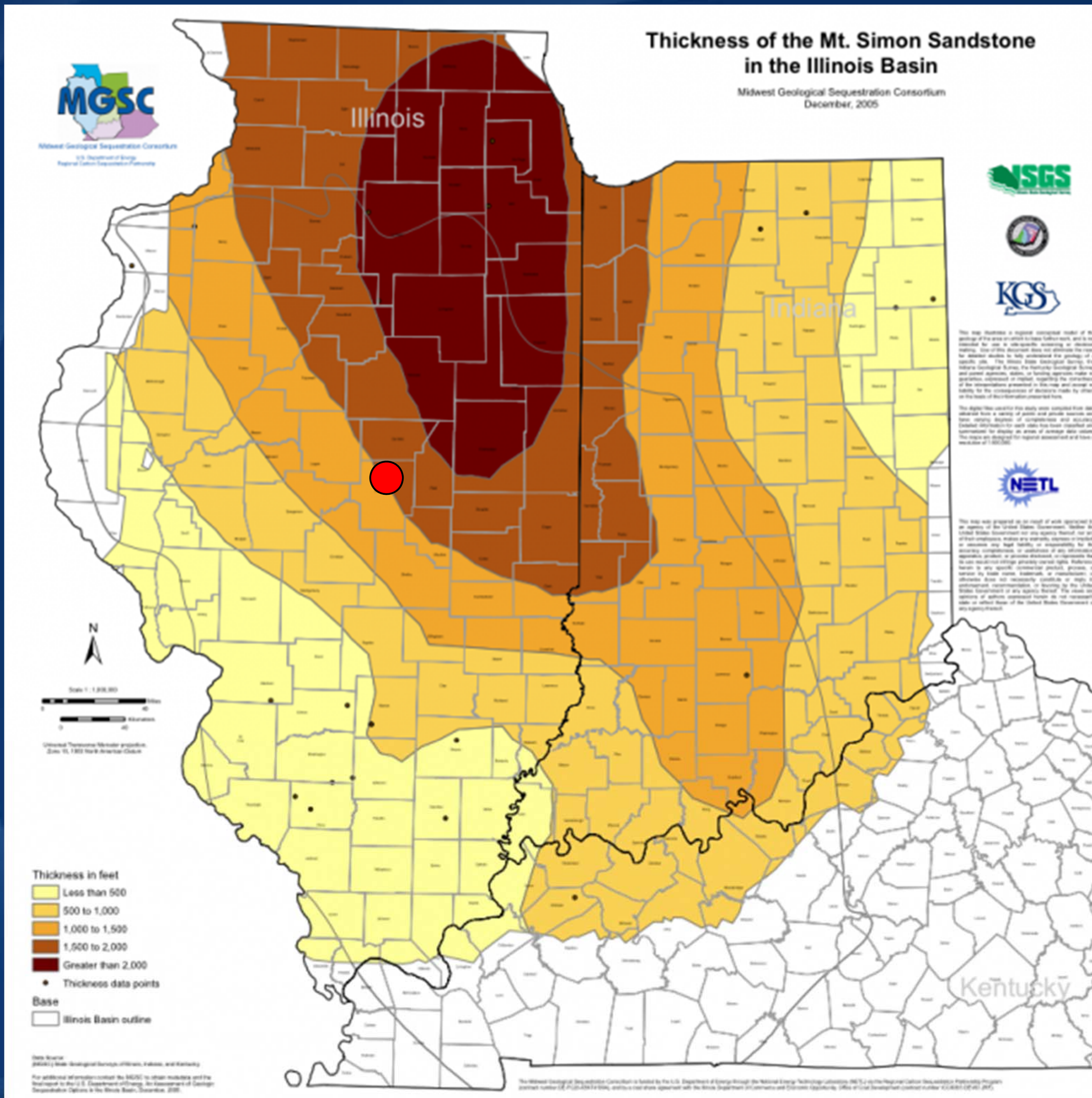
Sleipner Oil & Gas Field

- 250 km west of Norway
- owned and operated by Statoil
- started producing in 1974, CCS since 1996
- produces from the Heimdal Sandstone Formation (8200')



- ~300Mbbl of oil / day
- 36MMCF of gas / day
- 9.5% CO_2 (1 million tons / yr)
- Sequester the CO_2 in the Utsira Sandstone Formation (~2600')
- Statoil would have to pay $1 million / day in Norwegian taxes if they vented the CO_2 into the atmosphere
- Injection is saved Statoil over $6 billion over the last 18 years

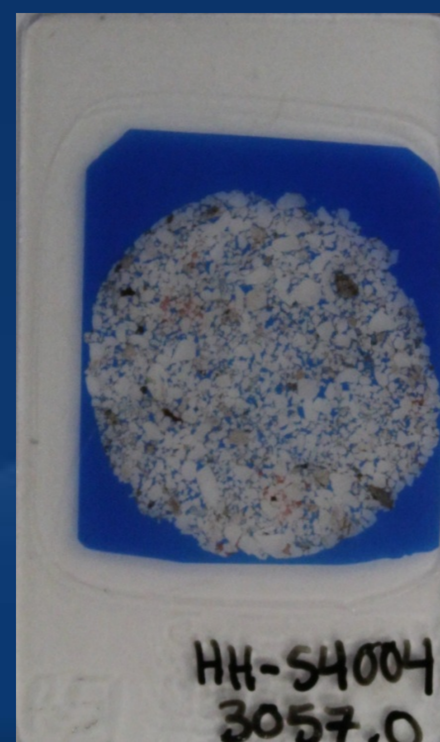
Illinois Basin – Decatur Project

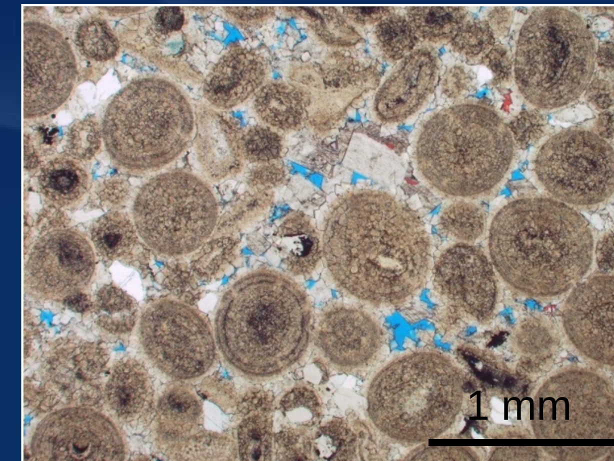


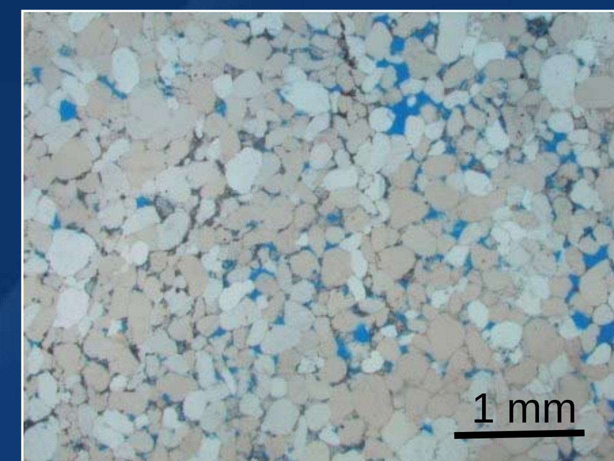
- Test project with the goal of storing 1 million tons of CO_2
- Partially funded by the Department of Energy with matching funds from private industry
- Target reservoir is Mt. Simon Sandstone which is 1,000 to 2,000 feet thick and over 6000' deep in central Illinois
- Sequester the CO_2 from the nearby ADM ethanol fermentation plant at a rate of 1,000 tons / day
- Injection began in November 2011 and had successfully sequestered over 500,000 by August 2013

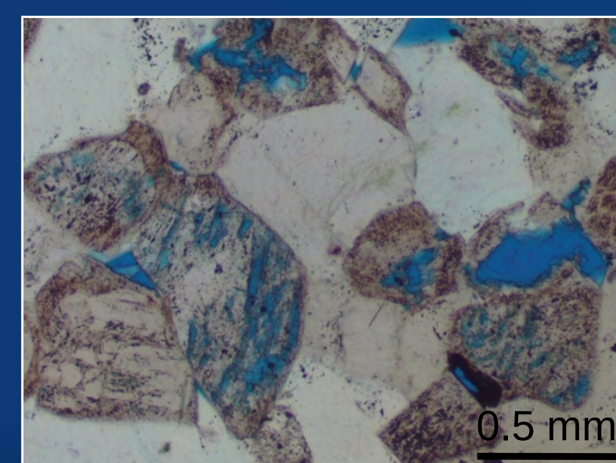
Rock Samples: Core and Cuttings

Rock Samples: Thin Sections

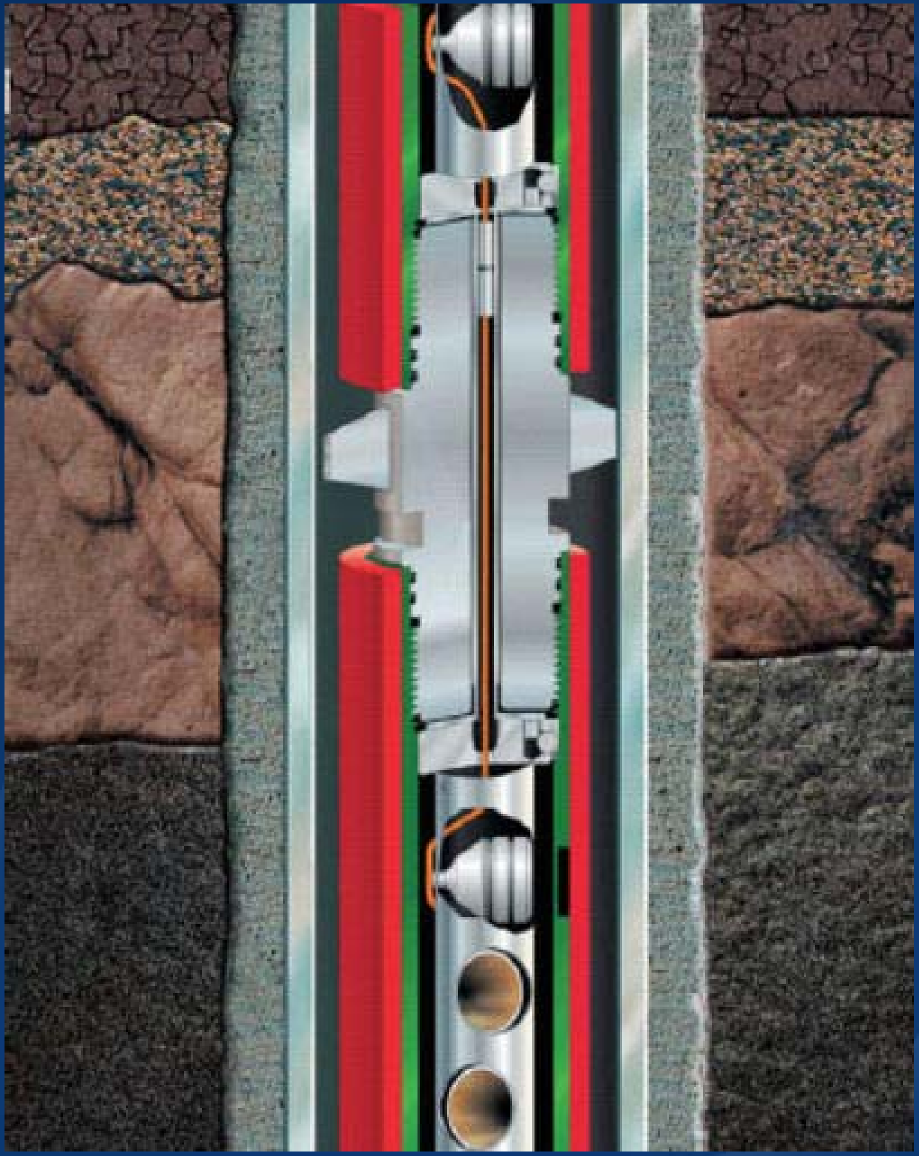


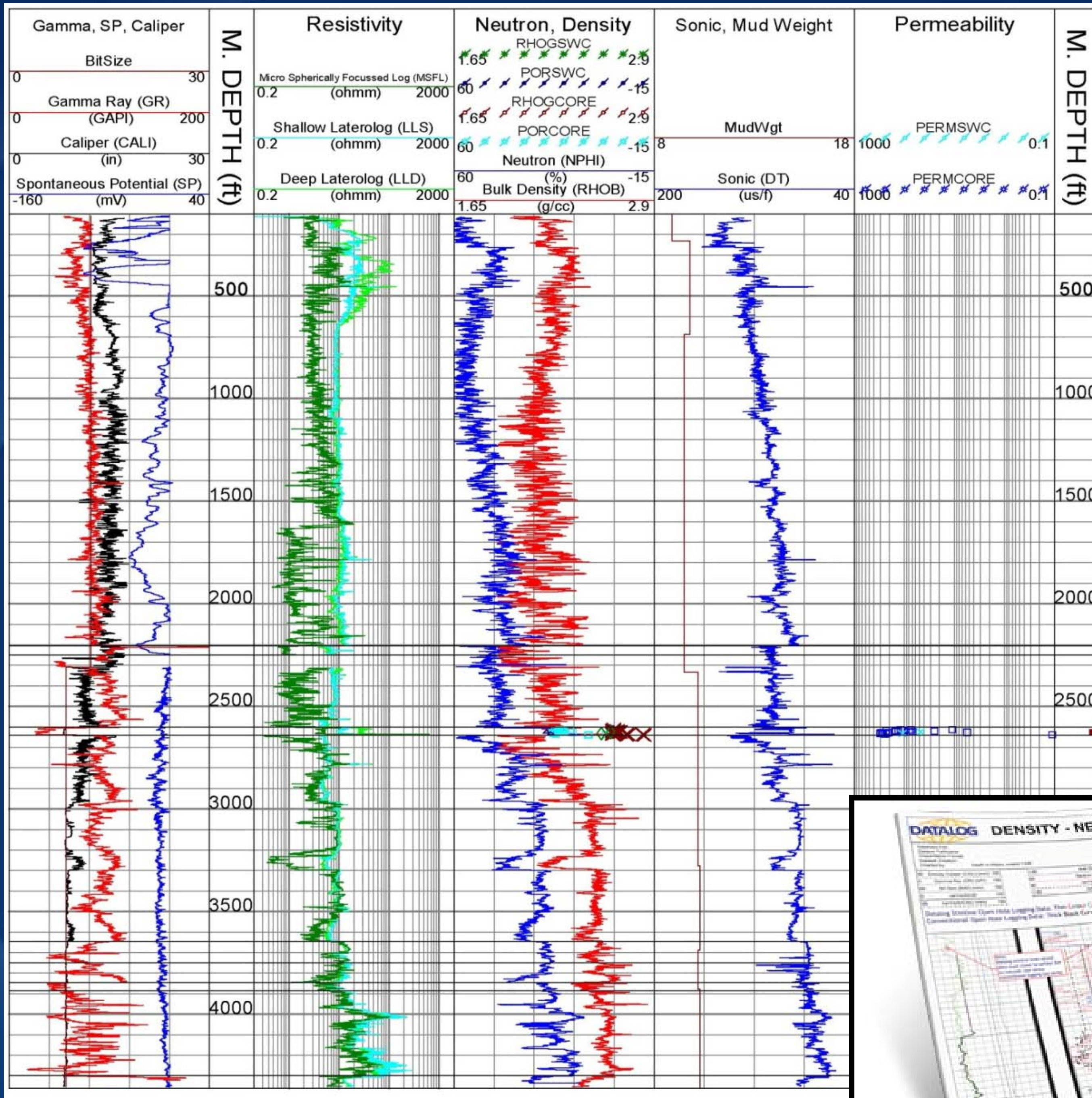


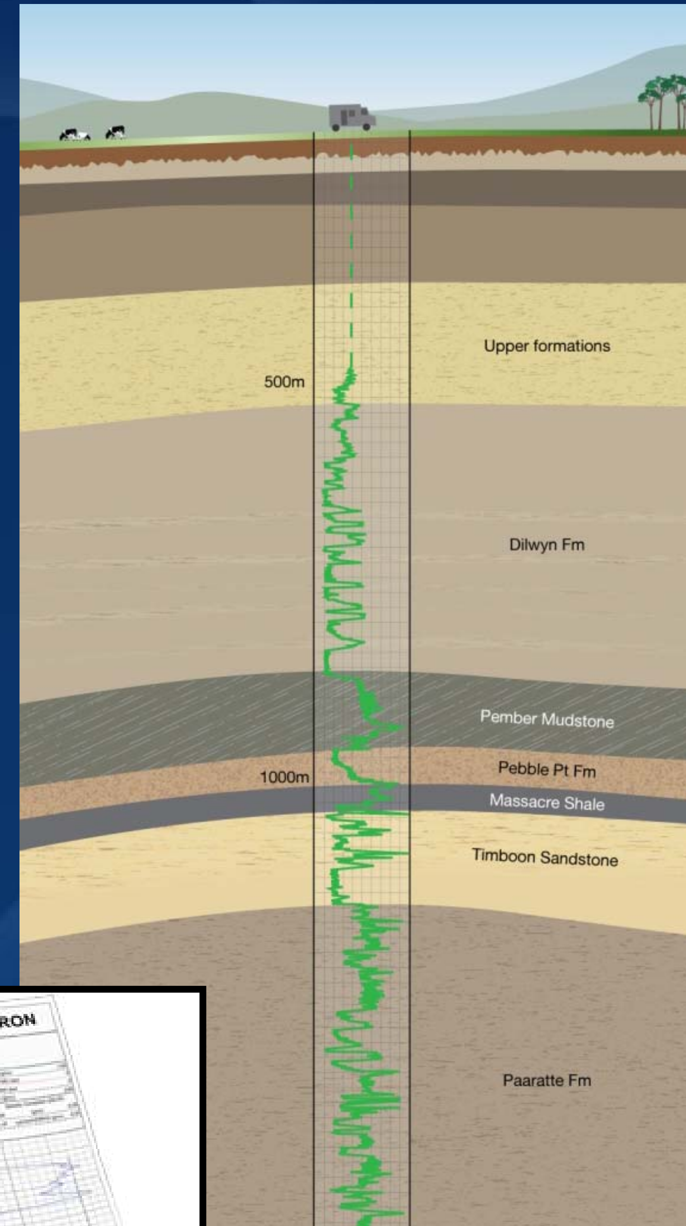


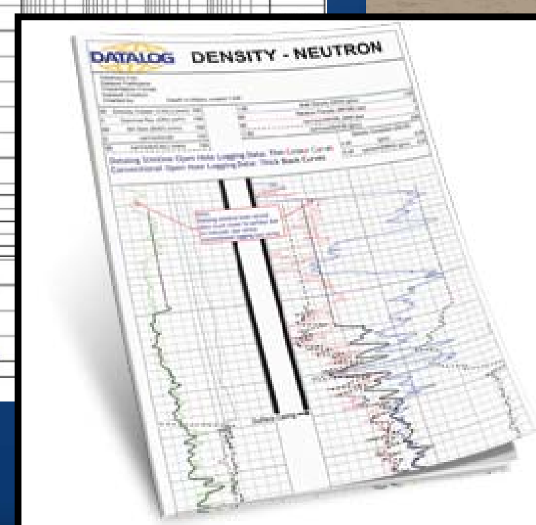


Wireline Well Logs

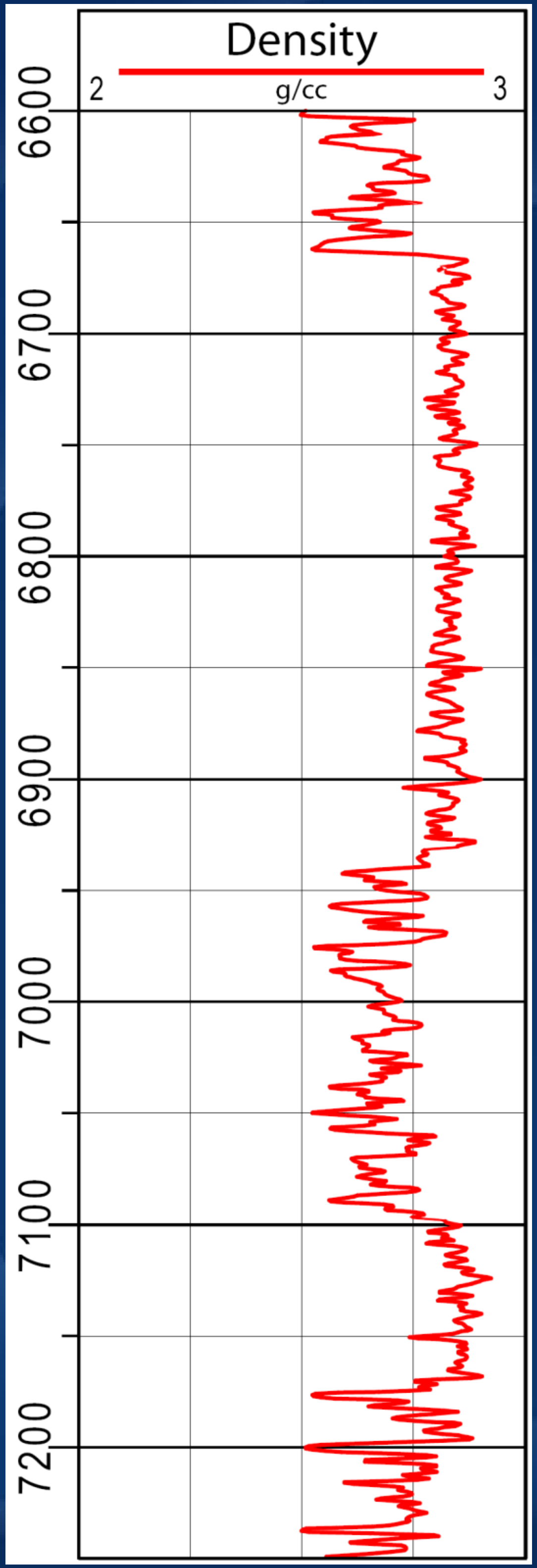



Gamma, SP, Caliper
BitSize
0 30
Gamma Ray (GR)
0 (GAPI) 200
Caliper (CALI)
0 (in) 30
Spontaneous Potential (SP)
-160 (mV) 40
M. DEPTH (ft)
Resistivity
Micro Spherically Focussed Log (MSFL)
0.2 (ohmm) 2000
Shallow Laterolog (LLS)
0.2 (ohmm) 2000
Deep Laterolog (LLD)
0.2 (ohmm) 2000
Neutron, Density
RHOGSWC
1.65 2.9
PORSWC
60 -15
RHOGCORE
1.65 2.9
PORCORE
60 -15
Neutron (NPHI)
60 (%) -15
Bulk Density (RHOB)
1.65 (g/cc) 2.9
Sonic, Mud Weight
MudWgt
8 18
Sonic (DT)
200 (us/f) 40
Permeability
PERMSWC
1000 0.1
PERMCORE
1000 0.1
M. DEPTH (ft)
500
1000
1500
2000
2500
3000
3500
4000


Upper formations
500m
Dilwyn Fm
Pember Mudstone
Pebble Pt Fm
1000m
Massacre Shale
Timboon Sandstone
Paaratte Fm

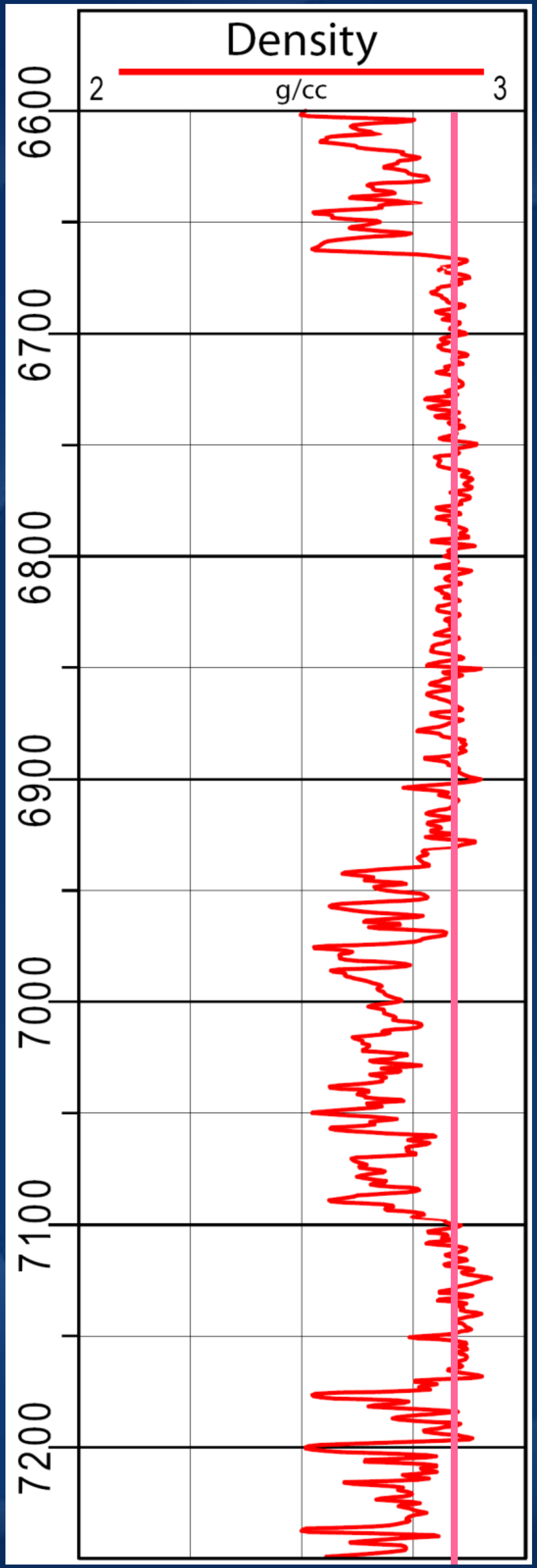

DATALOG
DENSITY - NEUTRON

Log Interpretation



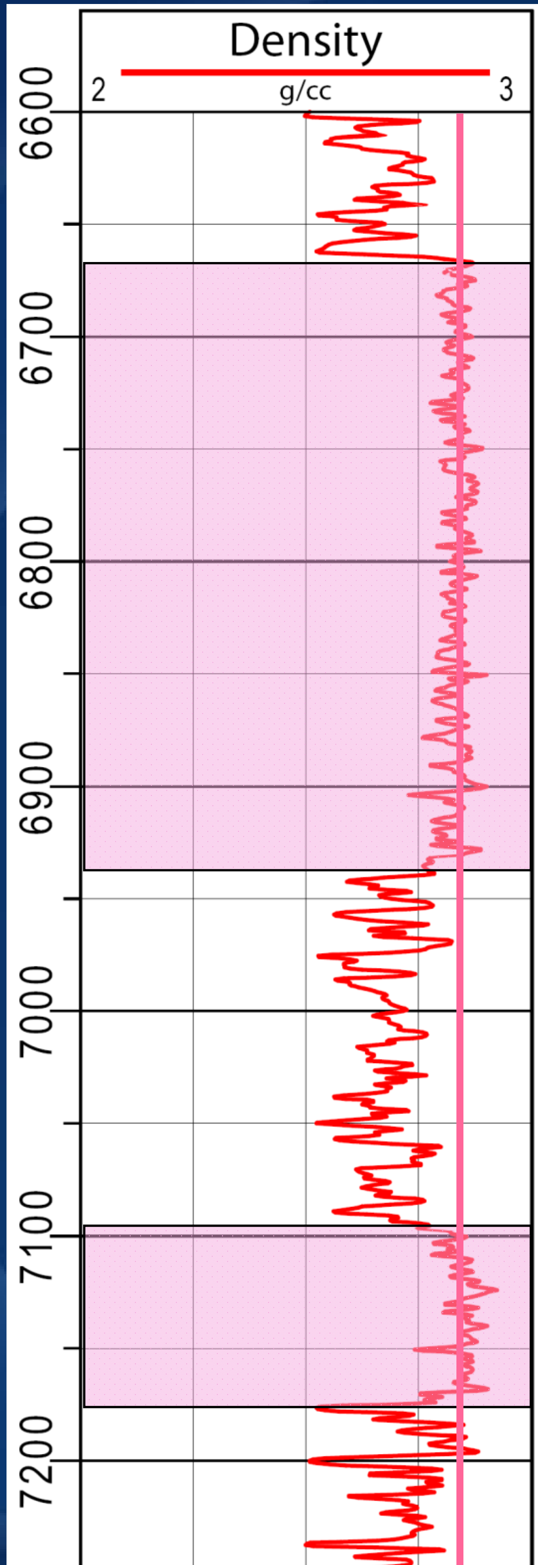
Grain Densities	
Clay (Shale)	2.45 g/cc
Quartz (Sandstone)	2.65 g/cc
Calcite (Limestone)	2.71 g/cc
Dolomite	2.86 g/cc
Anhydrite	2.95 g/cc
Pyrite	5.00 g/cc

Log Interpretation



Grain Densities	
Clay (Shale)	2.45 g/cc
Quartz (Sandstone)	2.65 g/cc
Calcite (Limestone)	2.71 g/cc
Dolomite	2.86 g/cc
Anhydrite	2.95 g/cc
Pyrite	5.00 g/cc

Log Interpretation

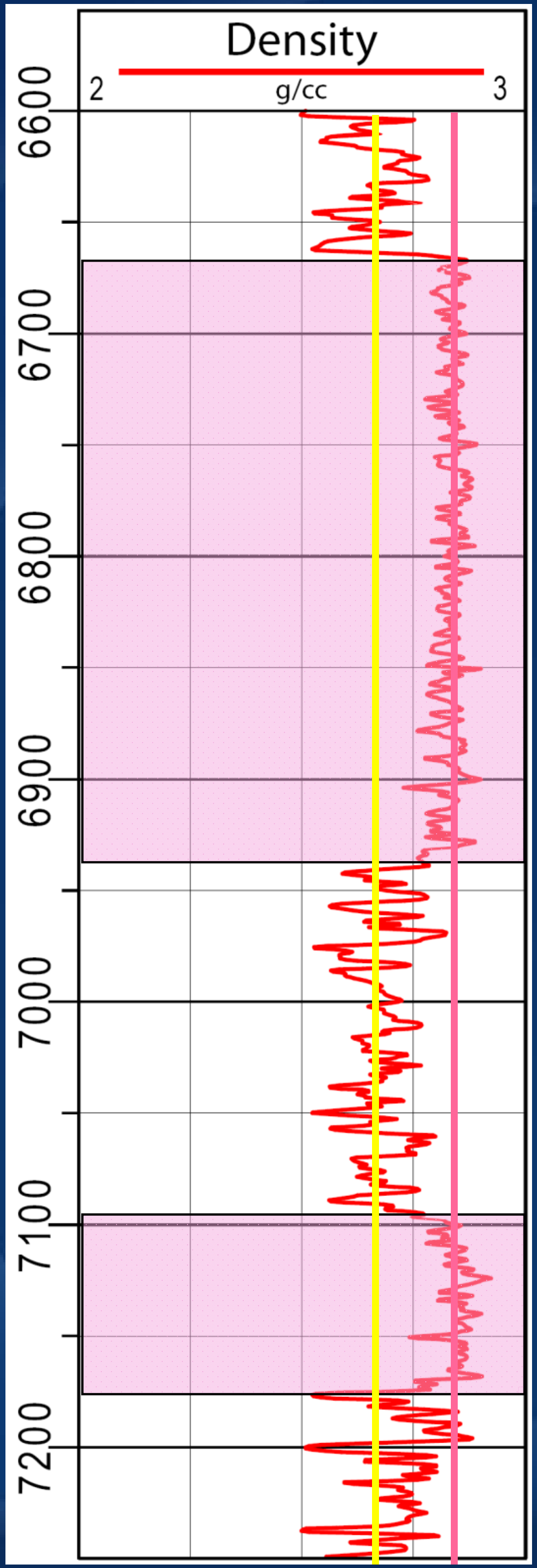


Dolomite

Dolomite

Grain Densities	
Clay (Shale)	2.45 g/cc
Quartz (Sandstone)	2.65 g/cc
Calcite (Limestone)	2.71 g/cc
Dolomite	2.86 g/cc
Anhydrite	2.95 g/cc
Pyrite	5.00 g/cc

Log Interpretation

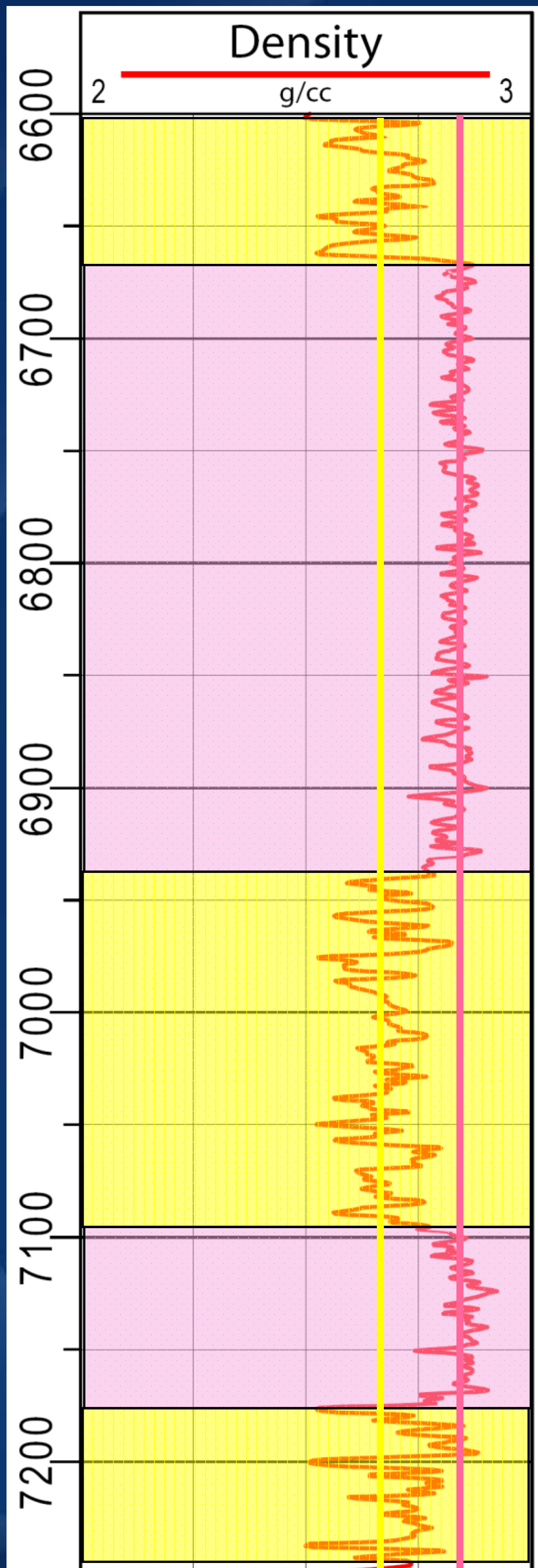


Dolomite

Dolomite

Grain Densities	
Clay (Shale)	2.45 g/cc
Quartz (Sandstone)	2.65 g/cc
Calcite (Limestone)	2.71 g/cc
Dolomite	2.86 g/cc
Anhydrite	2.95 g/cc
Pyrite	5.00 g/cc

Log Interpretation



Sandstone

Dolomite

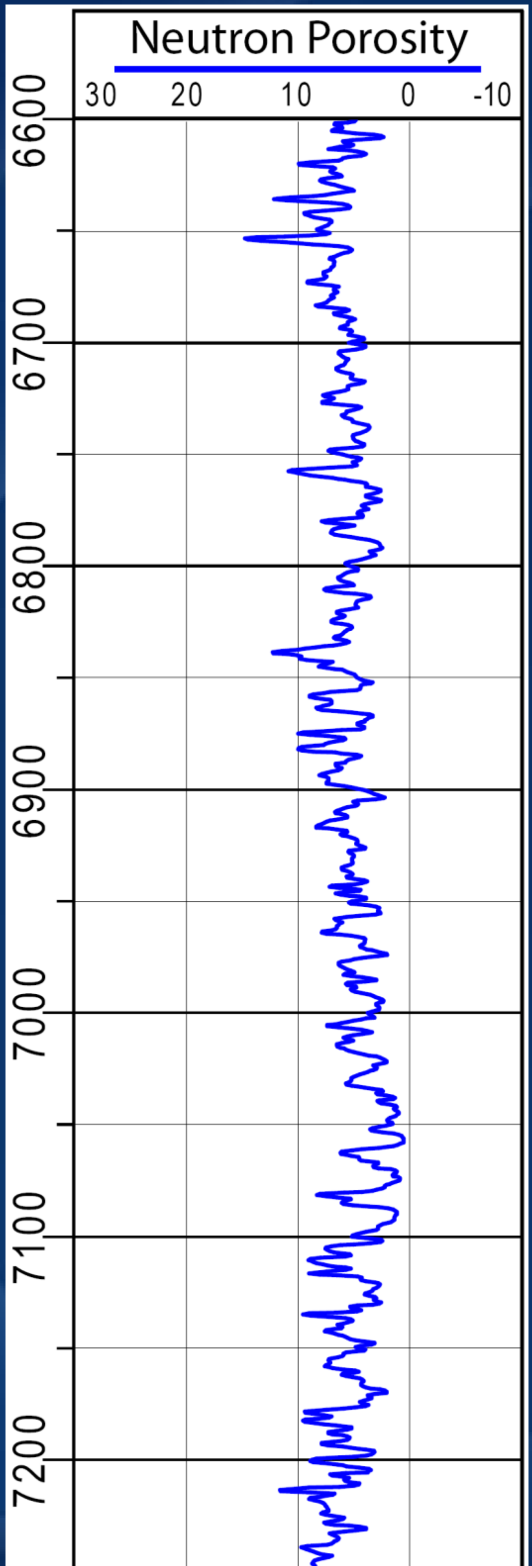
Sandstone

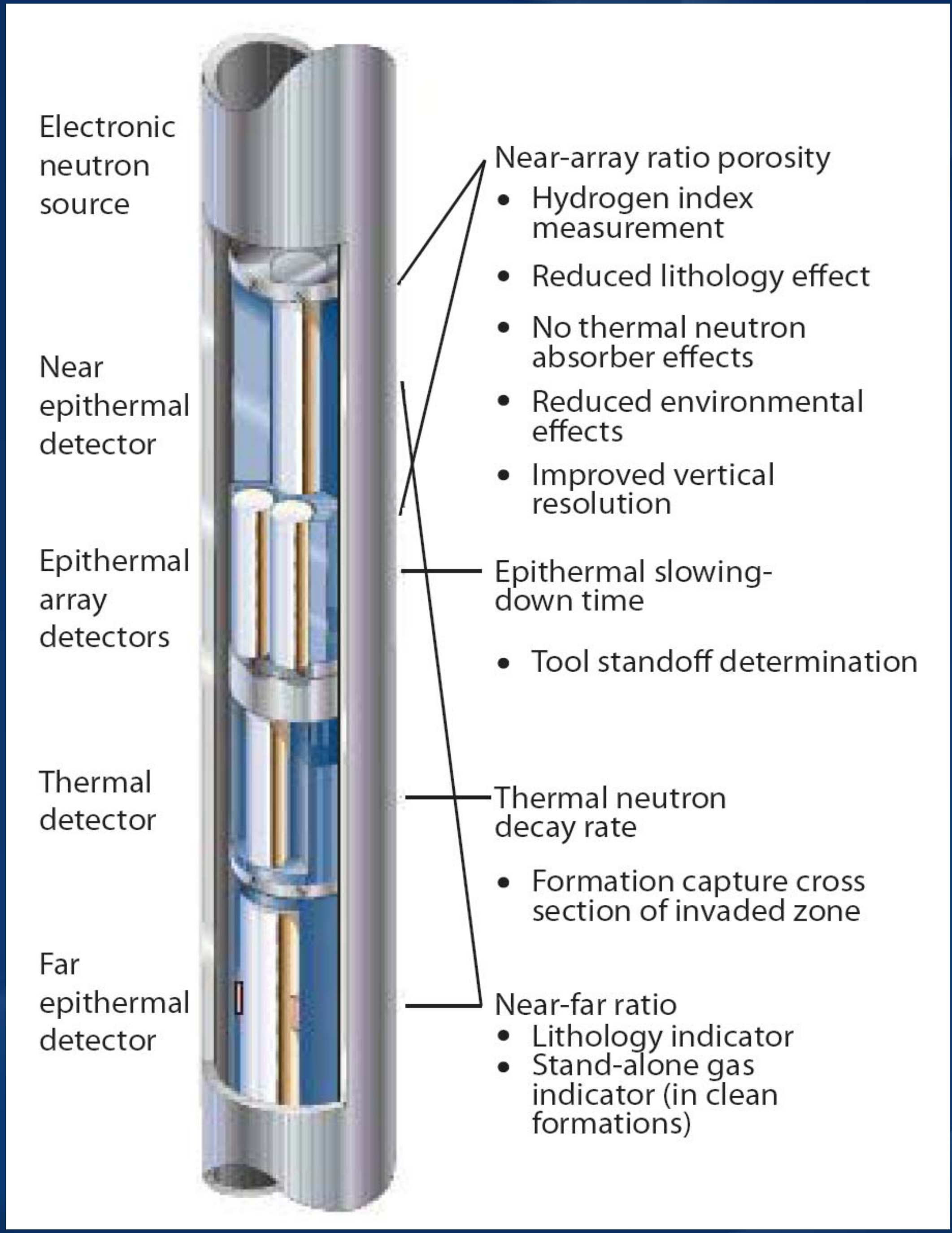
Dolomite

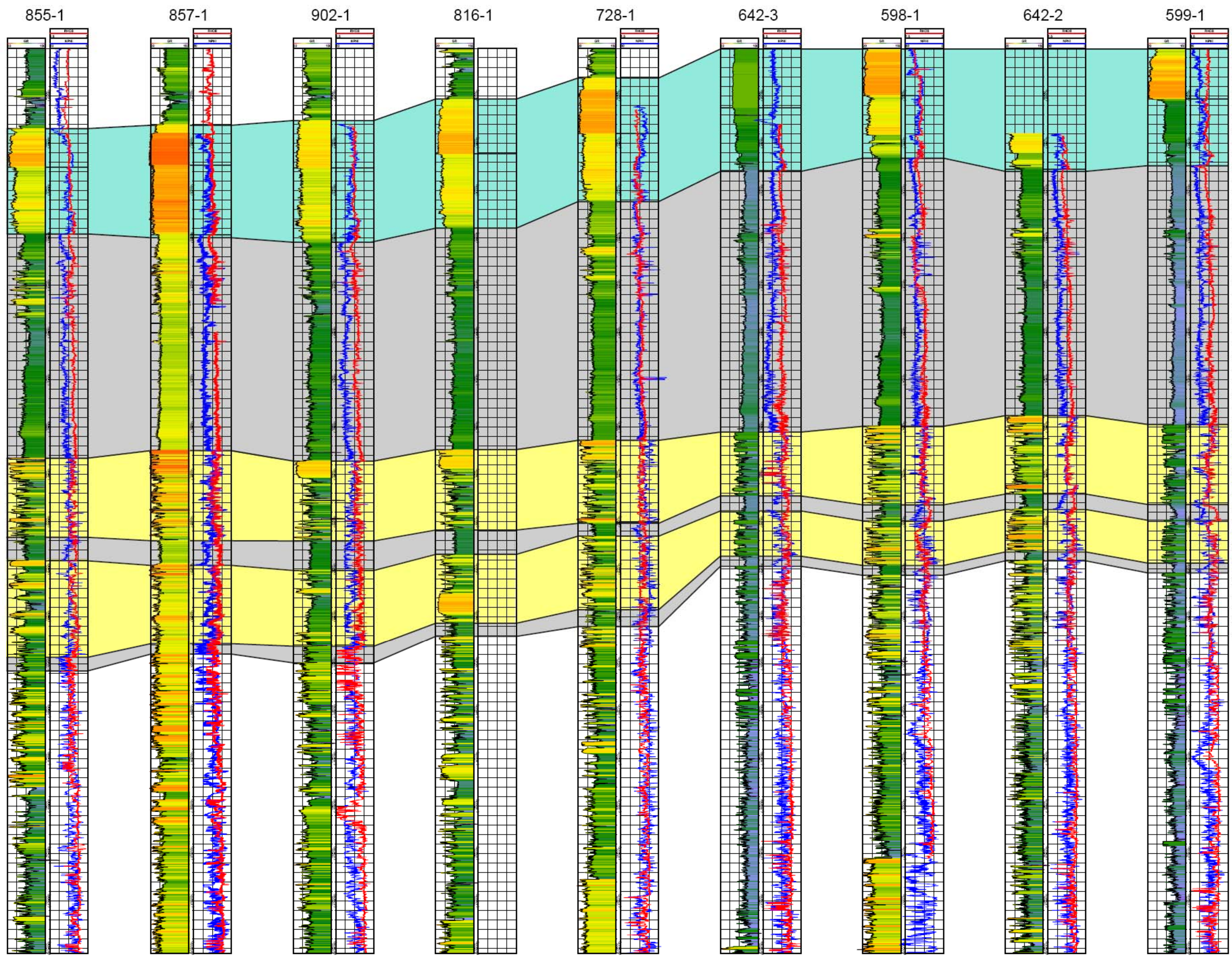
Sandstone

Grain Densities	
Clay (Shale)	2.45 g/cc
Quartz (Sandstone)	2.65 g/cc
Calcite (Limestone)	2.71 g/cc
Dolomite	2.86 g/cc
Anhydrite	2.95 g/cc
Pyrite	5.00 g/cc

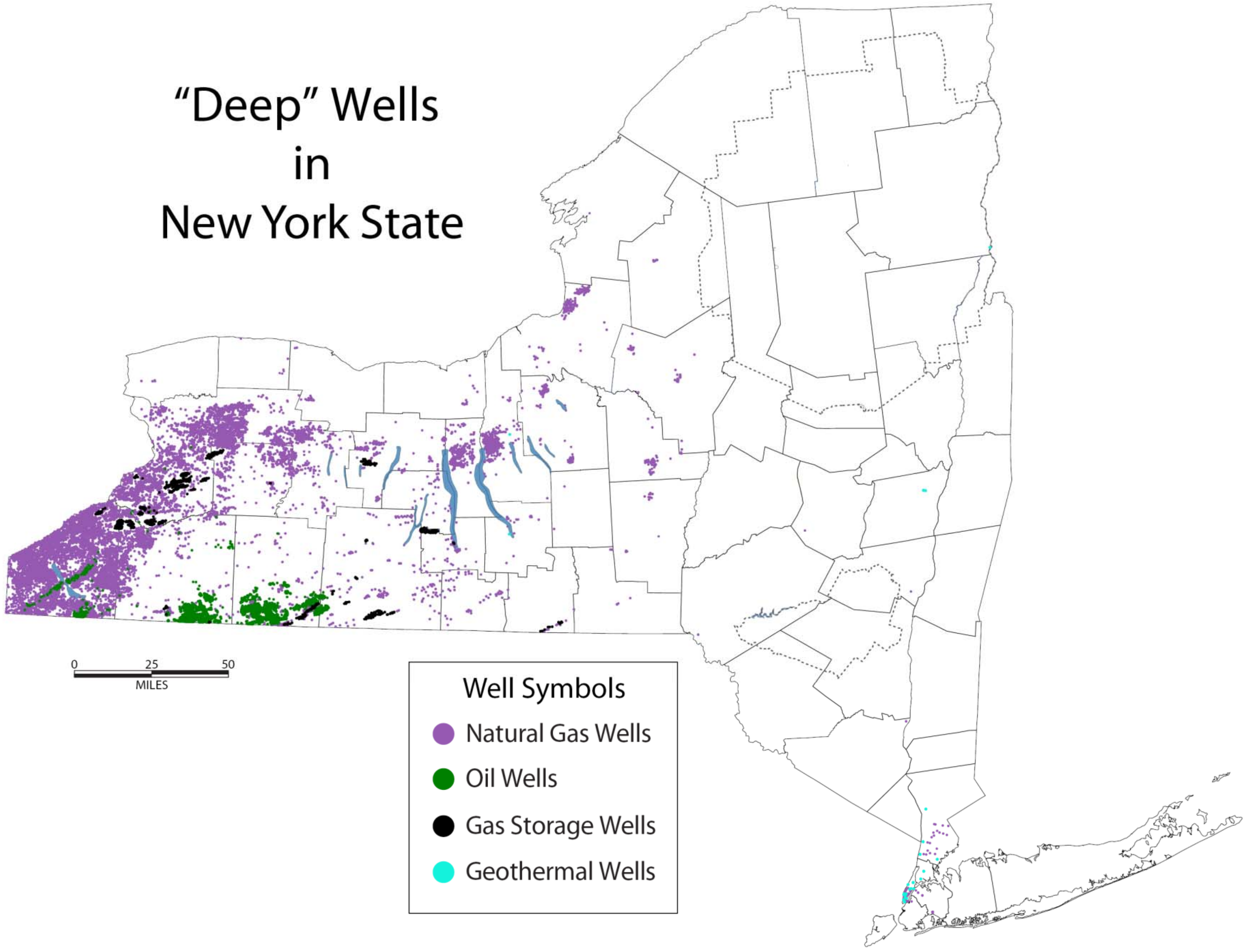
Log Interpretation



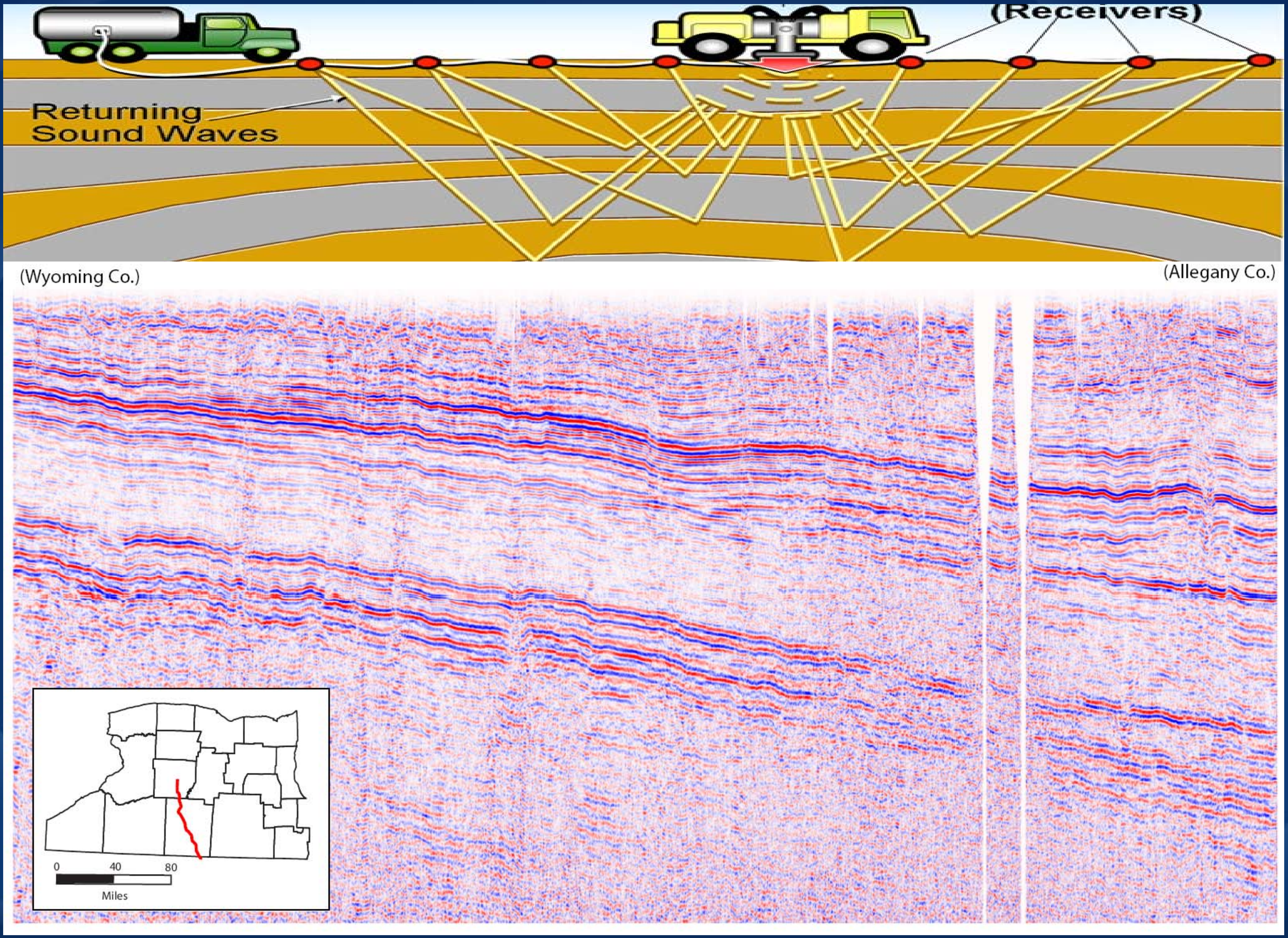


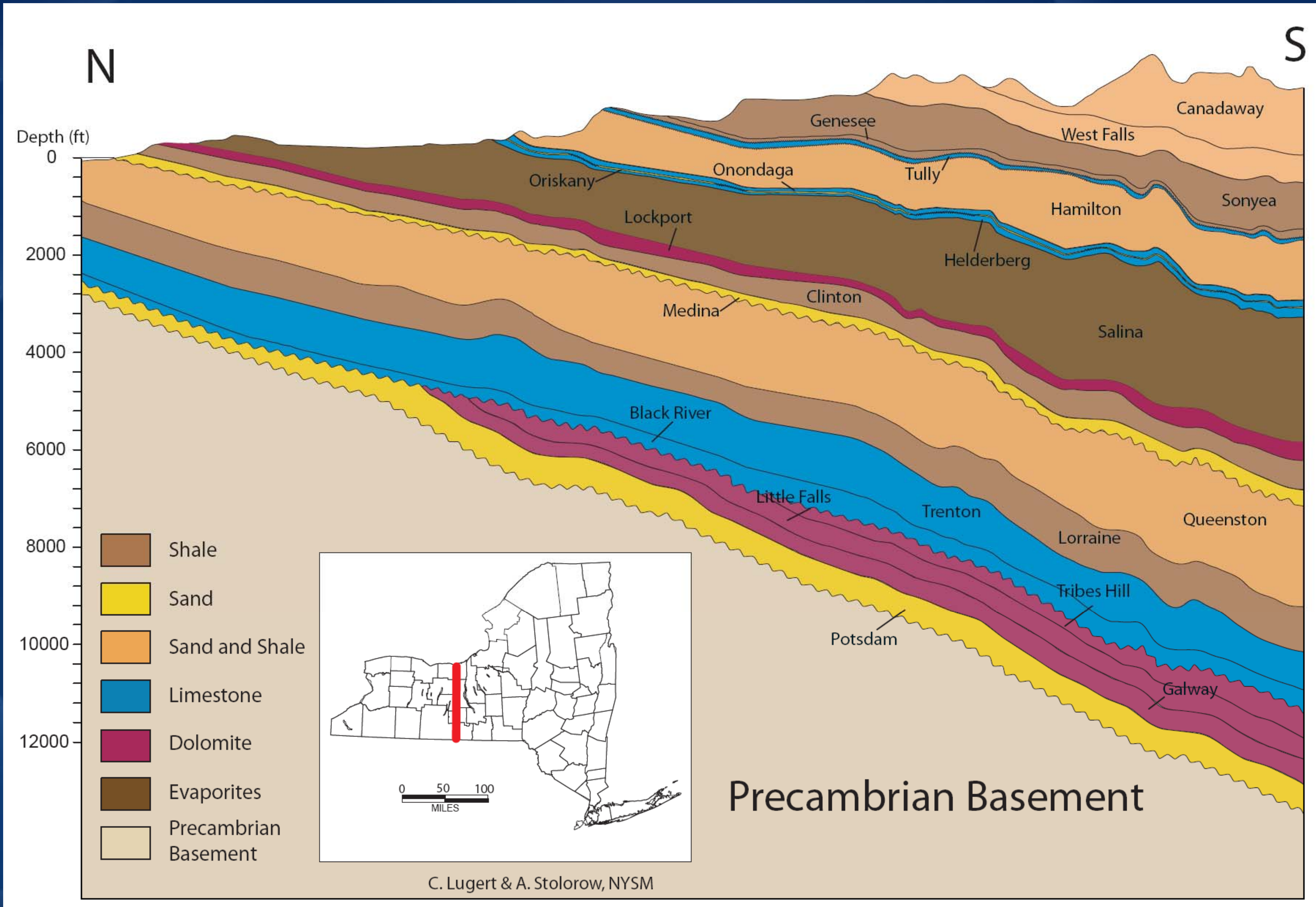

855-1
857-1
902-1
816-1
728-1
642-3
598-1
642-2
599-1

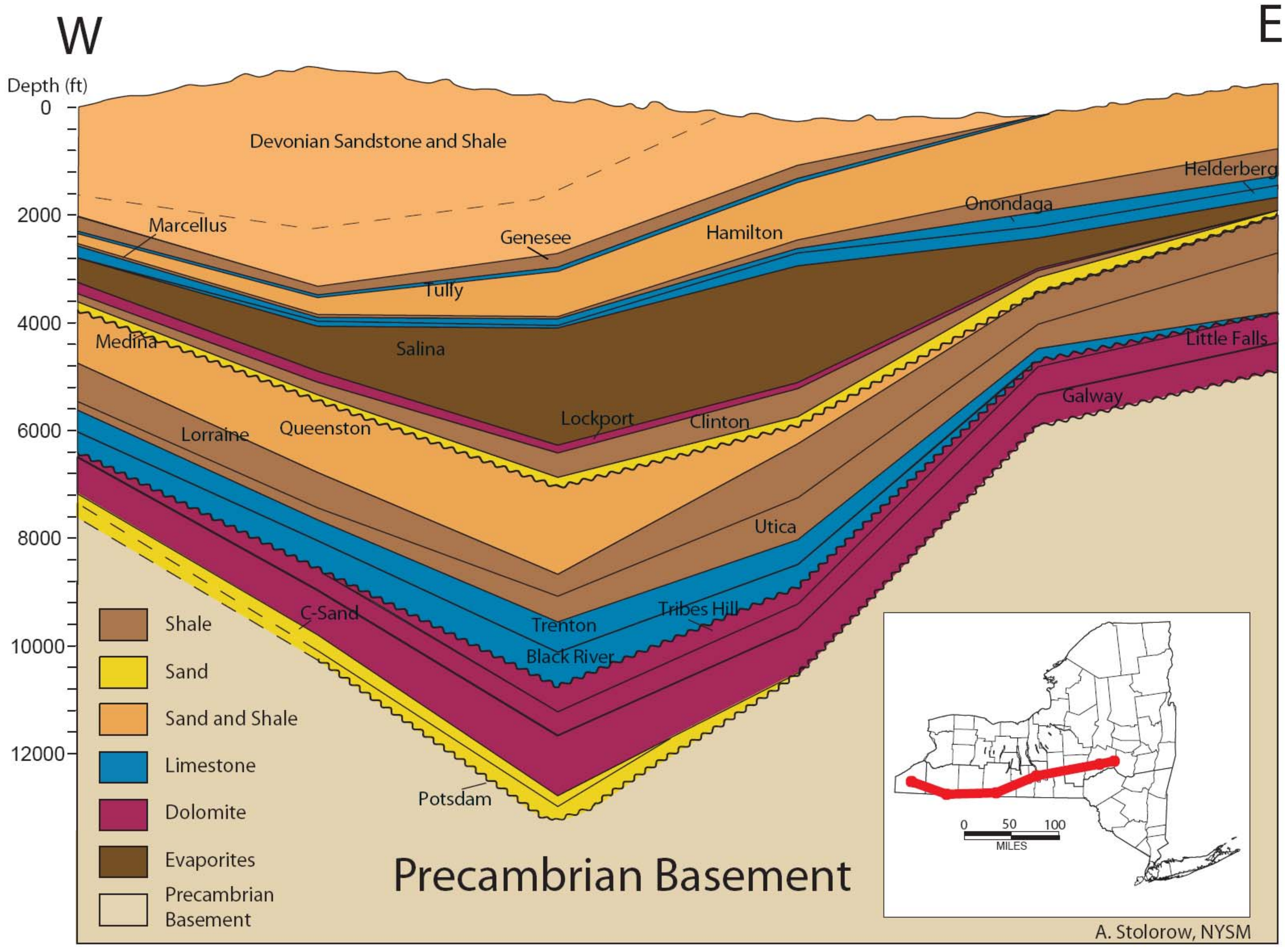
"Deep" Wells in New York State



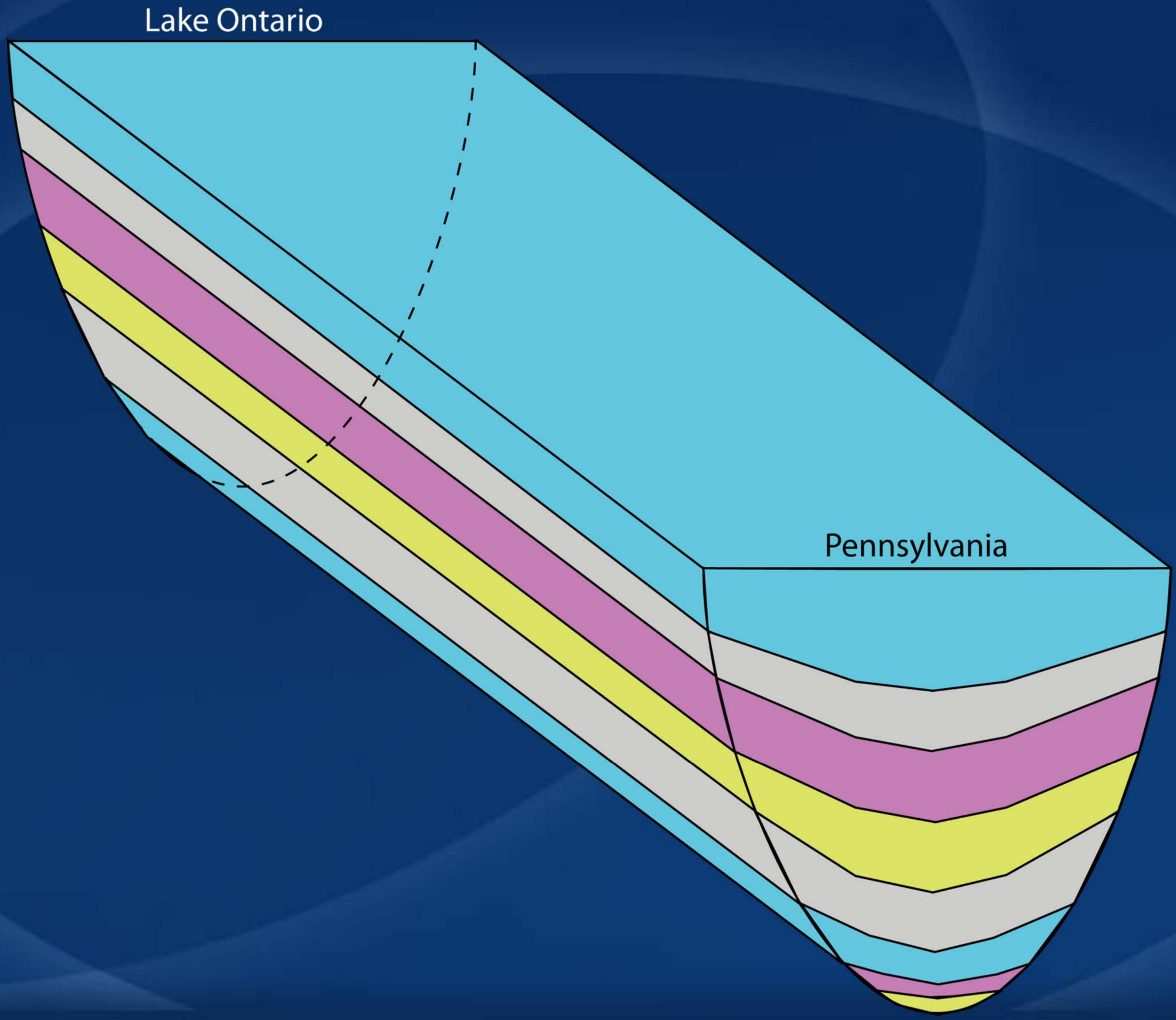
Seismic Imaging



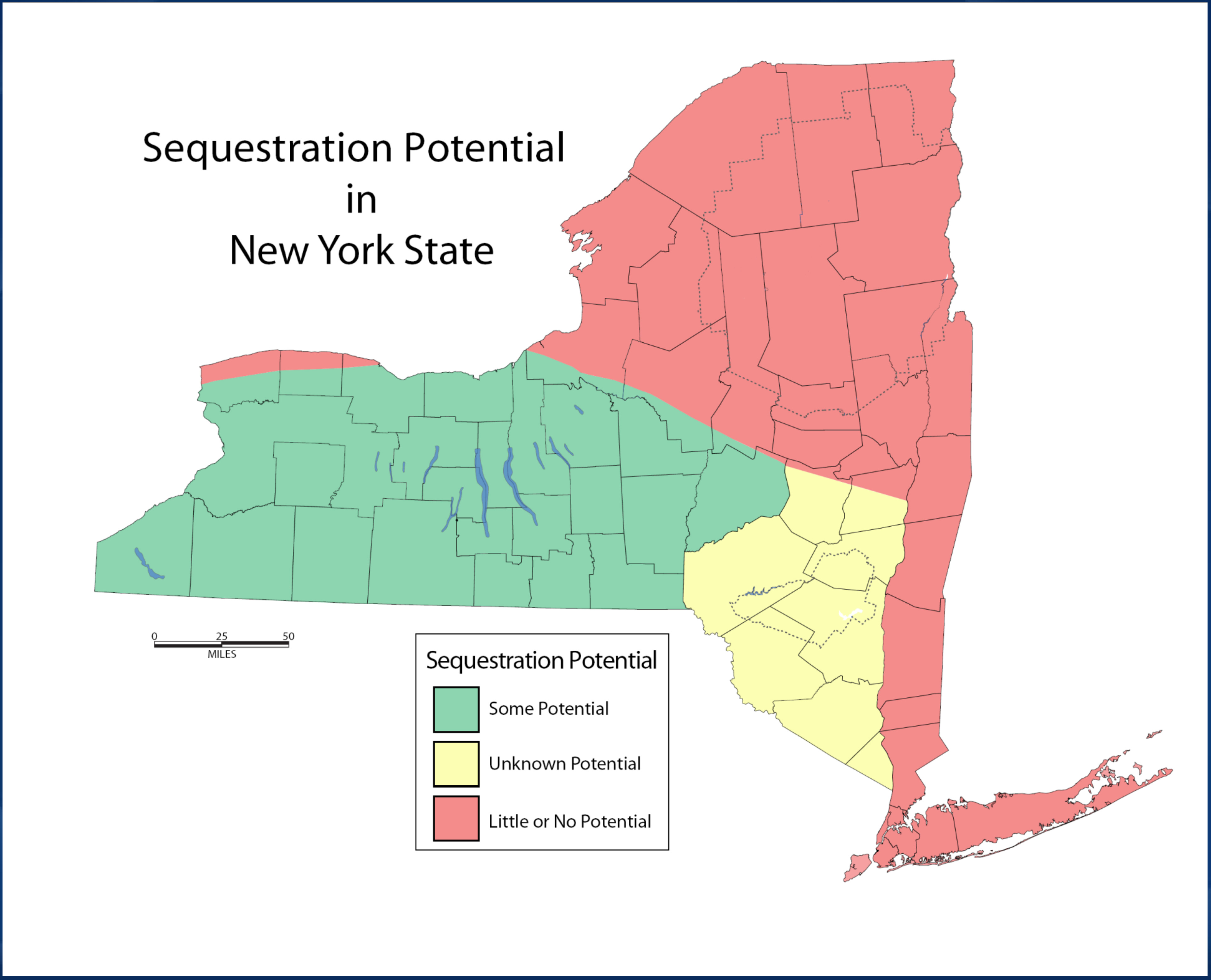

N
S
Depth (ft)
0
2000
4000
6000
8000
10000
12000
Canadaway
West Falls
Genesee
Sonyea
Tully
Onondaga
Oriskany
Hamilton
Lockport
Helderberg
Clinton
Medina
Salina
Black River
Little Falls
Trenton
Queenston
Lorraine
Tribes Hill
Potsdam
Galway
Precambrian Basement
Shale
Sand
Sand and Shale
Limestone
Dolomite
Evaporites
Precambrian Basement
0 50 100
MILES
C. Lugert & A. Stolorow, NYSM



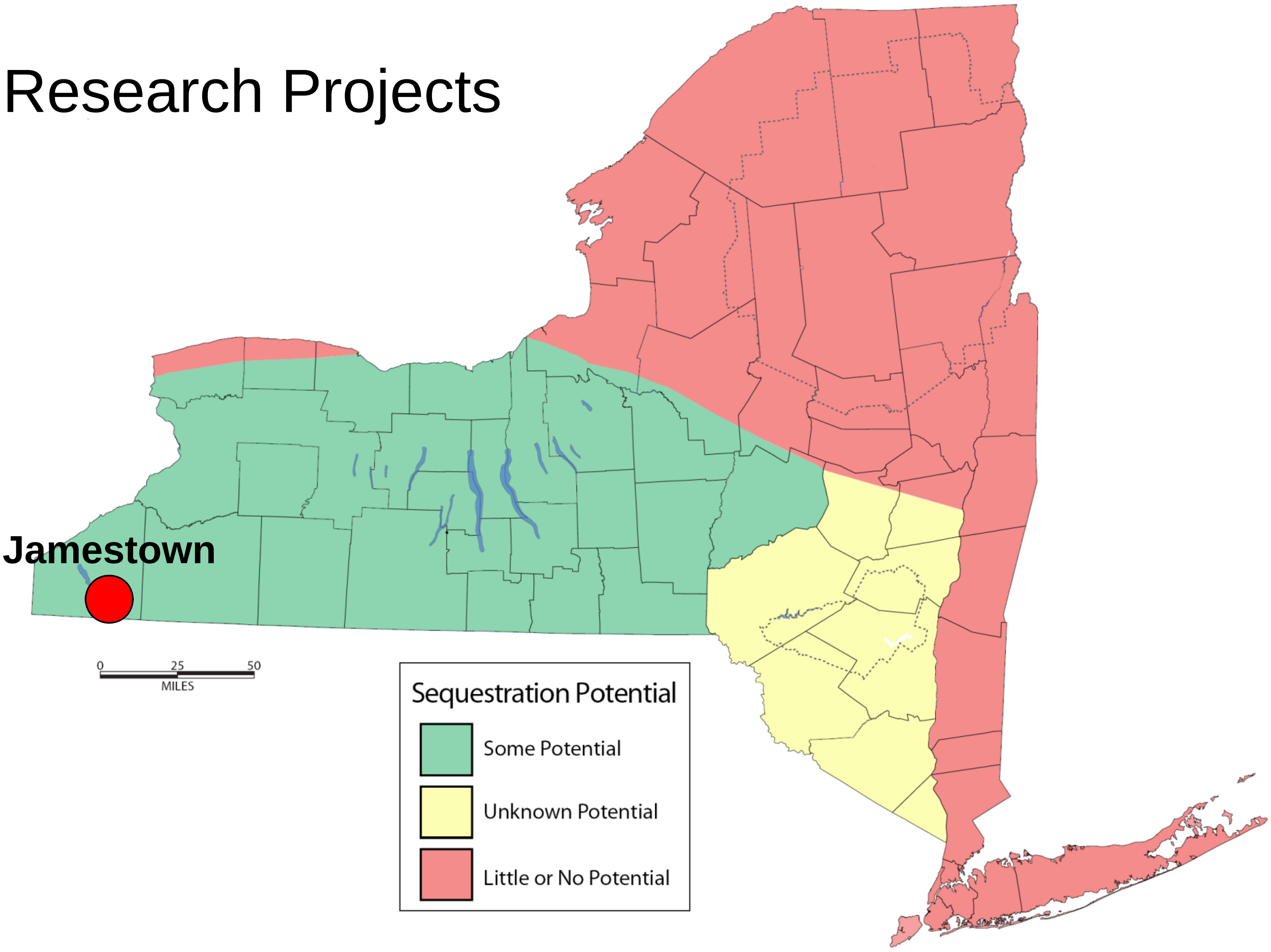
W
E
Depth (ft)
0
2000
4000
6000
8000
10000
12000
Devonian Sandstone and Shale
Marcellus
Genesee
Hamilton
Helderberg
Onondaga
Tully
Salina
Medina
Lockport
Clinton
Lorraine
Queenston
Little Falls
Galway
Utica
C-Sand
Trenton
Tribes Hill
Black River
Potsdam
Shale
Sand
Sand and Shale
Limestone
Dolomite
Evaporites
Precambrian Basement
Precambrian Basement
0 50 100
MILES
A. Stolorow, NYSM



Lake Ontario
Pennsylvania

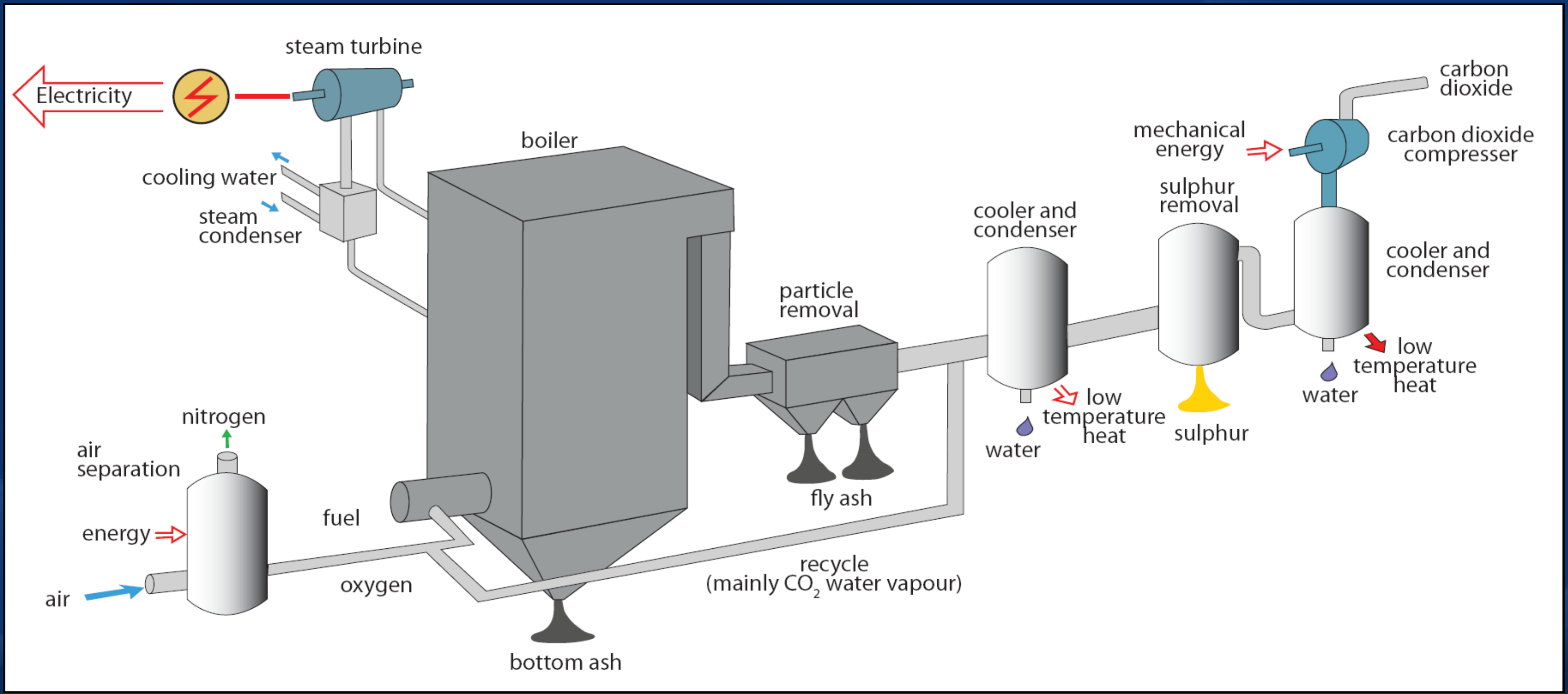

Sequestration Potential
in
New York State
0
25
50
MILES
Sequestration Potential
Some Potential
Unknown Potential
Little or No Potential

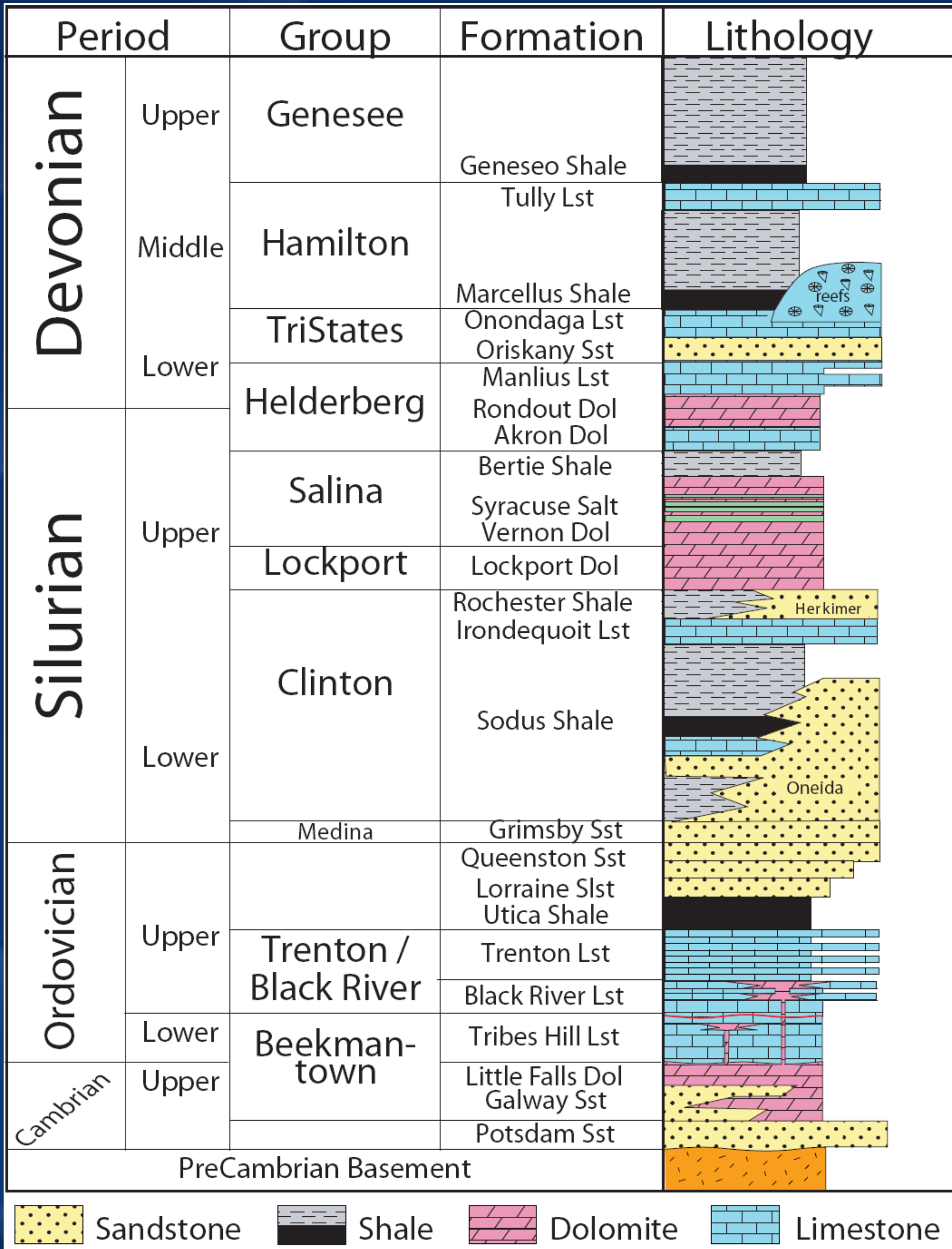
Research Projects



The Jamestown Project

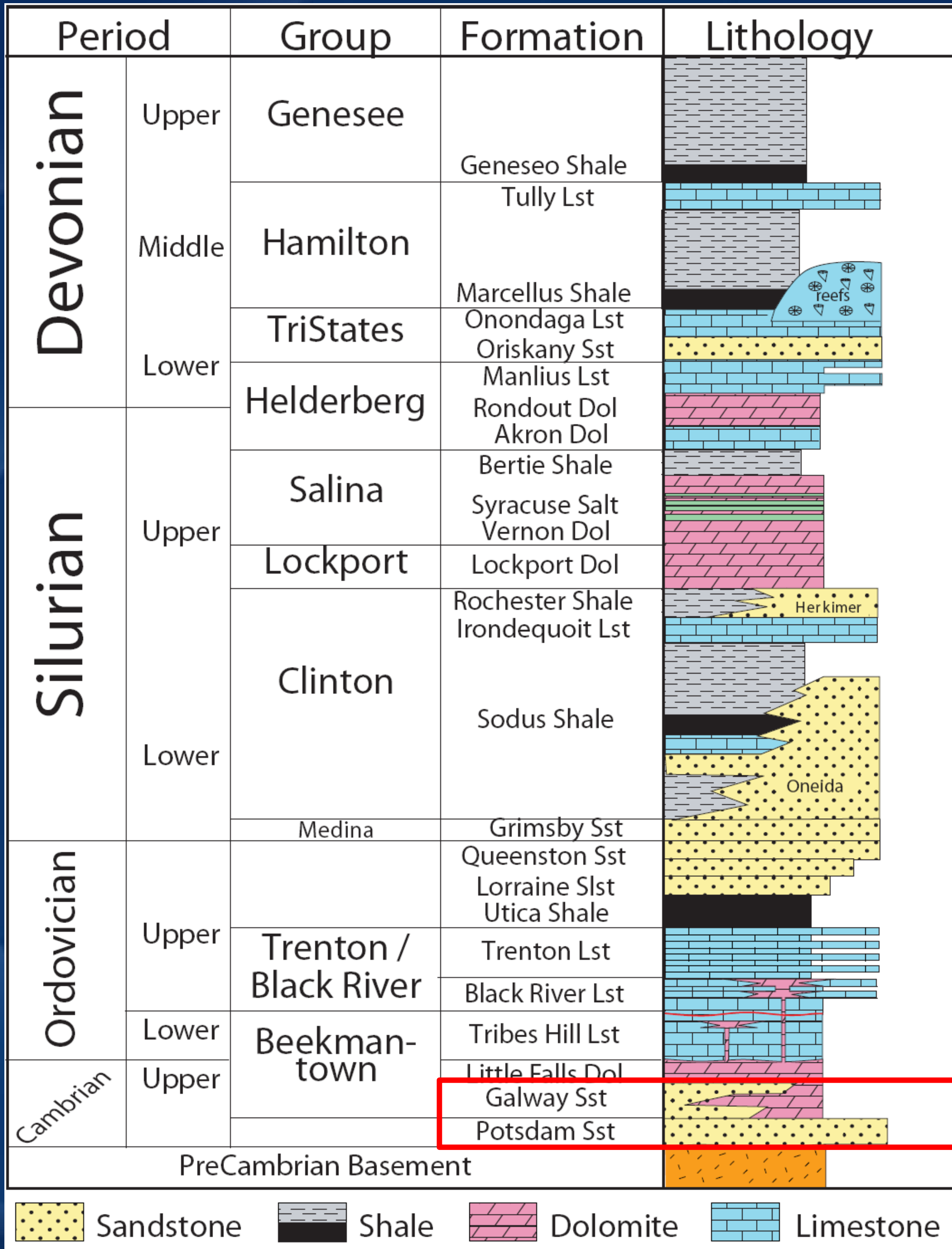
- Jamestown Bureau of Public Utilities (BPU) makes its own electricity using a 50MW coal fire power plant
- Plan to replace the current plant with an oxy-coal clean plant with near-site sequestration
- Received partial funding from the Department of Energy to investigate CCS potential in the area





Period
Group
Formation
Lithology
Devonian
Upper
Middle
Lower
Genesee
Geneseo Shale
Tully Lst
Hamilton
Marcellus Shale
reefs
TriStates
Onondaga Lst
Oriskany Sst
Helderberg
Manlius Lst
Rondout Dol
Akron Dol
Silurian
Upper
Lower
Salina
Bertie Shale
Syracuse Salt
Vernon Dol
Lockport
Lockport Dol
Clinton
Rochester Shale
Herkimer
Irondequoit Lst
Sodus Shale
Oneida
Medina
Grimsby Sst
Ordovician
Upper
Lower
Queenston Sst
Lorraine Slst
Utica Shale
Trenton / Black River
Trenton Lst
Black River Lst
Beekman-town
Tribes Hill Lst
Cambrian
Upper
Little Falls Dol
Galway Sst
Potsdam Sst
PreCambrian Basement
Sandstone
Shale
Dolomite
Limestone

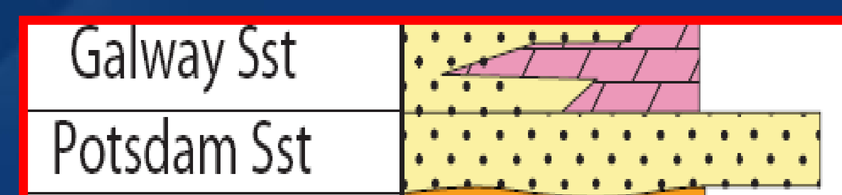
Target Reservoir



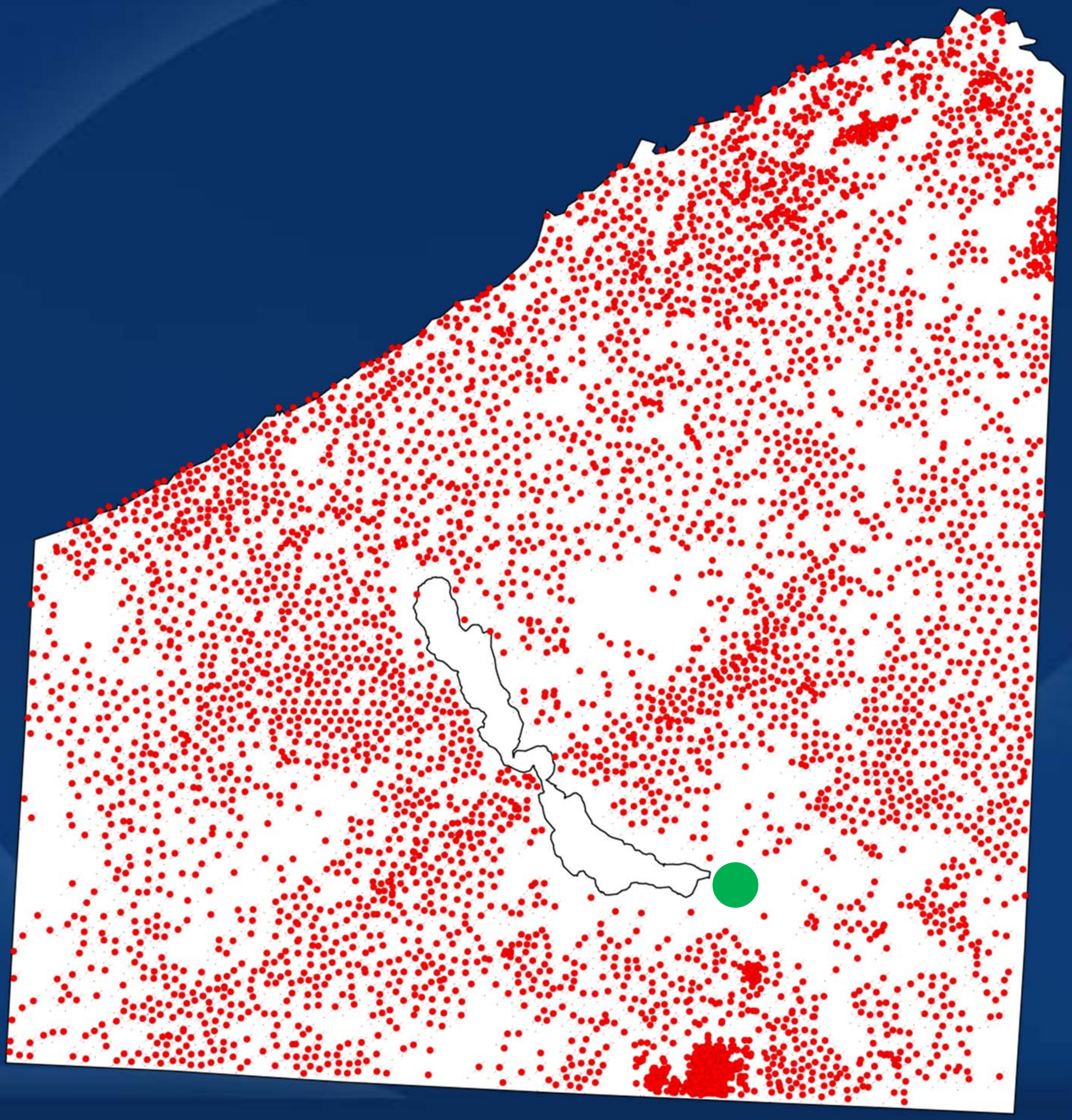
Potsdam Sandstone and the Interbedded Sandstones and dolomites of the Galway Formation.

Between 6,000 and 7,000 ft. deep near Jamestown

Approximately 1,000 ft. thick



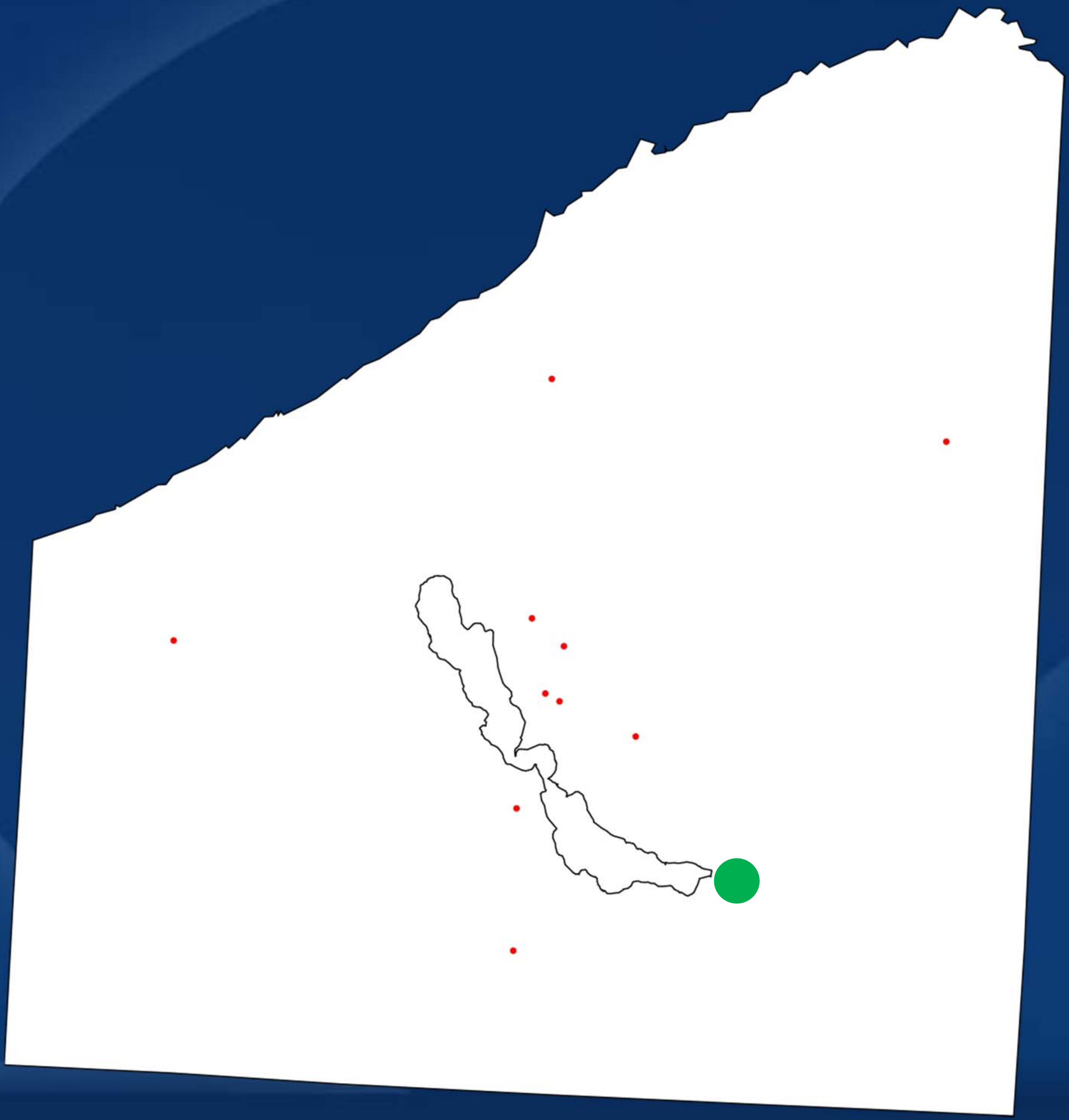
Existing Data: Wells in Chautauqua County



Over 6,200 deep wells in Chautauqua County

Most are natural gas wells producing from the Medina Sandstone

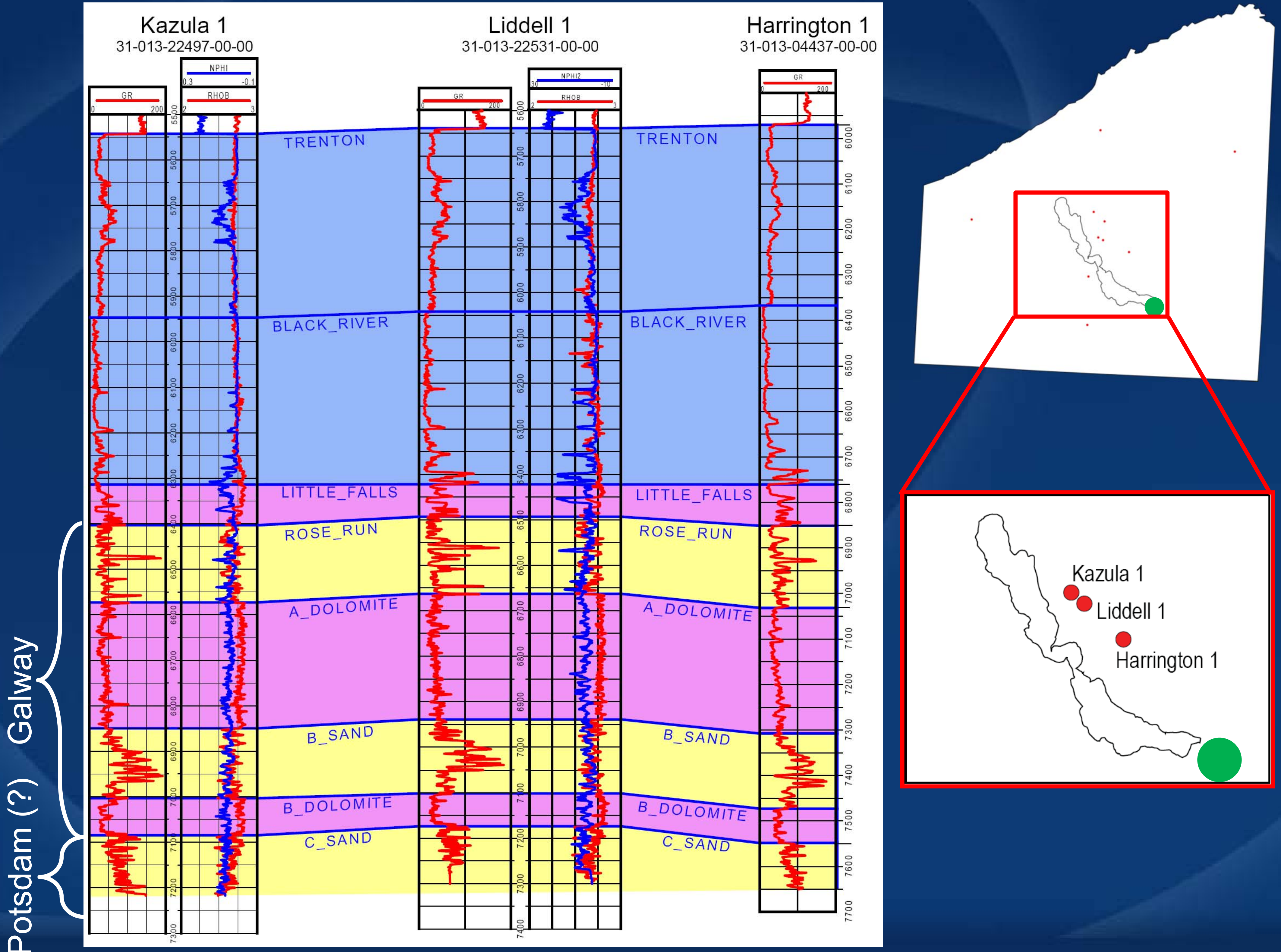
Existing Data: Wells in Chautauqua County



Over 6,200 deep wells in Chautauqua County

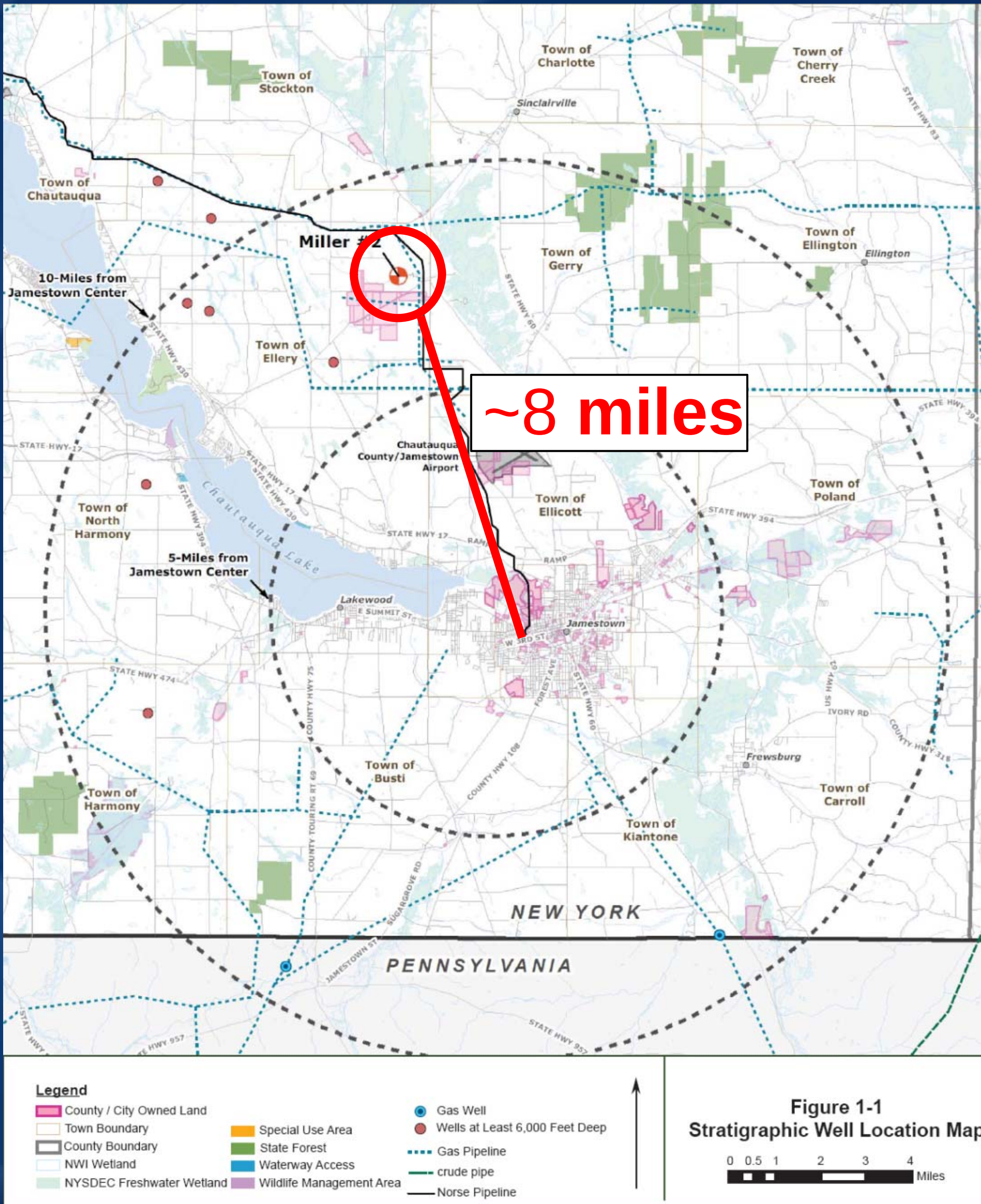
Most are natural gas wells producing from the Medina Sandstone

Only 10 wells deeper than 6,000 feet


Kazula 1
31-013-22497-00-00
Liddell 1
31-013-22531-00-00
Harrington 1
31-013-04437-00-00
GR
NPHI
RHOB
NPHI2
TRENTON
BLACK_RIVER
LITTLE_FALLS
ROSE_RUN
A_DOLOMITE
B_SAND
B_DOLOMITE
C_SAND
Galway
Potsdam (?)
Kazula 1
Liddell 1
Harrington 1

Miller #2

31-013-25737-00-00

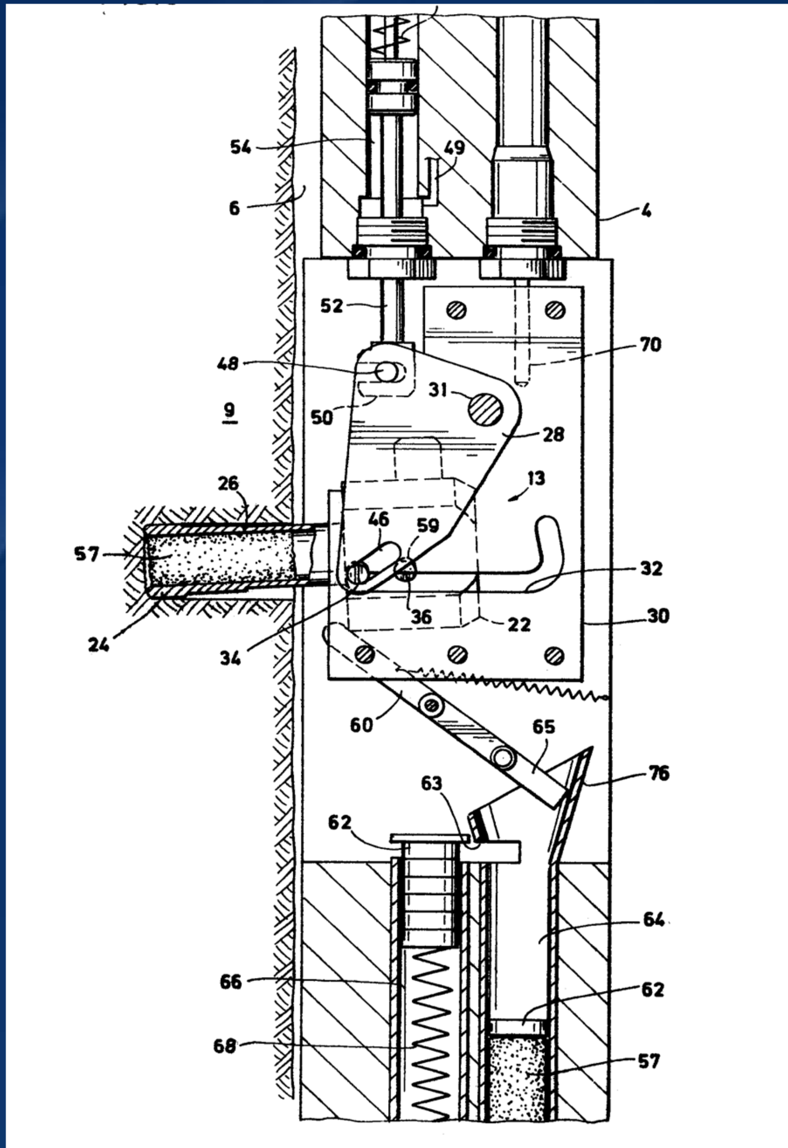


- Piggyback with Unbridled Energy
- Drilling March – May 2009
- Total Depth: 7,308 feet

Approximately 155' of core

- Run 1: Little Falls
- Run 2: Rose Run
- Run 3: Upper C-Sand

Core Run	Top (feet)	Bottom (feet)	Length (feet)	Recovery (%)
1	6254	6308	54	100%
GAP	6308	6328	20	
2	6328	6342	13.2	94%
3	6342	6372	30	100%
GAP	6372	7060	688	
4	7060	7120	58.5	98%
		TOTAL	155.7	

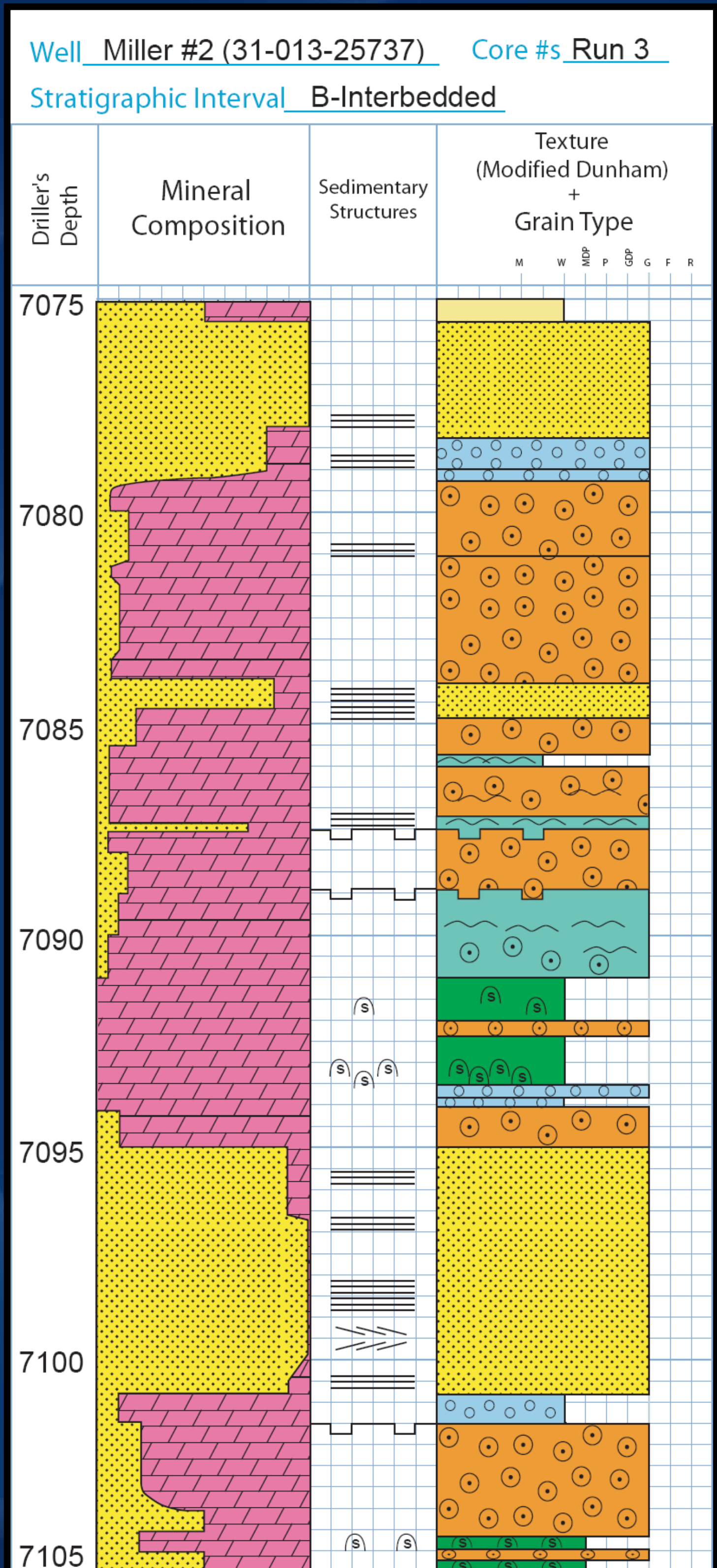


Sidewall Cores

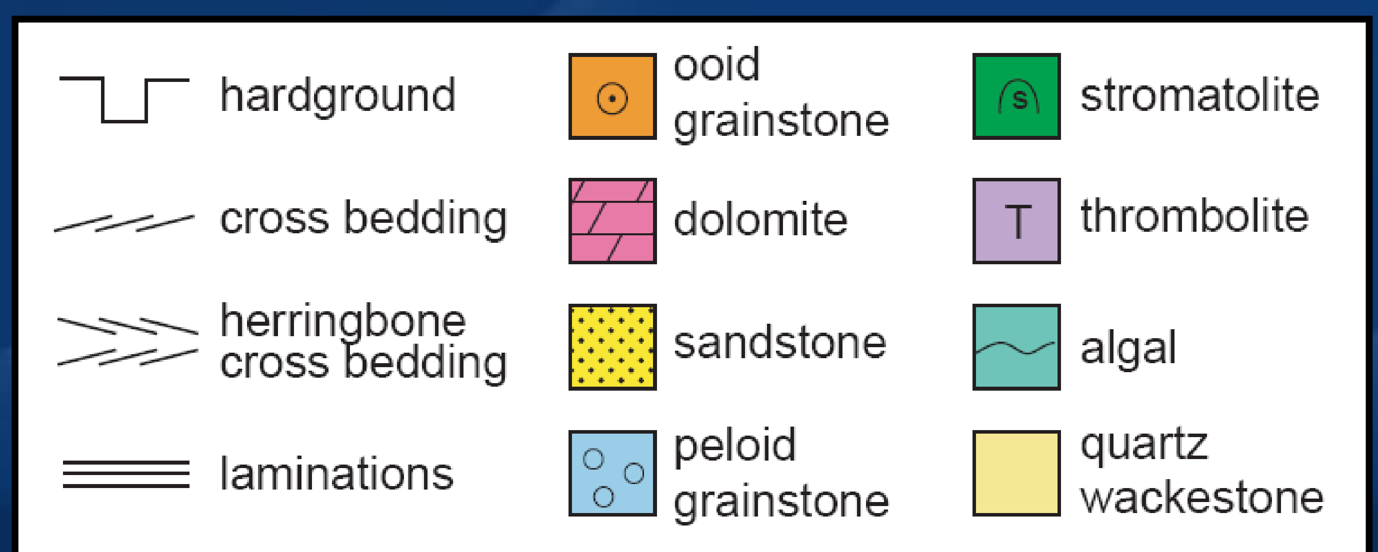
31 sidewall core collected

- 13 from Rose Run Sand
- 12 from B-Sand
- 6 from C-Sand

Core Description

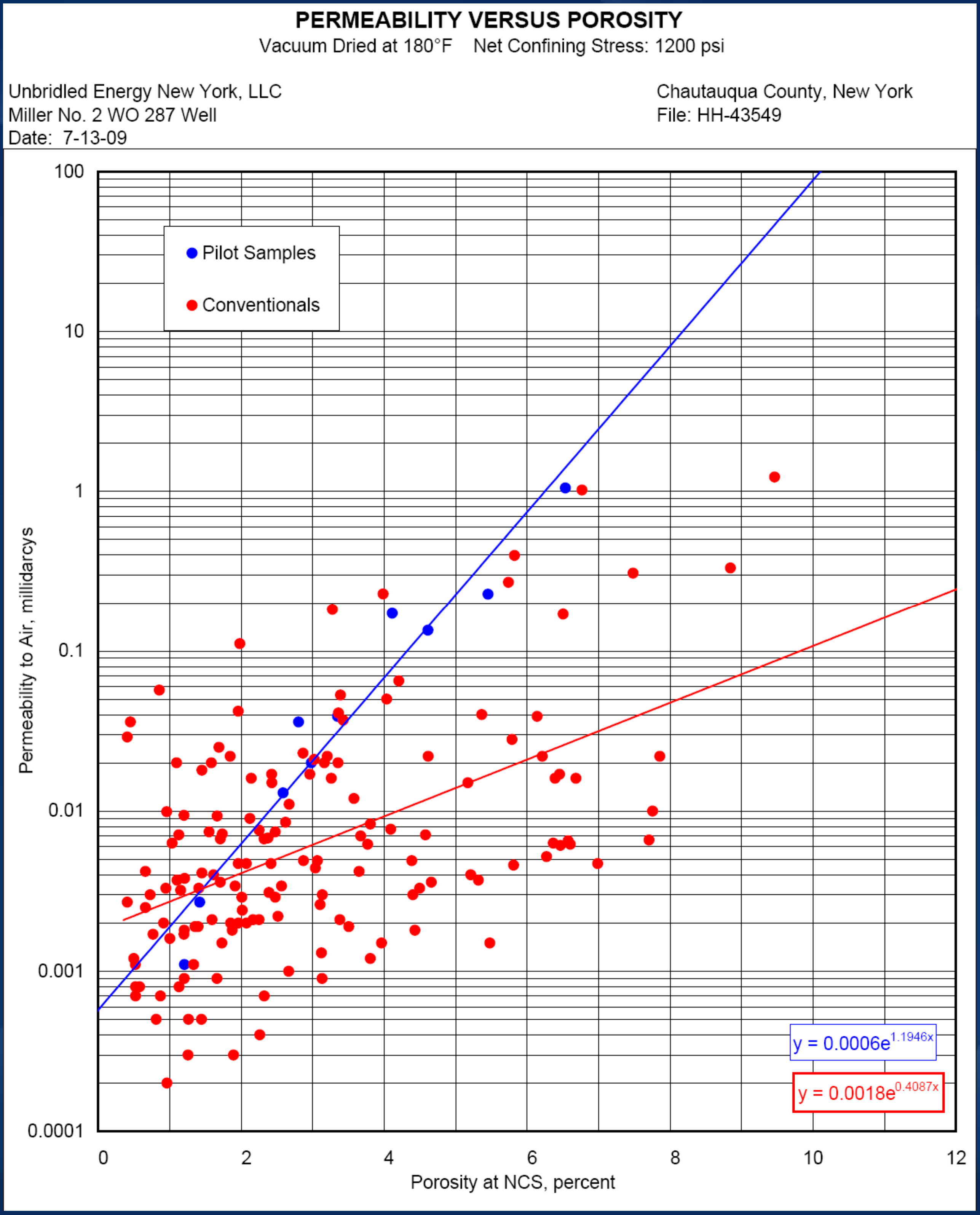


Rock properties such as mineral composition, sedimentary structures, texture, and grain type were recorded at a 6" resolution and displayed in graphical



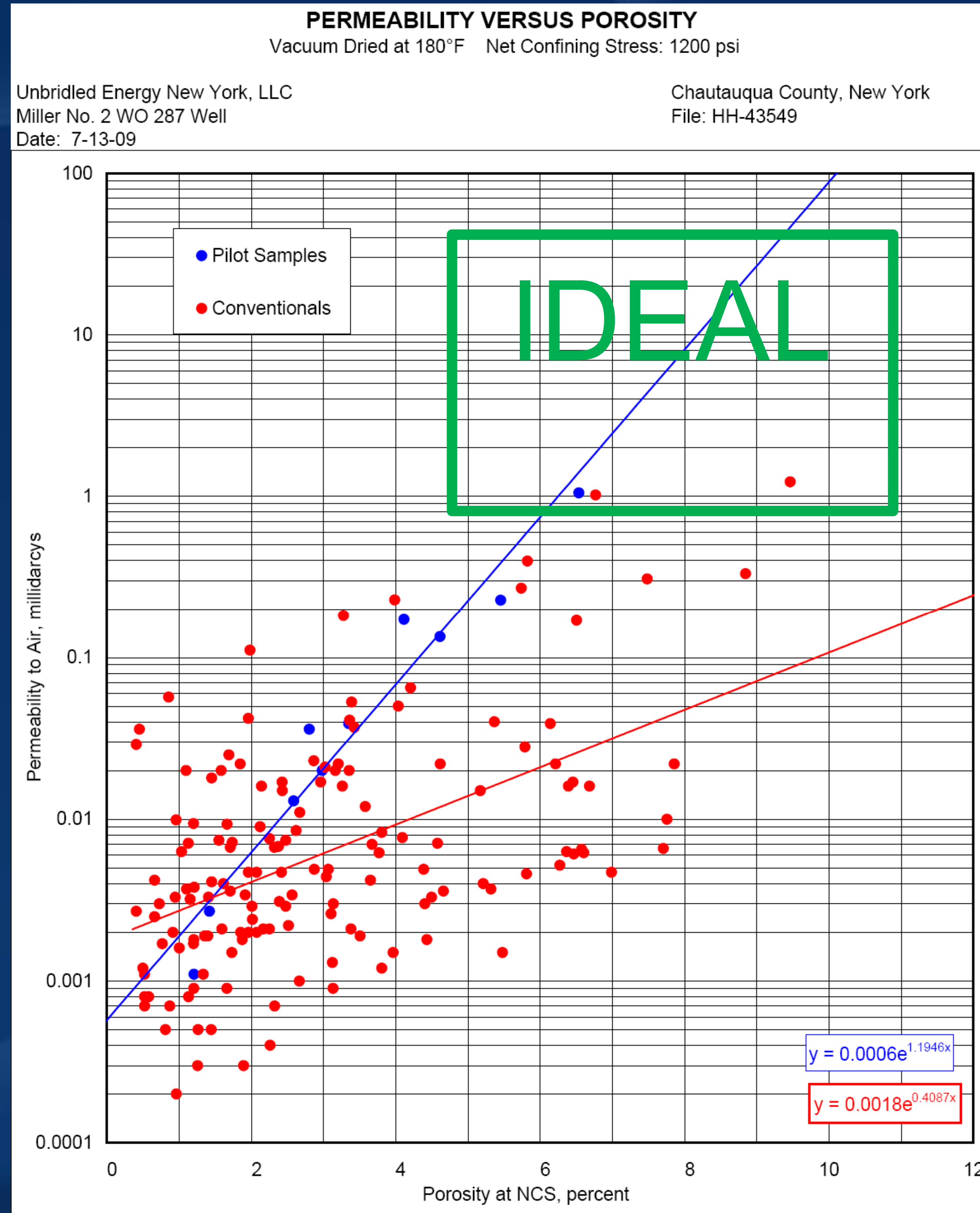
Lab Results

- Porosity and permeability measurements from Weatherford Labs
- Data includes samples of reservoir rock and cap rock
- Blue points are sidewall cores
- Red points are samples from continuous core



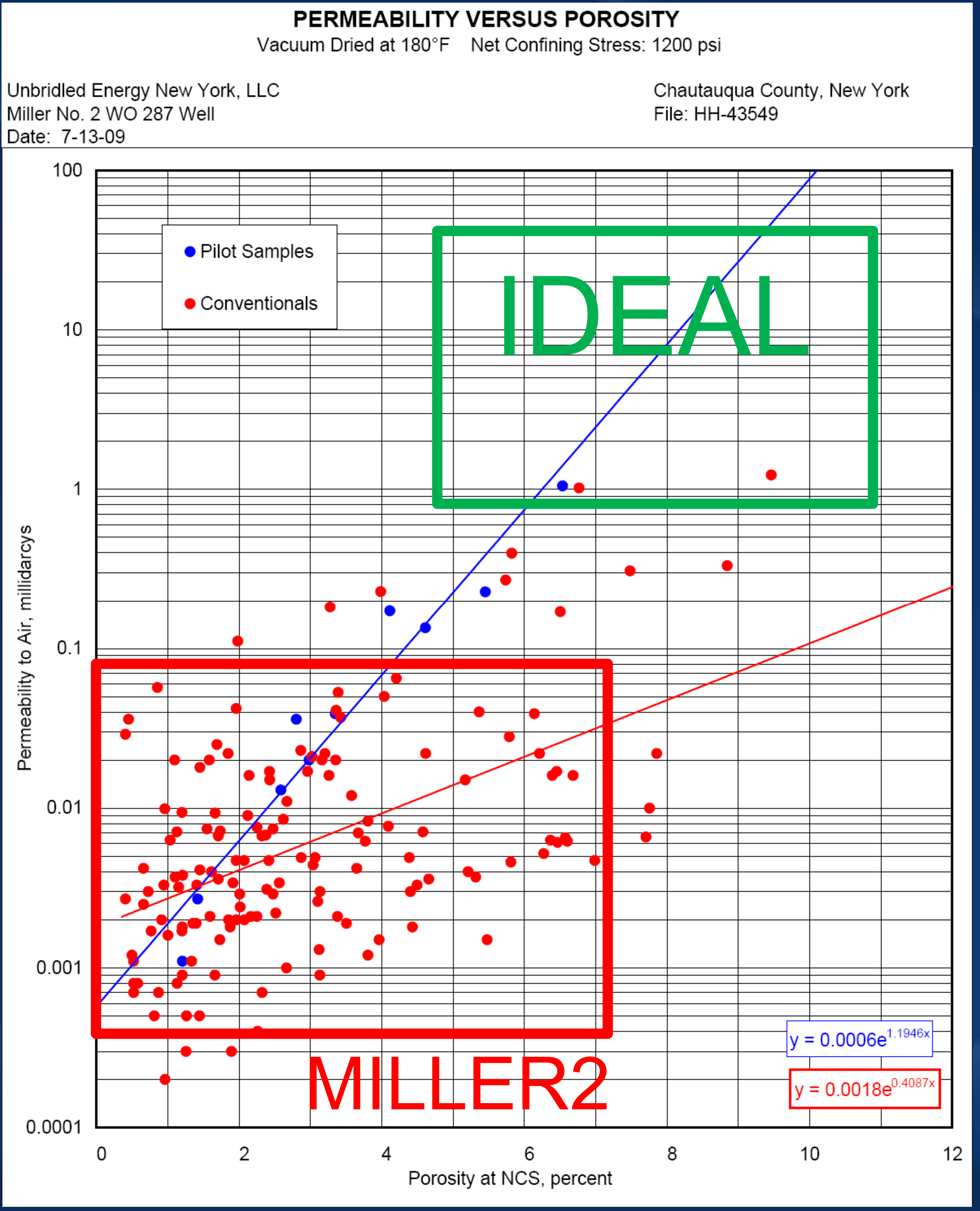
Lab Results

- Ideal sequestration reservoirs have porosities greater than 5% and permeabilities over 1 millidarcy

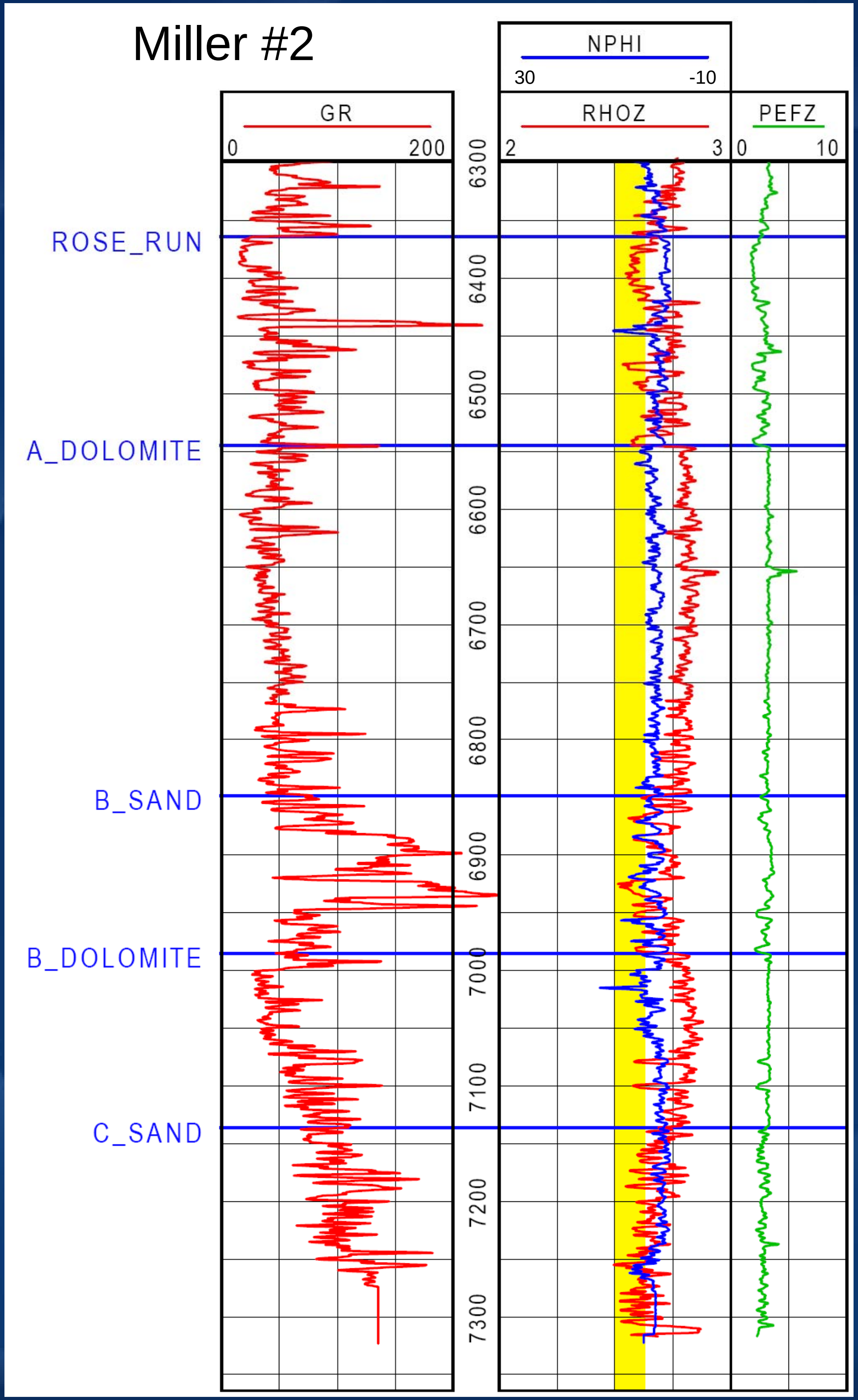


Lab Results

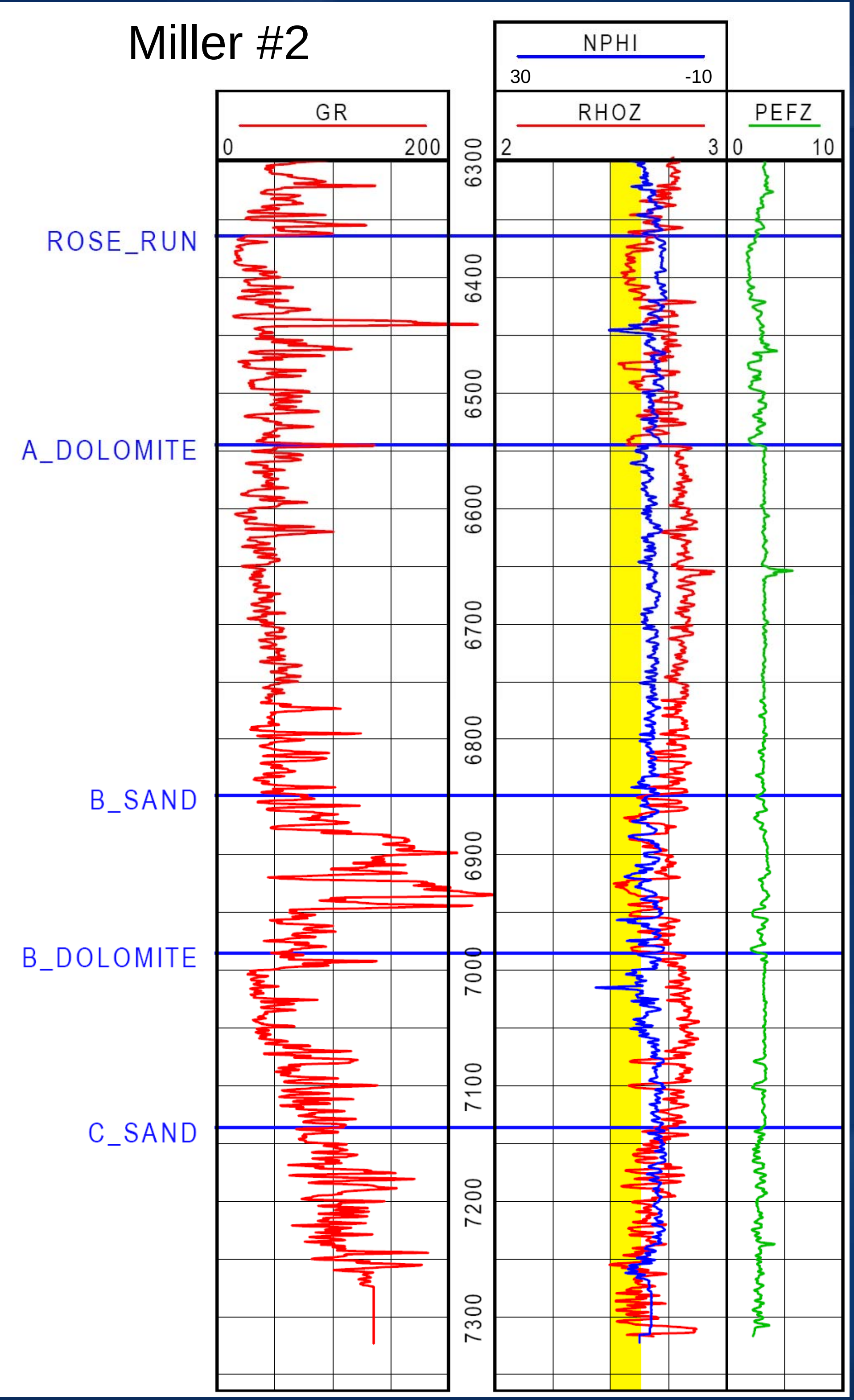
- Ideal sequestration reservoirs have porosities greater than 5% and permeabilities over 1 millidarcy
- Miller 2 samples group at around 1 to 6% porosity and <0.1 millidarcys

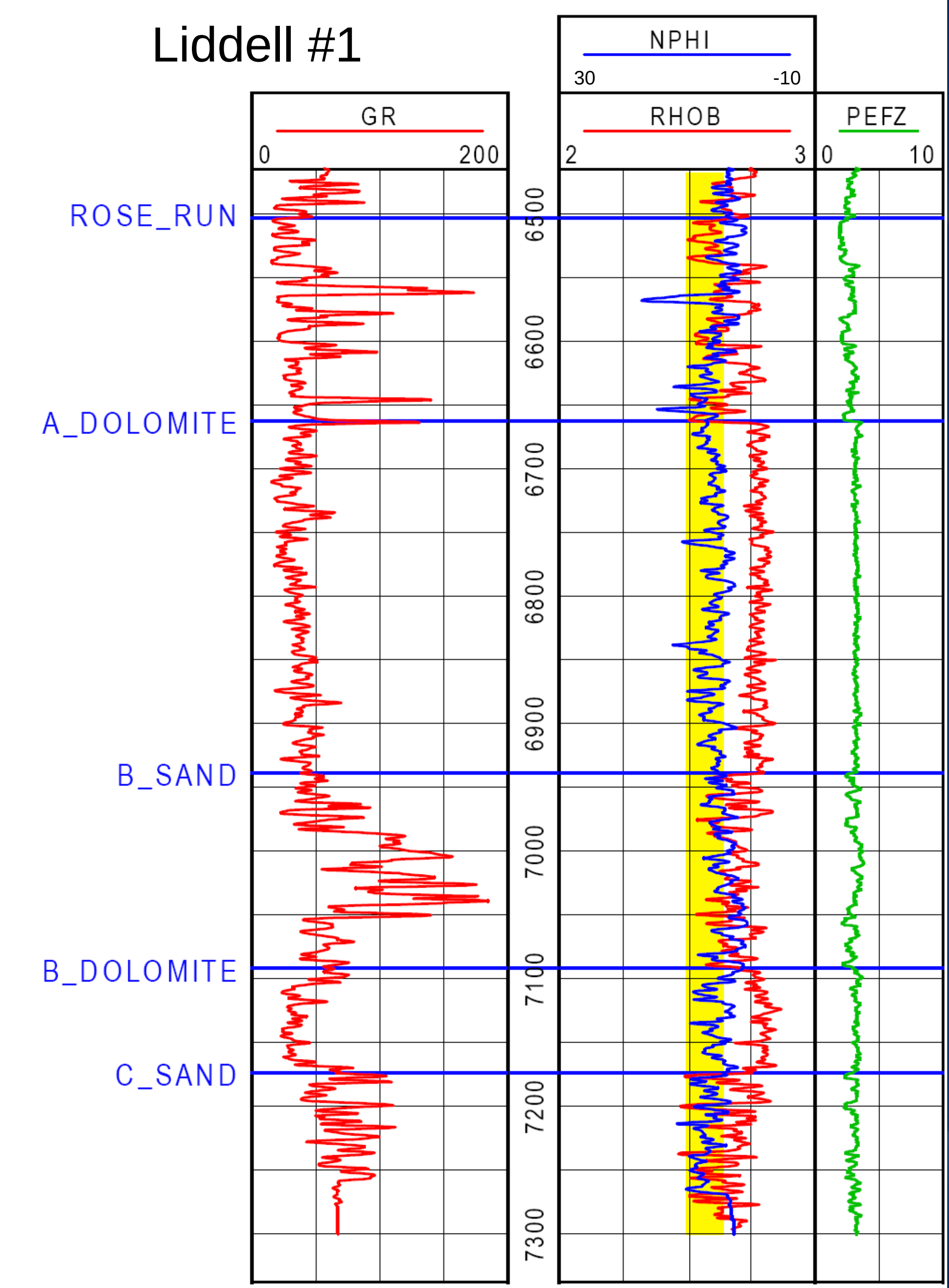


Borehole Logs

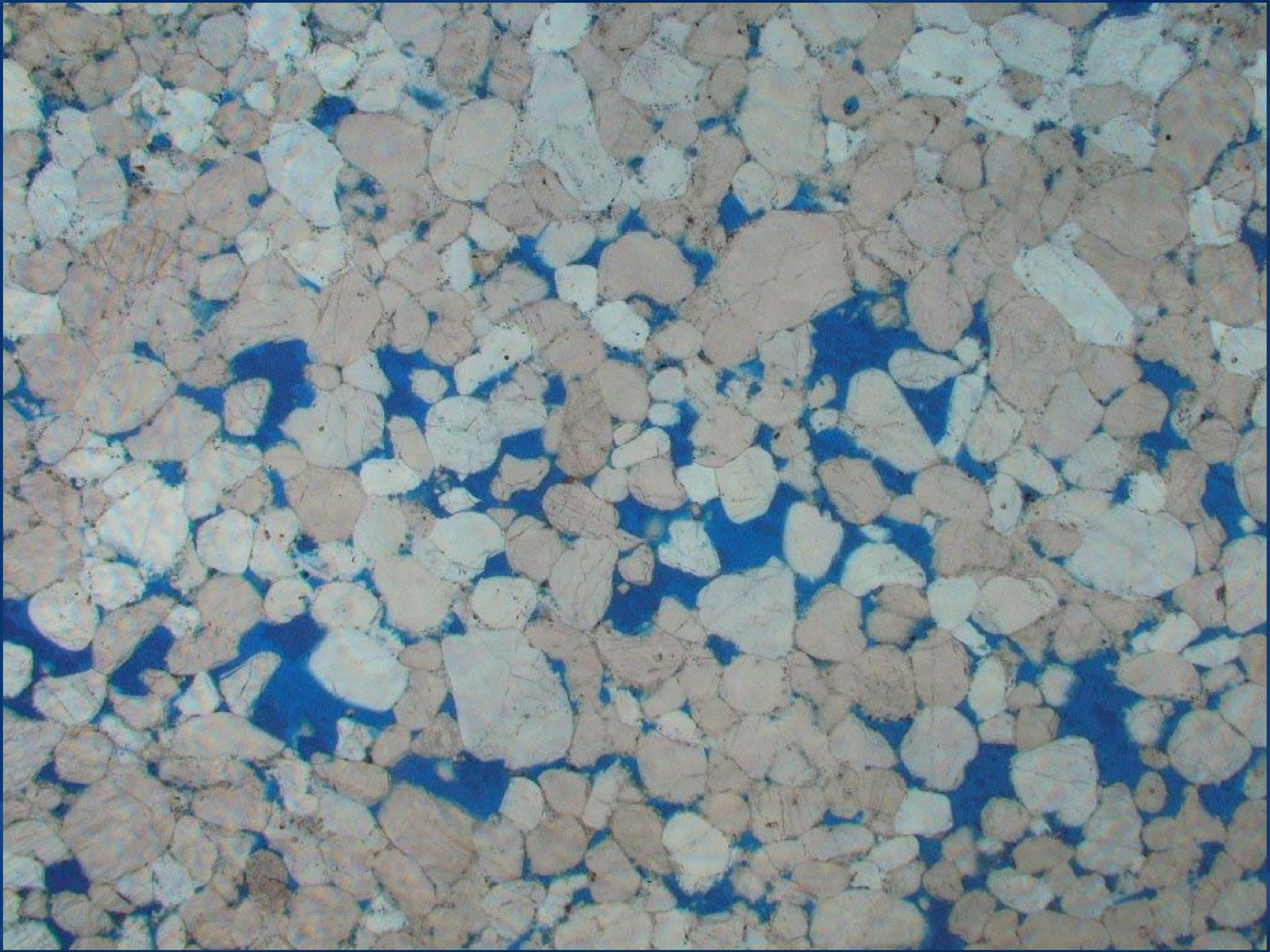


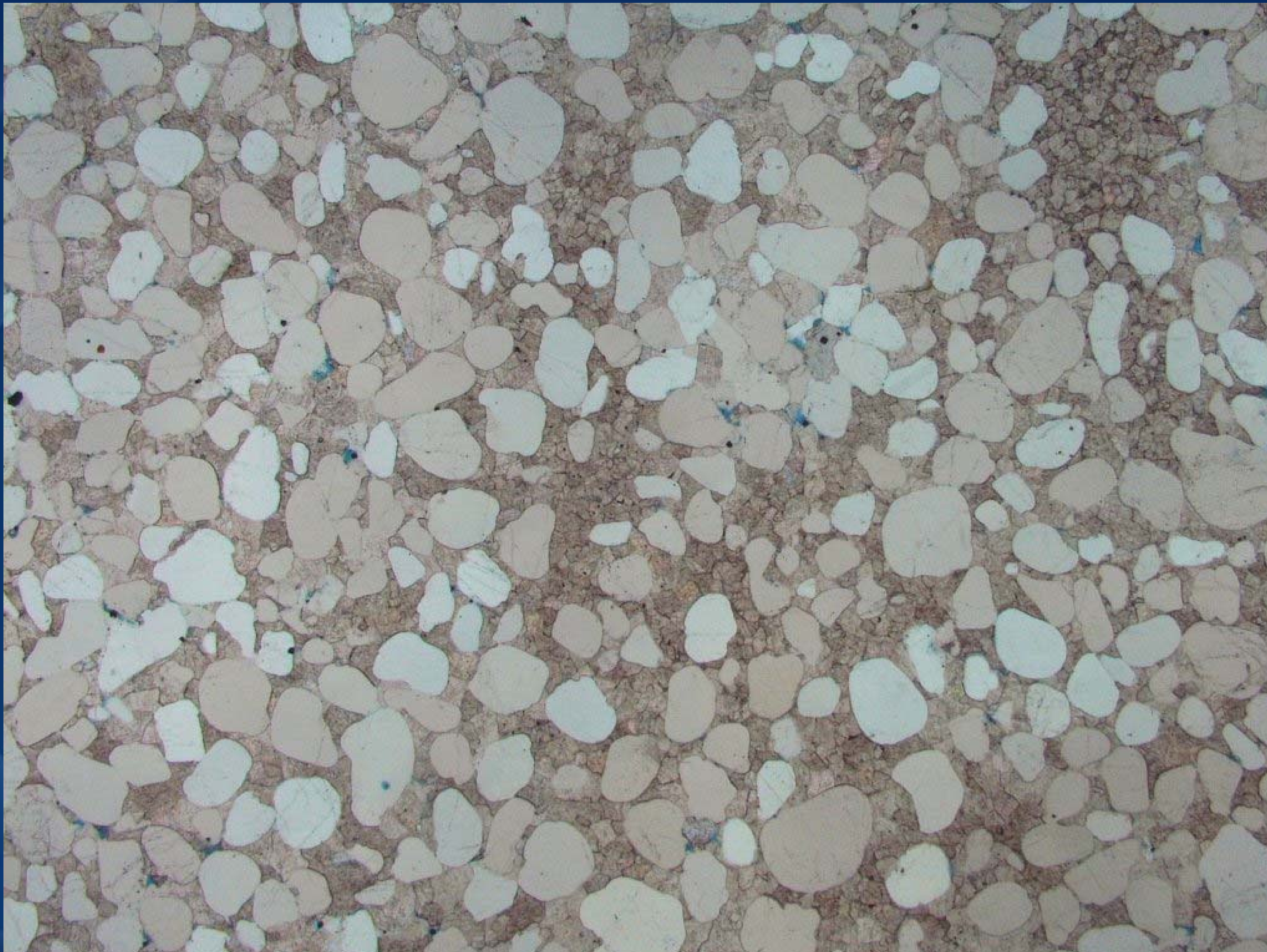
Borehole Logs



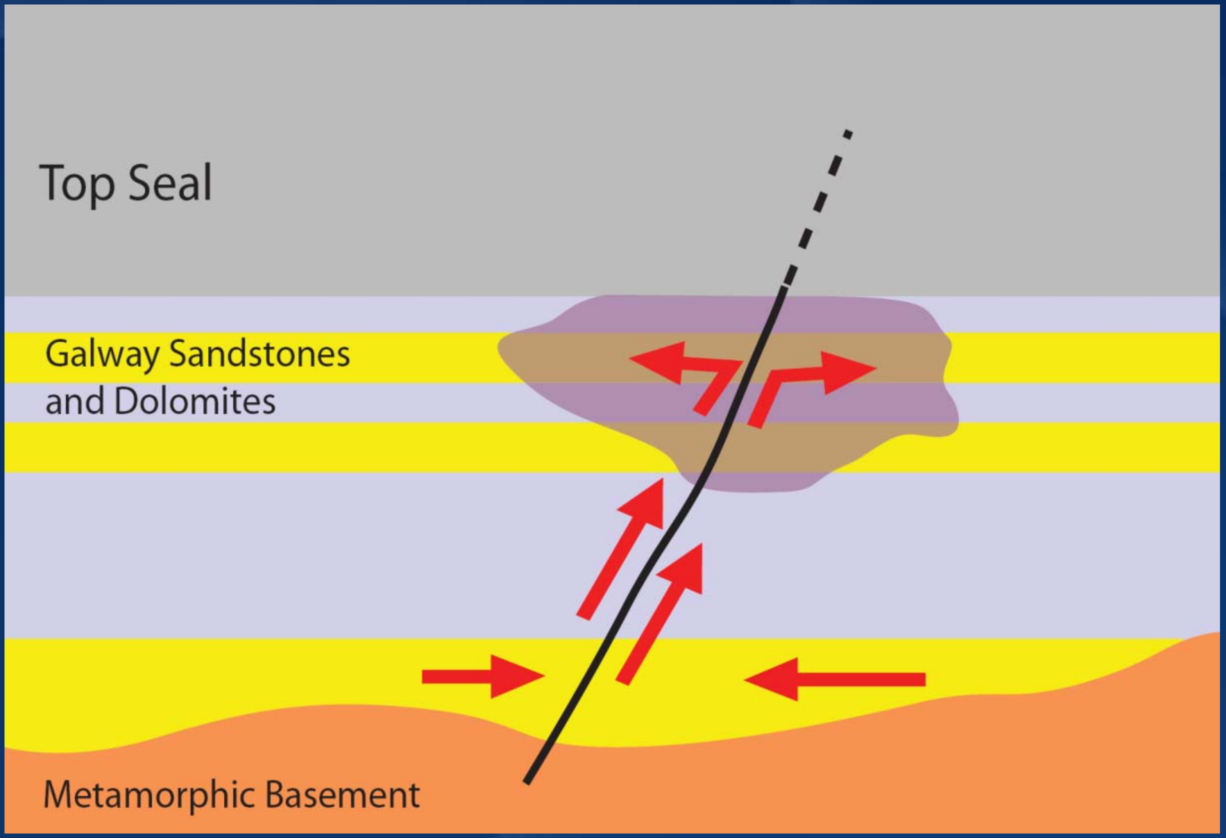


Thin Sections: Rose Run (Reservoir)



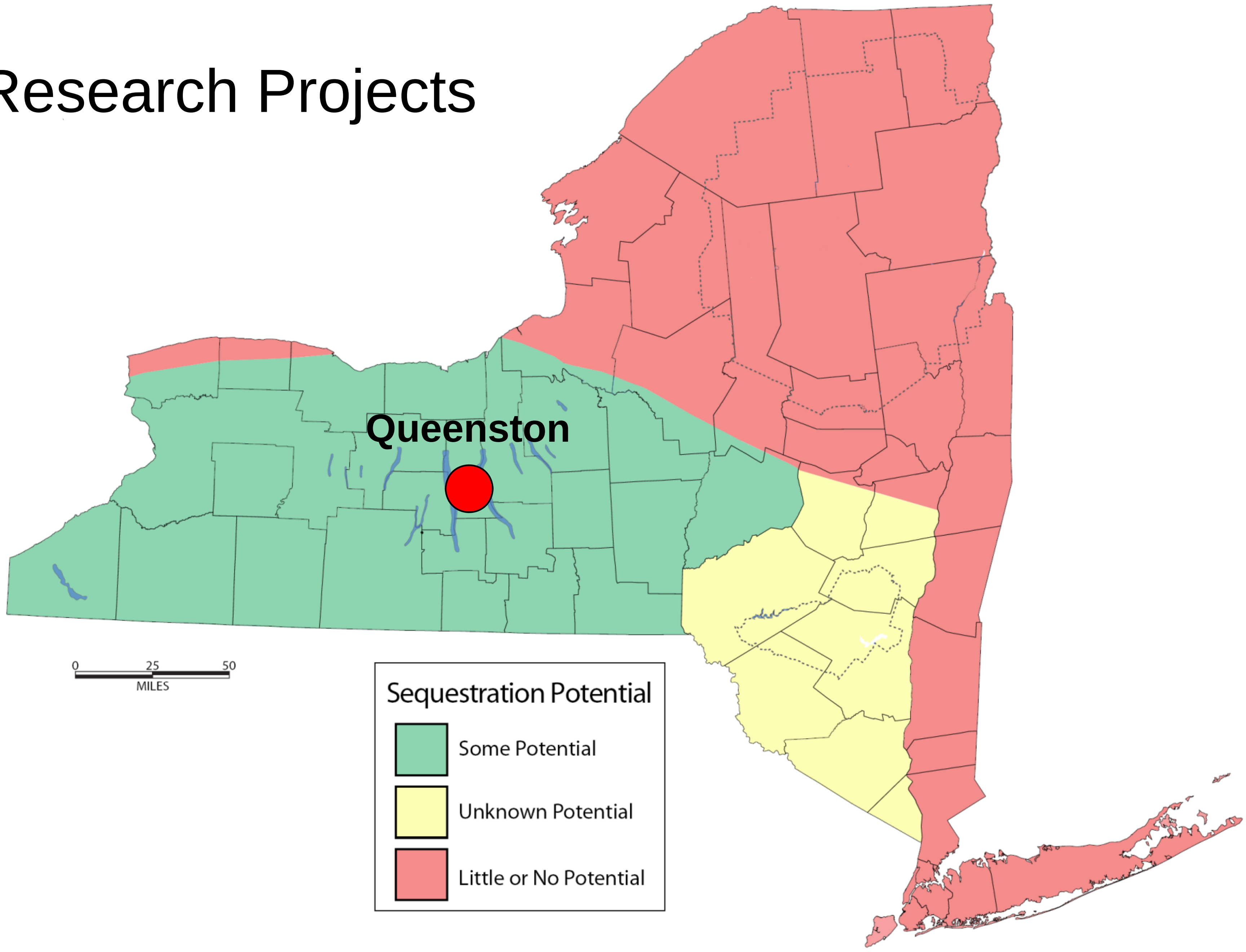


Interpretation

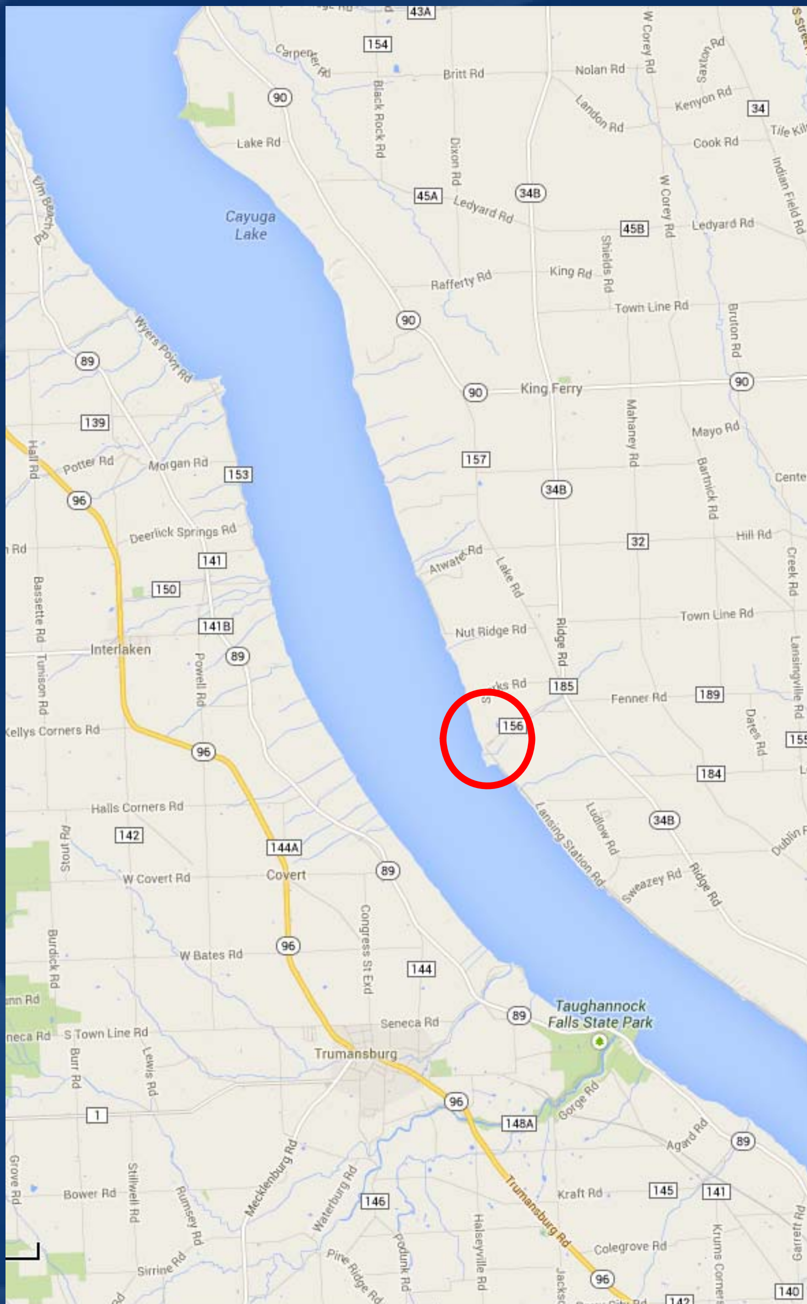


Secondary mineralization: The sandstones of the Galway and Potsdam formations may have been porous and permeable when they were deposited, but at some point after deposition, mineral-rich fluids were introduced to the area which led to the precipitation of dolomite. The Miller #2 site is not suitable for sequestration of CO_2, however, other nearby areas may not have been altered in this way and therefore could have reservoir qualities more appropriate for injection of CO_2.

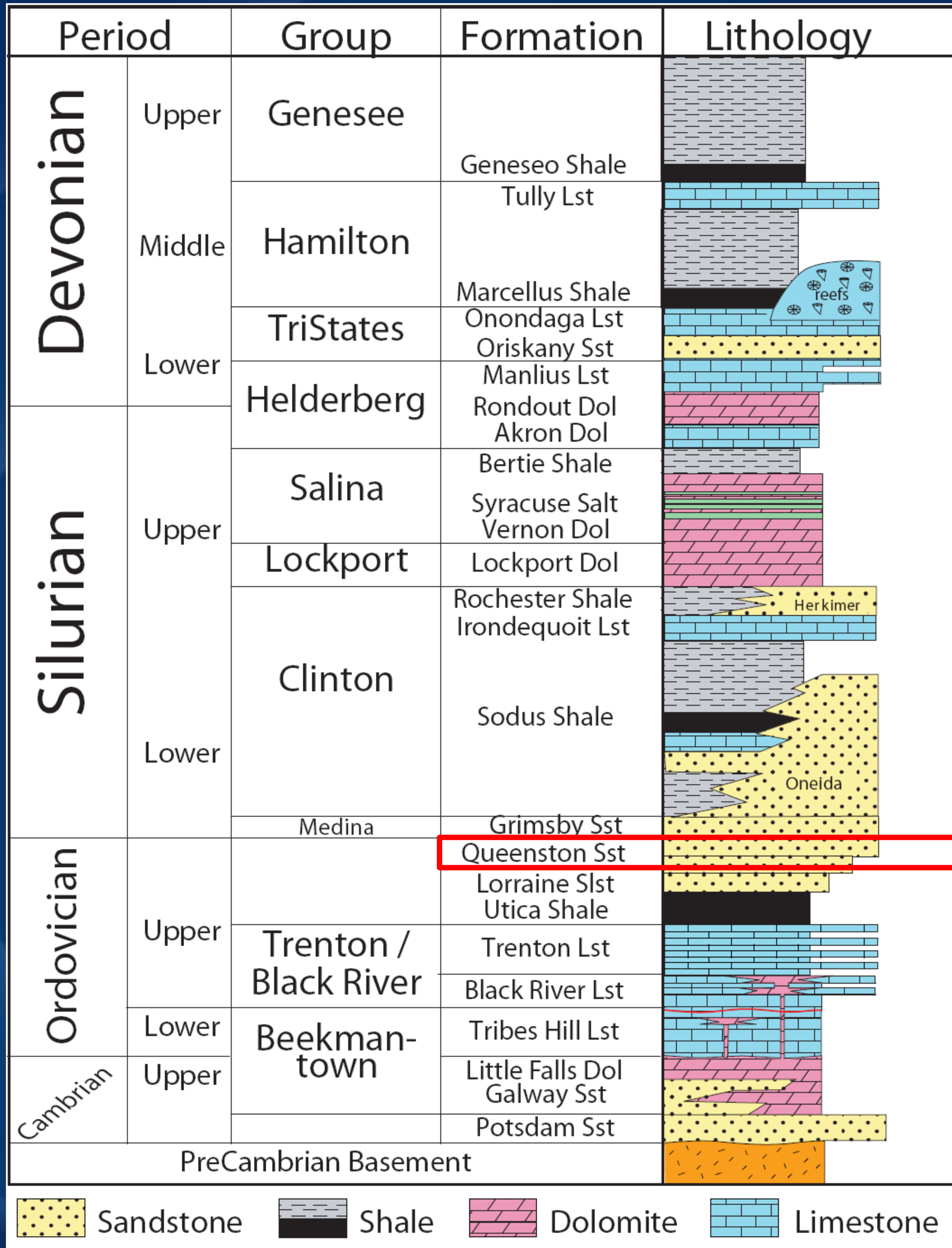
Research Projects



AES Cayuga Power Plant Project



- Coal-fired power plant located on the eastern shore of Cayuga Lake
- Produces 306 mW of electricity and 2.4 million tons of CO_2 per year

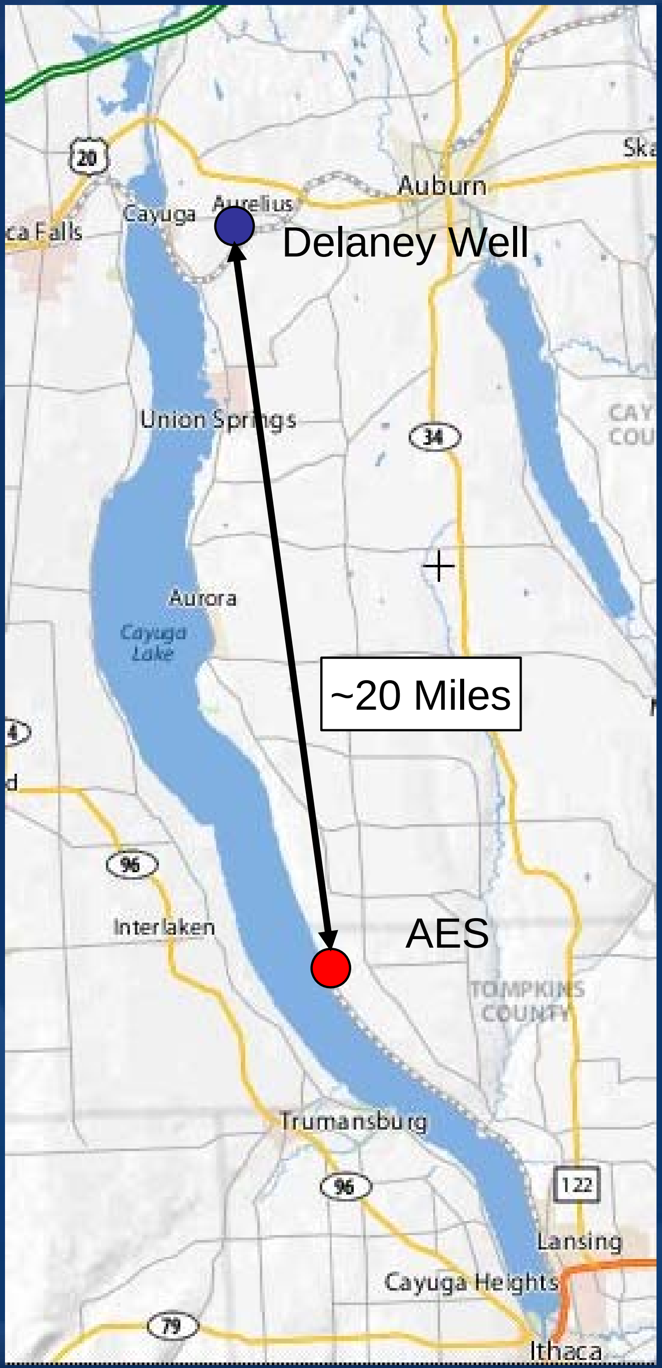


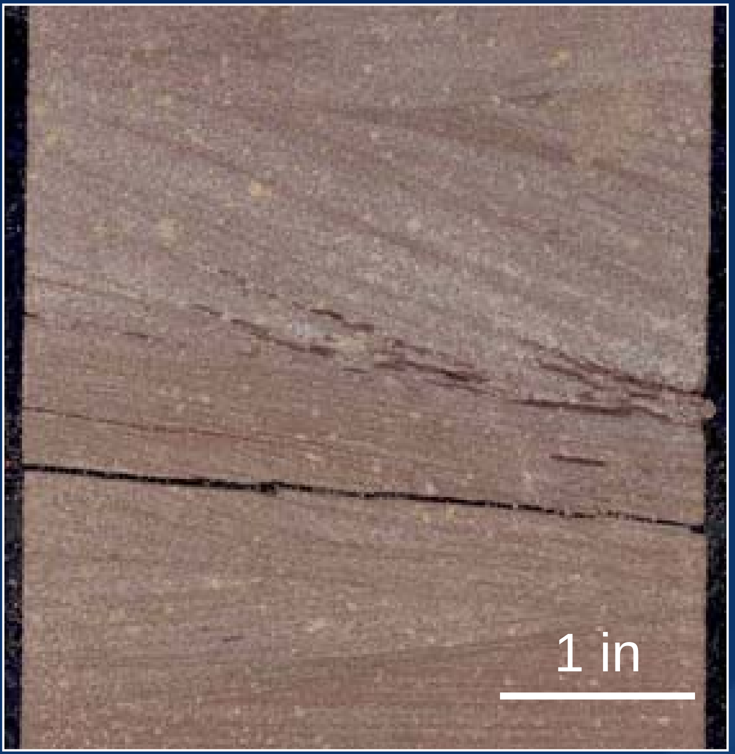
Target Reservoir

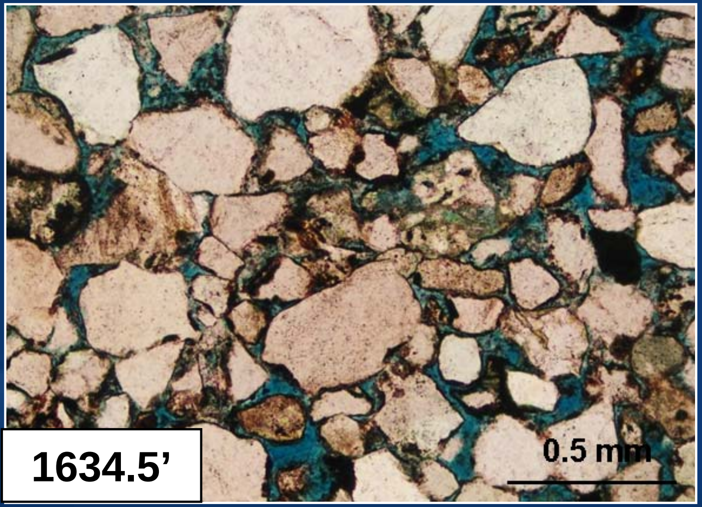
The Queenston is actually a shale in some parts of the State, however it occurs as a sandstone in portions of central and western NY.

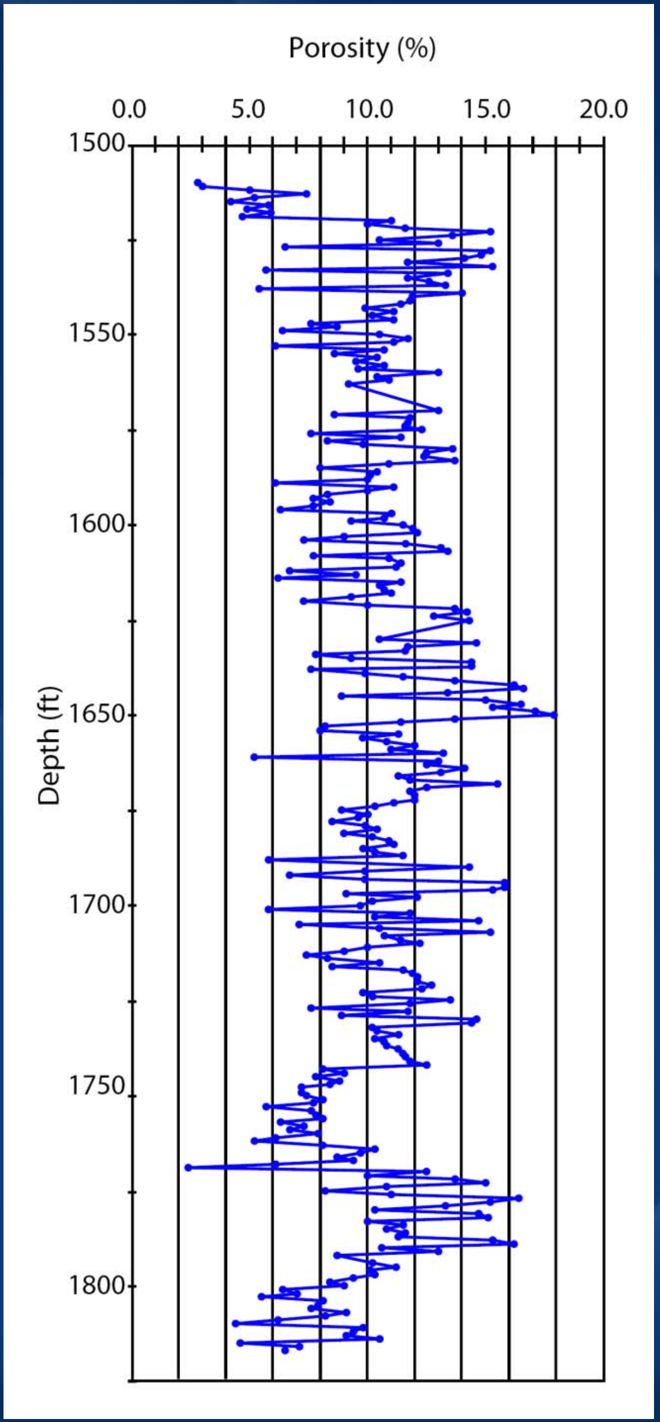
With the help of the State Museum, Kathryn Tamulonis studied the sequestration potential near the Cayuga power plant as part of her PhD dissertation from Cornell.

Queenston Core – Delaney Well



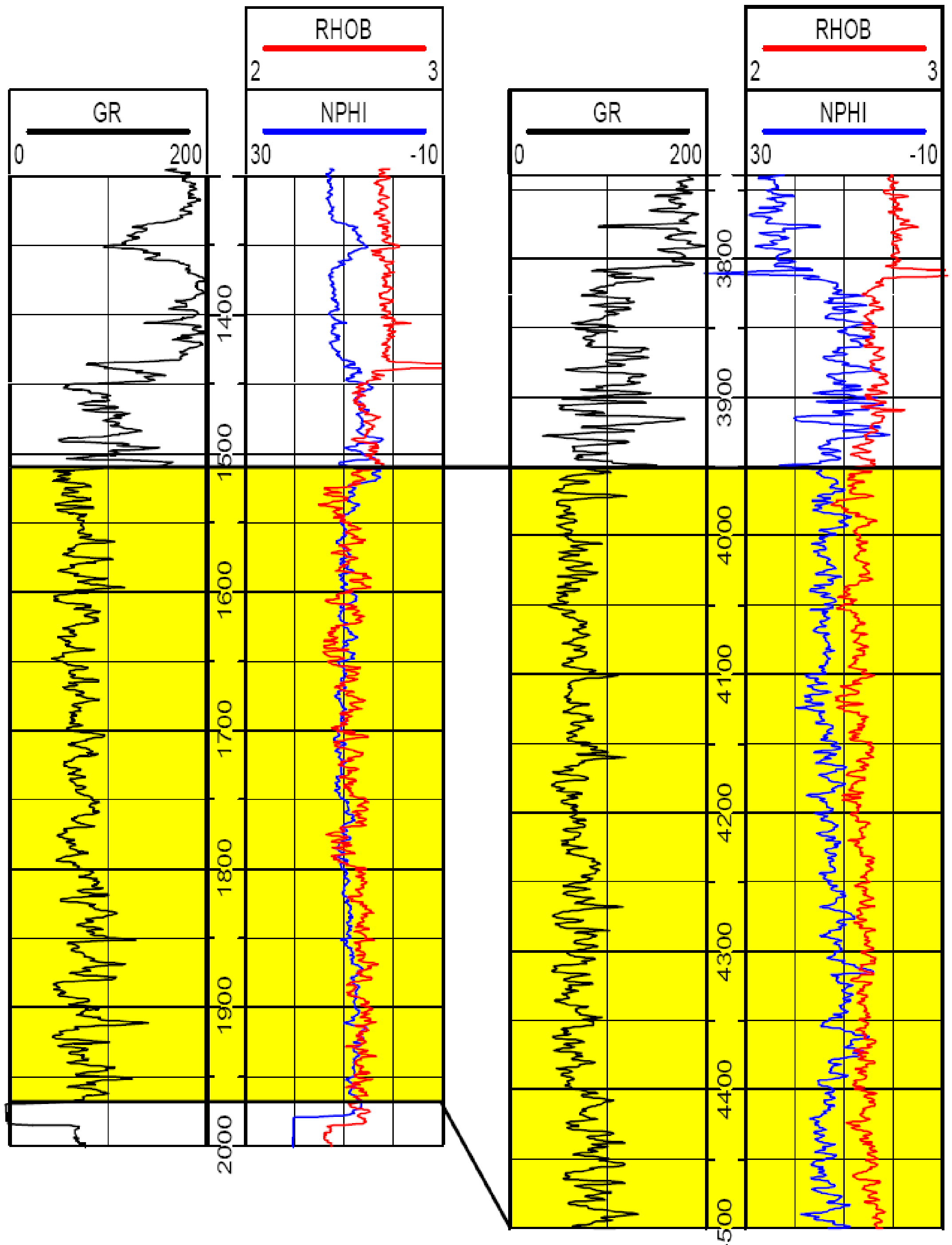


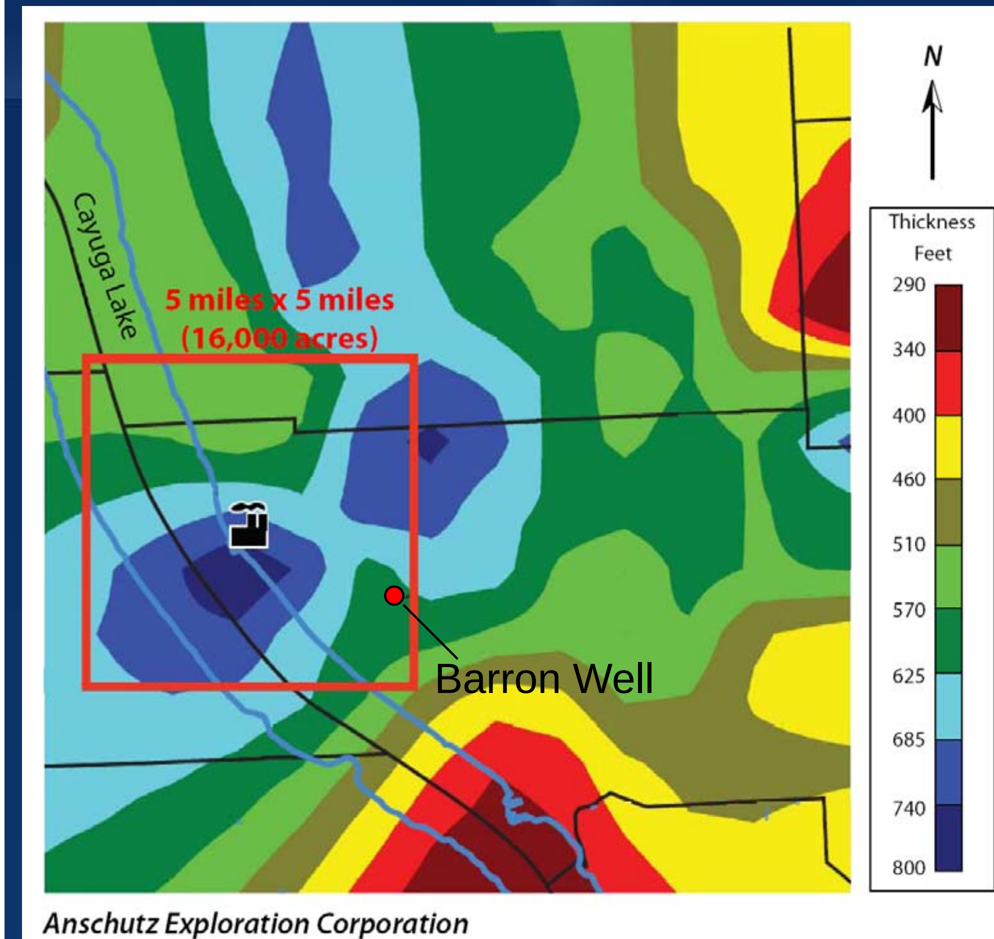




Delaney Well
13645-00-00

Barron Well
26039-00-00





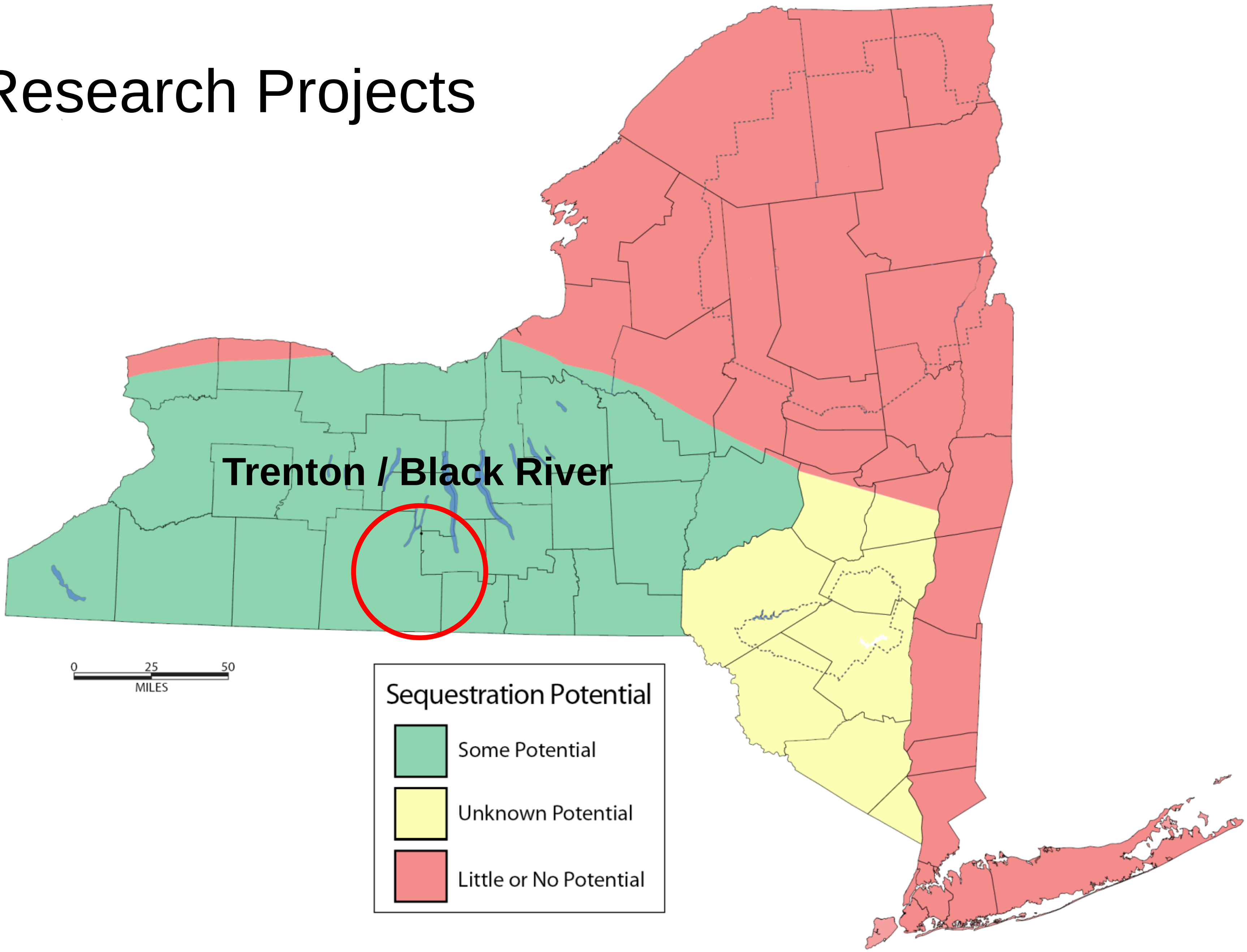
CO_2 Density	Reservoir Thickness	Reservoir Area	Reservoir Porosity	Water Saturation

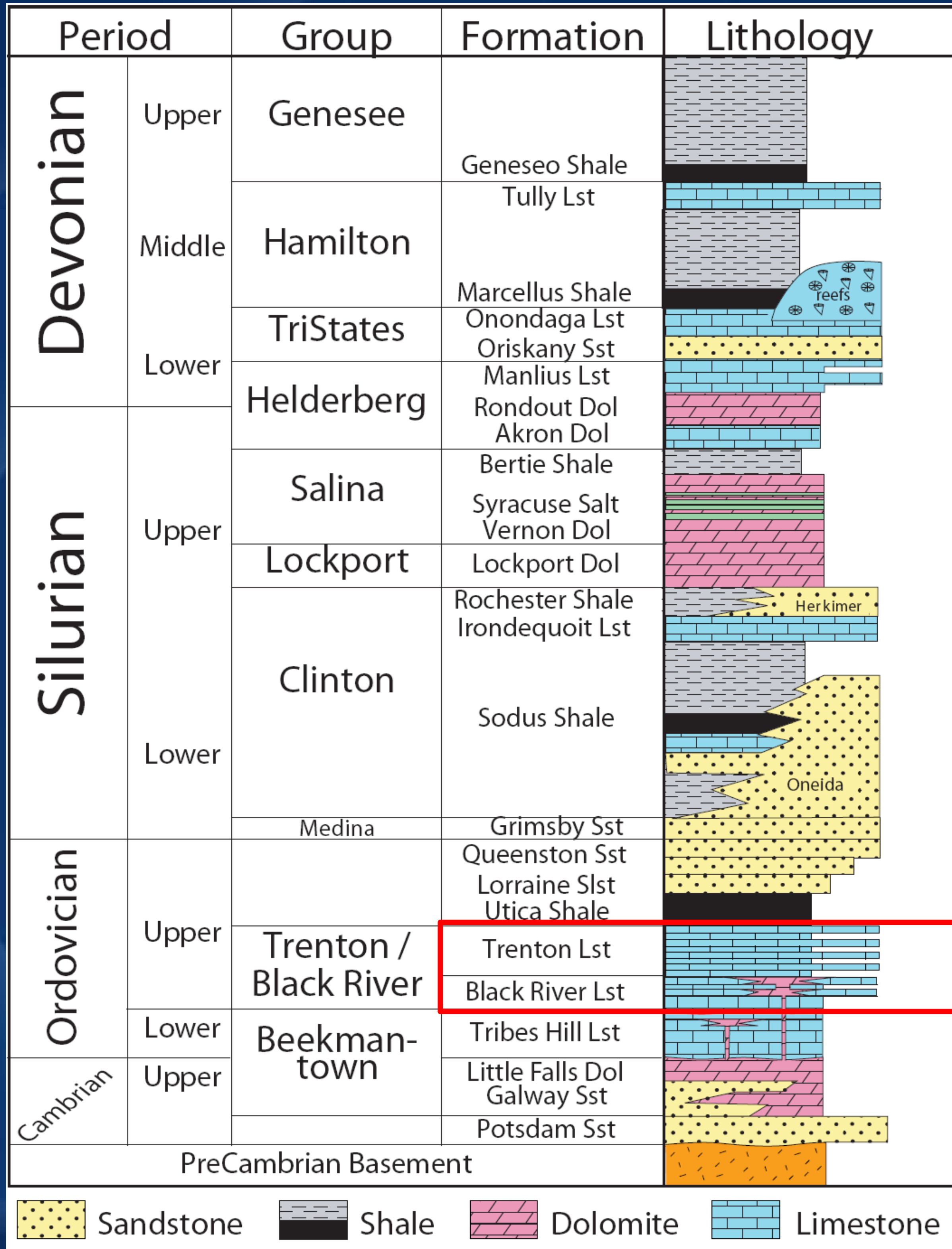
$$CO_2\ \text{Capacity} = \frac{40.5\ \text{lbs/ft}^3 \times 600\ \text{ft} \times 16{,}000\ \text{ac} \times 10\% \times (1 - 95\%)}{2200}$$

= 38.5 million tons of CO_2

= 16 years of output

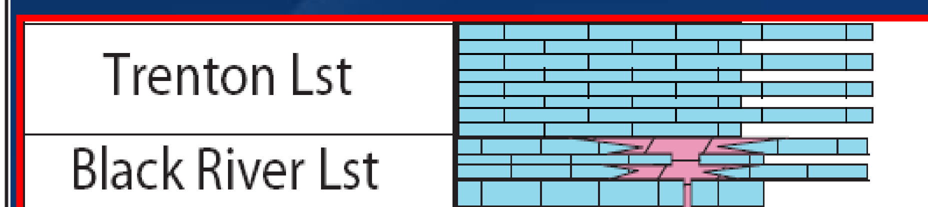
Research Projects



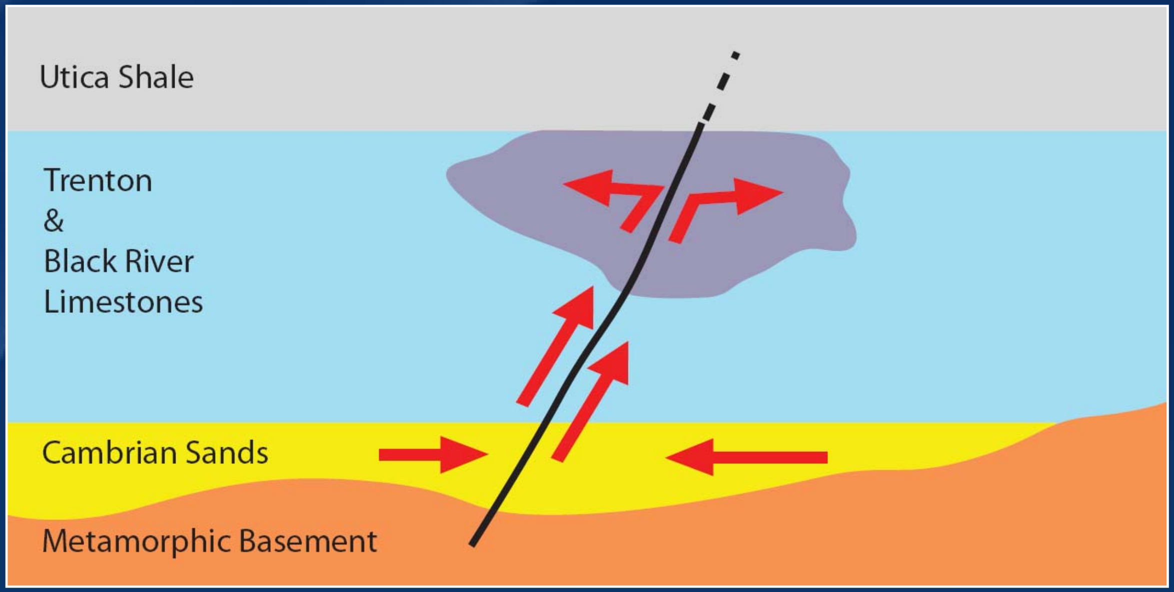


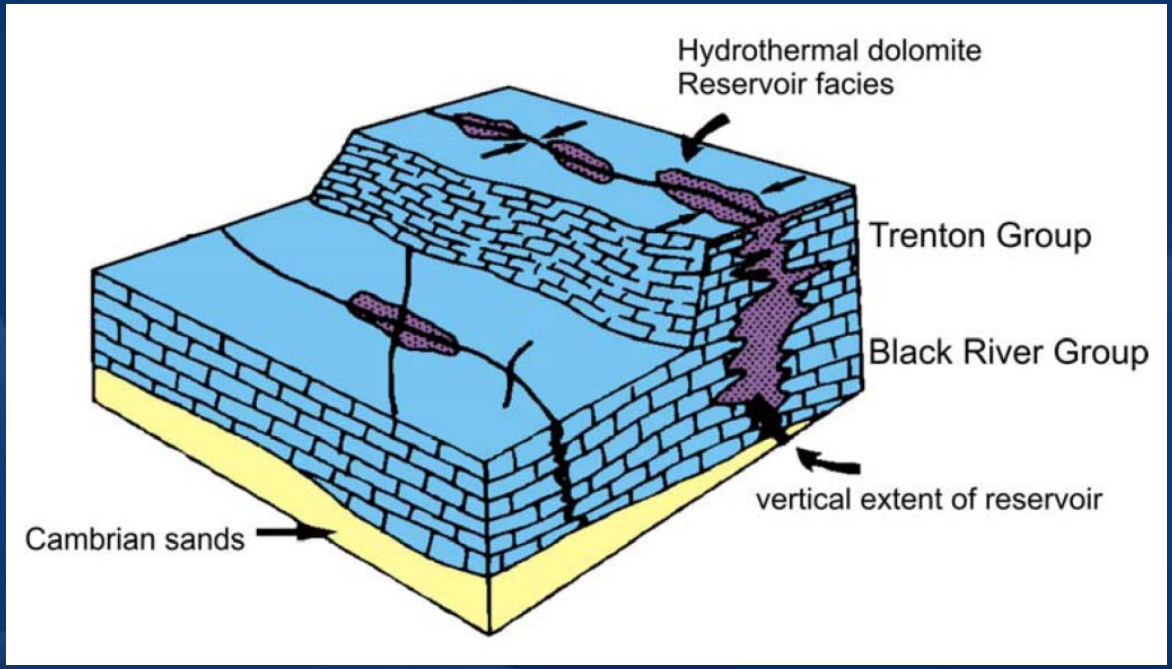
Target Reservoir

The Trenton – Black River Formations are low-porosity limestones across most of the state, but there are some areas where they occur as dolomites. These are the areas we're interested in.

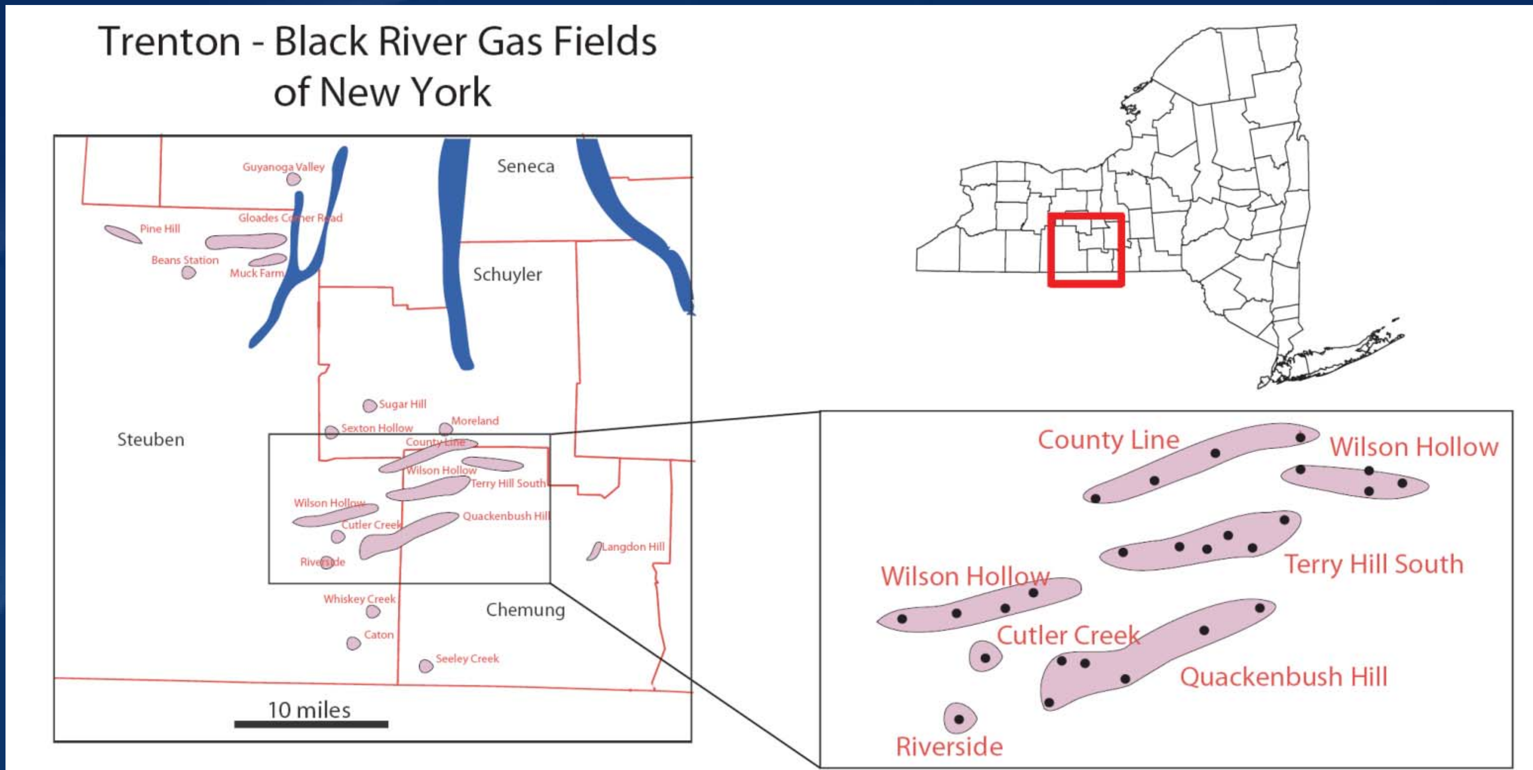


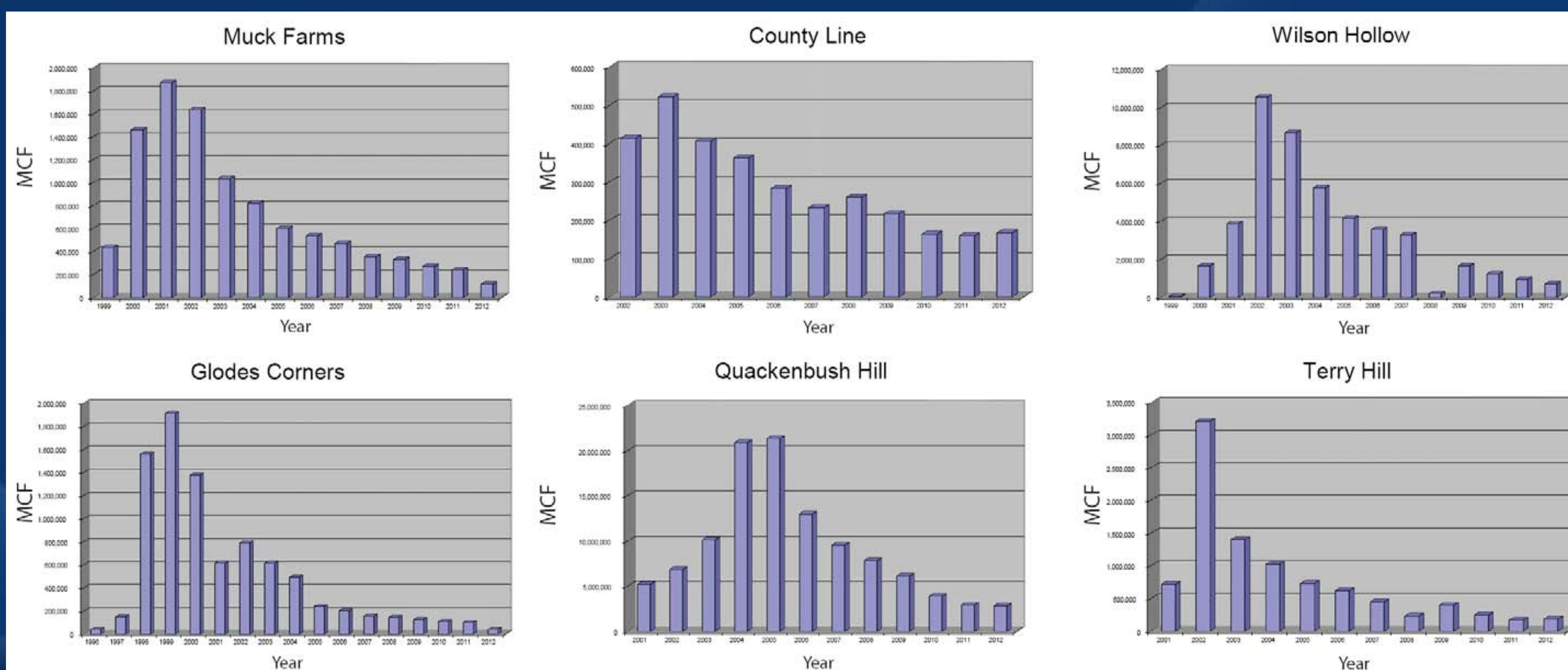
Hydrothermal Dolomite



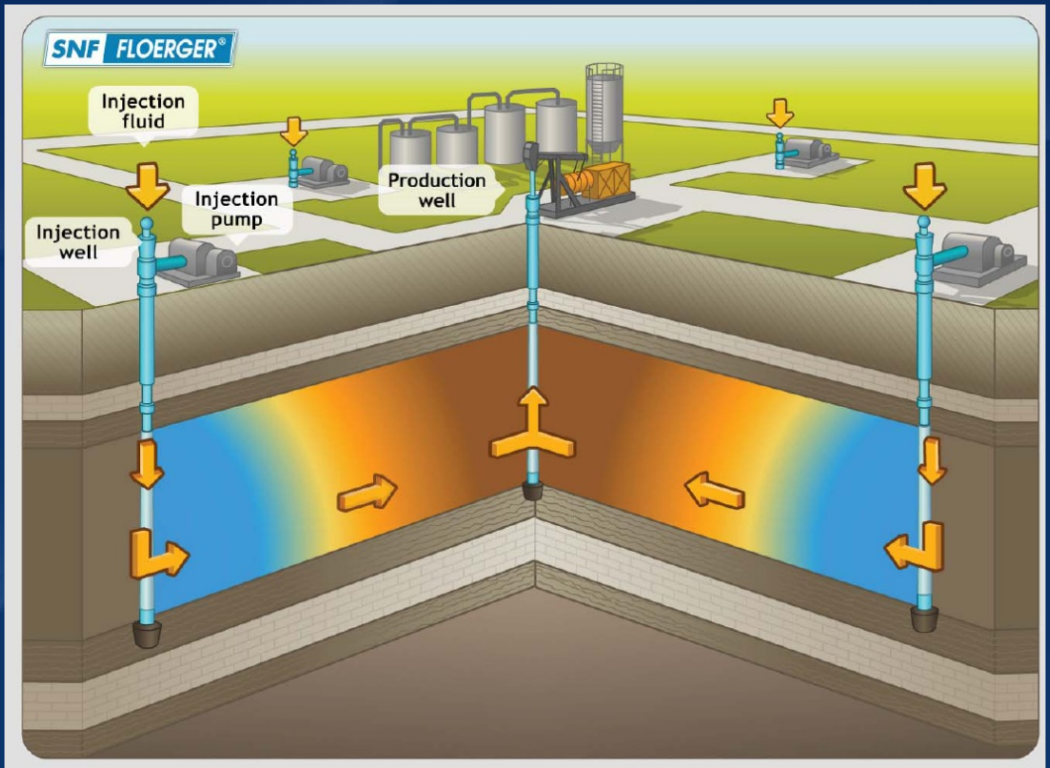


Trenton – Black River Gas Production





Enhanced Gas Recovery (EGR)



The use of injected fluids to repressurize a reservoir and push the remaining hydrocarbons toward production wells.

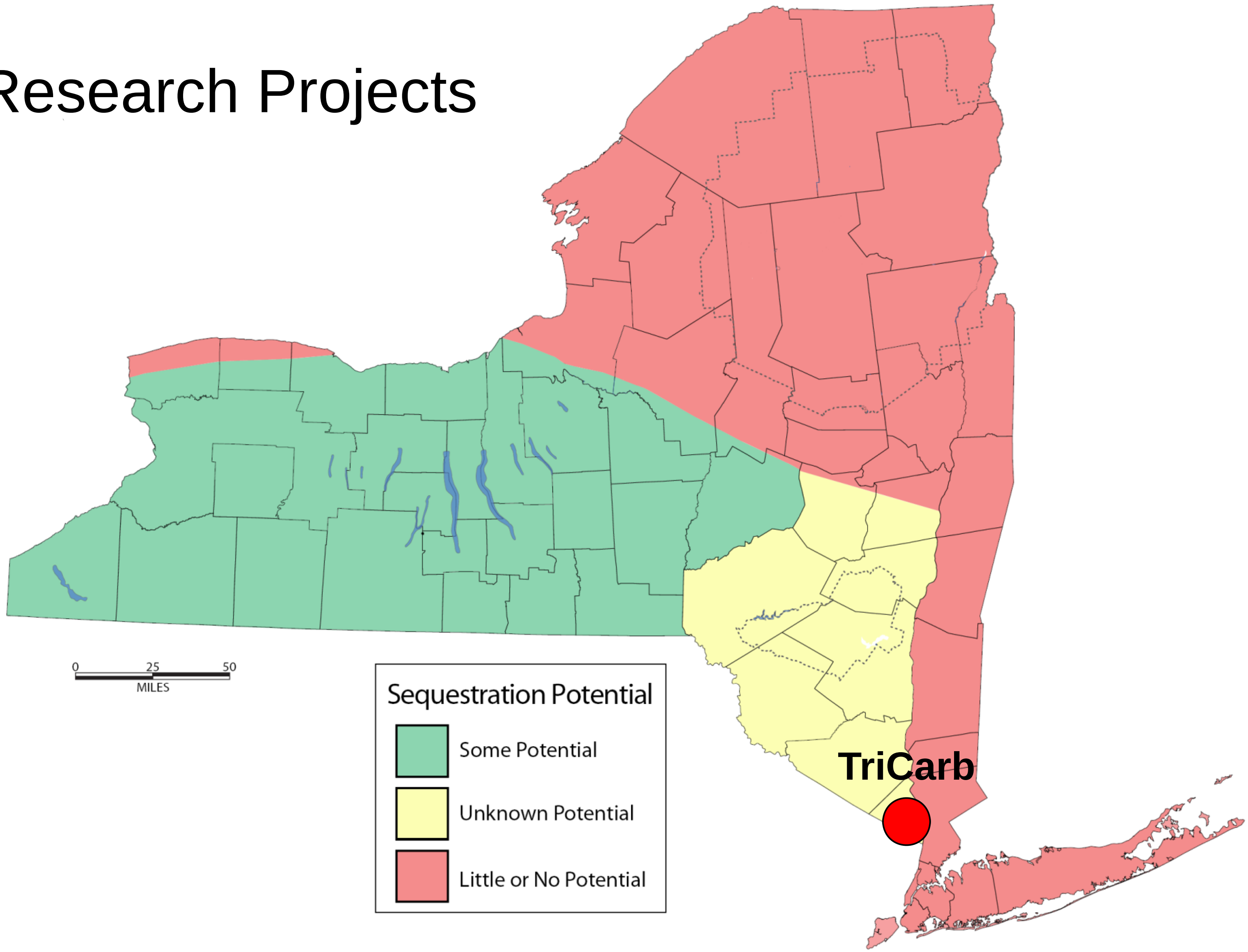
This technique has bee in practice for over a hundred years, but water is usually used for cost purposes.

Depleted oil and gas reservoirs are proven containers that have safely held hydrocarbons for millions of years.

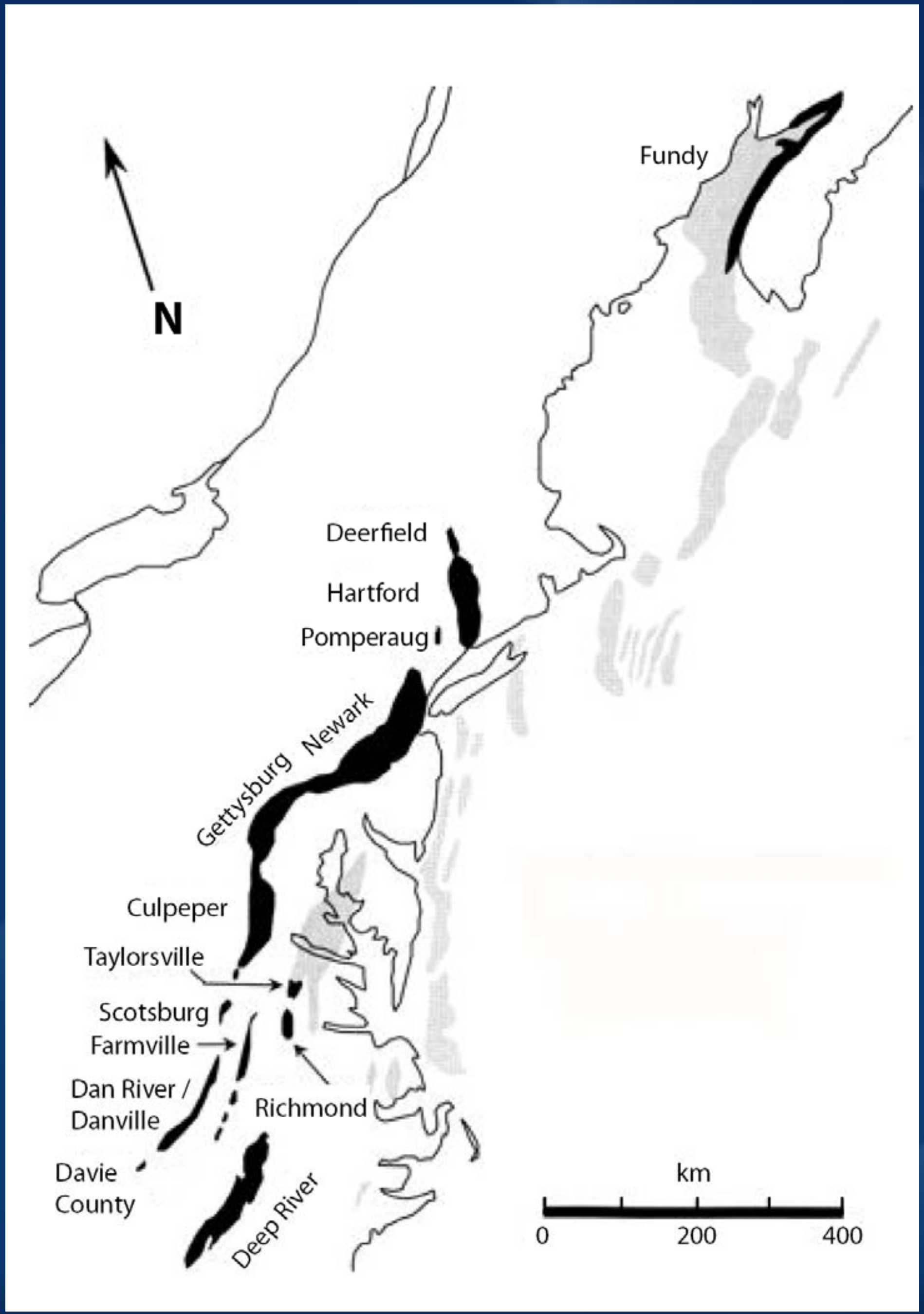
Companies can recoup the cost of sequestration by the production of more oil or gas.

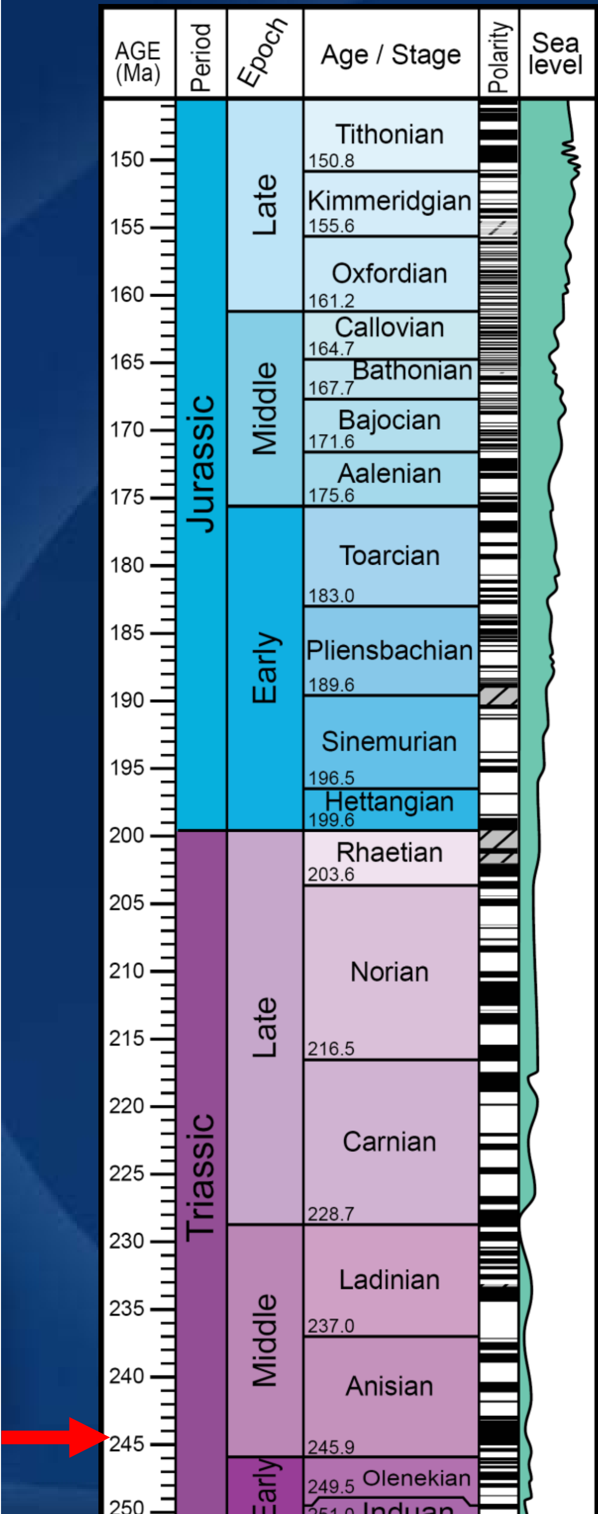
Field	Avg. Depth (feet)	# Wells	Production (mmcf)	Storage Capacity
Quakenbush Hill	9500	12	110,438	15.83
Wilson Hollow	9500	11	46,417	6.65
Muck Farm	7000	4	10,165	1.46
Glodes Corners Road	7000	15	8,678	1.24
Terry Hill South	9000	7	9,371	1.34
County Line	9000	4	3,190	0.46
TOTAL			188,260 billion ft^3	**26.98** million tons

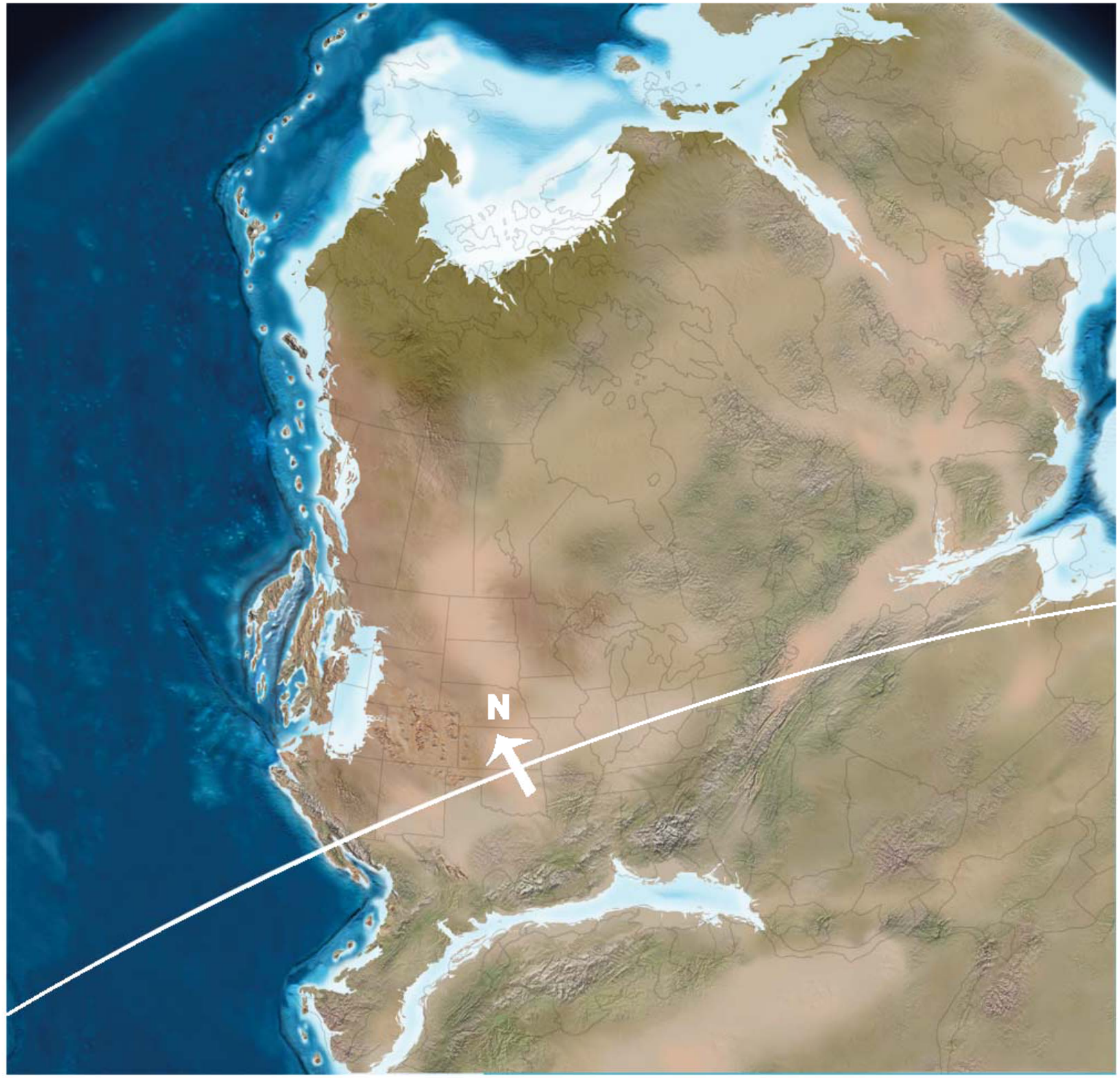
Research Projects



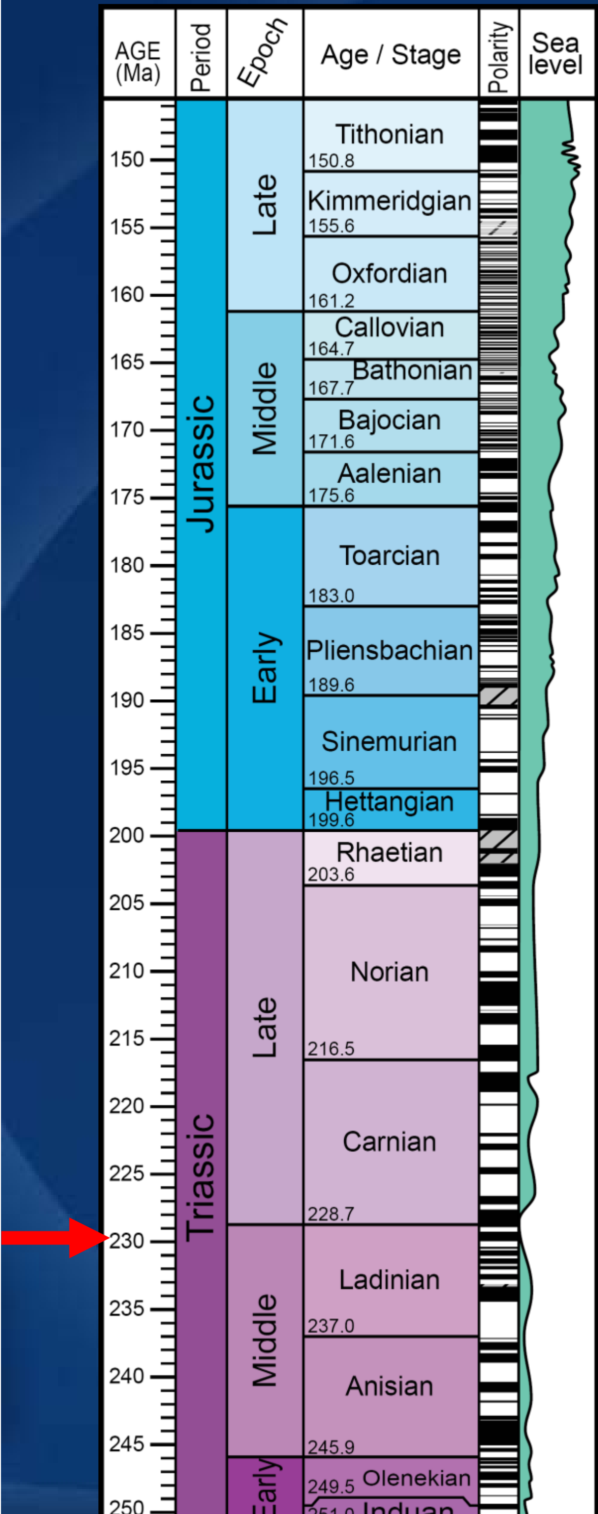
Newark Rift Basin – TriCarb Project

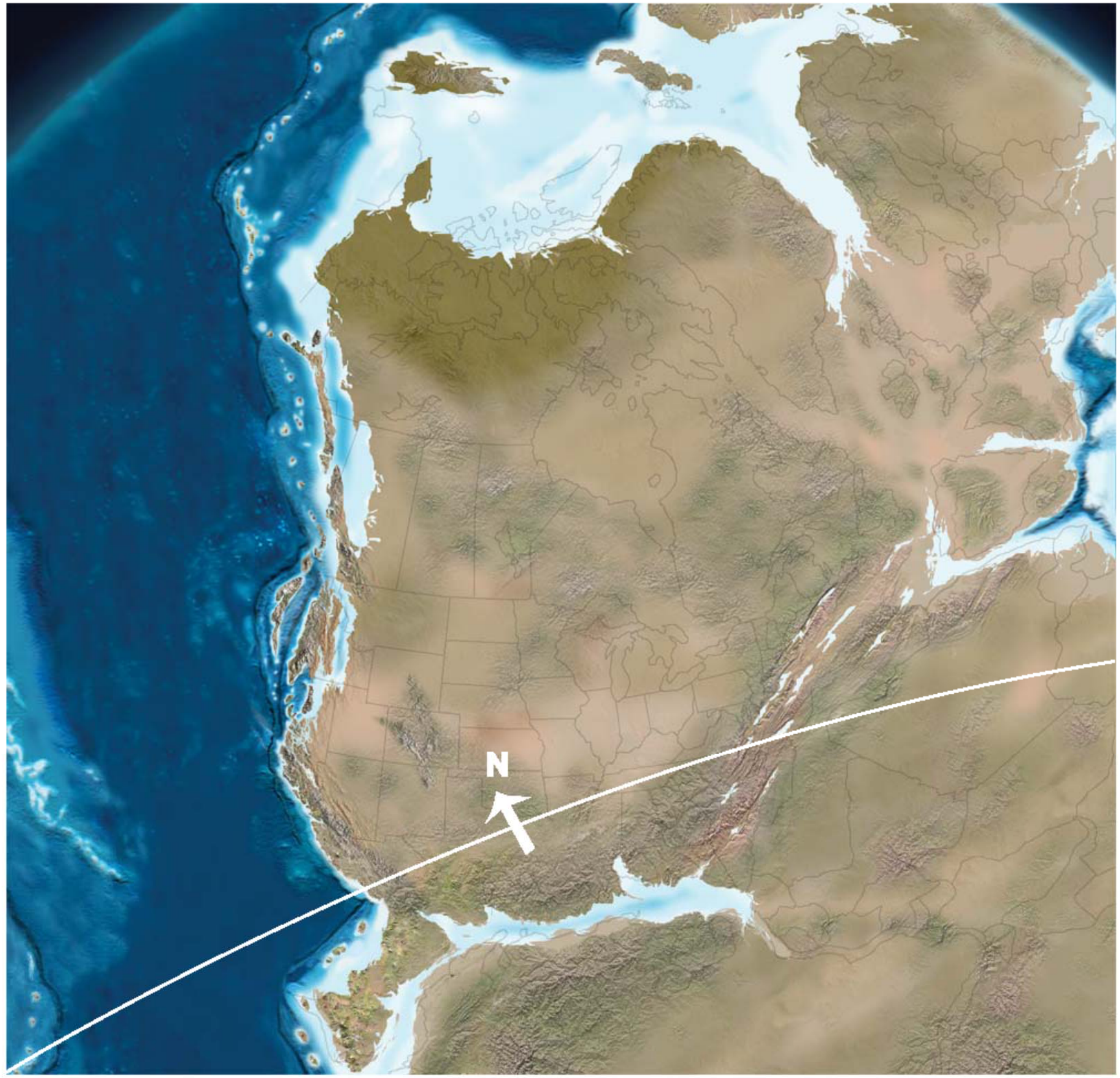




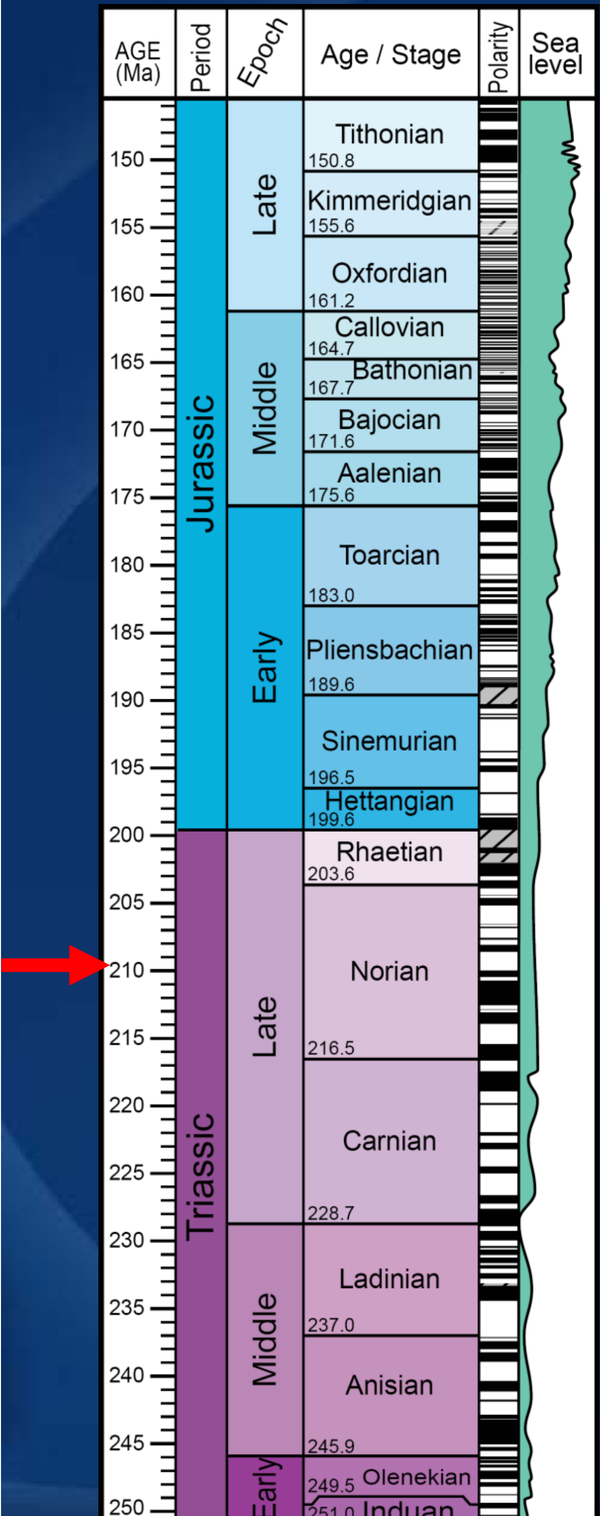


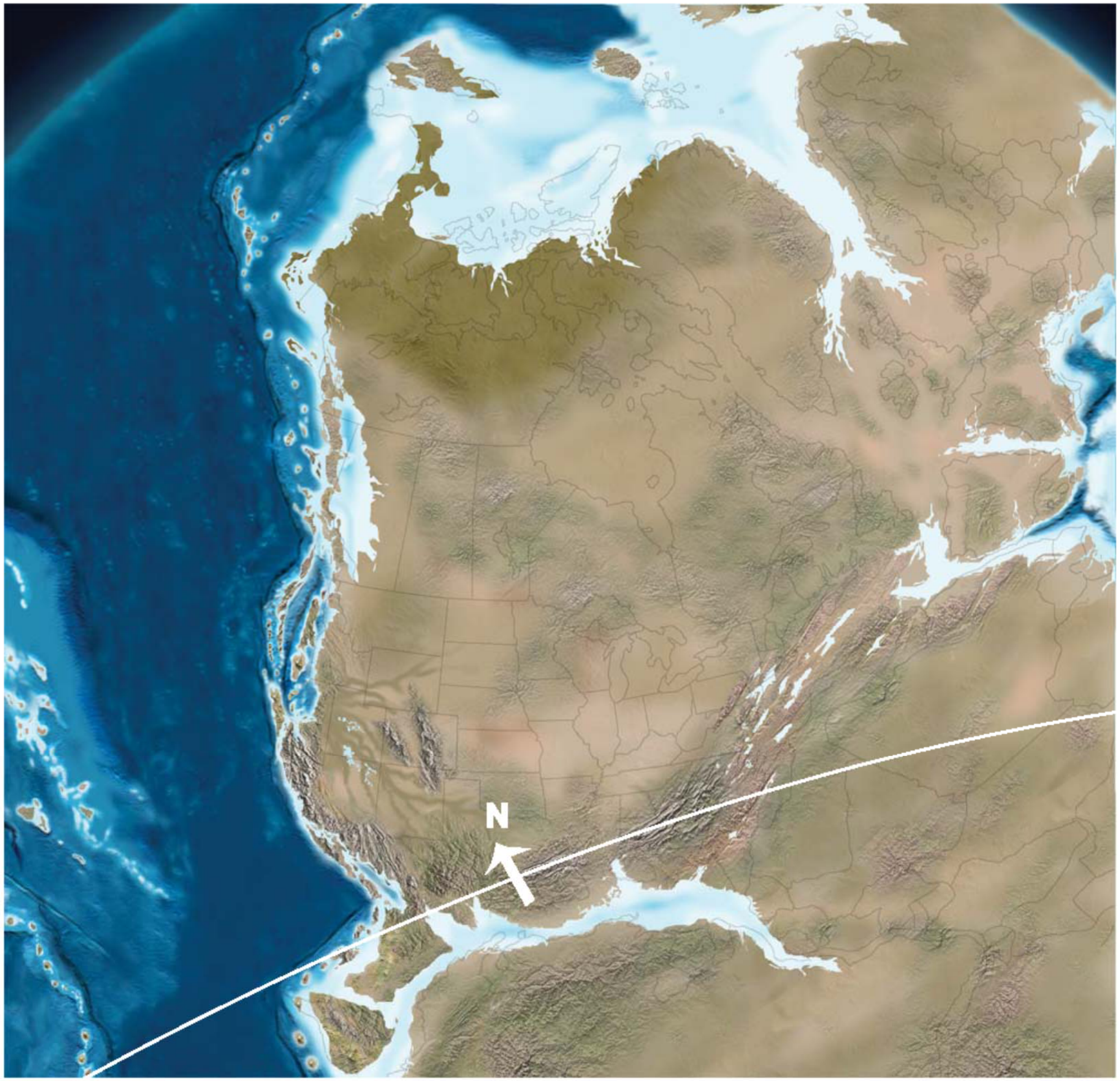
(From Ron Blakey website)



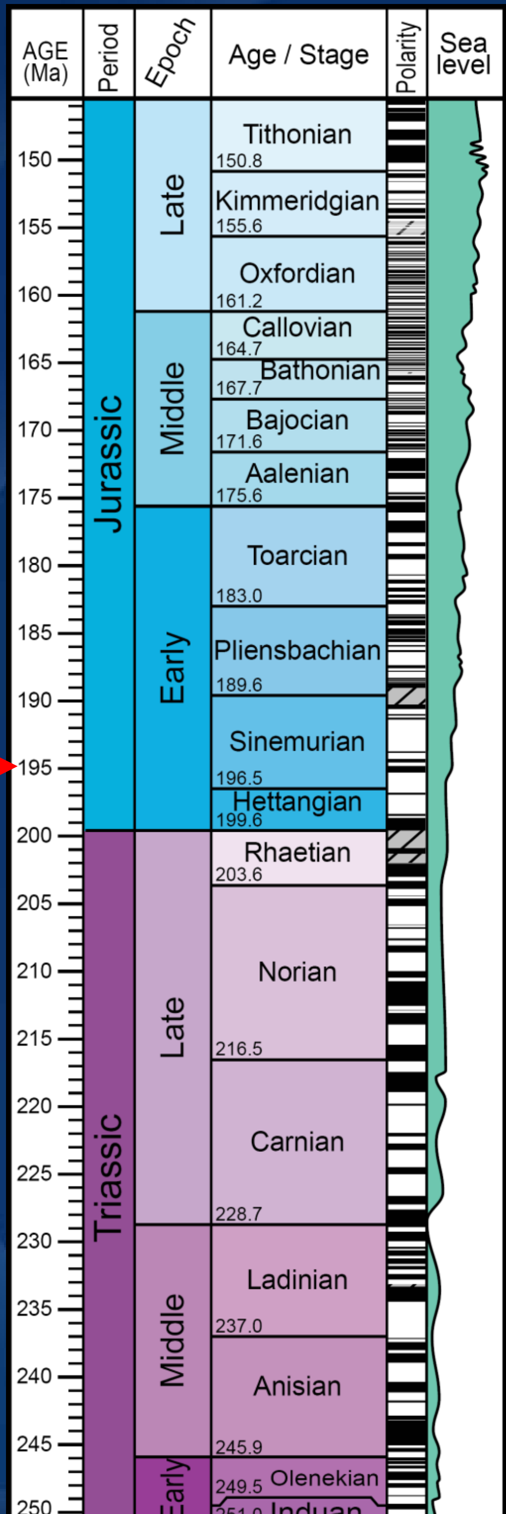


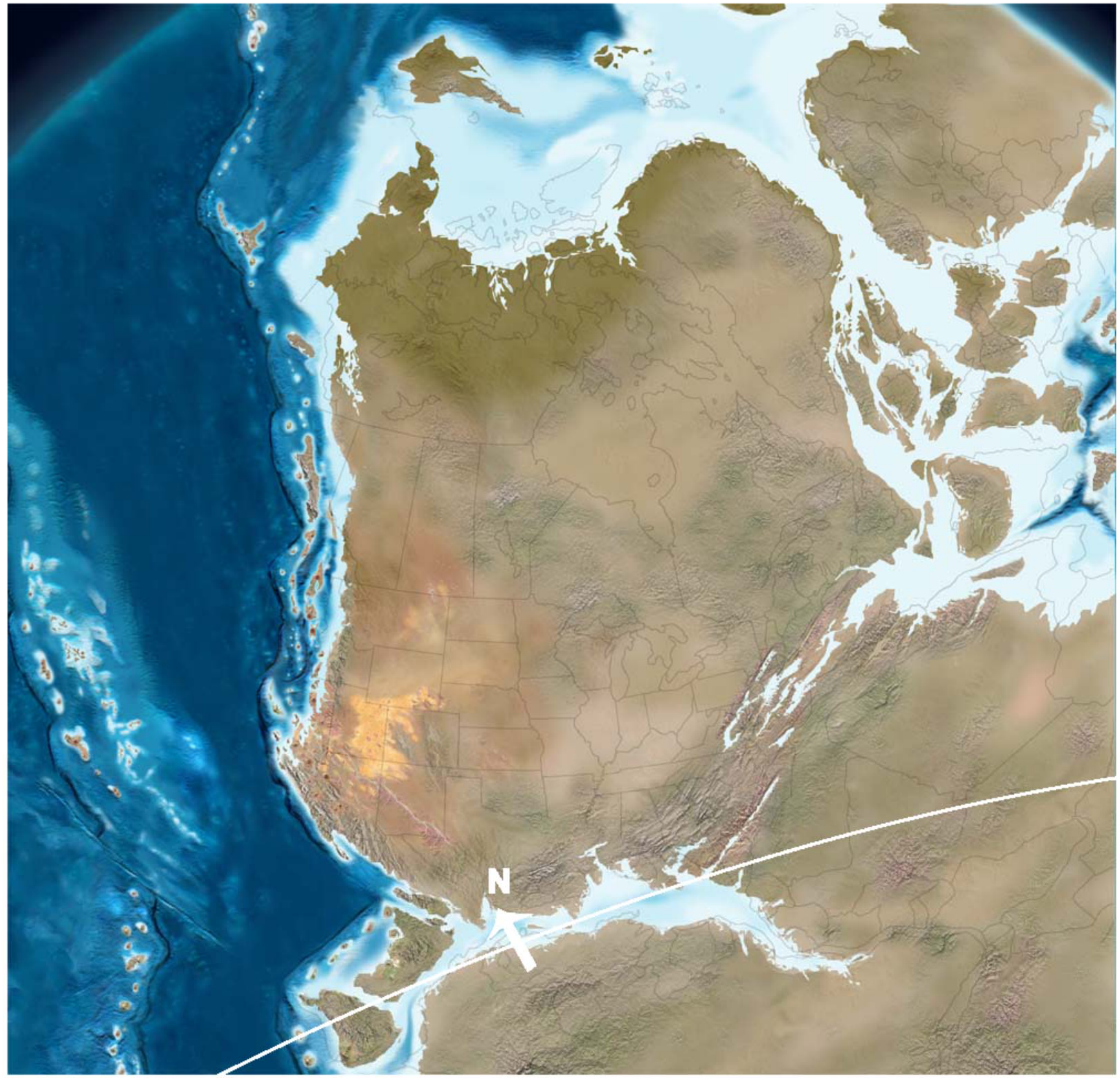
(From Ron Blakey website)



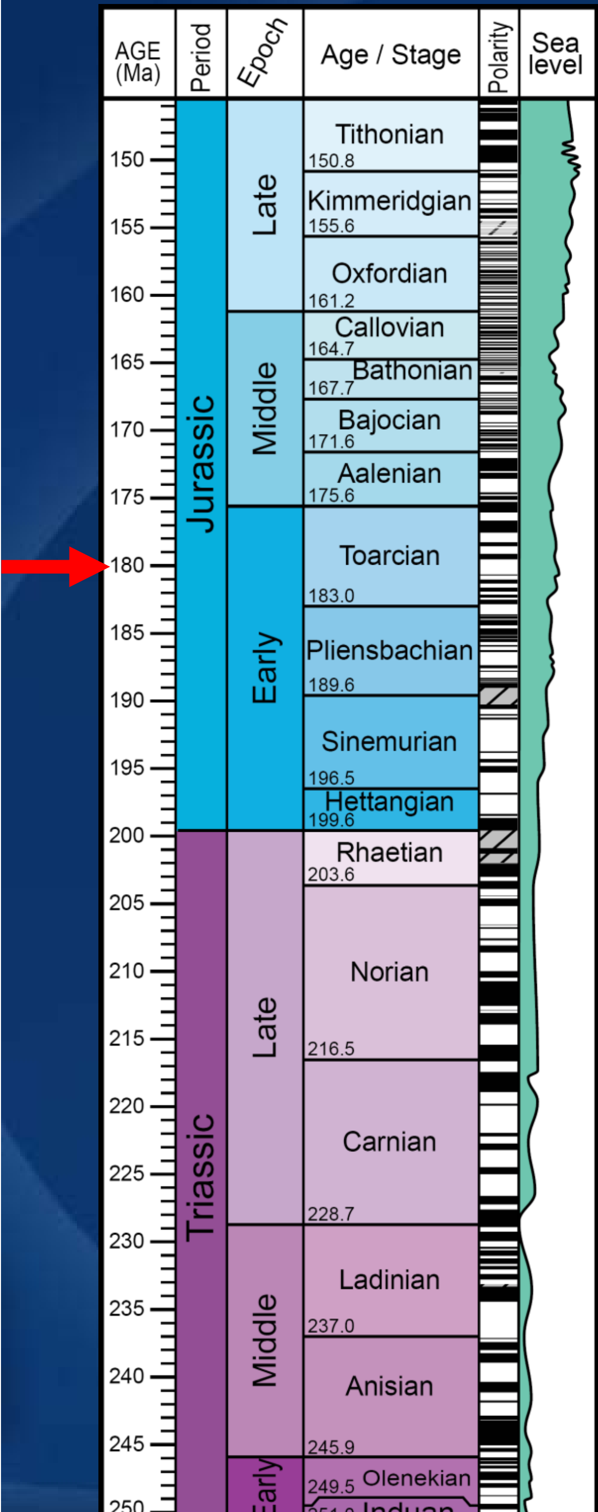


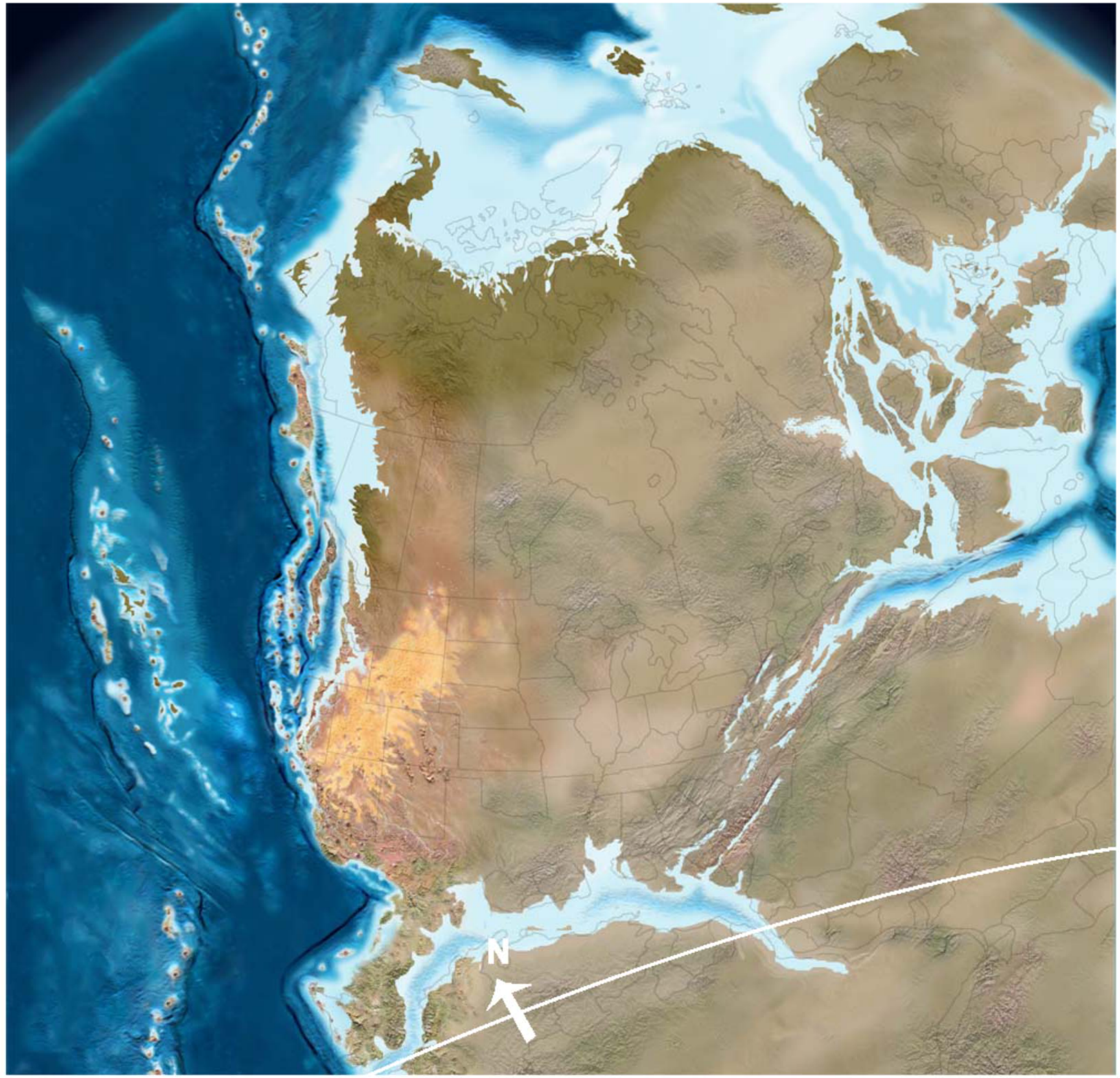
(From Ron Blakey website)





(From Ron Blakey website)





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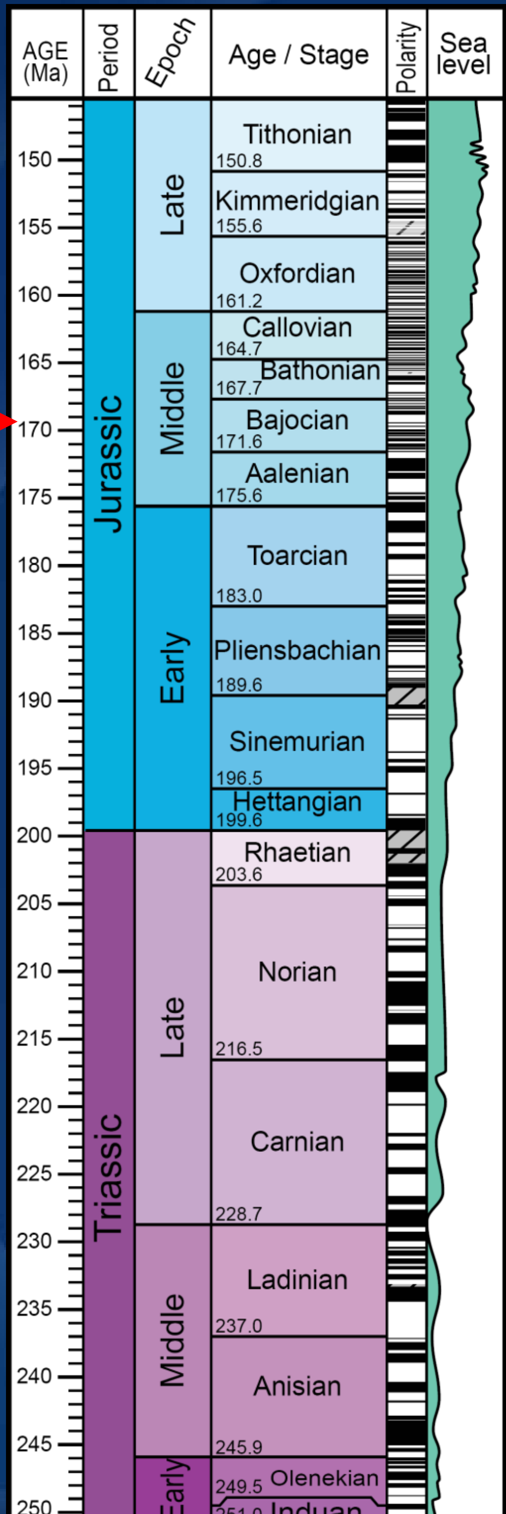
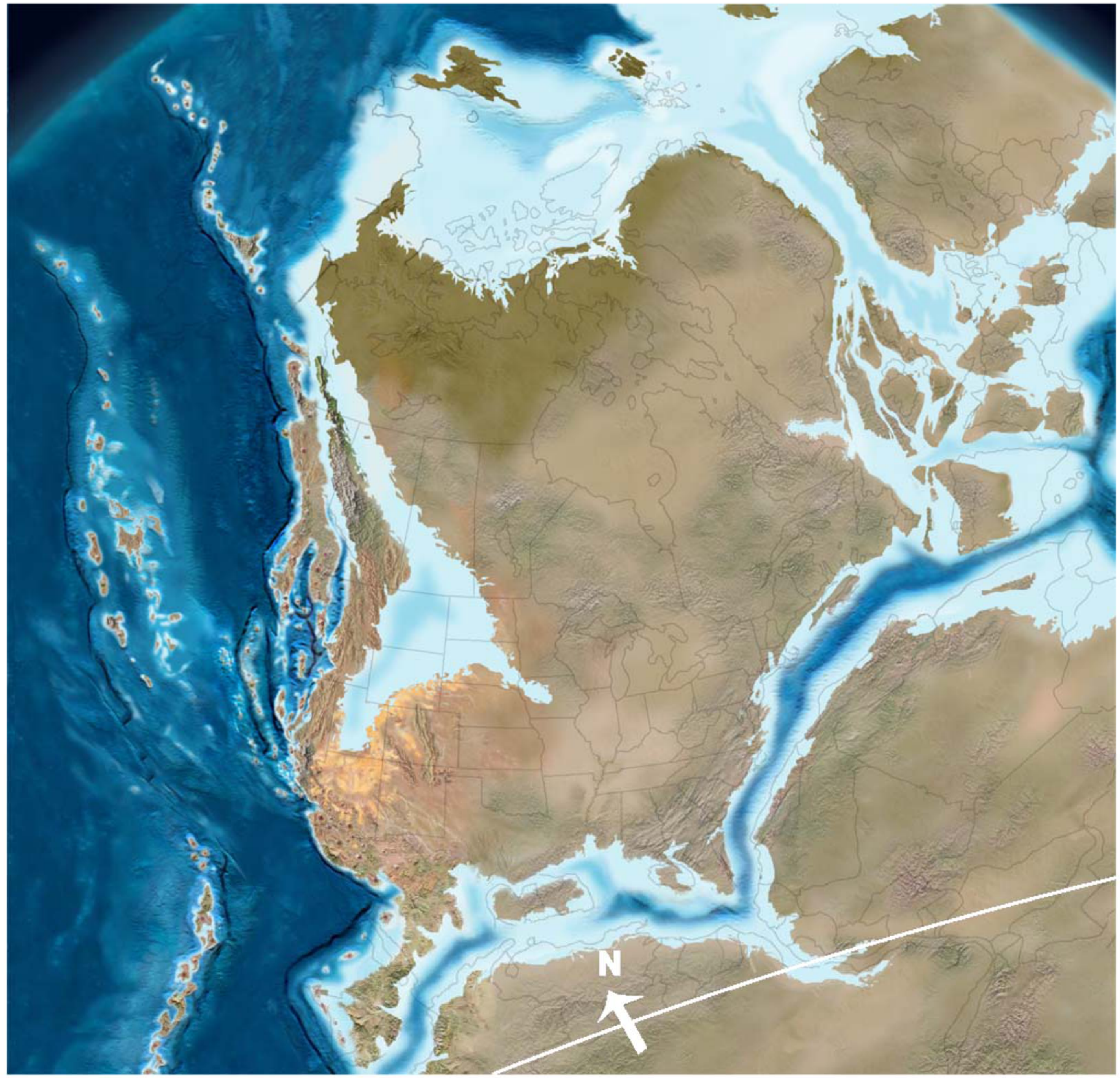
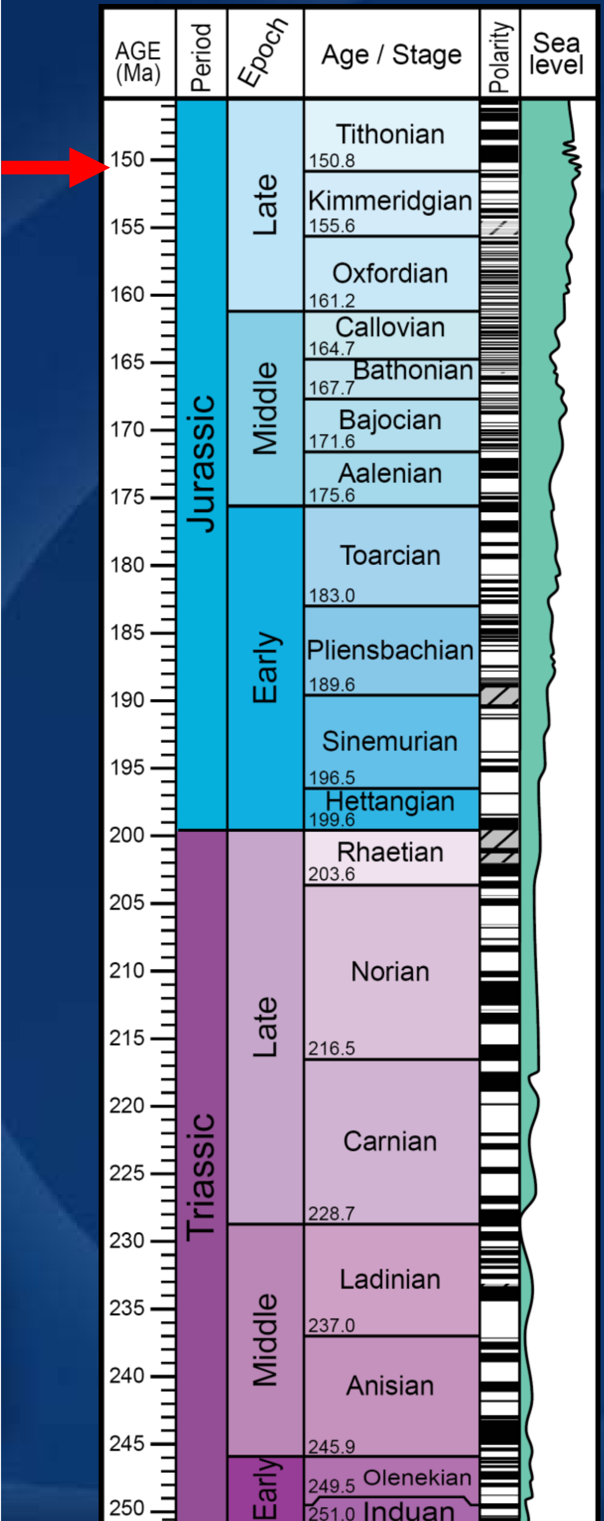
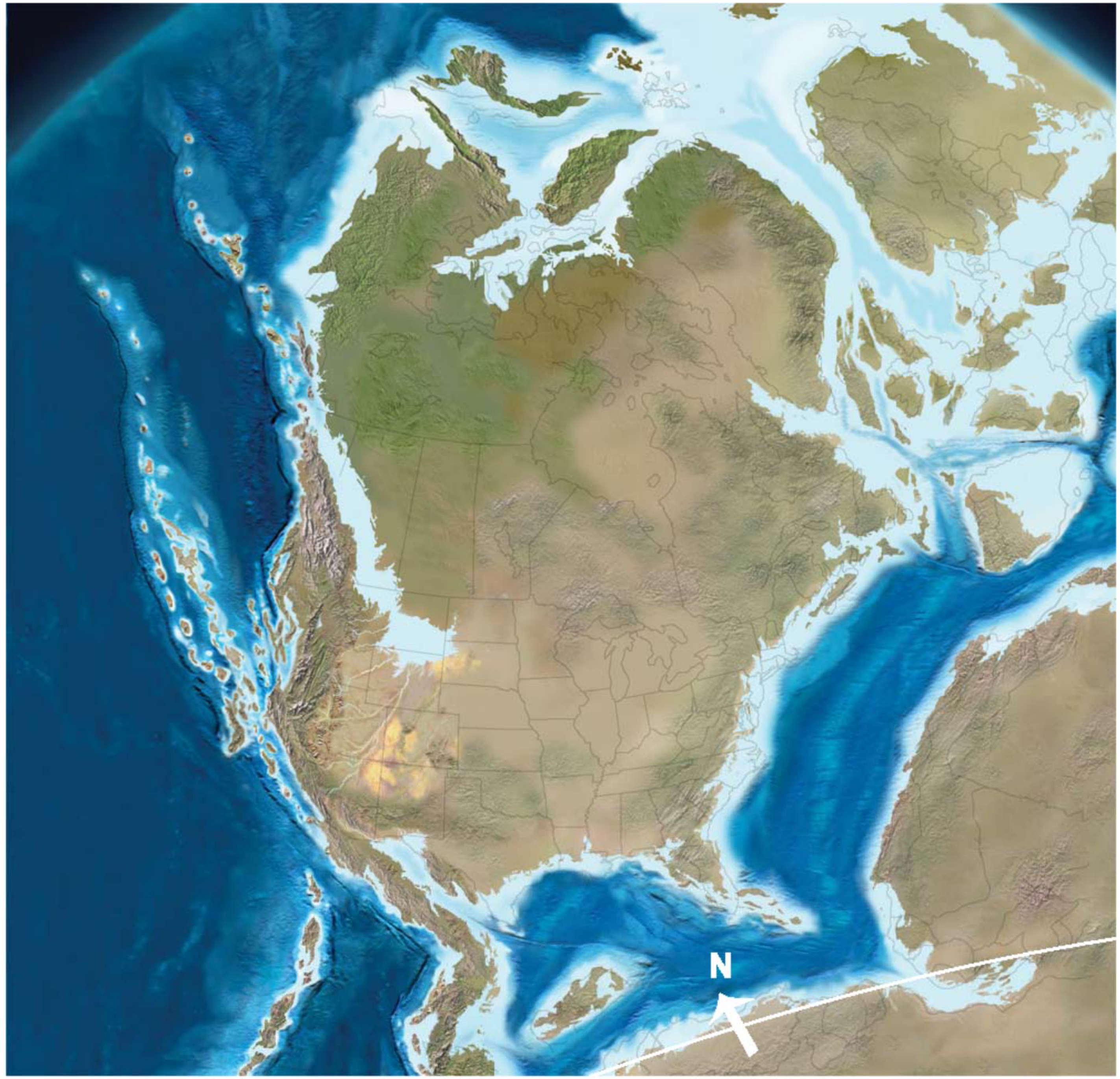


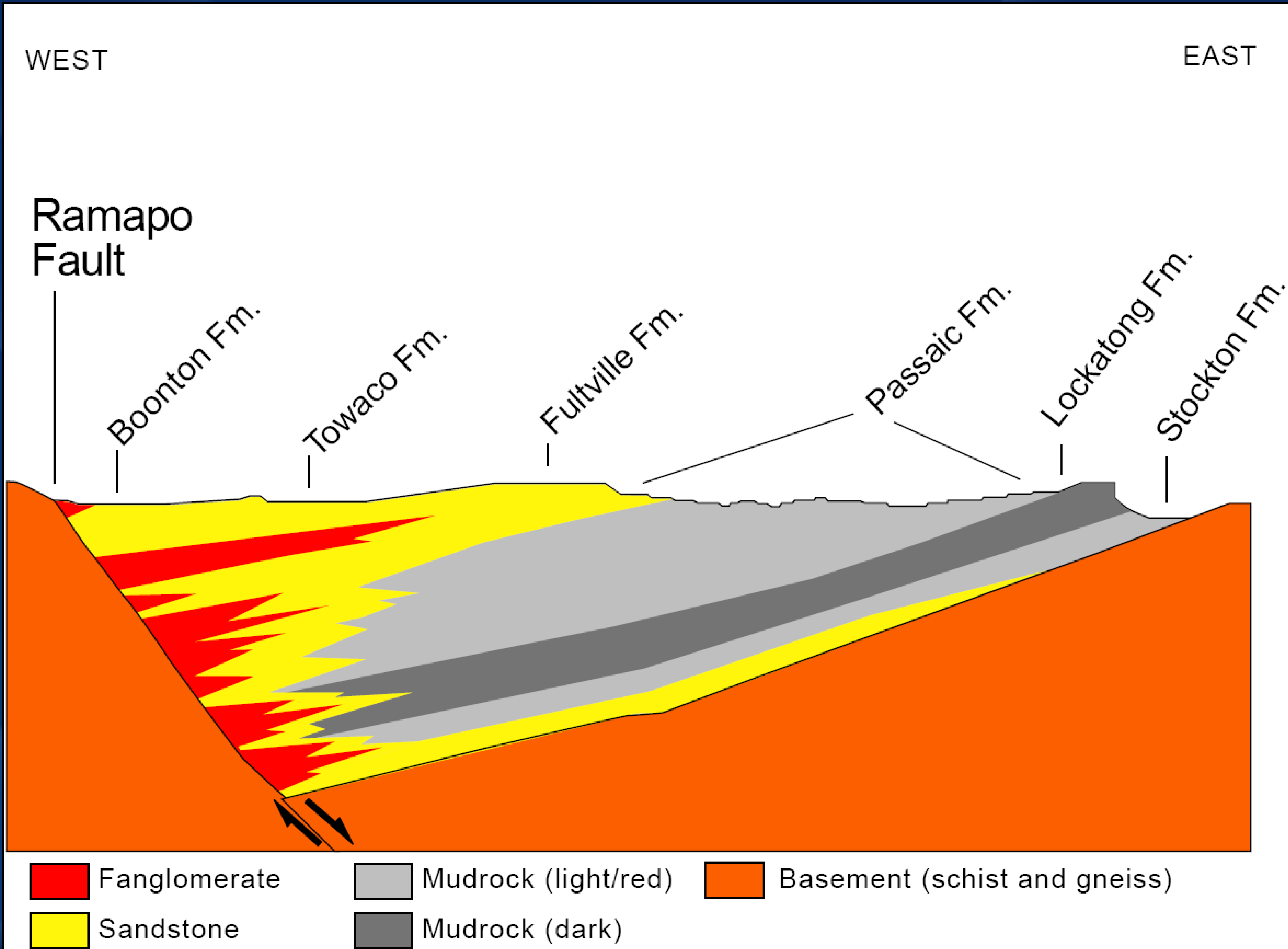


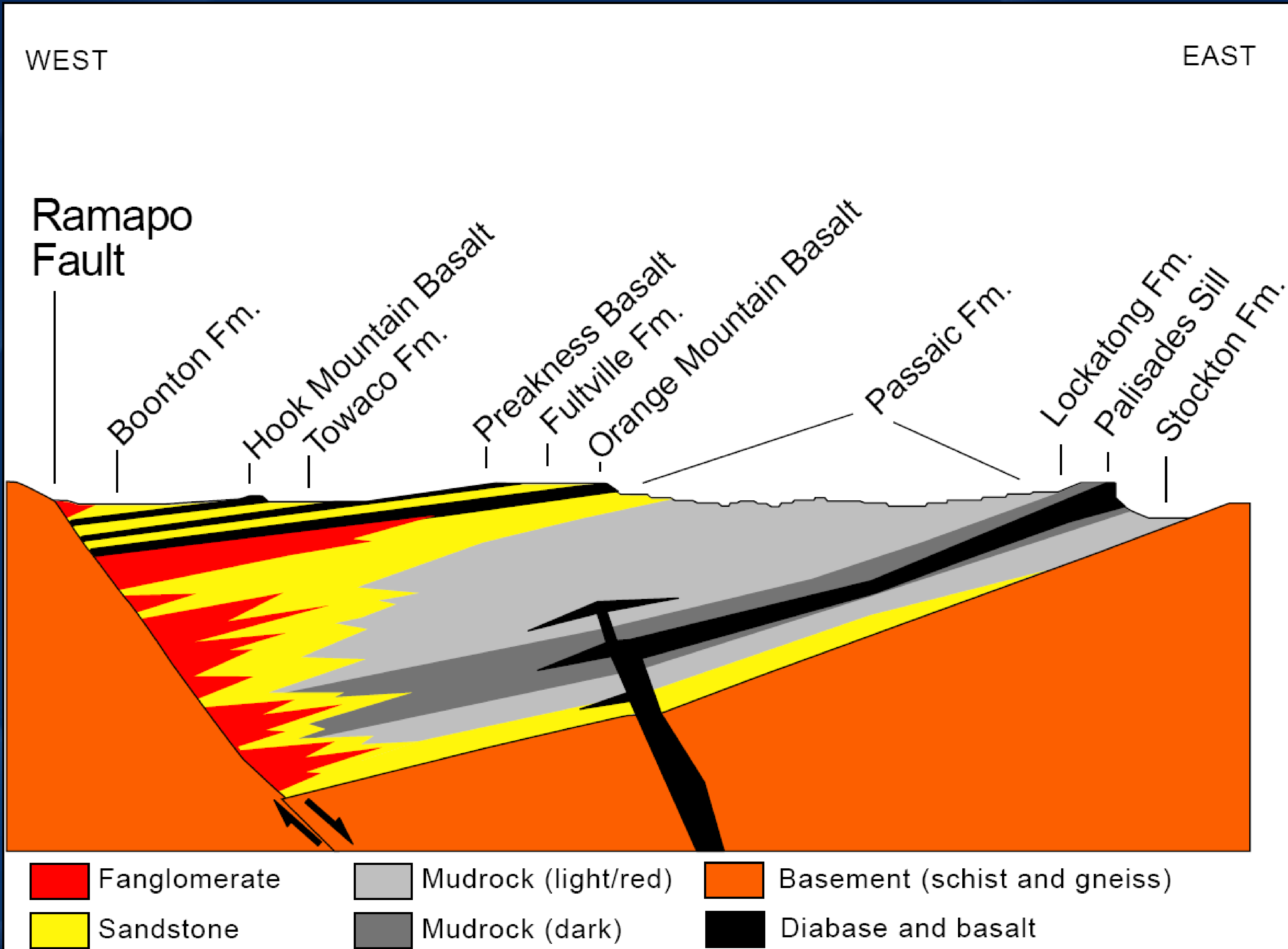
(From Ron Blakey website)





(From Ron Blakey website)


WEST
EAST
Ramapo Fault
Boonton Fm.
Towaco Fm.
Fultville Fm.
Passaic Fm.
Lockatong Fm.
Stockton Fm.
Fanglomerate
Mudrock (light/red)
Basement (schist and gneiss)
Sandstone
Mudrock (dark)


WEST
EAST
Ramapo Fault
Boonton Fm.
Hook Mountain Basalt
Towaco Fm.
Preakness Basalt
Fultville Fm.
Orange Mountain Basalt
Passaic Fm.
Lockatong Fm.
Palisades Sill
Stockton Fm.
Fanglomerate
Sandstone
Mudrock (light/red)
Mudrock (dark)
Basement (schist and gneiss)
Diabase and basalt

Palisades Sill

TriCarb CO_2
Consortium for Carbon Sequestration

nyserda
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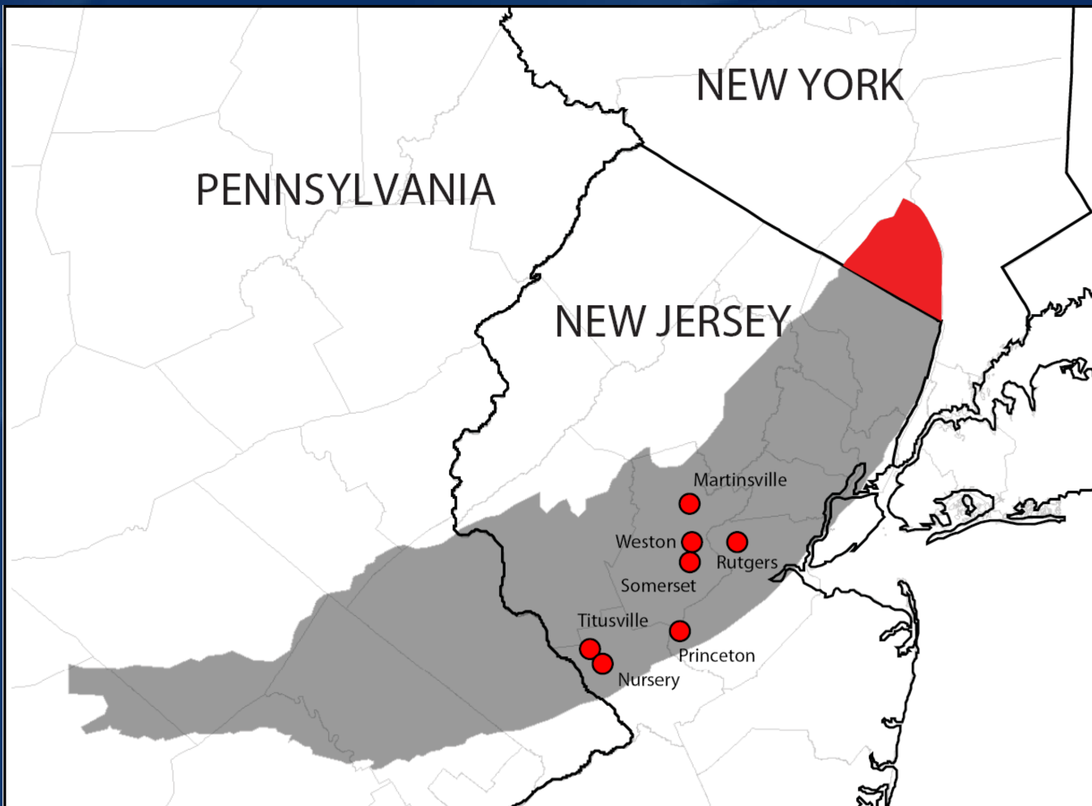
TriCarb CO_2

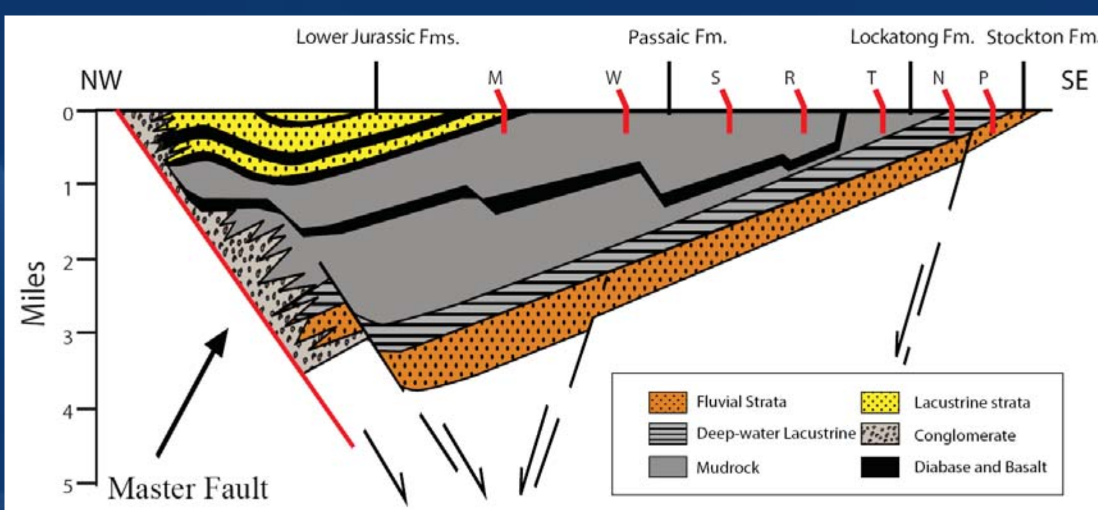
Consortium for Carbon Sequestration

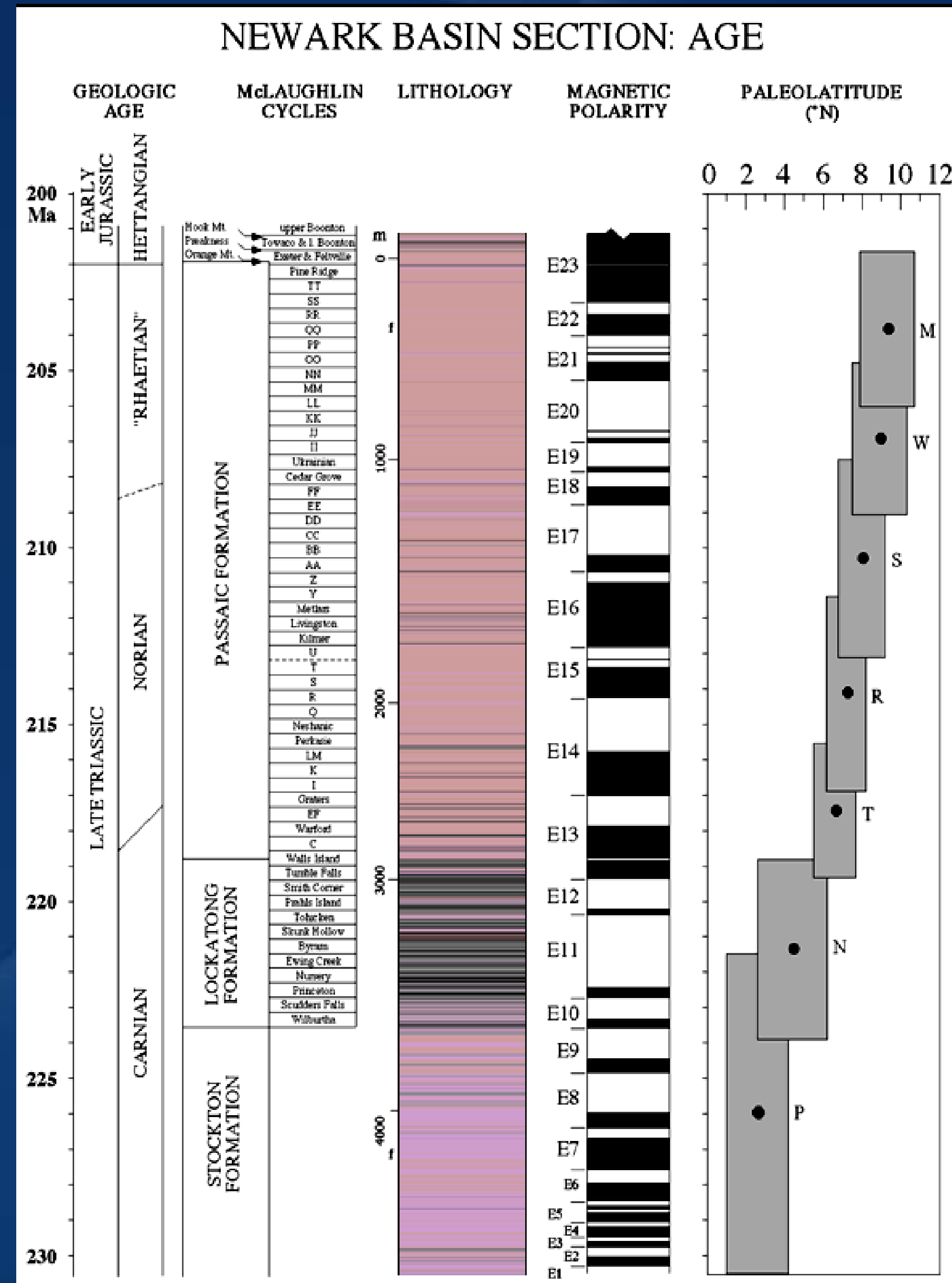
nyserda

Energy. Innovation. Solutions.

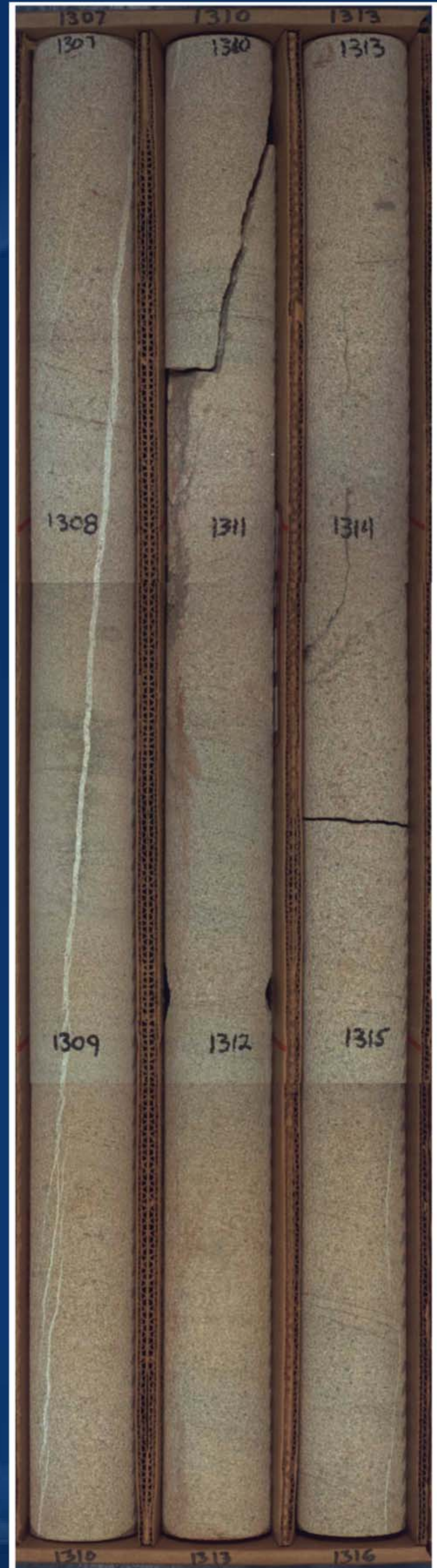
Previous Work: The Newark Basin Coring Project

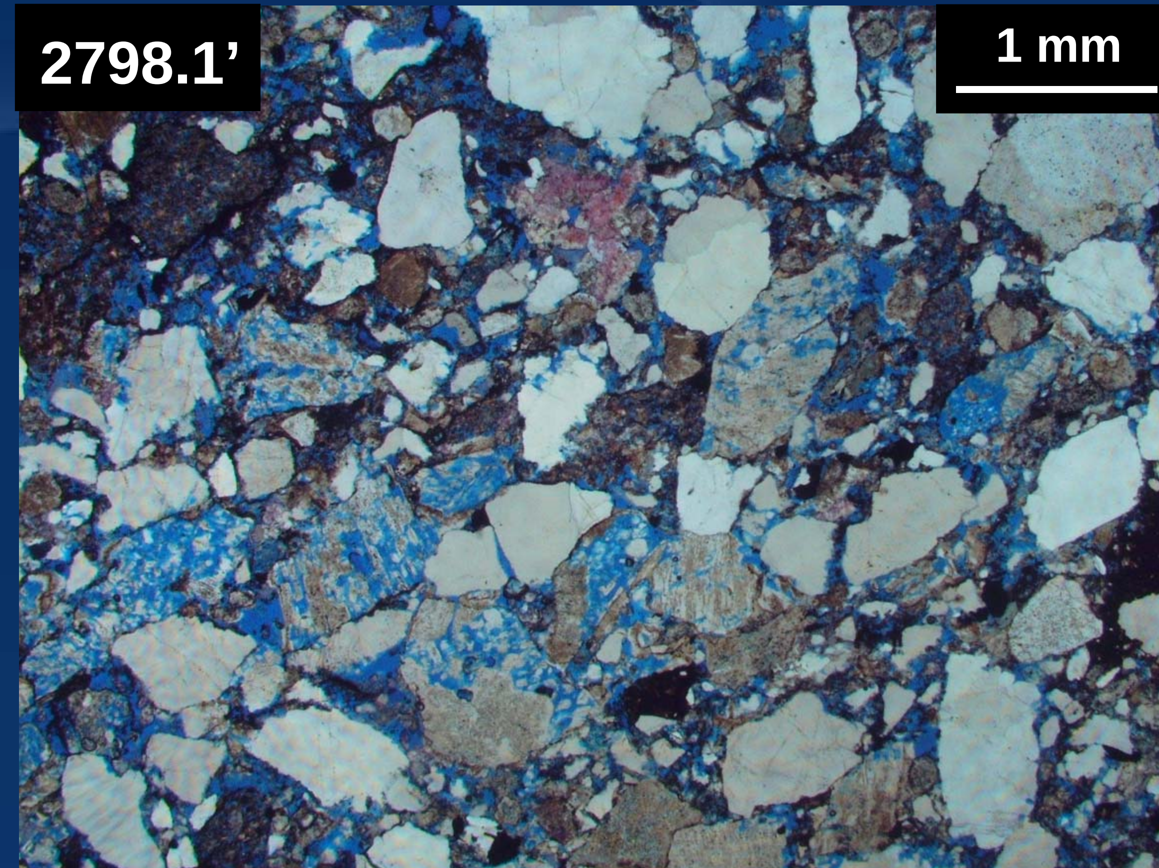






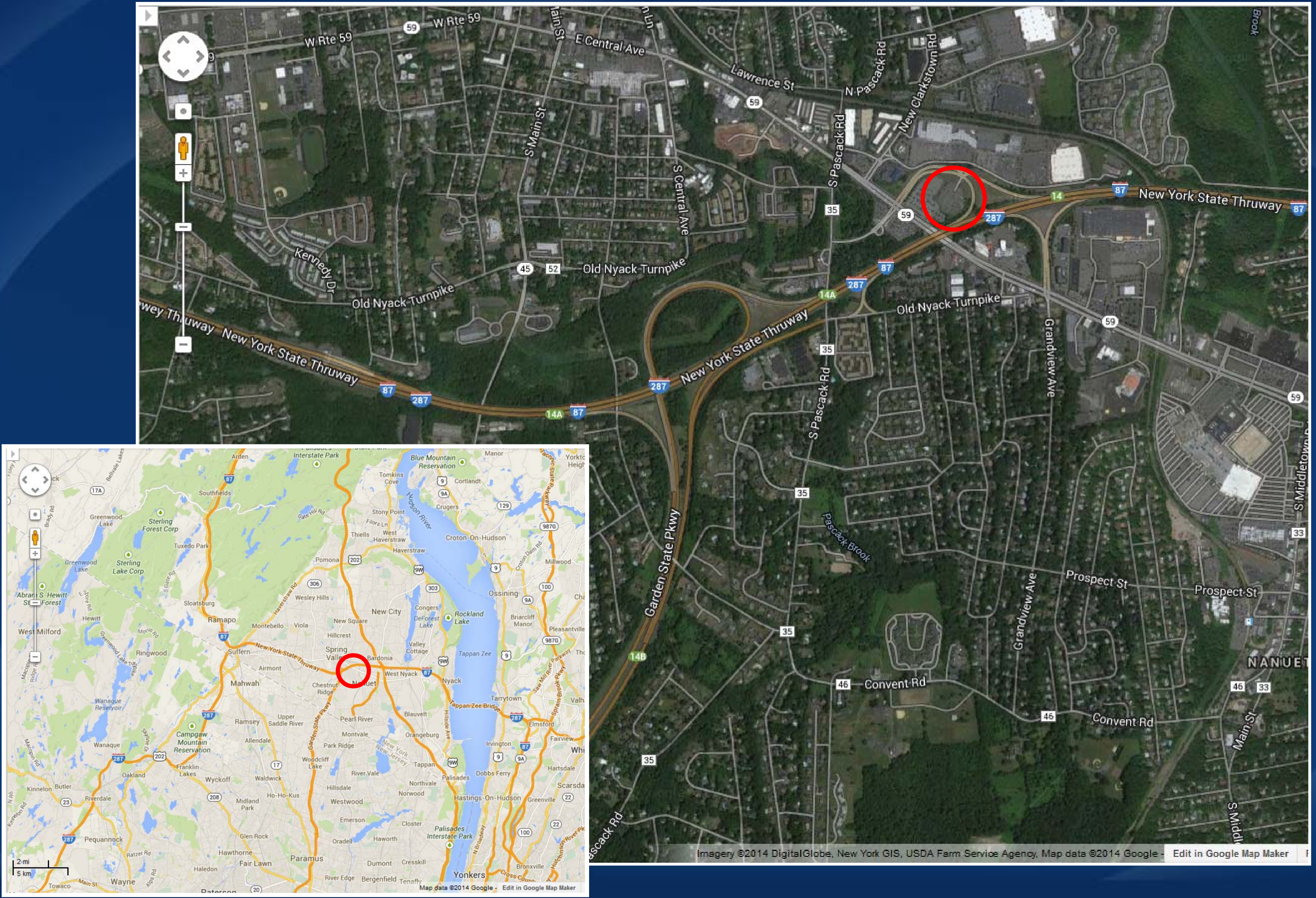
From Olsen et al., 1996



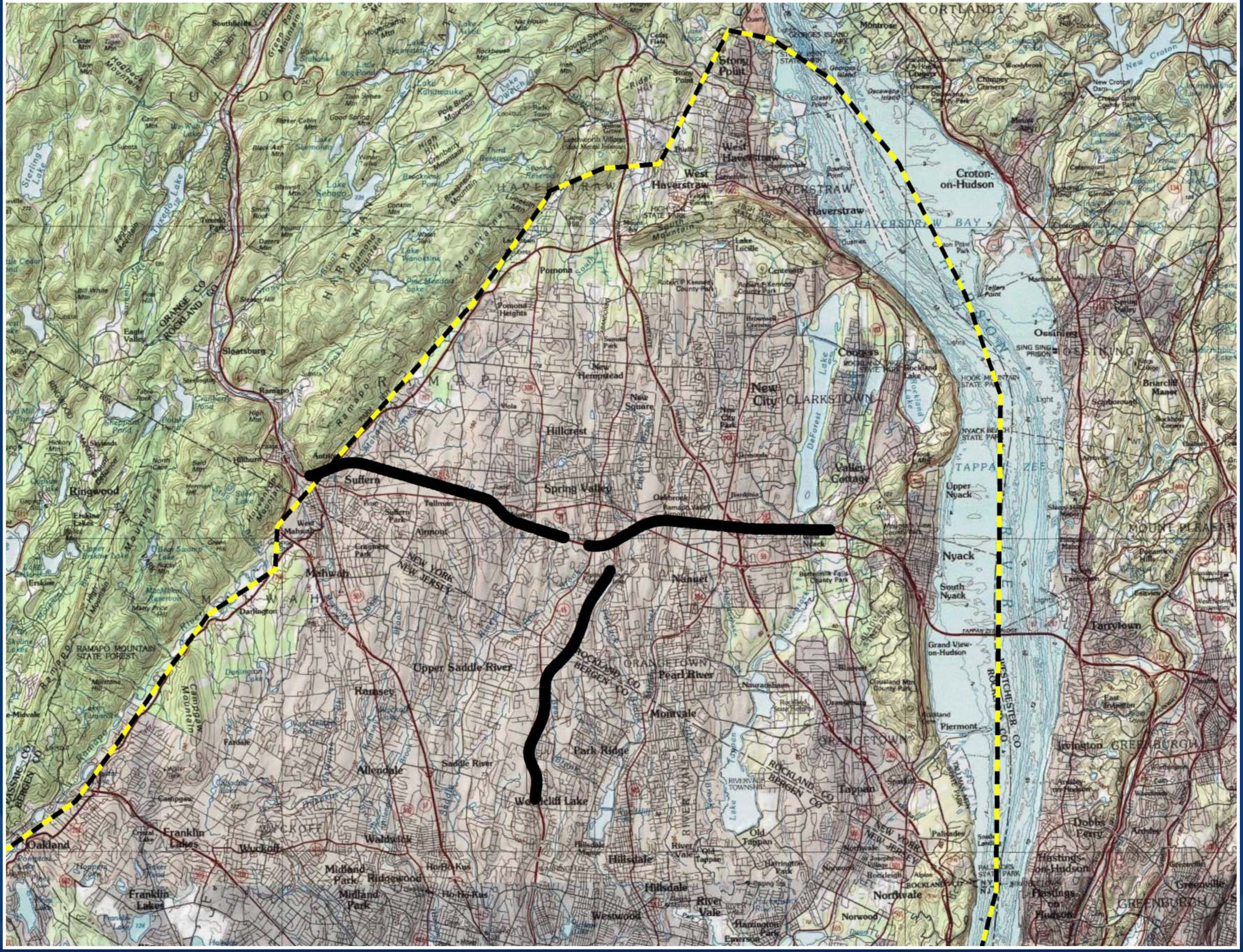


- 54 samples collected
- 9 sent to OMNI labs for analysis
- Lab results indicate average porosity of 9% and permeabilities average 0.9 mD
- Thinsections made from all 54 samples agree with lab results

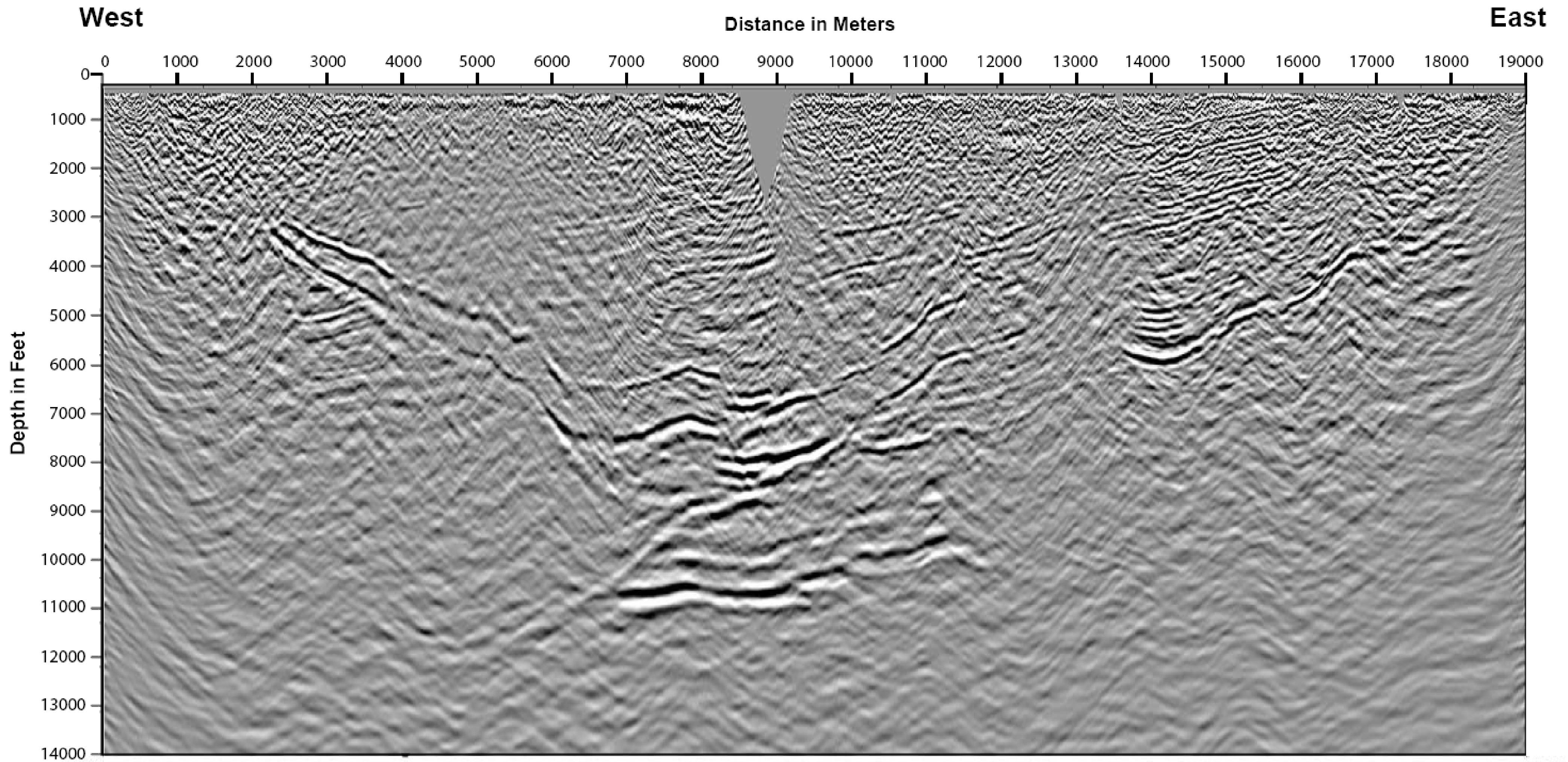
The Tandem Lot Well



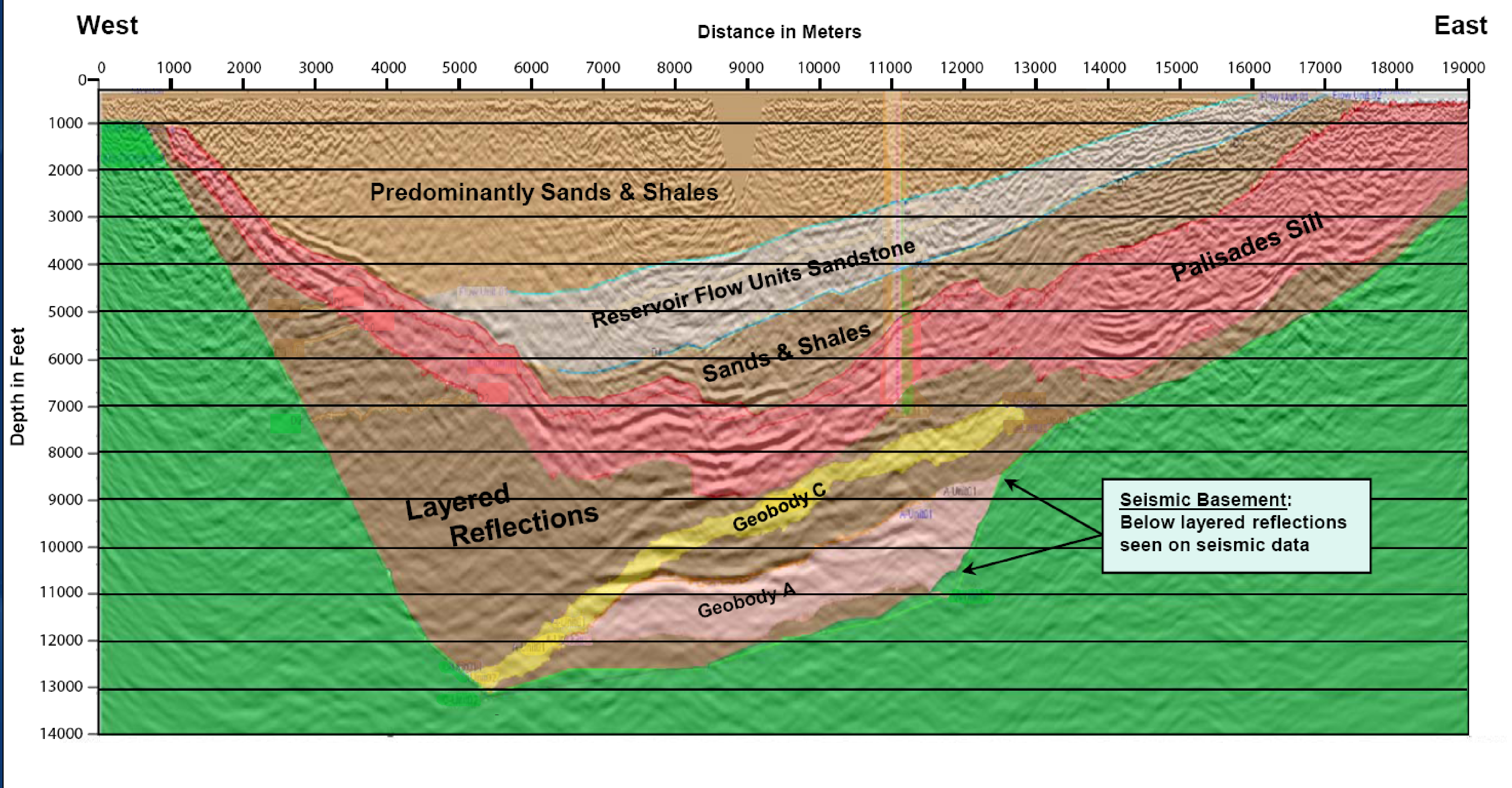
Seismic Survey



Uninterpreted Seismic Line

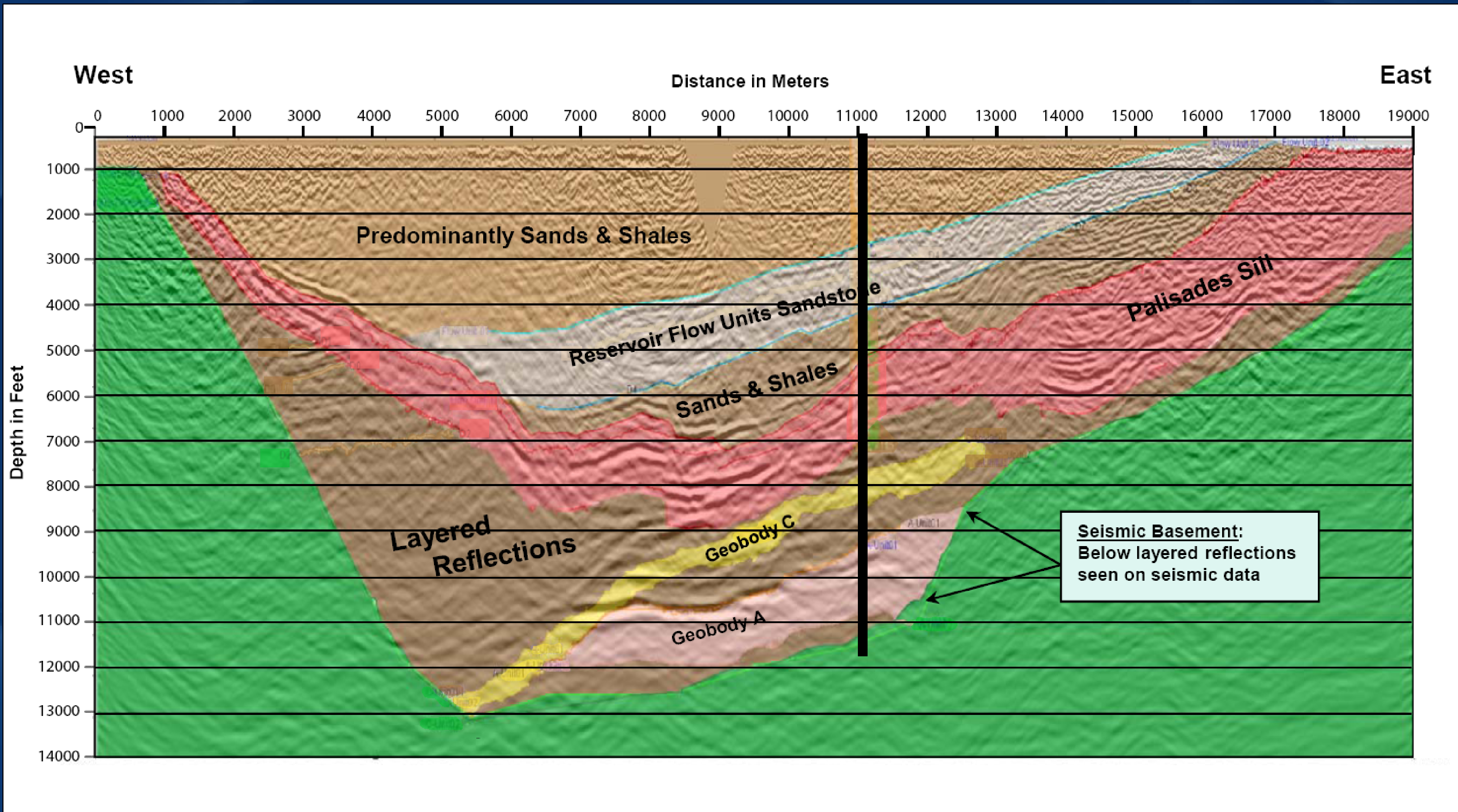


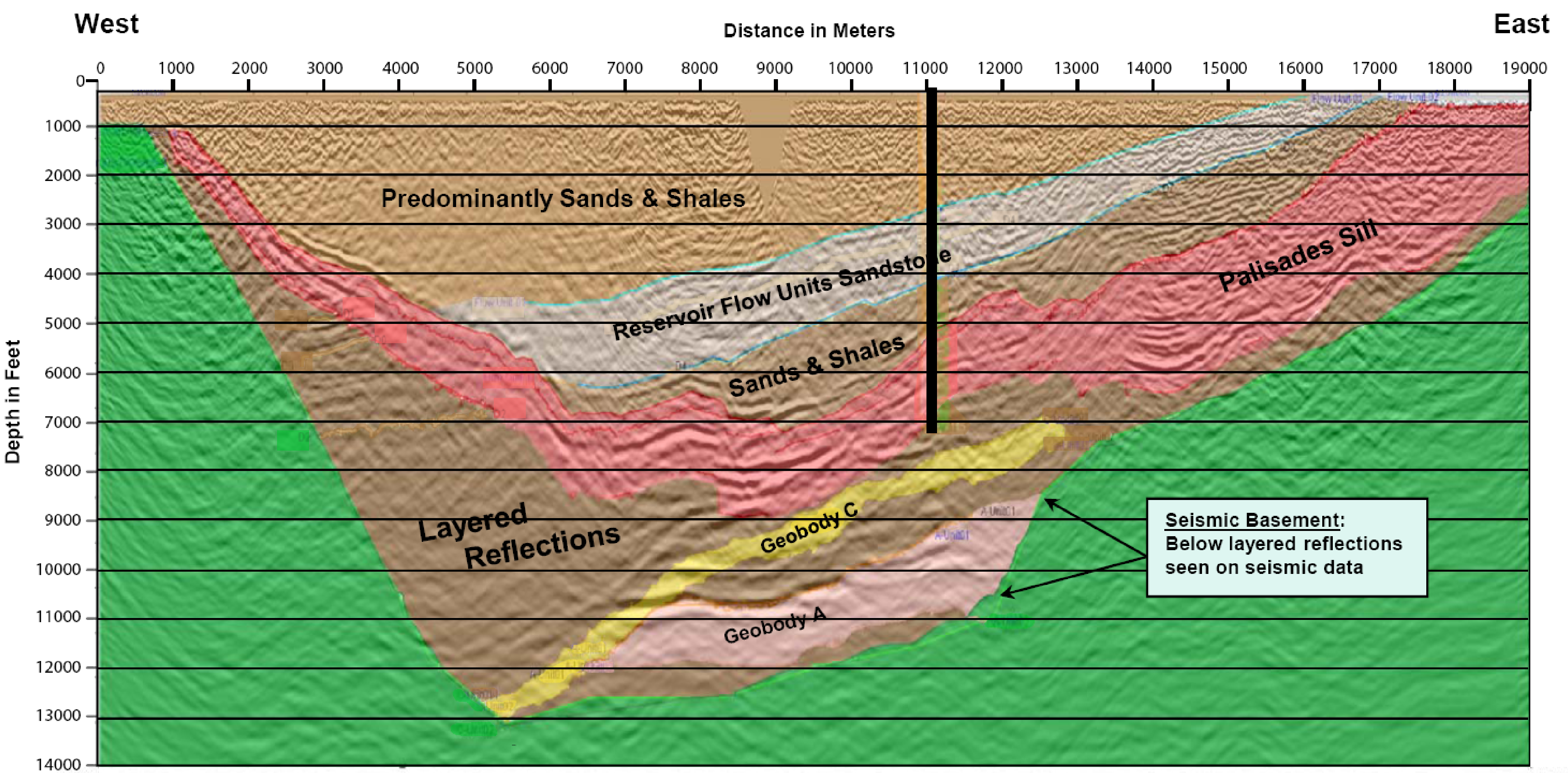
Interpreted Seismic Line



The Tandem Lot Well

- Drilling began on August 7, 2011
- Reached a Total Depth of 6,881 feet
- 150’ feet of continuous core collected
- 50 sidewall cores
- Full suite of well logs
- The well was plugged and site was completely restored by December 2011


West
Distance in Meters
East
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
19000
Depth in Feet
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
Predominantly Sands & Shales
Reservoir Flow Units Sandstone
Sands & Shales
Palisades Sill
Layered Reflections
Geobody C
Geobody A
Seismic Basement:
Below layered reflections seen on seismic data


West
East
Distance in Meters
Depth in Feet
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
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Predominantly Sands & Shales
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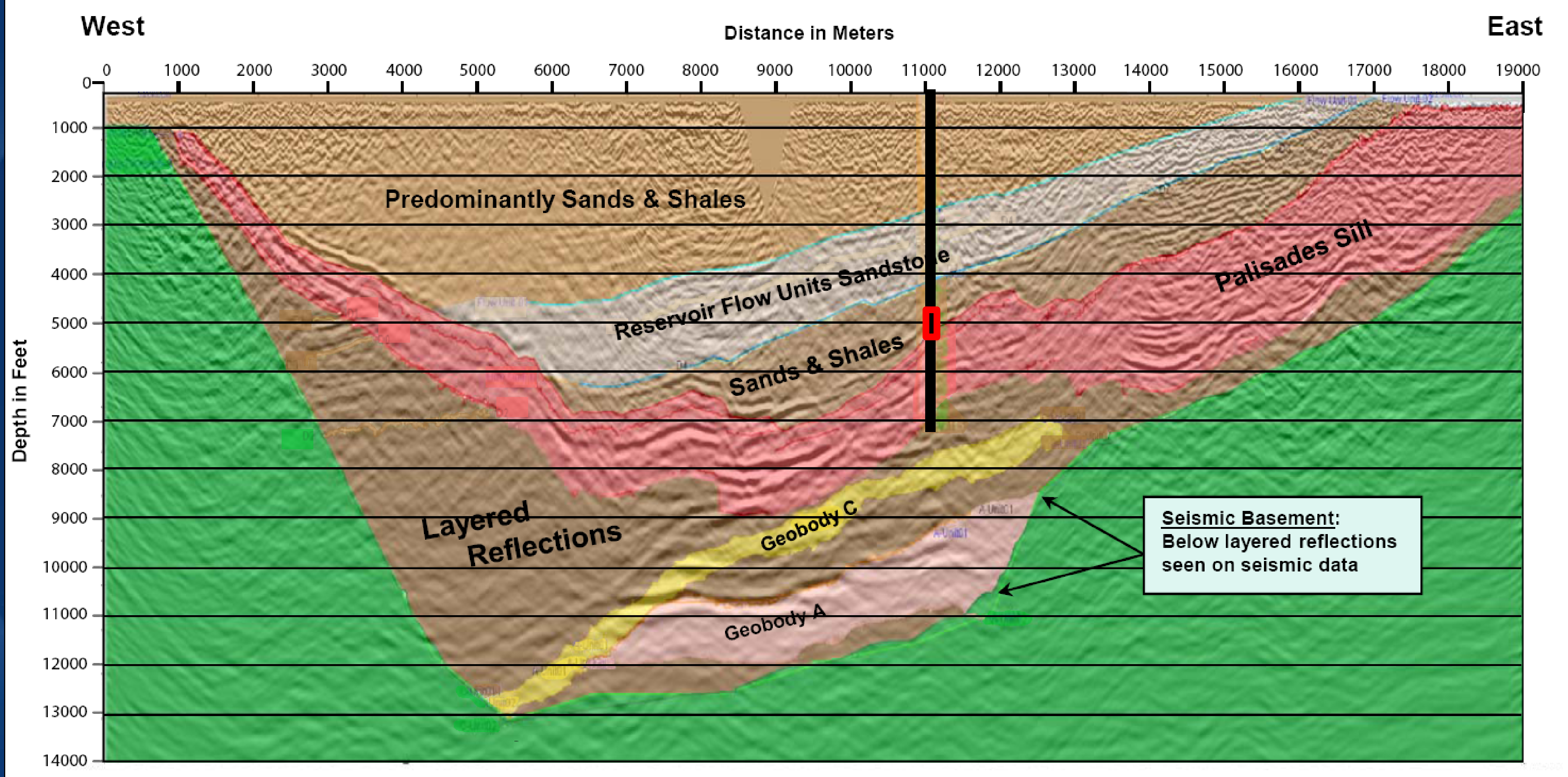

West
Distance in Meters
East
0
1000
2000
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16000
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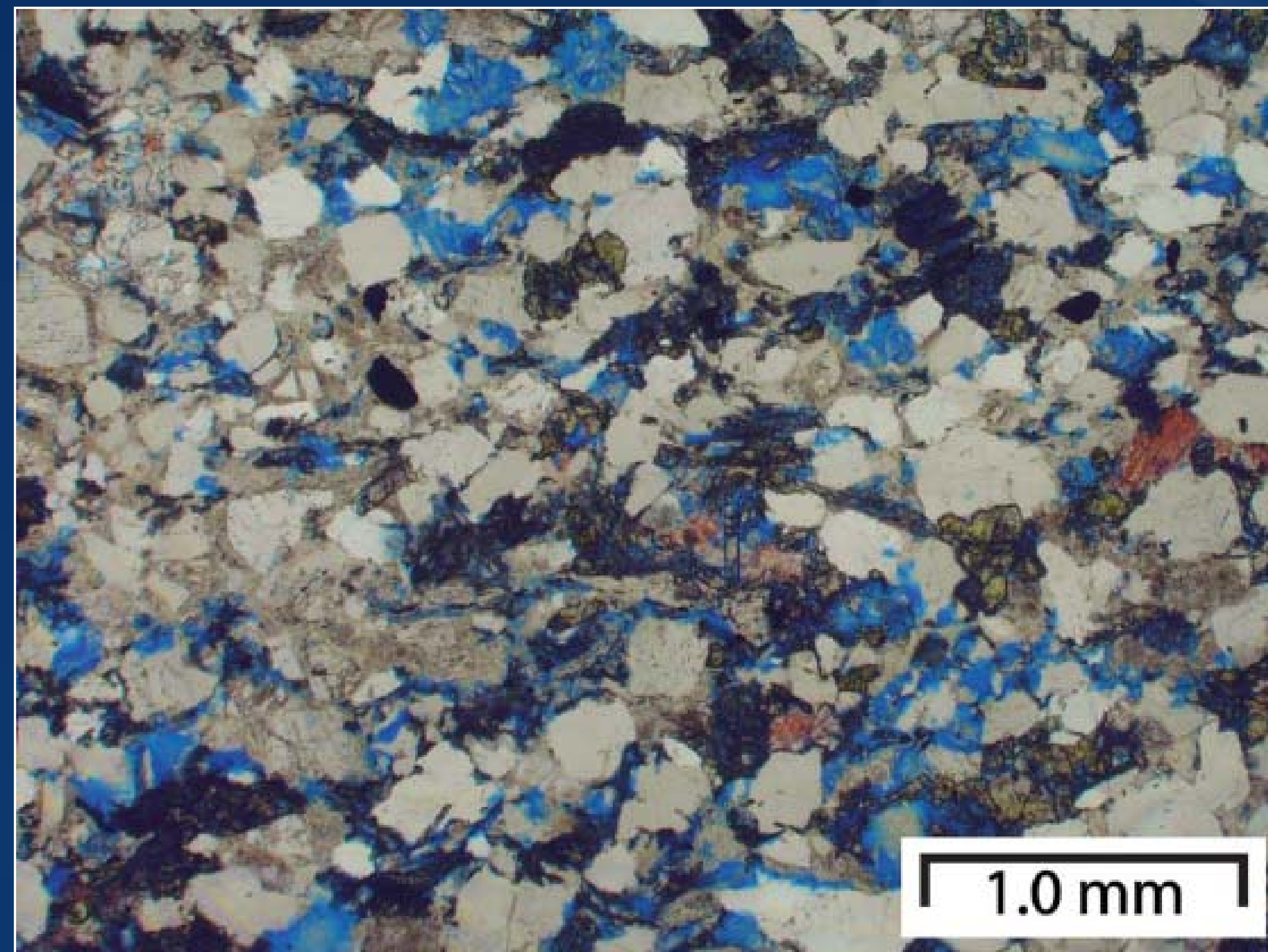
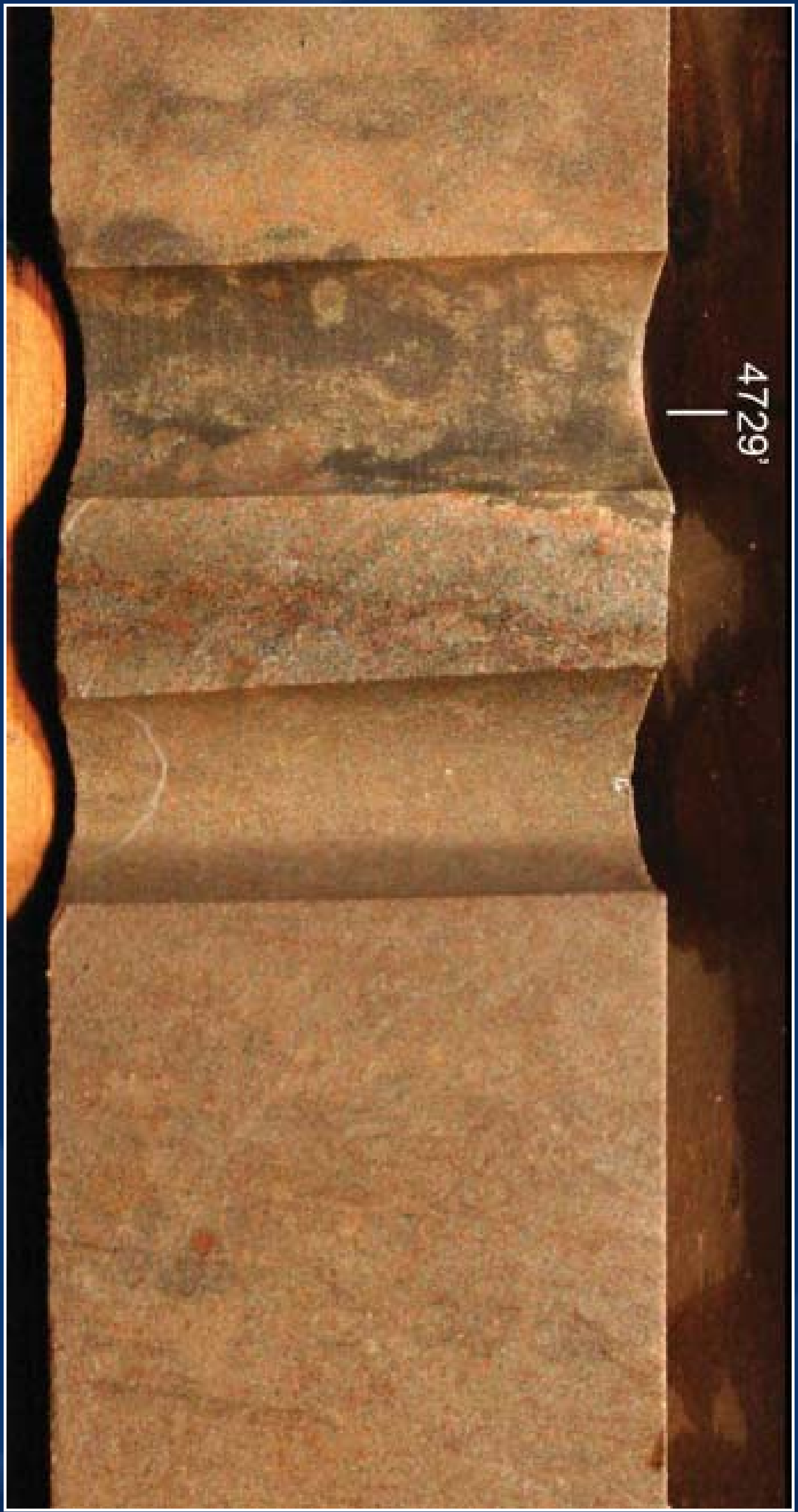
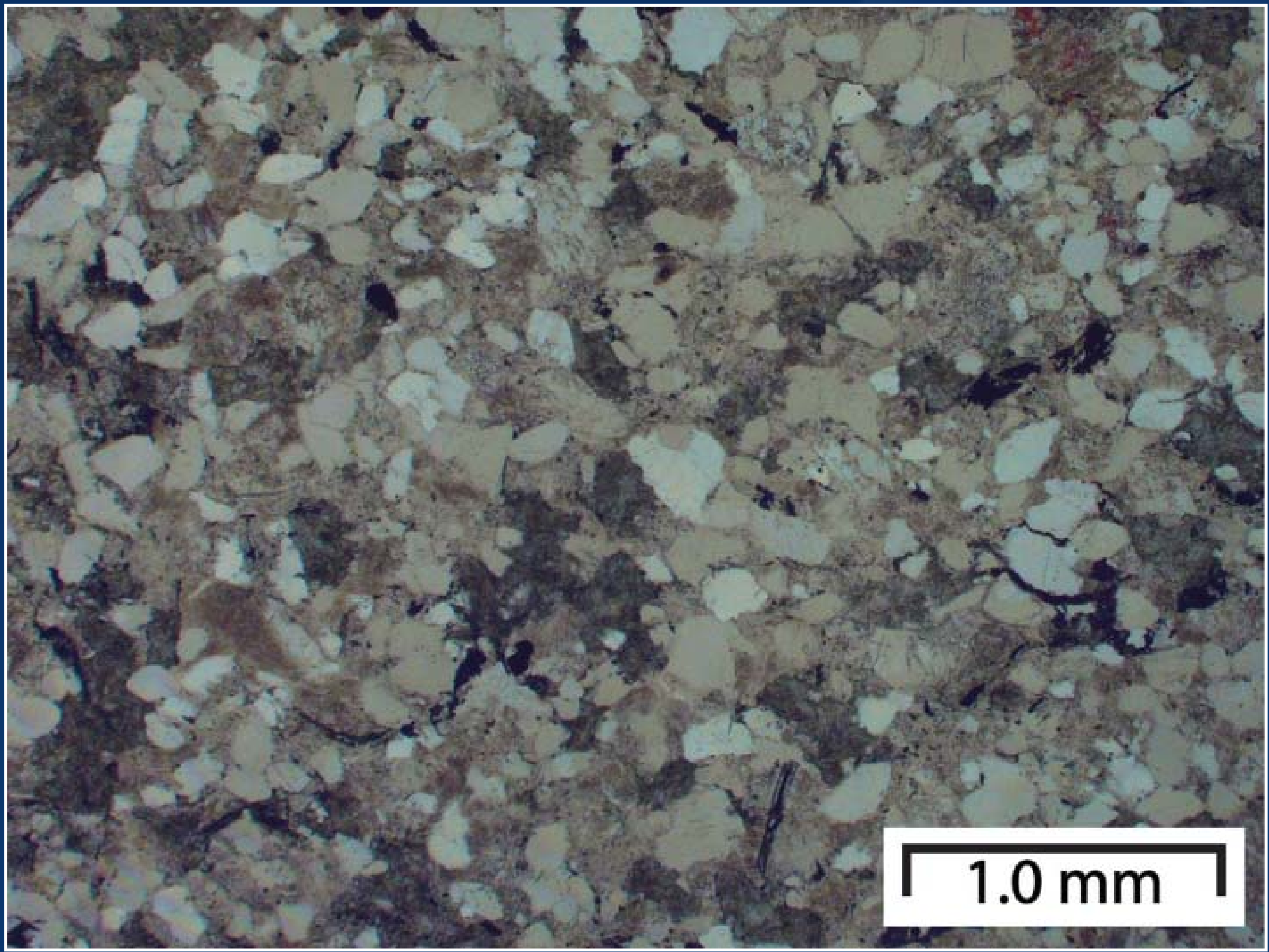
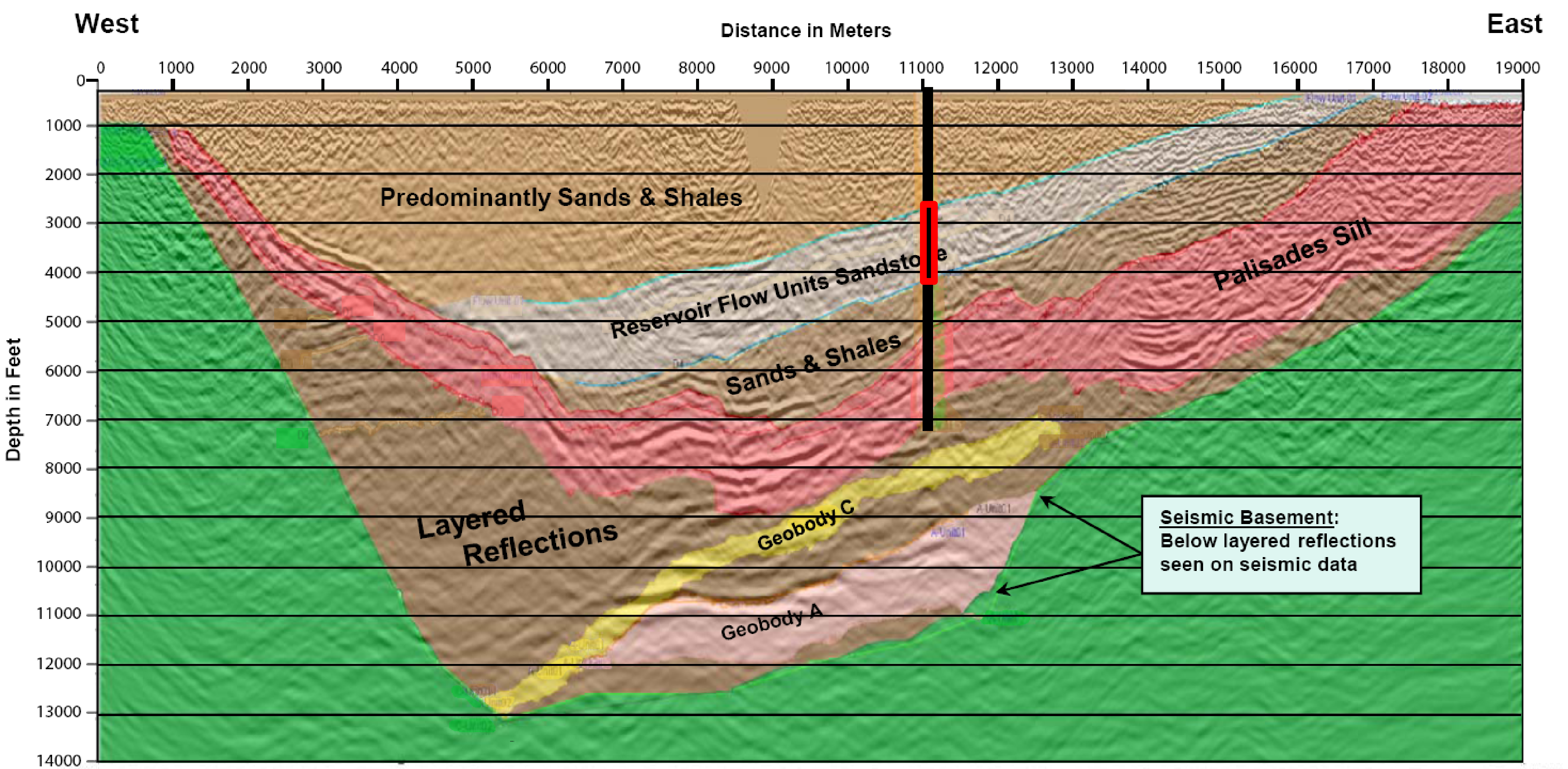
19000
Depth in Feet
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
Predominantly Sands & Shales
Reservoir Flow Units Sandstone
Sands & Shales
Palisades Sill
Layered Reflections
Geobody C
Geobody A
Seismic Basement:
Below layered reflections
seen on seismic data


4625'

1.0 mm


4729'


1.0 mm


West
Distance in Meters
East
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
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18000
19000
Depth in Feet
1000
2000
3000
4000
5000
6000
7000
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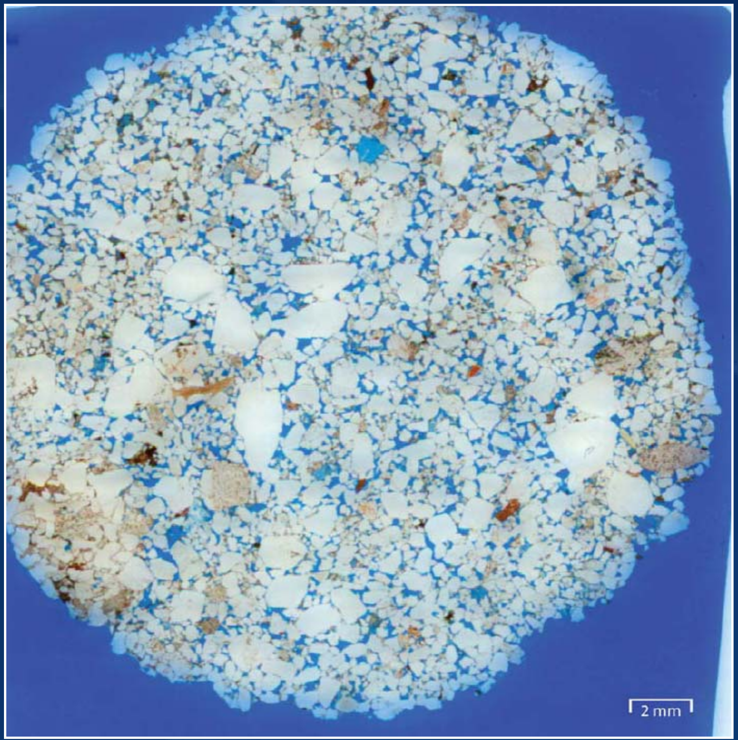
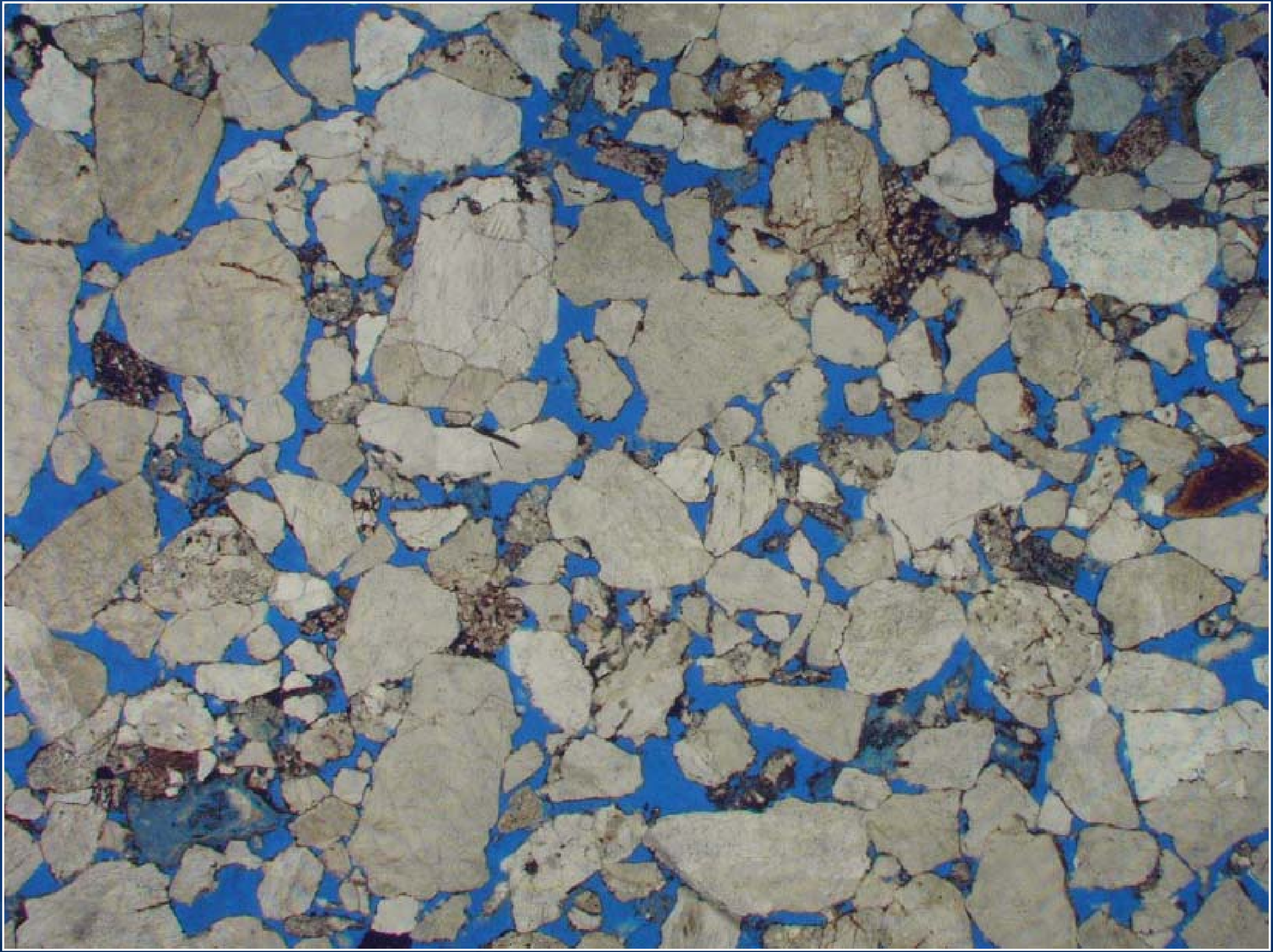
9000
10000
11000
12000
13000
14000
Predominantly Sands & Shales
Reservoir Flow Units Sandstone
Sands & Shales
Palisades Sill
Layered Reflections
Geobody C
Geobody A
Seismic Basement: Below layered reflections seen on seismic data

Sidewall Core: 2,832 feet





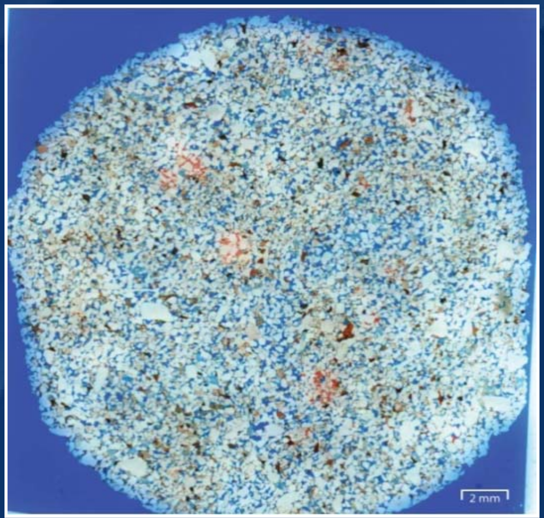
Porosity

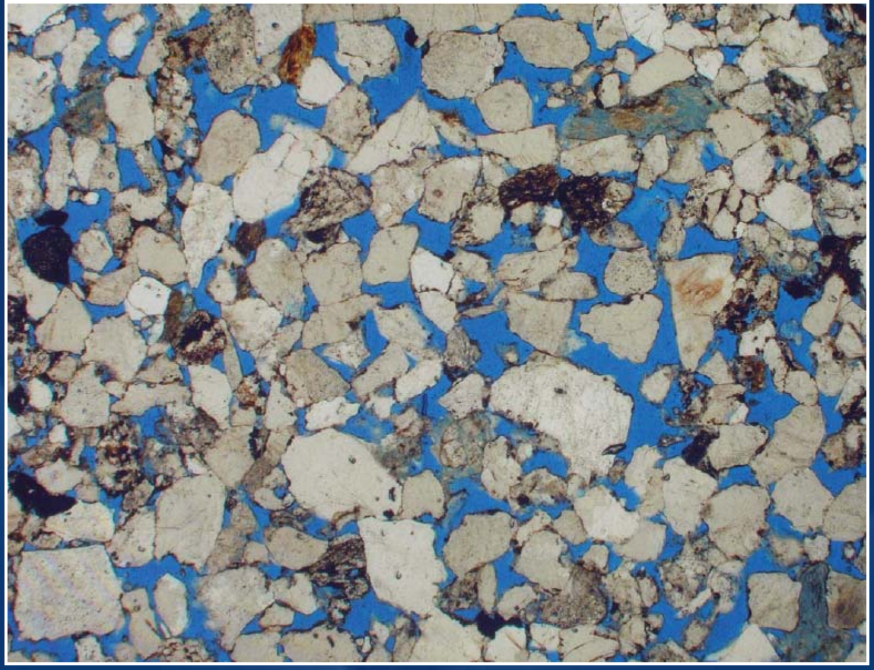
15.4 %

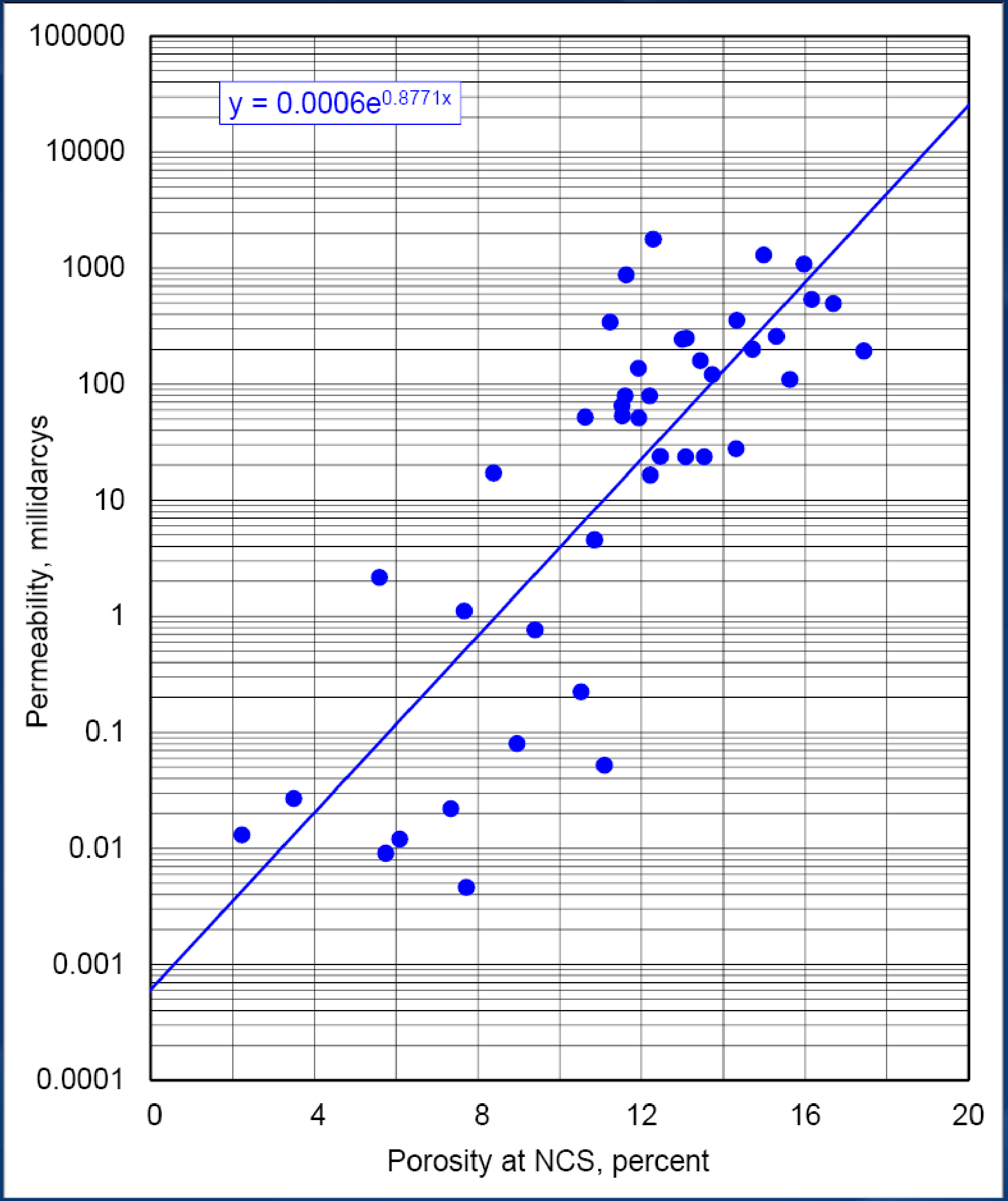
Permeability

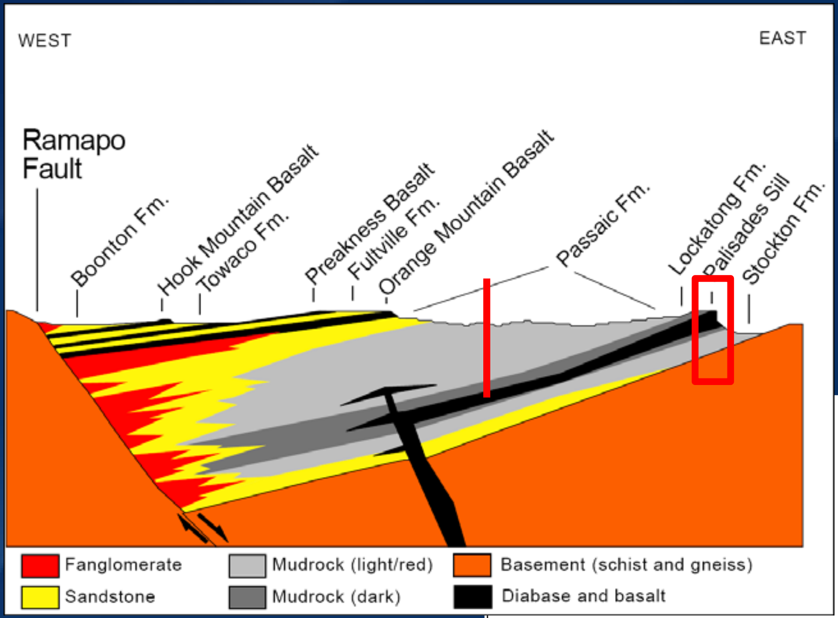
257.00 mD

Sidewall Core: 3,053 feet

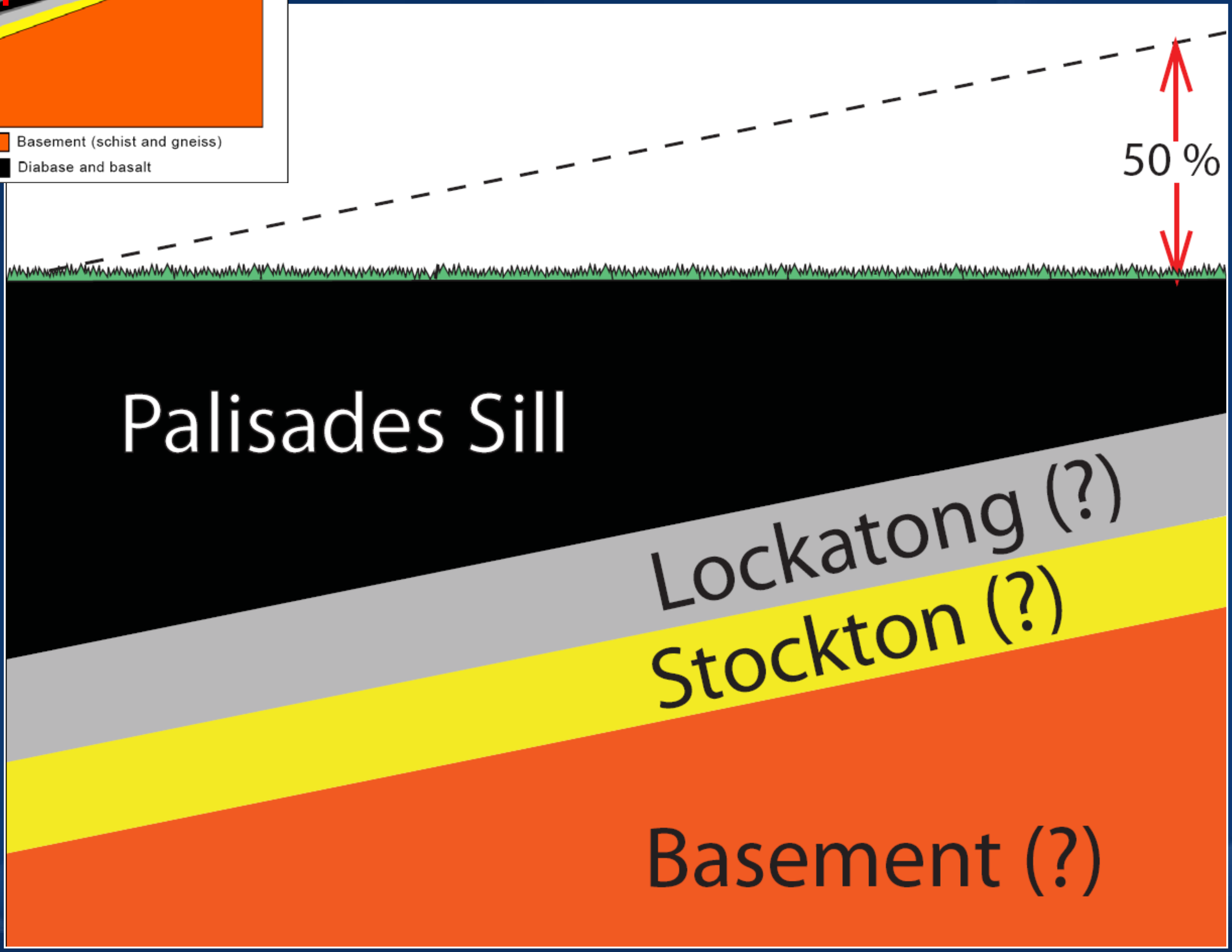






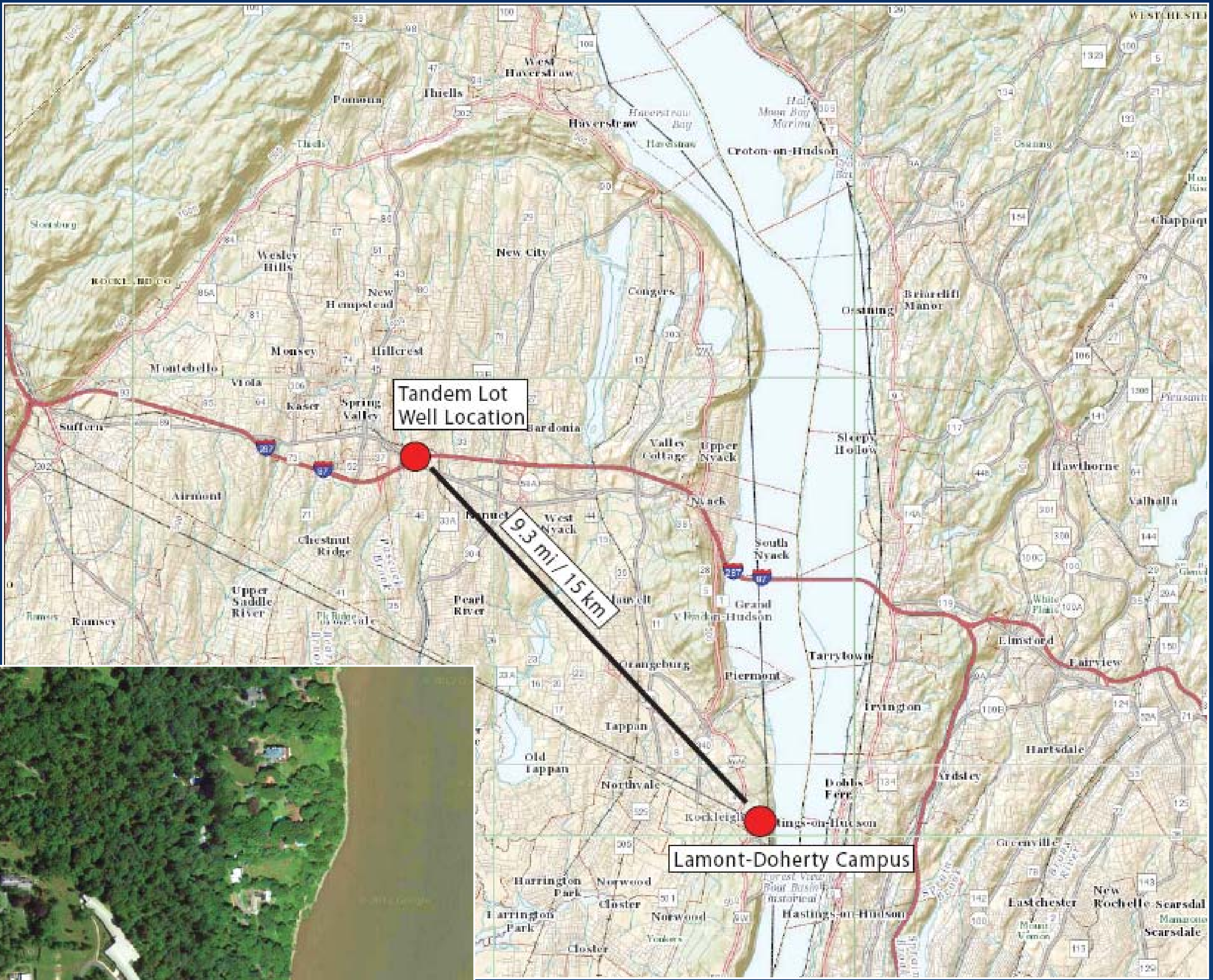


Not only are the target formations shallower along the eastern edge of the basin, but the Palisades Sill is at the surface and has ben partially eroded, so less of it needed to be drilled through.



Test Well 4:

TW-4



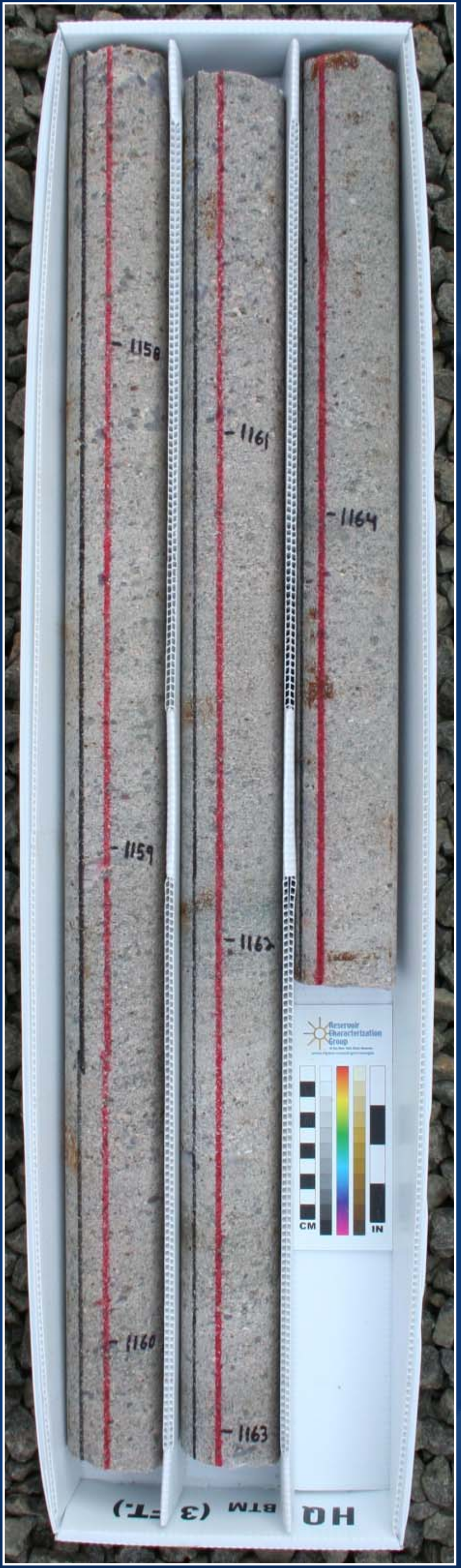
Test Well 4: TW-4

- Began drilling in August of 2013
- Drilled first 650 feet and collected cuttings
- Collected 4-inch core through the bottom of the sill
- Continued coring with a 2.5 inch bit to a depth of 1803 feet

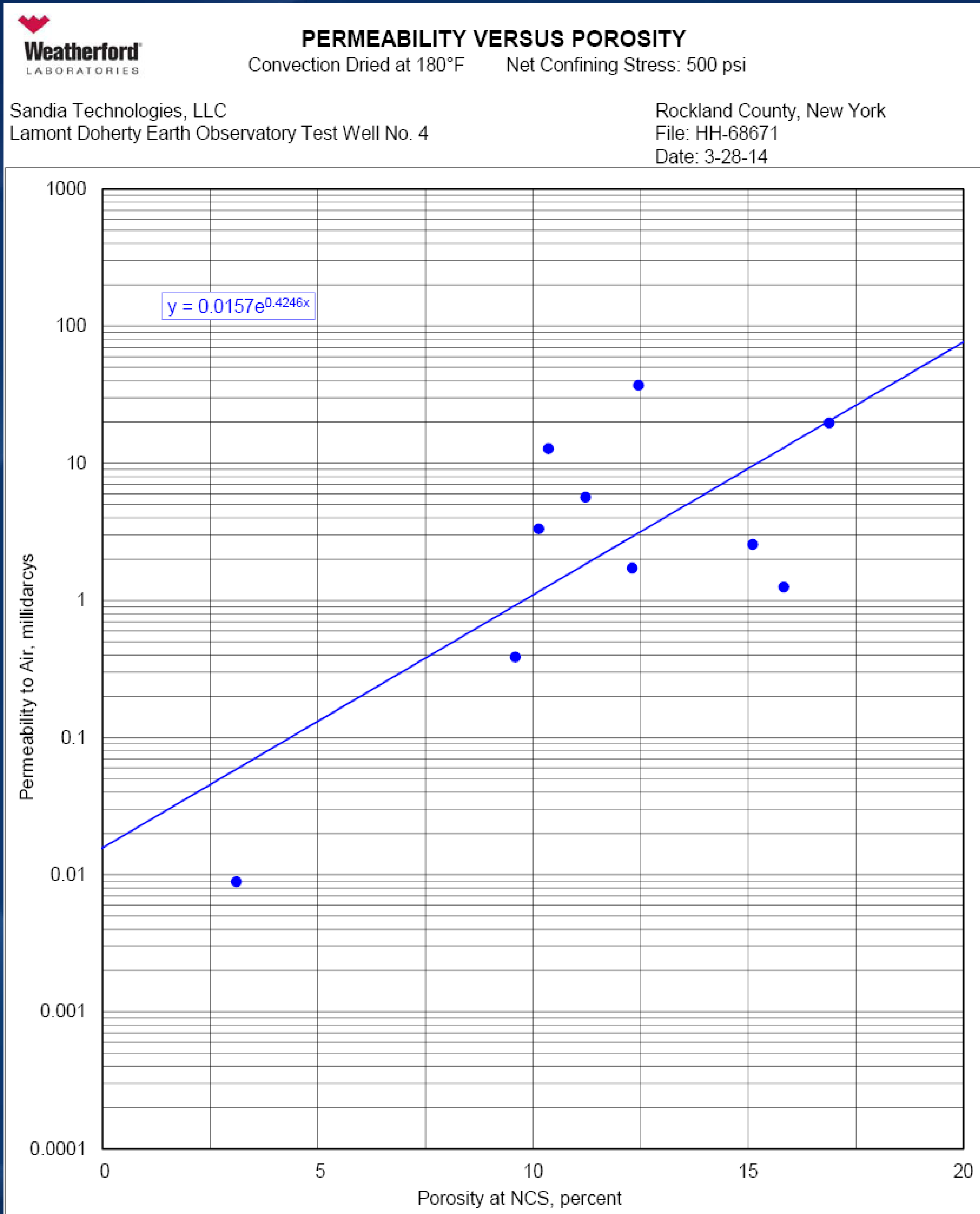
Bottom of Sill at 716.5 feet

Predominantly Sandstone (>85%) from 1000' – 1700'

Stockton Formation?



Preliminary Lab Results



- 10 samples taken from the TW-4 core
- 1 mudstone, 9 sandstones
- Porosity in Sandstones range from 9.6 to 17%
- Most permeabilities over 1 mD

The Future of TriCarb

- Analyze thin sections and logs from TW-4 well.

- Try to correlate units from the TW-4 well and Tandem Lot well

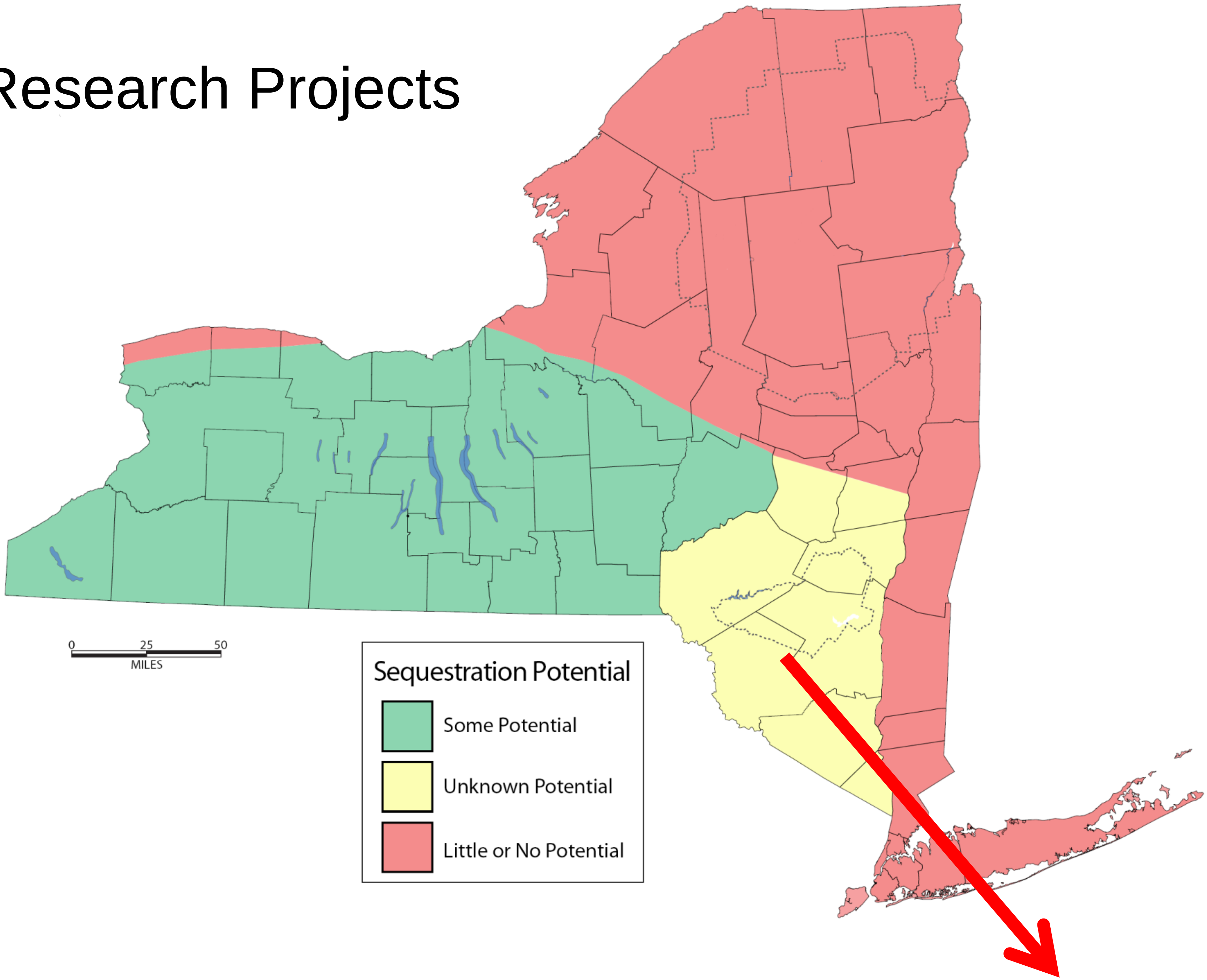
2 Questions to be answered

- Is the porous zone from the Tandem Lot Well present / deeper as you move to the center of the basin (central New Jersey)?

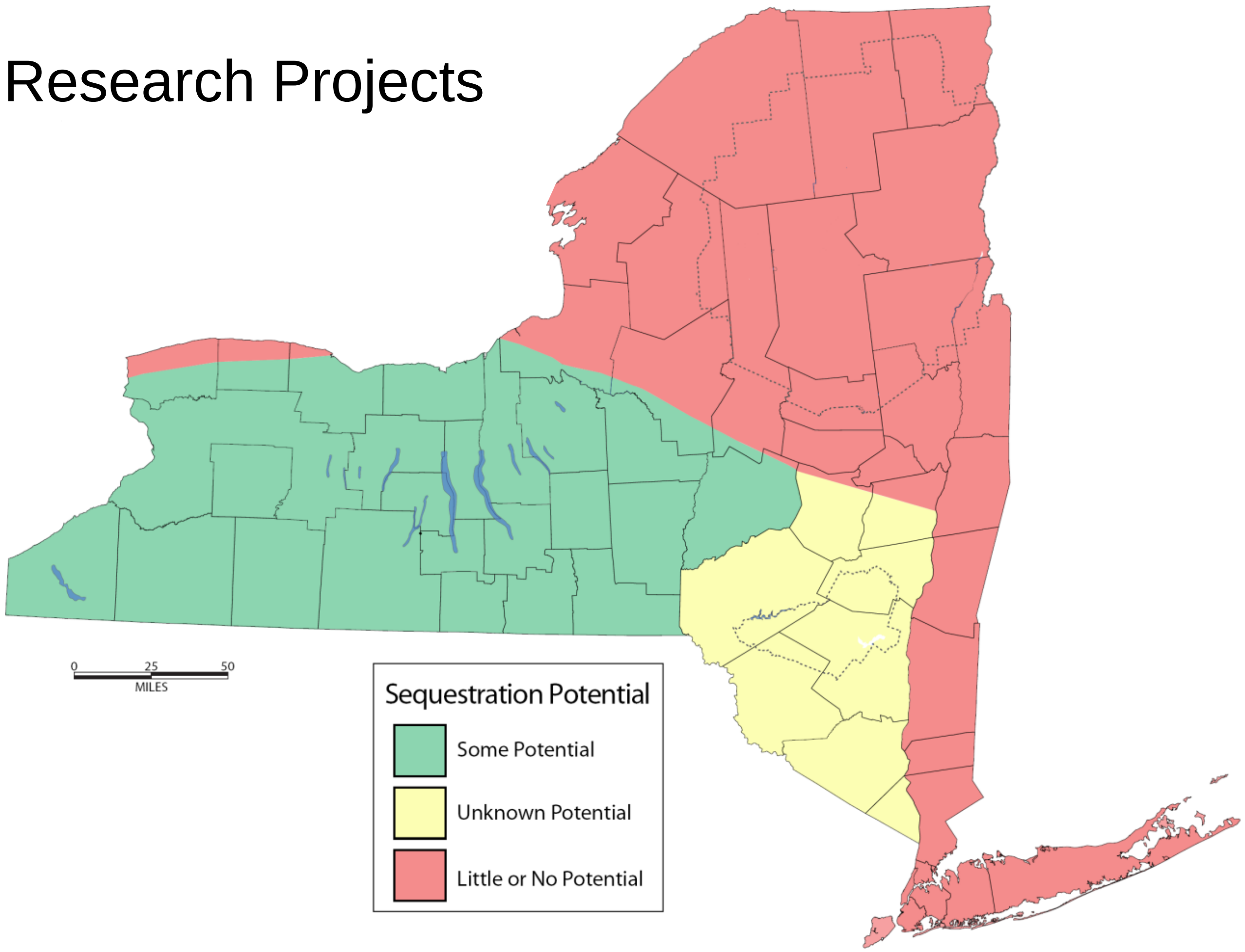
- Are there places in the center of the basin where the Stockton Formation is as porous as it is in the TW-4 well?

With additional funding and support, a deep well drilled in near the center of the basin would help answer these questions and justify additional research into the sequestration potential of the Newark Rift Basin

Research Projects

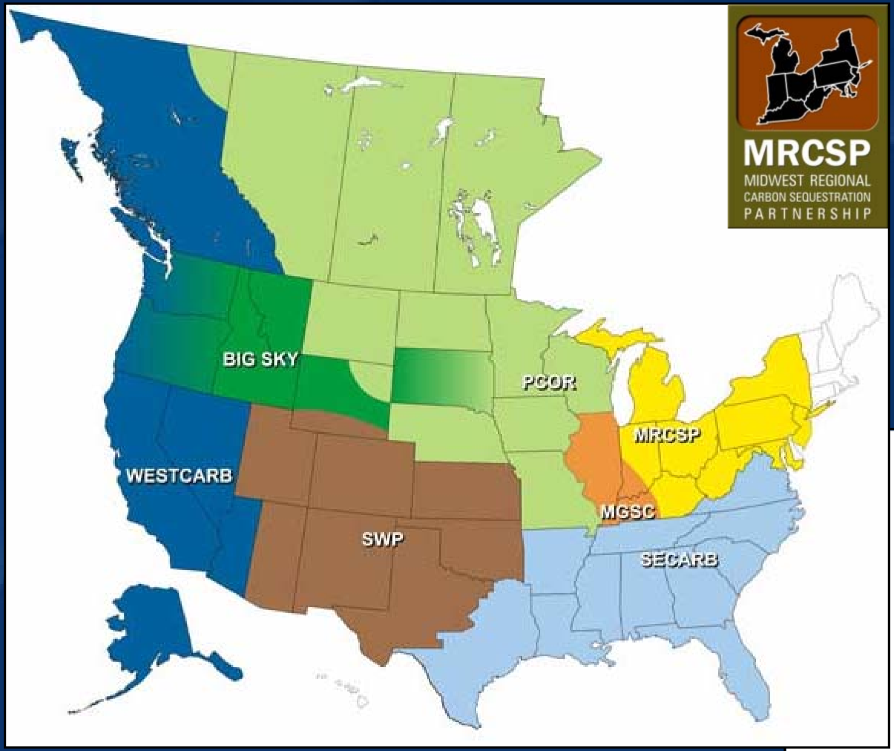


Research Projects



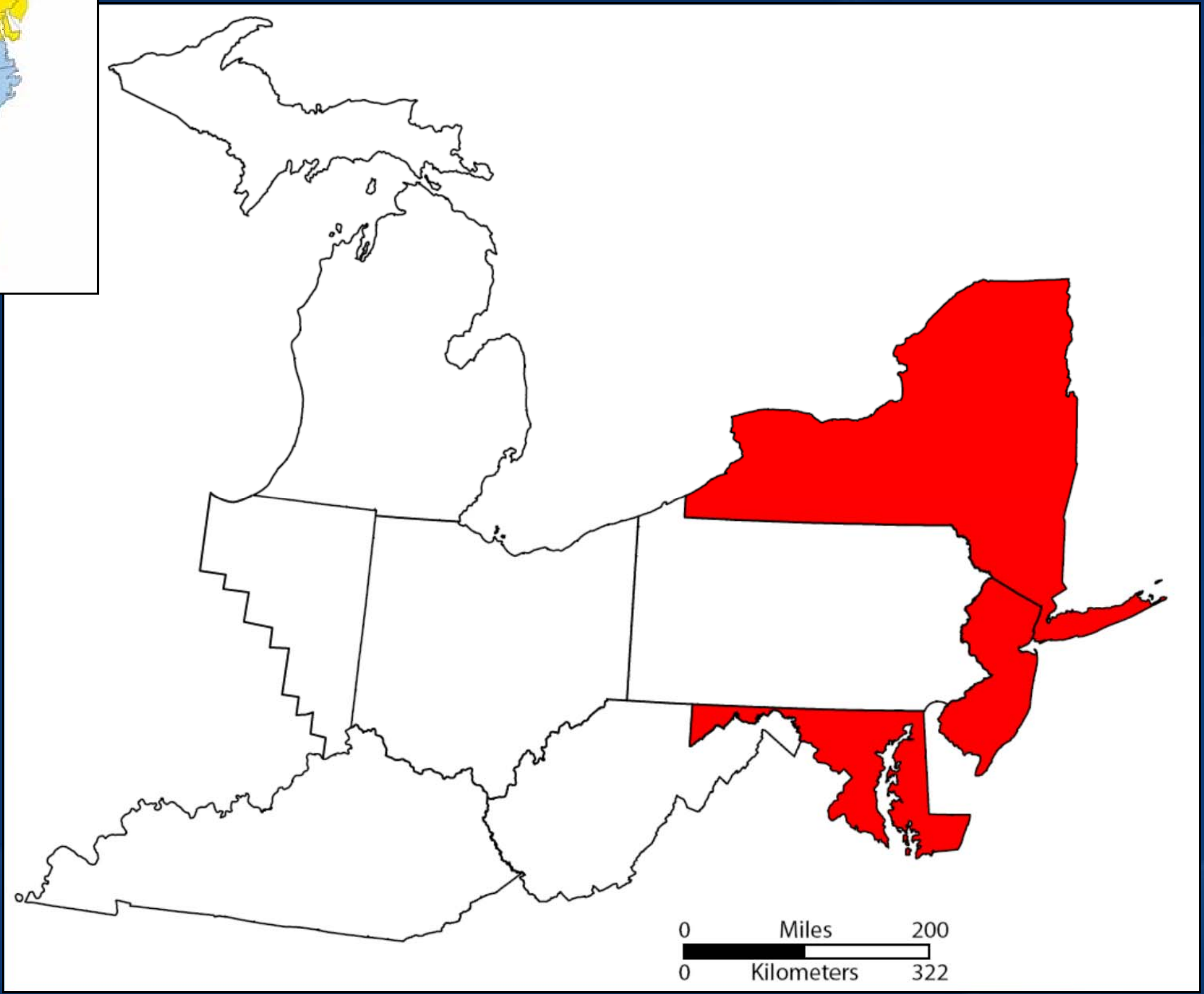
Offshore
(Baltimore Canyon Trough)

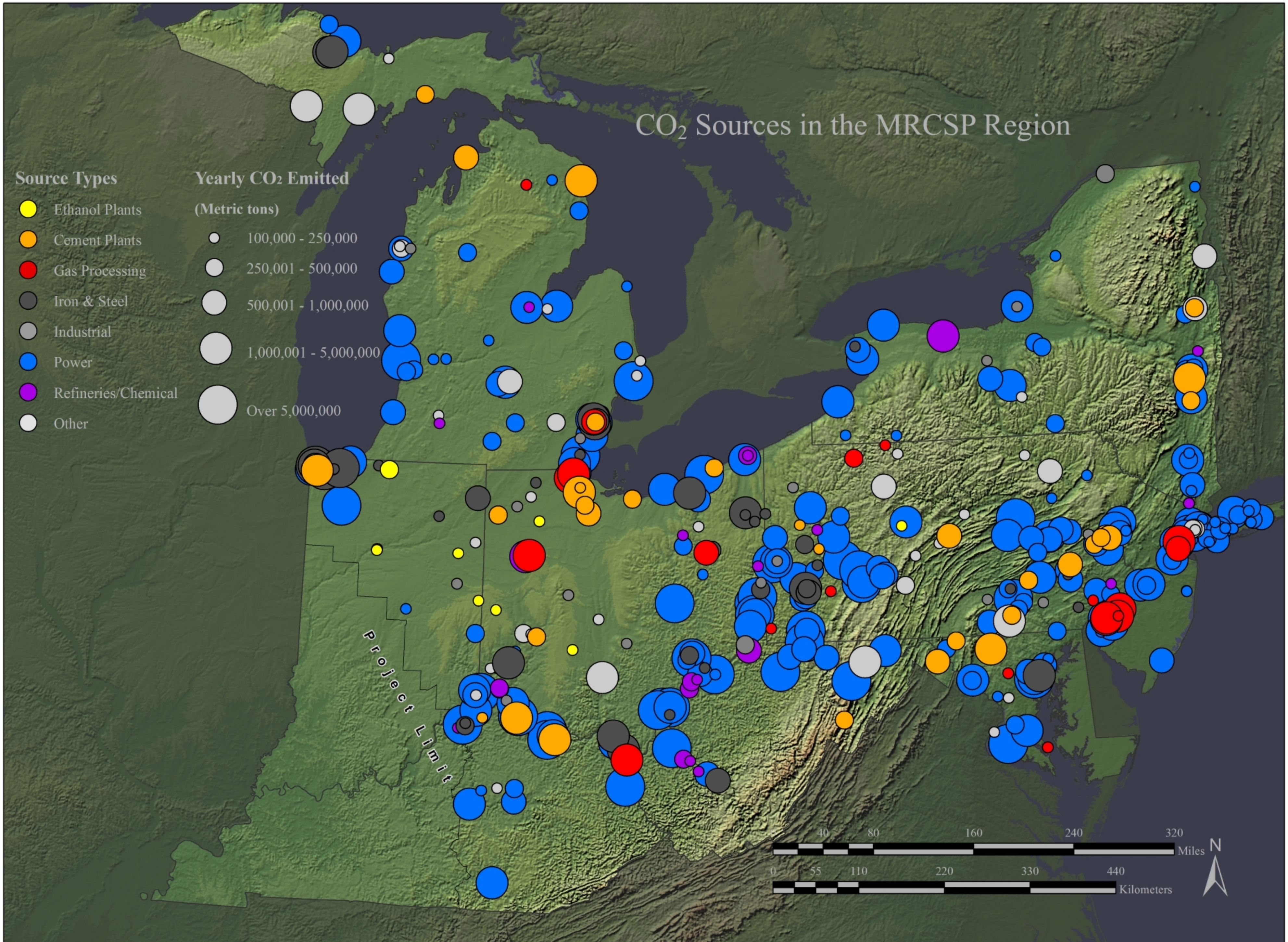
Midwest Region Carbon Sequestration Partnership



Phases I and II focused on characterization of potential onshore geologic sequestration targets

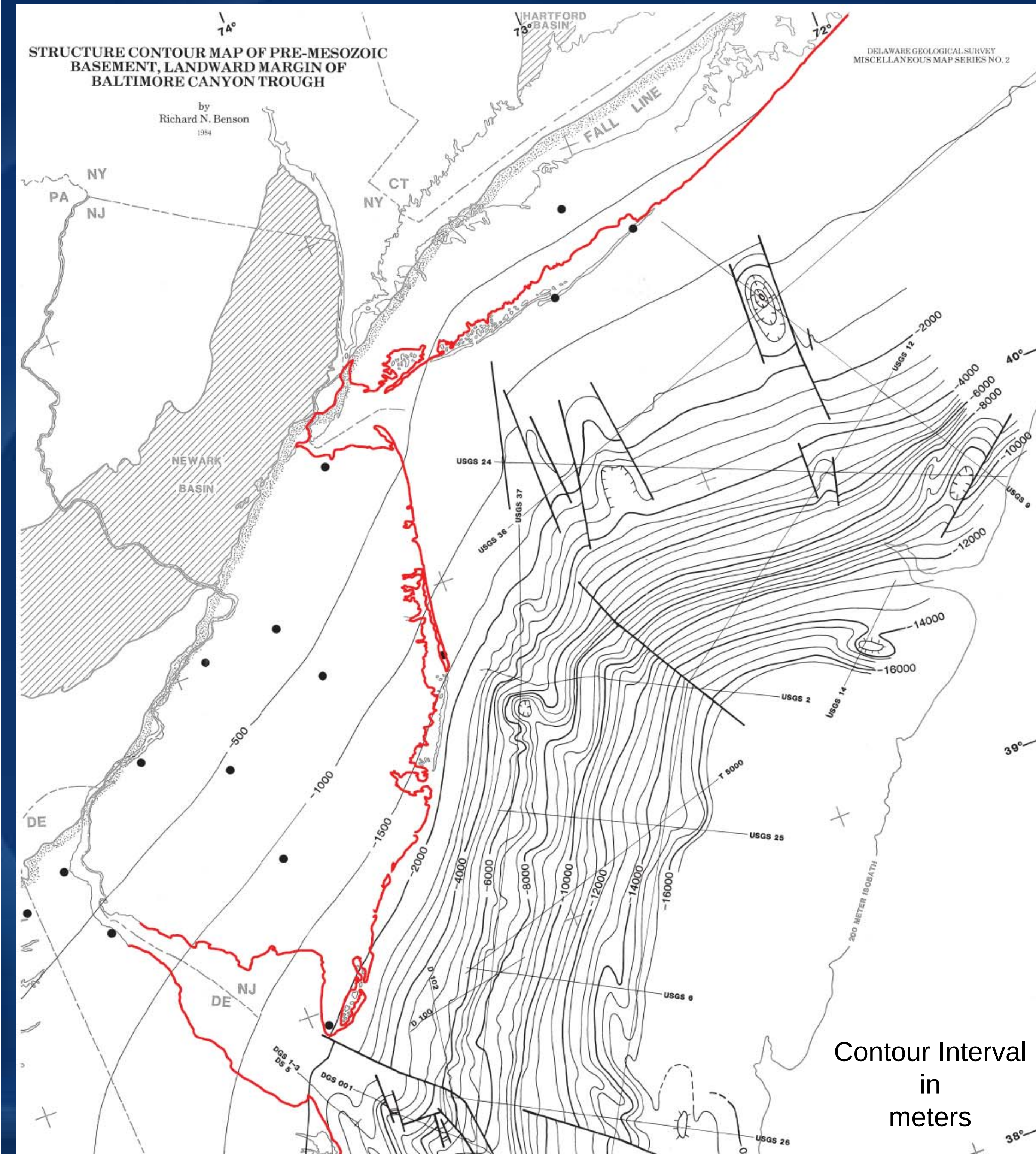
With New York and Maryland, the addition of New Jersey in 2011 increased the coastline of the partnership to over 400 miles





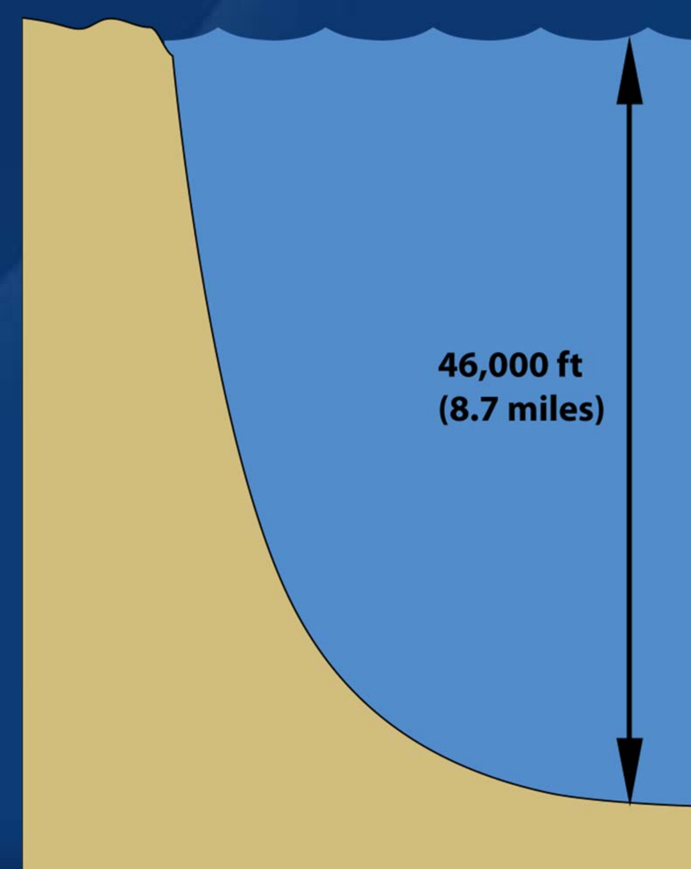
CO_2 Sources in the MRCSP Region
Source Types
Ethanol Plants
Cement Plants
Gas Processing
Iron & Steel
Industrial
Power
Refineries/Chemical
Other
Yearly CO_2 Emitted
(Metric tons)
100,000 - 250,000
250,001 - 500,000
500,001 - 1,000,000
1,000,001 - 5,000,000
Over 5,000,000
Project Limit
0 40 80 160 240 320 Miles
0 55 110 220 330 440 Kilometers
N

Basement Contour Map



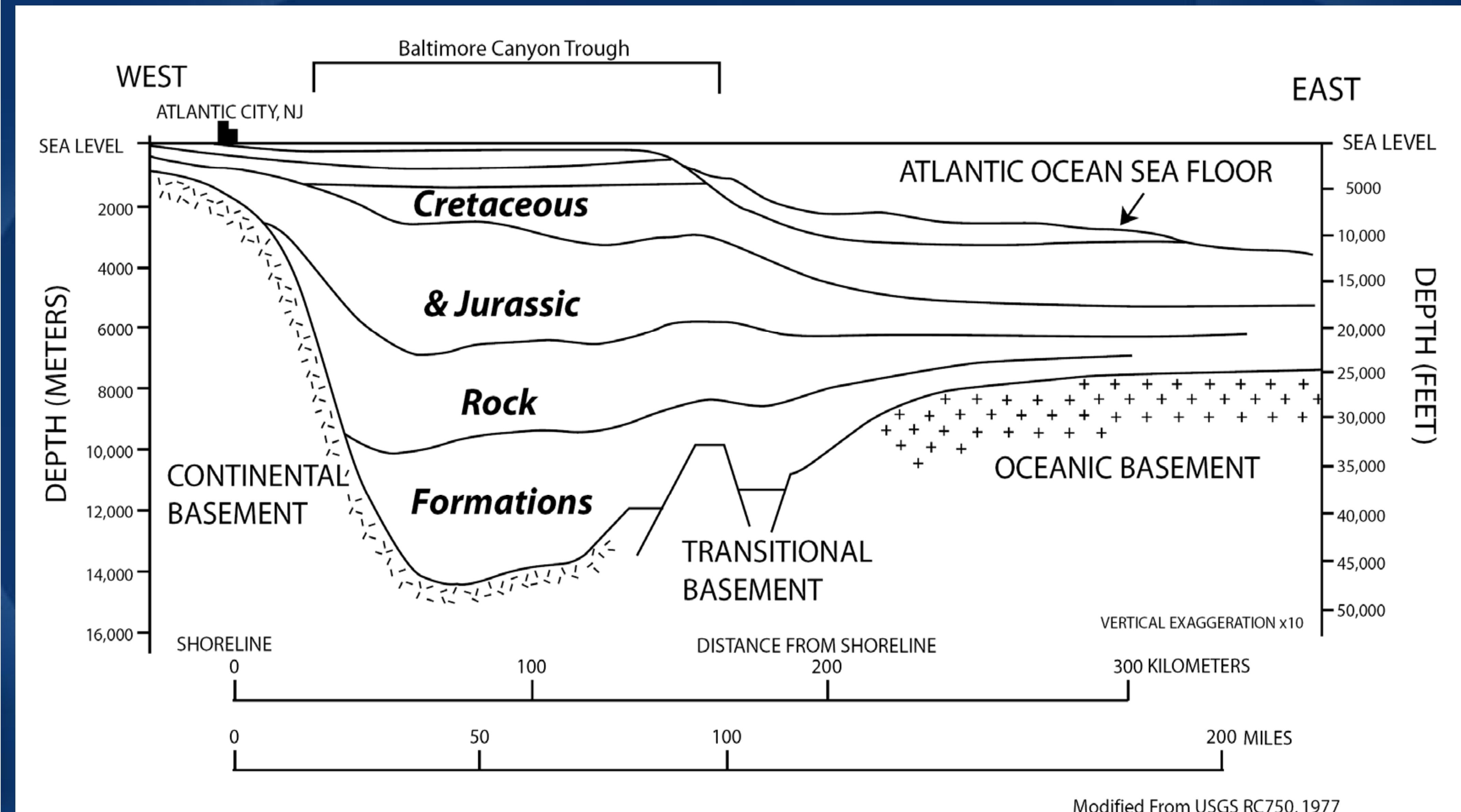
Contour Interval in meters

Basement drops off 14,000 meters (46,000 feet) in 50 miles from the New Jersey coastline.



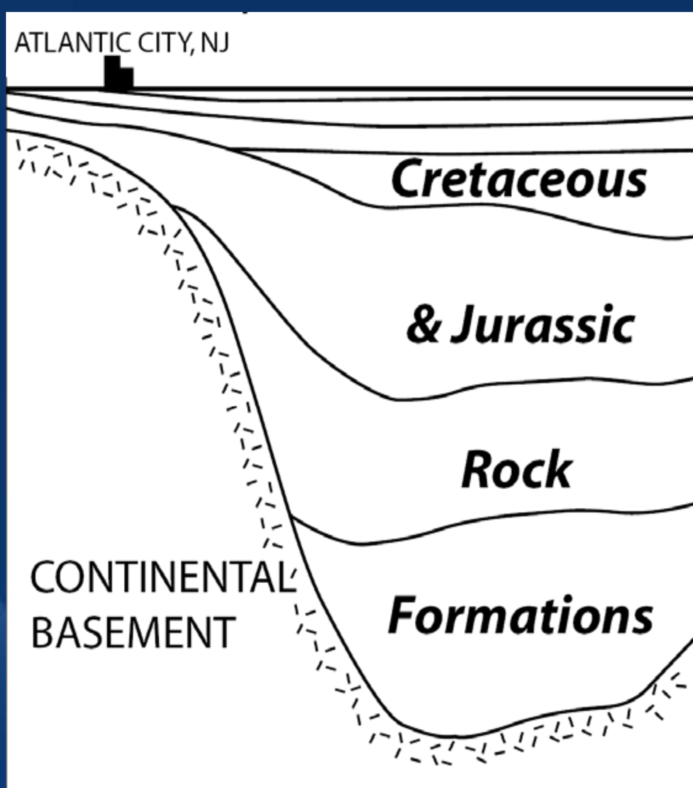
Basement Contour vs. Continental Shelf

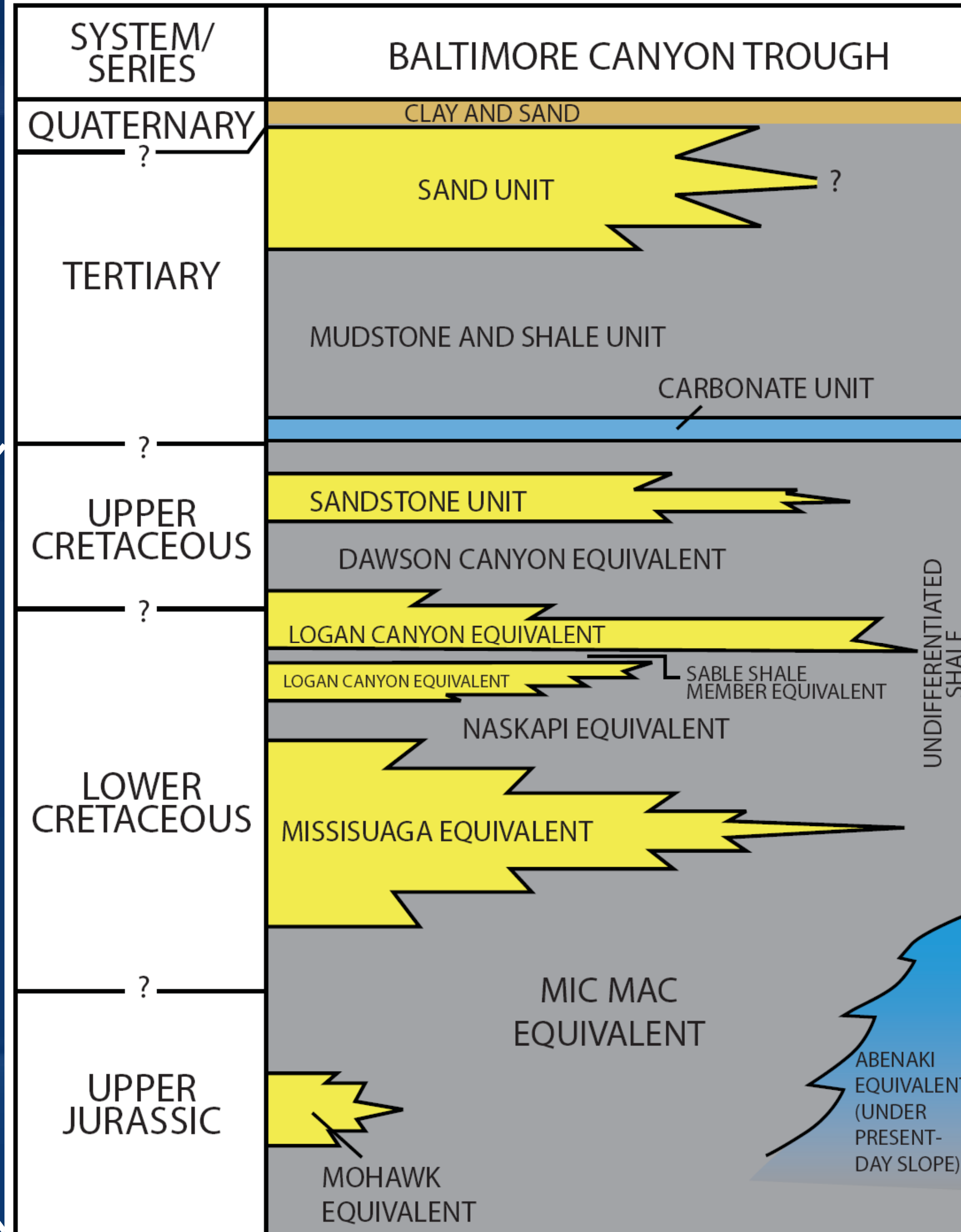
The Baltimore Canyon Trough
(BCT)



BCT Stratigraphy

Simplified stratigraphic column shows several sandstone units (potential reservoirs) and shale units (potential cap rocks)



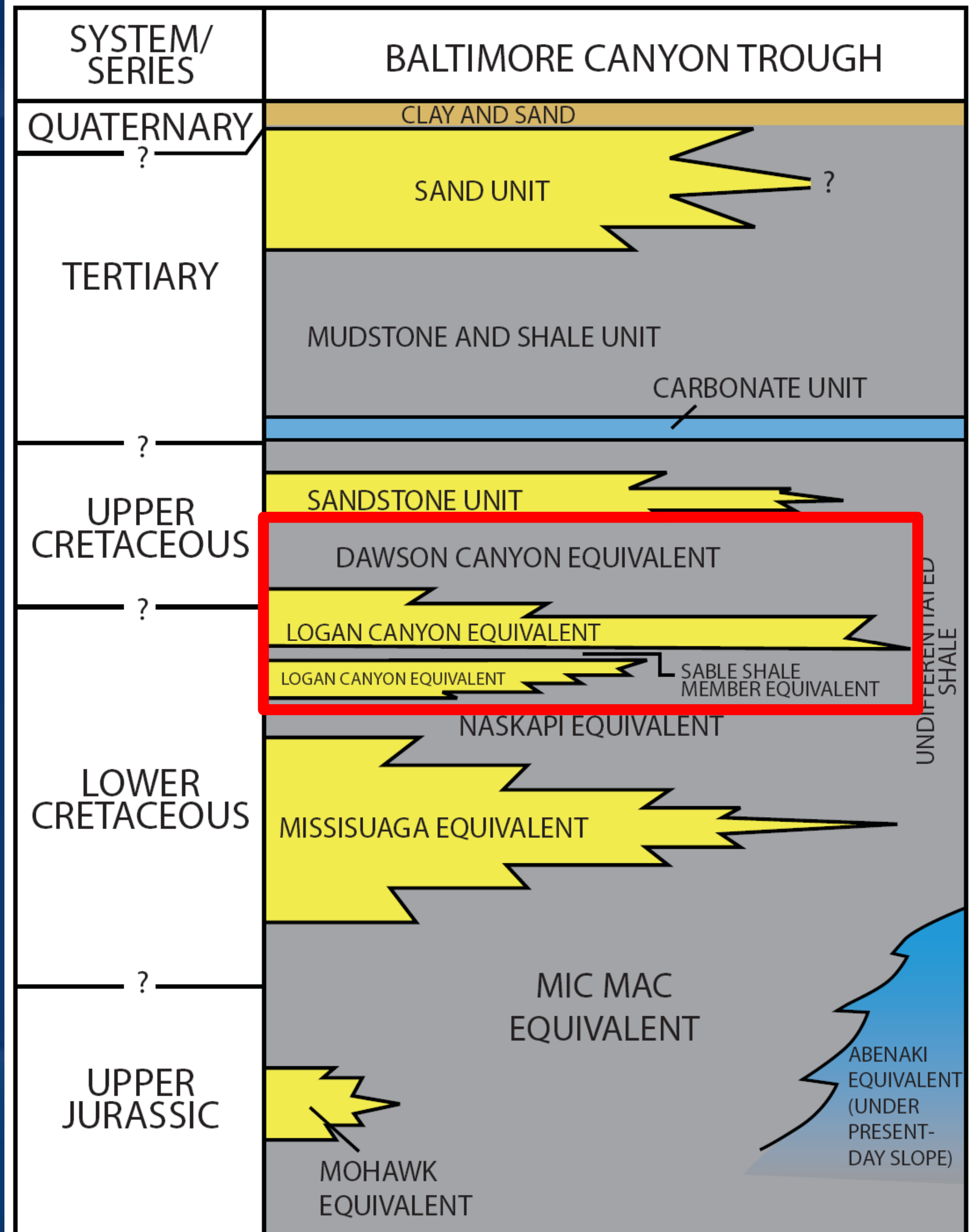


(From Libby-French, 1984)

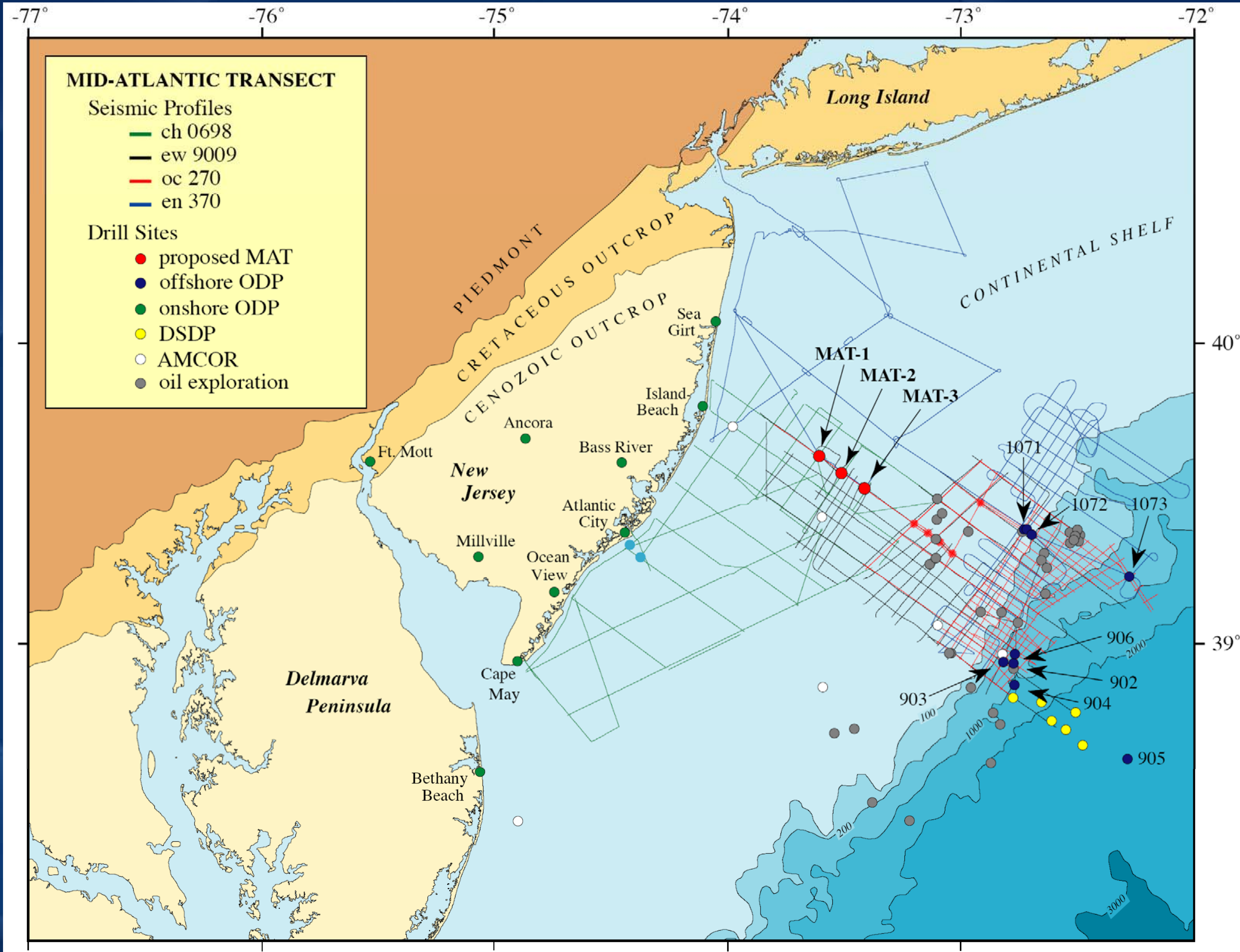
BCT Stratigraphy

Simplified stratigraphic column shows several sandstone units (potential reservoirs) and shale units (potential cap rocks)

Our initial research has focused on the Logan Canyon Sandstone with the Dawson Canyon and Sable Shale acting as primary sealing units.

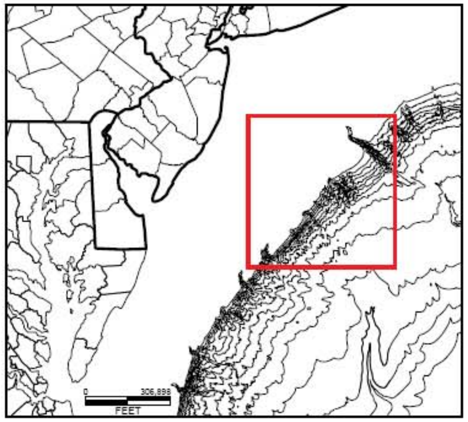


(From Libby-French, 1984)

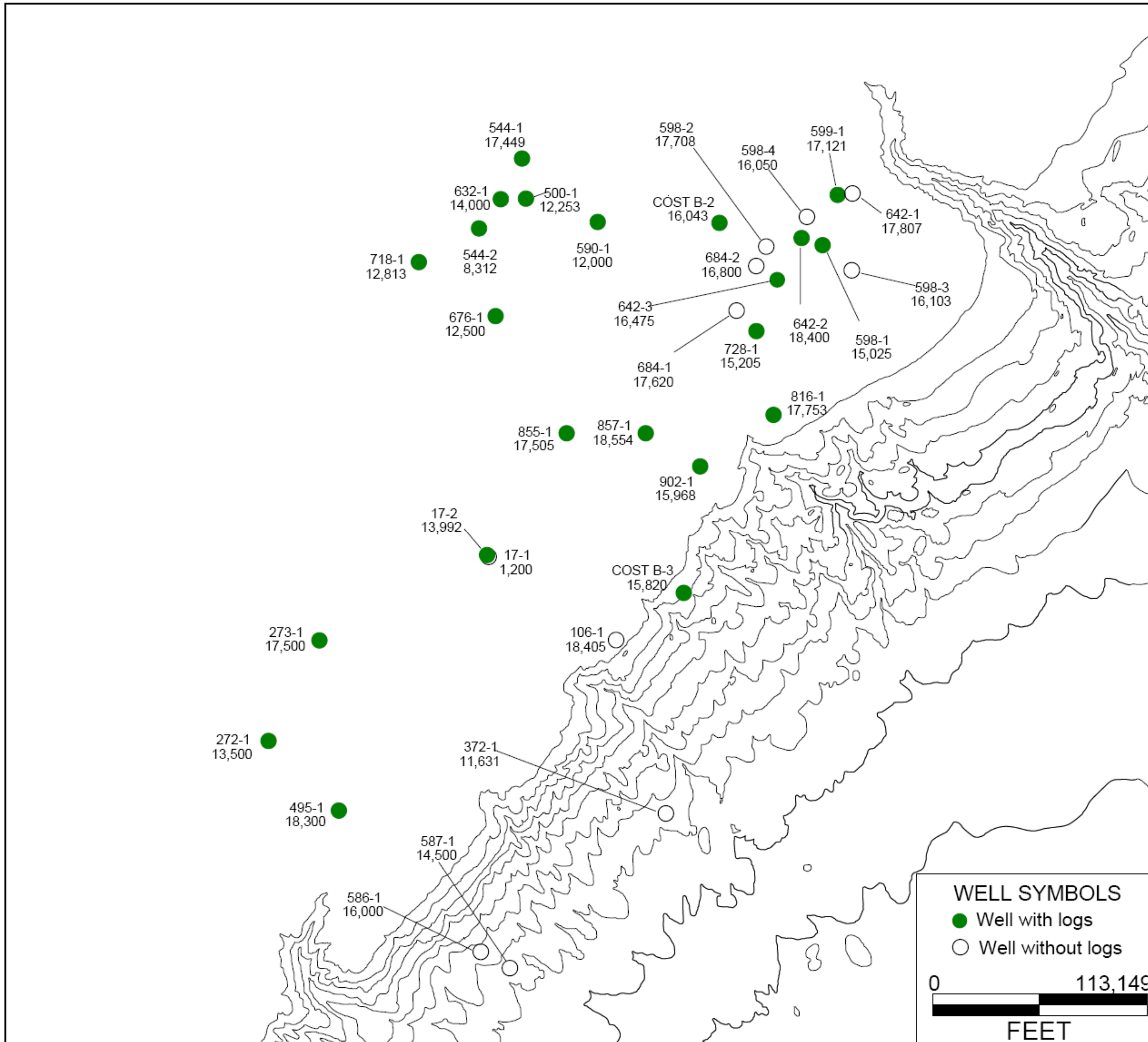


-77°
-76°
-75°
-74°
-73°
-72°
40°
39°
MID-ATLANTIC TRANSECT
Seismic Profiles
ch 0698
ew 9009
oc 270
en 370
Drill Sites
proposed MAT
offshore ODP
onshore ODP
DSDP
AMCOR
oil exploration
PIEDMONT
CRETACEOUS OUTCROP
CENOZOIC OUTCROP
CONTINENTAL SHELF
Long Island
New Jersey
Delmarva Peninsula
Sea Girt
Island Beach
Ancora
Bass River
Ft. Mott
Atlantic City
Millville
Ocean View
Cape May
Bethany Beach
MAT-1
MAT-2
MAT-3
1071
1072
1073
906
902
903
904
905
100
200
1000
2000
3000

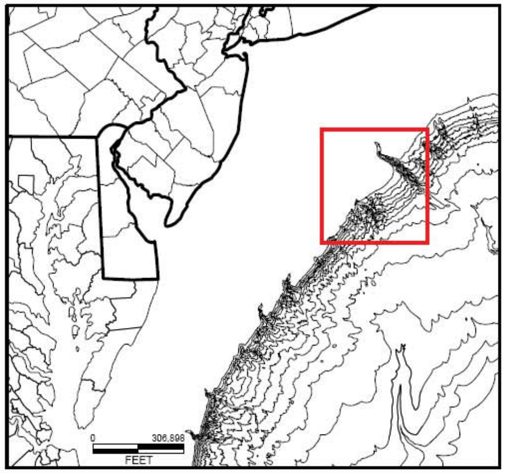
Petroleum Exploration (1940's – 1980's)



Company	Well name	T.D. (m)	T.D. (ft.)
----------	COST B-2	4863	15954.7
Shell	273-1	5237	17181.8
Shell	587-1	4420	14501.3
Shell	586-1	3076	10091.9
Shell	93-1	5407	17739.5
Gulf	857-1	5527	18133.2
Texaco	598-2	5244	17204.7
Mobil	17-2	4160	13648.3
Mobil	544-1	2543	8343.2
Exxon	684-2	4969	16302.5
Tenneco	495-1	5443	17857.6
----------	COST B-3	3991	13093.8
Conoco	590-1	3562	11686.4
Shell	632-1	4180	13713.9
Texaco	598-1	4423	14511.2
Houston	676-1	3713	12181.8
Exxon	684-1	5226	17145.7
Mobil	17-1	261	856.3
Houston	855-1	5217	17116.1
Shell	272-1	4024	13202.1
Gulf	718-1	3825	12549.2
Exxon	902-1	4713	15462.6
Tenneco	642-2	5447	17870.7
Exxon	500-1	3647	11965.2
Texaco	642-1	5264	17270.3
Murphy	106-1	4908	16102.4
Tenneco	642-3	4861	15948.2
Exxon	599-1	5058	16594.5
Texaco	598-4	4724	15498.7
Exxon	816-1	5257	17247.4
Exxon	728-1	4477	14688.3
Shell	372-1	3545	11630.6



BCT Cross Section



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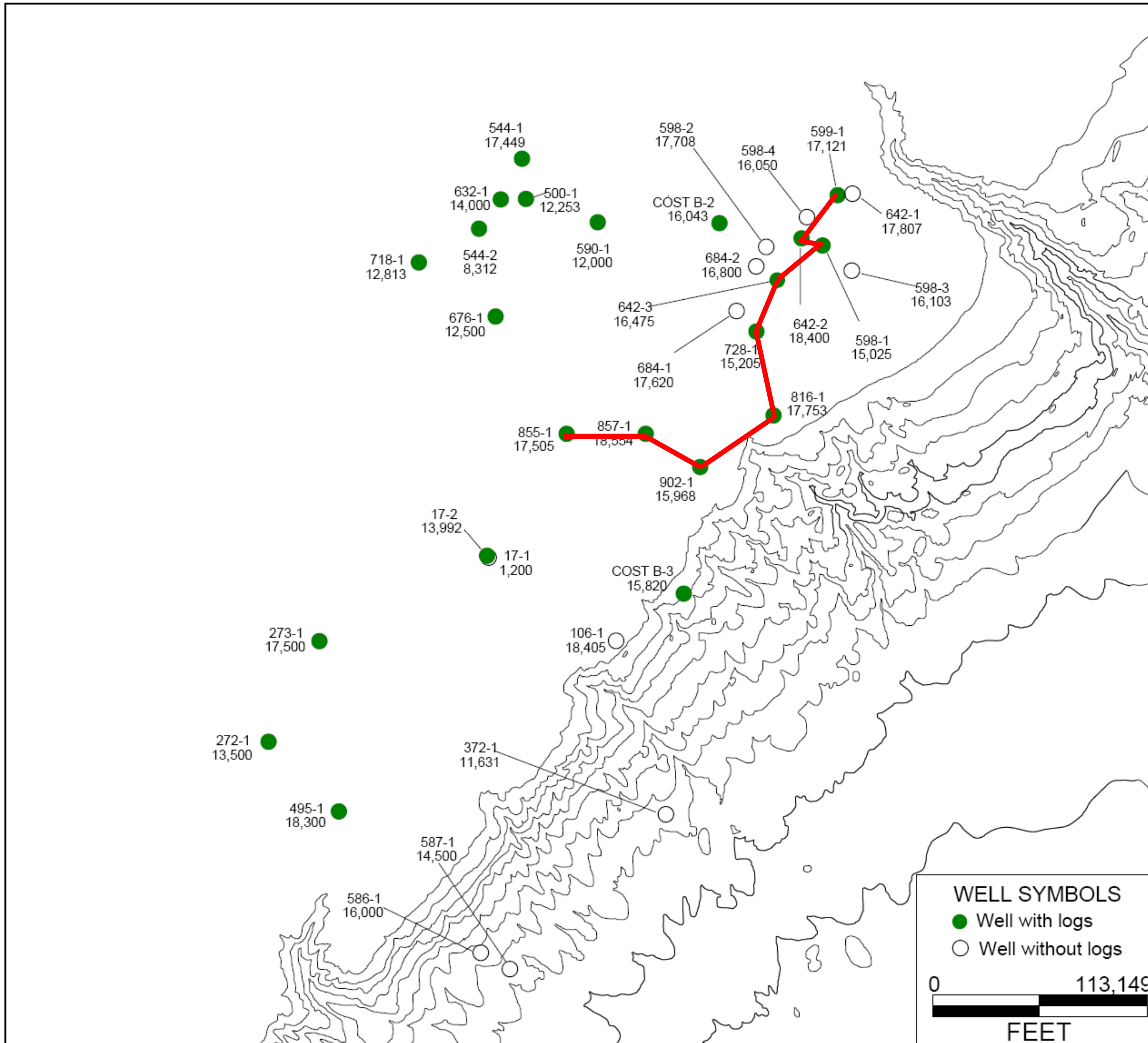
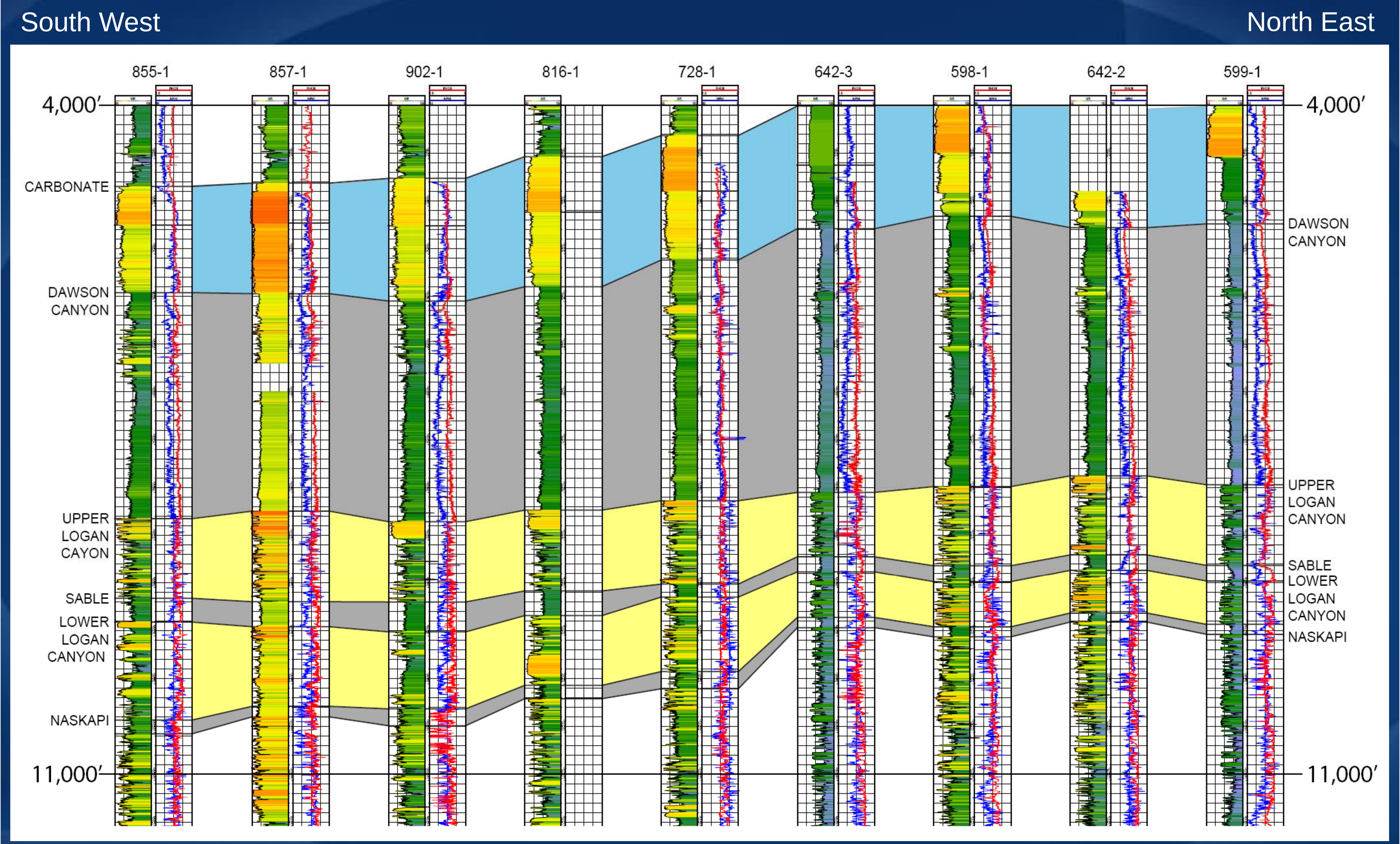
Shell	93-1
Gulf	857-1
Texaco	598-2
Mobil	17-2
Mobil	544-1
Exxon	684-2
Texaco	598-4
----------	COST B-3
Conoco	590-1
Shell	632-1
Texaco	598-1
Houston	676-1
Exxon	684-1
Mobil	17-1
Houston	855-1
Exxon	599-1
Gulf	718-1
Exxon	902-1
Tenneco	642-2
Exxon	500-1
Texaco	642-1
Murphy	106-1
Tenneco	642-3
Mobil	544-2



BCT Cross Section



Porosity

Facies / Lithology	n*	Ave. Φ (%)
Prograded shelf margin limestones	277	2.4
Transitional marine sandstones	619	6.1
Coastal Plain sandstones	1391	8.7
Fine-grained deltaic sandstones	729	9.2
Aggradded shelf-margin limetsones	189	8.5
Limestone buildups	3	12.2
Chalky *Tubiphytes* packstone	84	6.3
Shoal-water oolite grainstone	53	17
Shelf-margin deltaic sandstones	163	18.2

(From Prather, 1991)

*n = number of beds

Porosity data from 3 exploratory wells in the study area show high porosity beds in both sandstone and limestone units.

Capacities for the 2,000 square mile target area

Reservoir Unit	Reservoir Depth	Reservoir Temperature	Resevoir Pressure	Reservoir Thickness	Reservoir Area	CO_2 Mass Storage Capacity (in MMT) @ 20% Porosity		
	feet	deg F	psi	feet	acre	displace 1%	displace 2.5%	displace 4%
Upper Logan Canyon	8,000	160	3,300	932	1,280,000 (2,000 mi^2)	2,066	5,165	8,263
Lower Logan Canyon	8,900	180	3,600	650	1,280,000 (2,000 mi^2)	1,383	3,457	5,531
Total				1,582		3,449	8,622	13,794

2010 CO_2 Emissions (Million Metric Tonnes, MMT)

State	Electric Power	Industrial	
Pennsylvania	116.58	39.20	
New York	37.76	10.29	
Maryland	24.52	4.57	
Massachusetts	17.99	3.62	
New Jersey	17.62	9.18	
Connecticut	7.62	1.99	
Delaware	4.17	1.55	
TOTAL	109.68	70.4	**180.08**

Capacity ranges from 19 - 77 years of storage at current emission levels

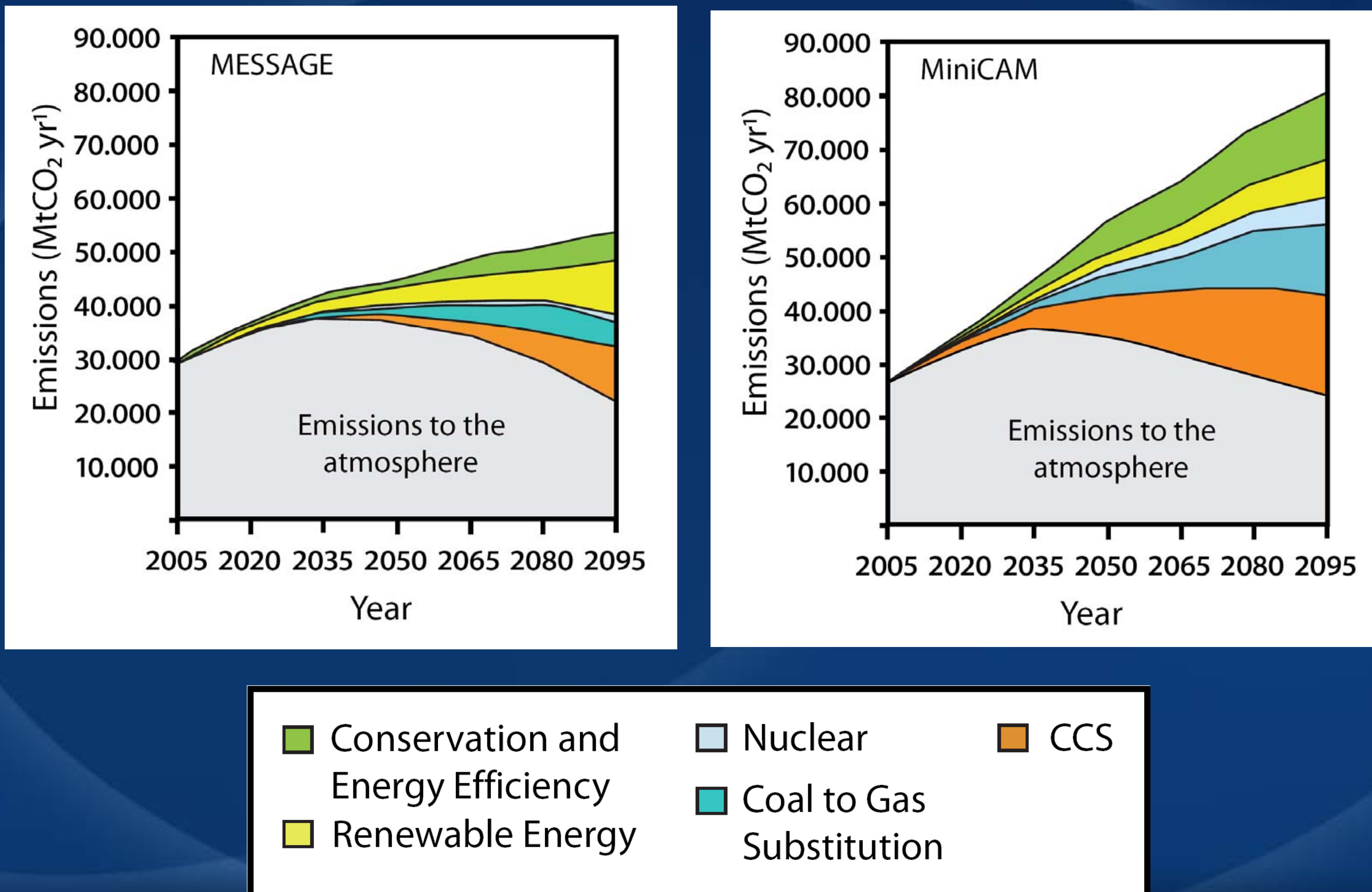
Future Offshore Work

Phase 3.2 is about to begin

- Acquire core samples from the Delaware Geological Survey to make thin sections and test for porosity and permeability
- Use lab porosity and permeability measurements to calibrate well logs
- Look at seismic data to investigate continuity of sandstone units between wells
- Detailed analysis of shale units and other cap rocks

With additional funding and support, an offshore well could be drilled to supplement current data with new, more accurate measurements

Just a piece of the pie



Thank You

Formation Fluid Chemistry

Water Quality	TDS mf/L
Fresh Water	< 1,000
Brackish Water	1,000 - 10,000
Saline Water	10,000 - 30,000
Brine	> 30,000

1.01 — 3,058 ft.

Parameter	Result		Units
General Analysis			
Specific Gravity	1.004	@ 25°C	
Observed pH	7.448	@ 25°C	
Resistivity at 77°F	97.675		ohm-cm
Conductivity at 77°F	10.2		mS/cm
Salinity	1099		
Total Dissolved Solids			
Evaporated @ 110°C	9742		mg/L
Measured	7550		mg/L
Calculated	6552		mg/L
Anions	mg/kg	meq/L	
Fluoride (F)			
Chloride (Cl)	608.2	17.224	
Nitirite (NO2)			
Bromide (Br-)	5.59	0.070	
Nitrate (NO3)			
Phosphate (PO4)			
Sulfate (SO4)	2331.72	48.741	
Cations	mg/kg	meq/L	
Lithium (Li)	0.4	0.05	
Sodium (Na)	2108.7	92.09	
Ammonium (NH4)	44.0	2.45	
Potassium (K)	23.5	0.60	
Magnesium (Mg)	44.3	3.66	
Calcium (Ca)	259.9	13.02	
ICP Metals	mg/kg	meq/L	
Aluminum (Al)			
Boron (B)	2.0	0.6	
Barium (Ba)	0.27	0.0039	
Copper (Cu)			
Iron (Fe)	3.27	0.1	
Manganese (Mn)	0.65	0.0	
Phosphorus (P)	0.32	0.0	
Lead (Pb)			
Sulphur (S)	775.8	48.6	
Silicon (Si)	11.0	1.6	
Strontium (Sr)	3.221	0.074	
Zinc (Zn)	0.29	0.0088	
ORGANIC ACIDS	mg/kg		
Glycolic	27.3		
Formic	8.5		
Acetic	218.0		
Propionic	2.6		

1.02 — 2,322 ft.

Parameter	Result		Units
General Analysis			
Specific Gravity	1.002	@ 25°C	
Observed pH	7.499	@ 25°C	
Resistivity at 77°F	202.335		ohm-cm
Conductivity at 77°F	4.9		mS/cm
Salinity	552		
Total Dissolved Solids			
Evaporated @ 110°C	4308		mg/L
Measured	3537		mg/L
Calculated	3163		mg/L
Anions	mg/kg	meq/L	
Fluoride (F)			
Chloride (Cl)	287.6	8.1	
Nitirite (NO2)			
Bromide (Br-)	4.202	0.053	
Nitrate (NO3)			
Phosphate (PO4)			
Sulfate (SO4)	1110.7	23.2	
Cations	mg/kg	meq/L	
Lithium (Li)	0.403	0.058	
Sodium (Na)	898.3	39.2	
Ammonium (NH4)	16.0	0.89	
Potassium (K)	11.2	0.29	
Magnesium (Mg)	45.0	3.7	
Calcium (Ca)	134.5	6.7	
ICP Metals	mg/kg	meq/L	
Aluminum (Al)			
Boron (B)	2.0	0.21	
Barium (Ba)	0.27	0.0015	
Copper (Cu)	0.077	0.0024	
Iron (Fe)	0.021	0.0008	
Manganese (Mn)	0.17	0.012	
Phosphorus (P)	0.24	0.008	
Lead (Pb)			
Sulphur (S)	356.0	22.2	
Silicon (Si)	10.0	1.4	
Strontium (Sr)	1.7	0.039	
Zinc (Zn)	4.1	0.13	
ORGANIC ACIDS	mg/kg		
Glycolic	19.1		
Formic	3.4		
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Large CO_2 Point Sources in New York State