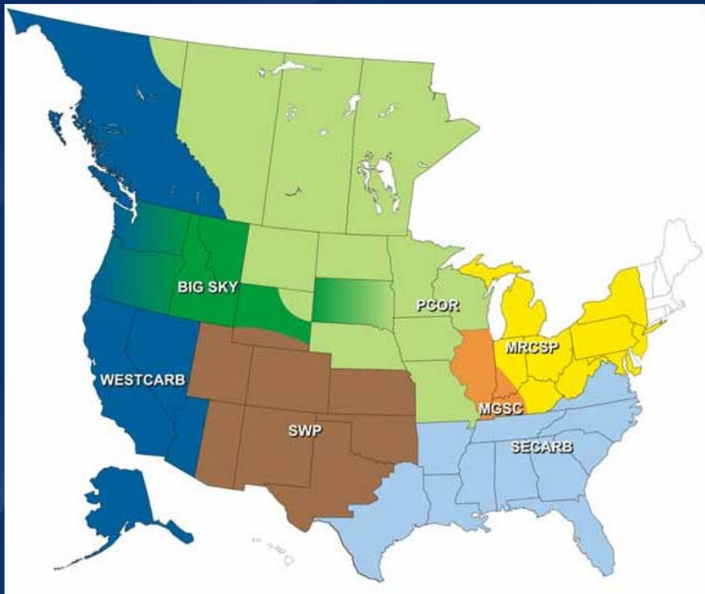
Wireline Log Interpretations and Preliminary CO2 Capacity Estimates for the Baltimore Canyon Trough

Brian Slater[1], Langhorne Smith[1], Ken Miller[2], Greg Mountain[2], Ying Fan Reinfelder[2]

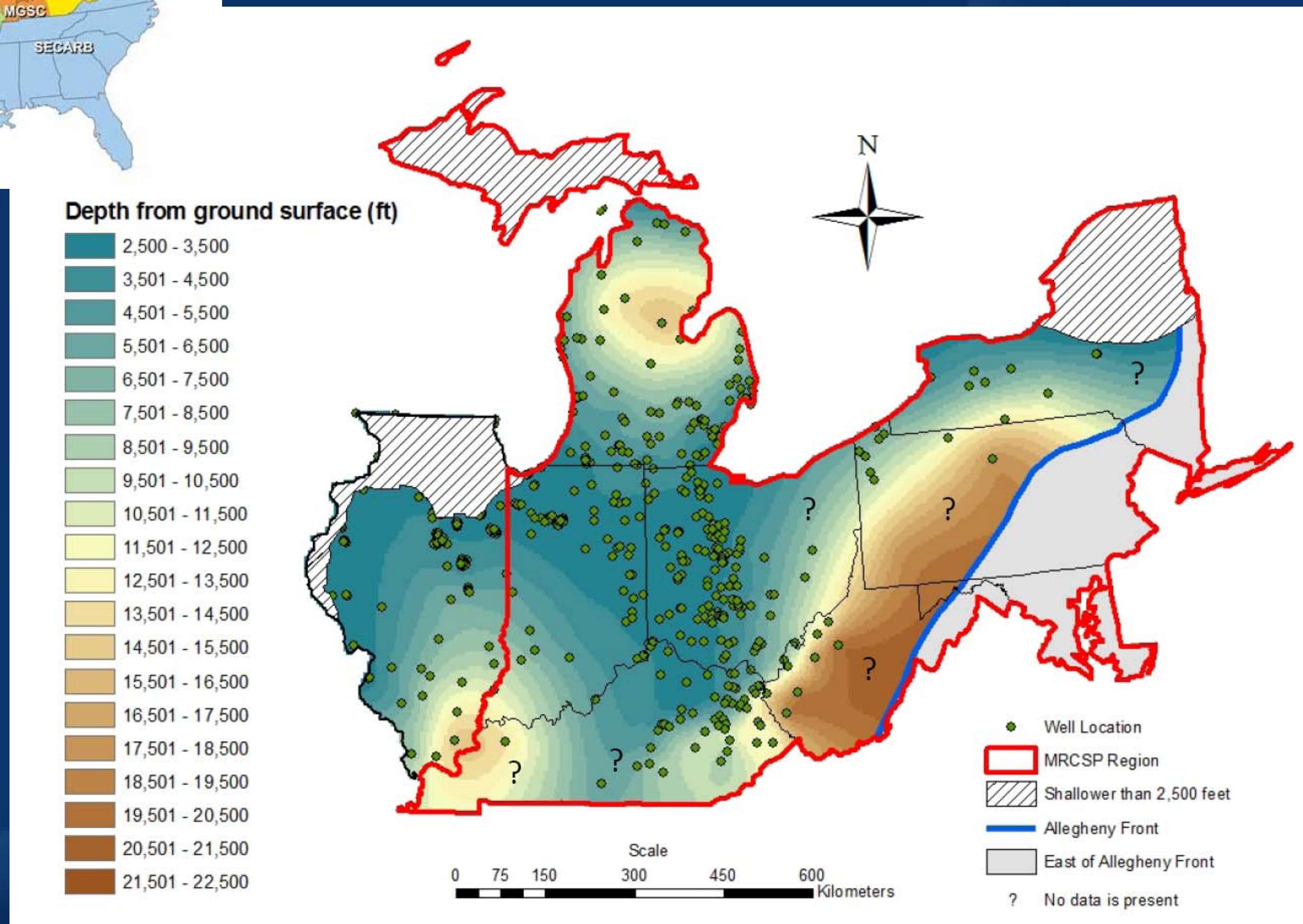
[1] New York State Geological Survey, Albany, New York
[2] Rutgers University, Piscataway, New Jersey

September 2012

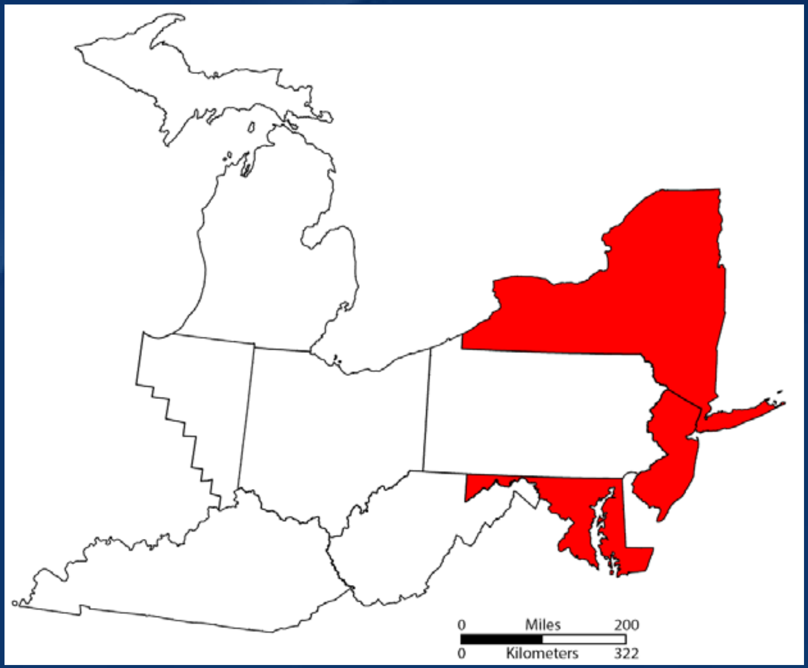
Midwest Region Carbon Sequestration Partnership



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



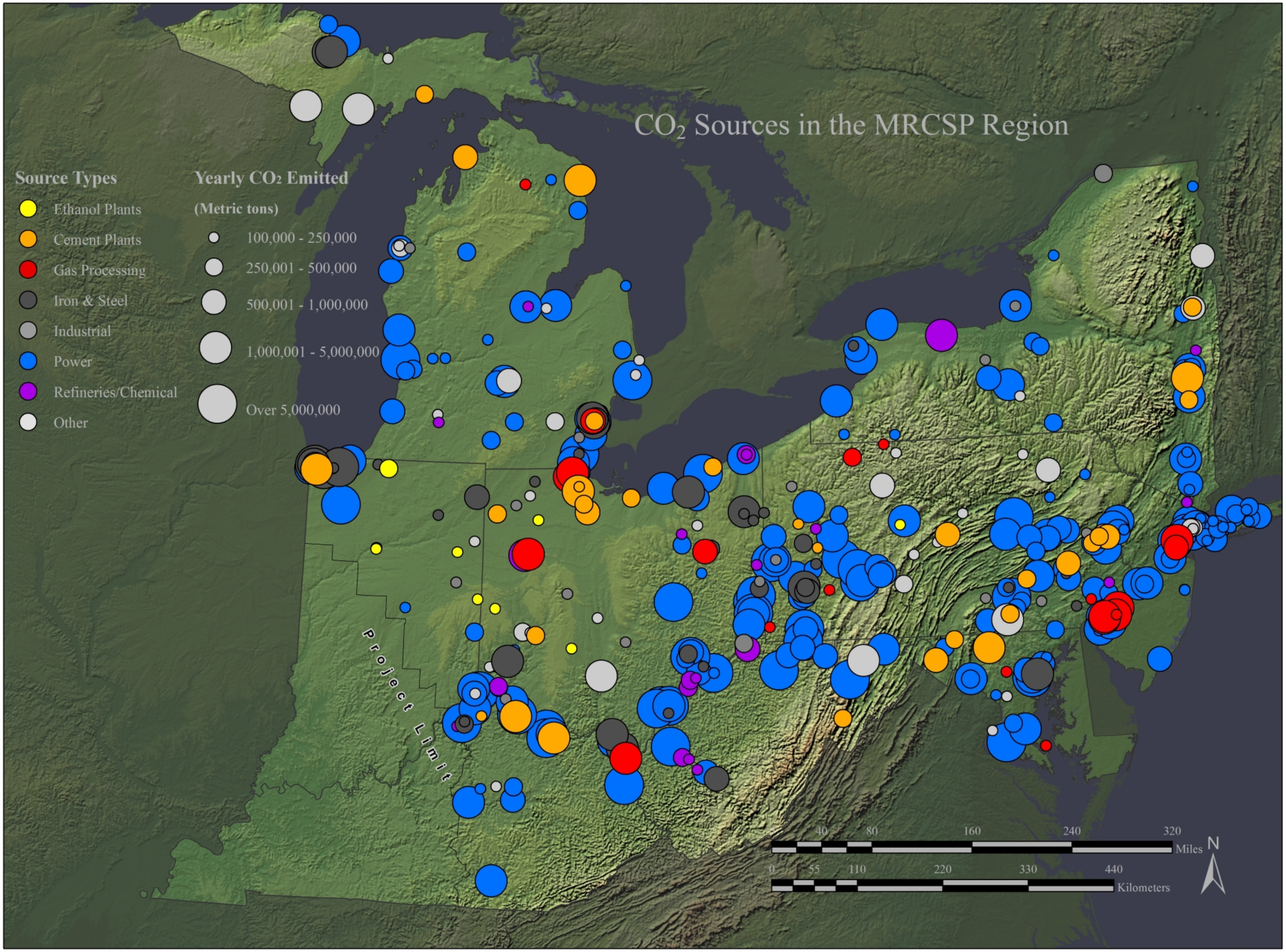
Phase III: Offshore Component



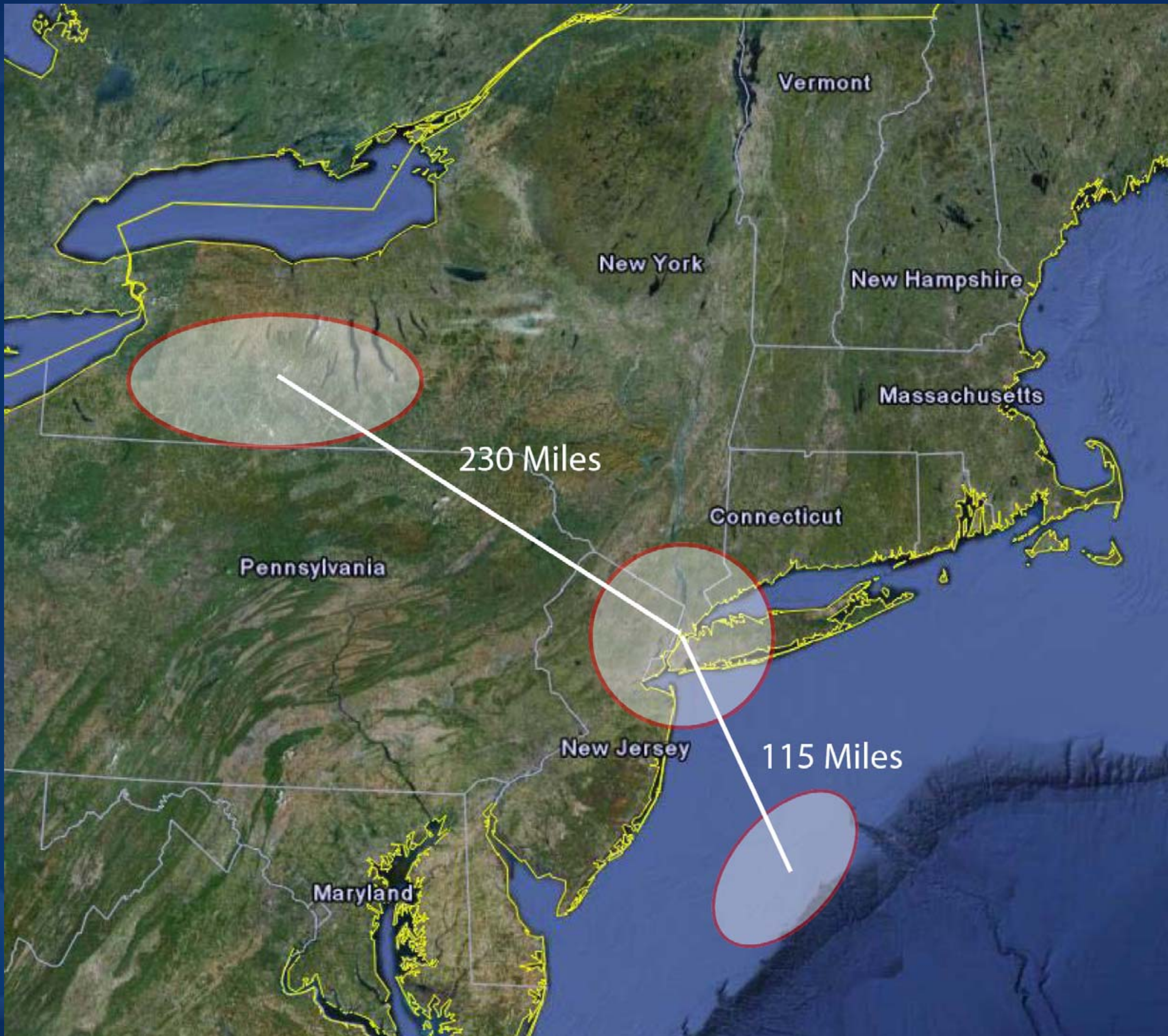
More than 450 miles of coastline

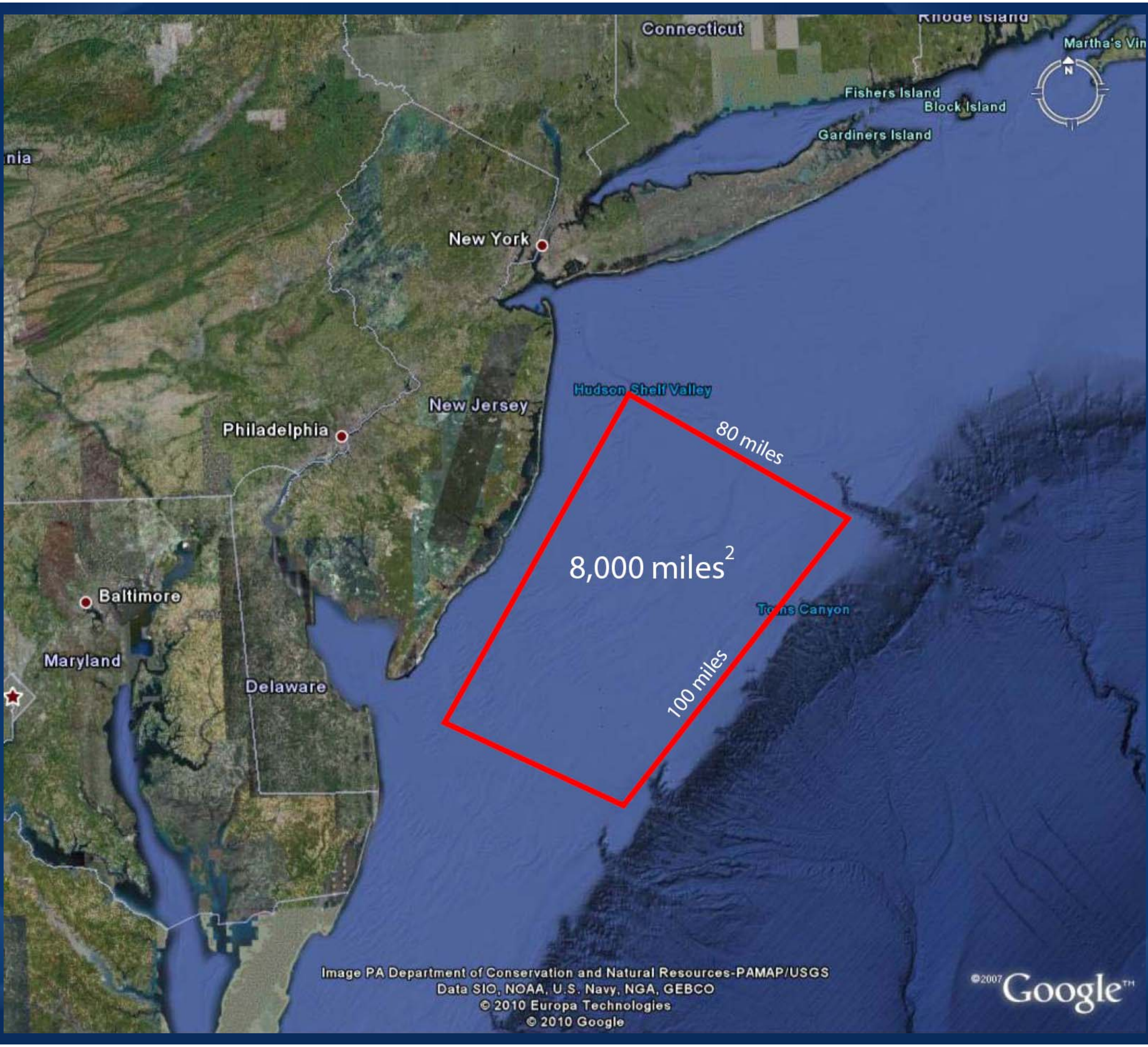
Why Offshore?

- Proximity to point sources
- Enormous potential capacity
- None of the on land leasing and legal issues
- Density inversion
- Low salinity formation water
- Hydrate formation
- Pressure management options



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


Vermont
New York
New Hampshire
Massachusetts
230 Miles
Connecticut
Pennsylvania
New Jersey
115 Miles
Maryland



Connecticut
Rhode Island
Martha's Vin
Fishers Island
Block Island
Gardiners Island
nia
New York
New Jersey
Philadelphia
Hudson Shelf Valley
80 miles
8,000 miles²
100 miles
Baltimore
Maryland
Delaware
Image PA Department of Conservation and Natural Resources-PAMAP/USGS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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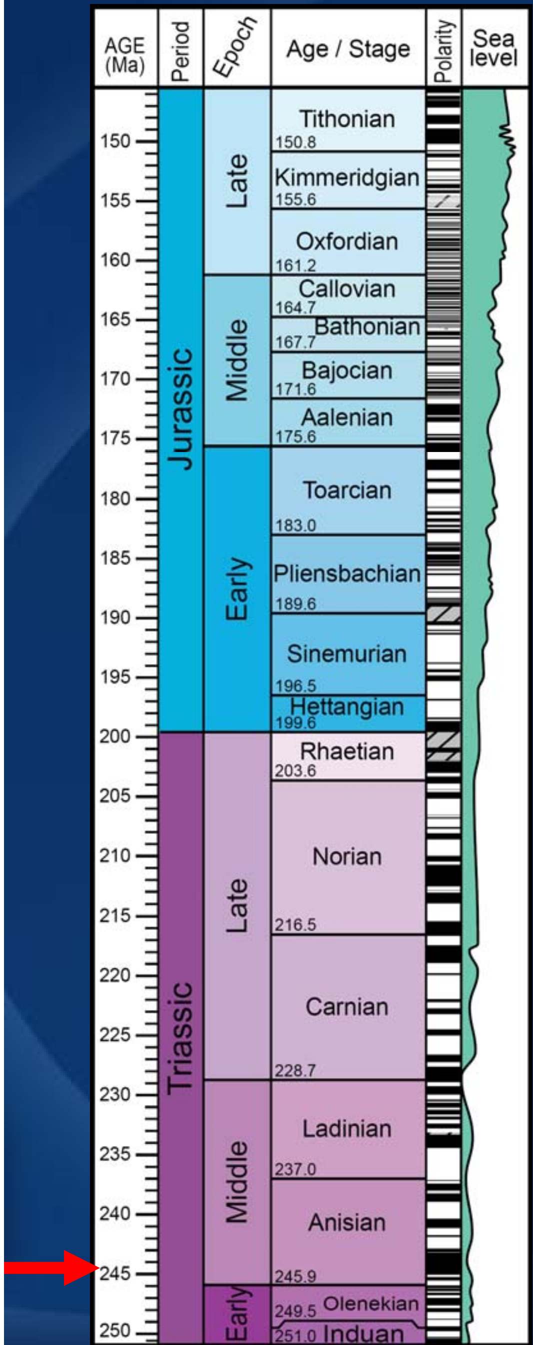
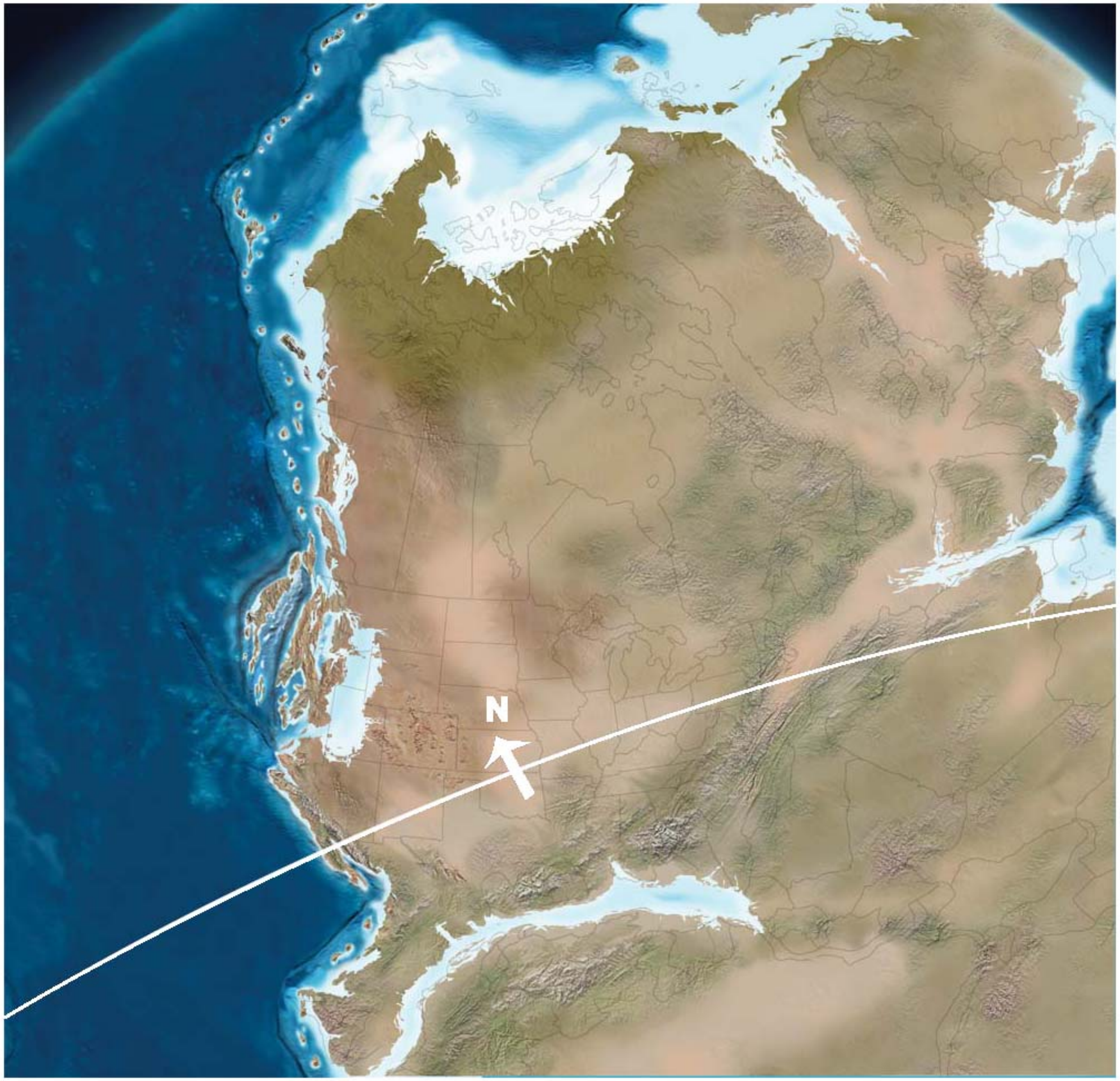
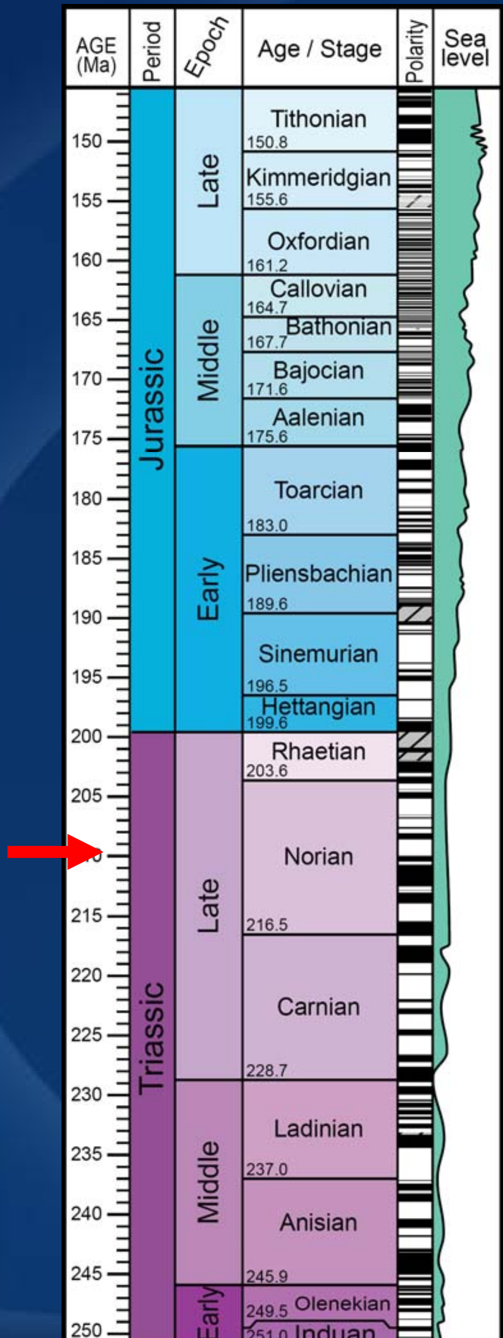
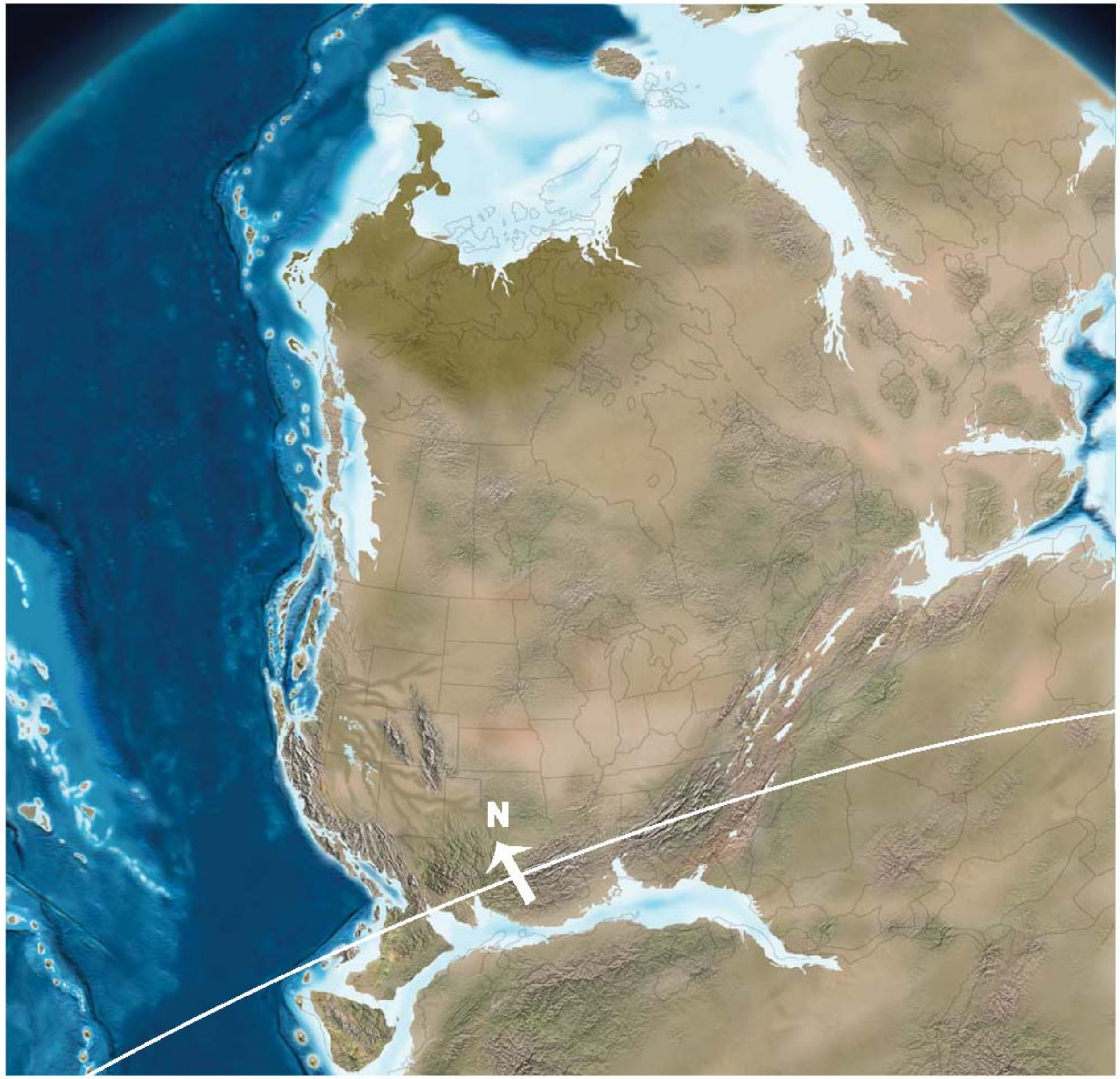




(From Ron Blakey website)





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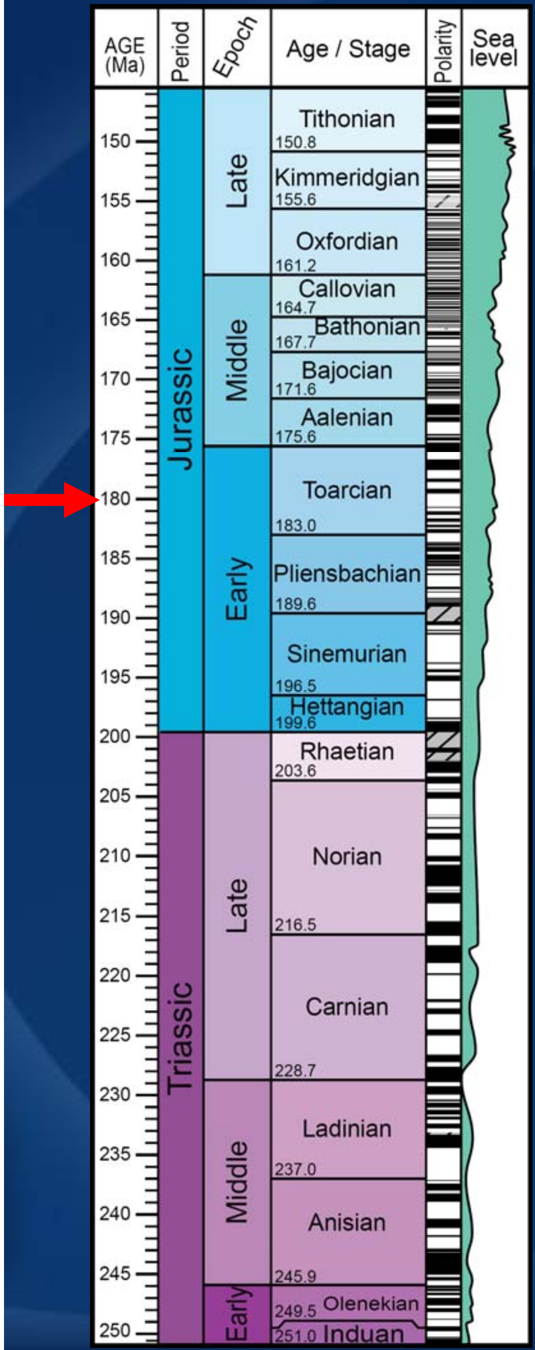

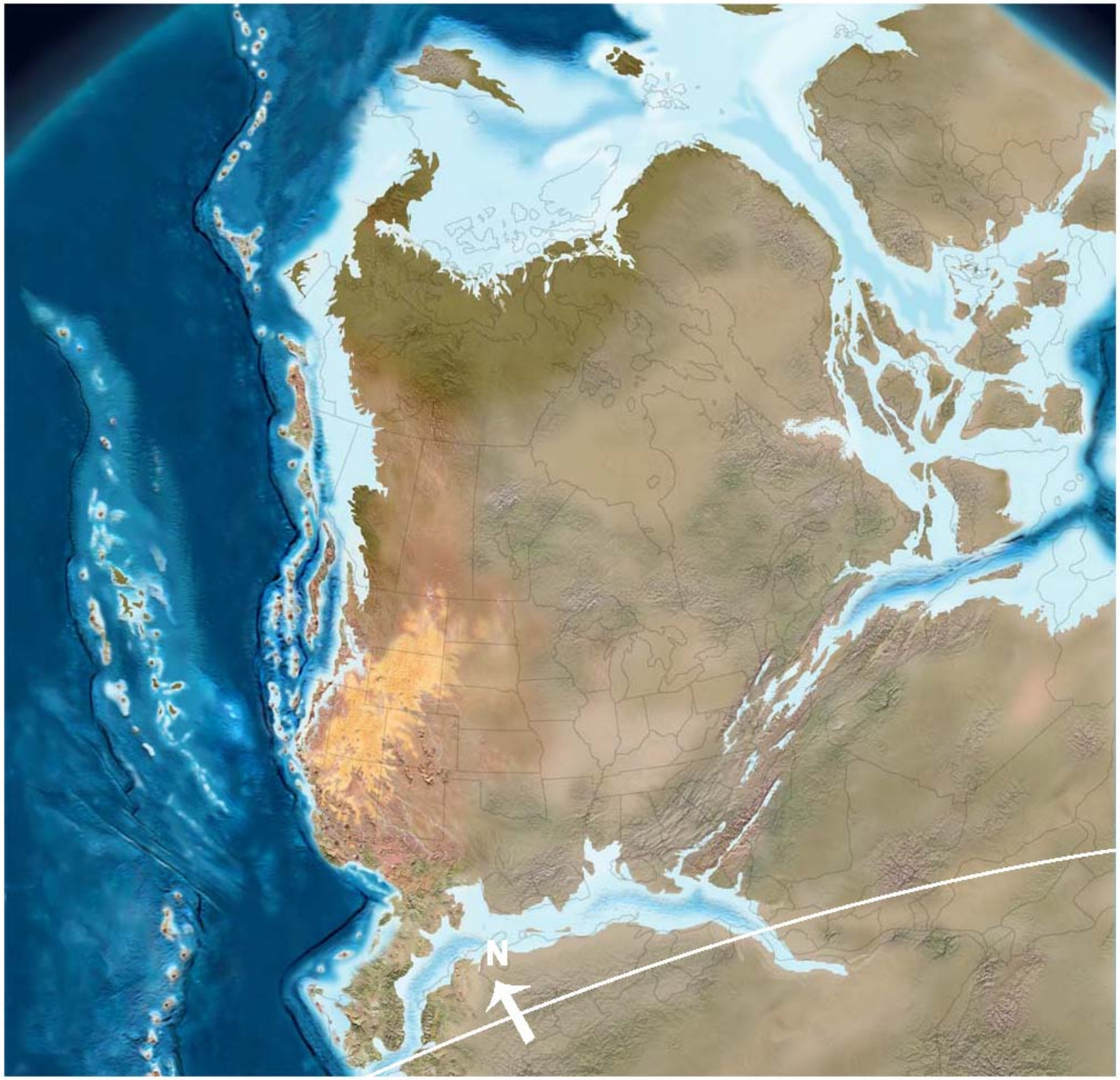

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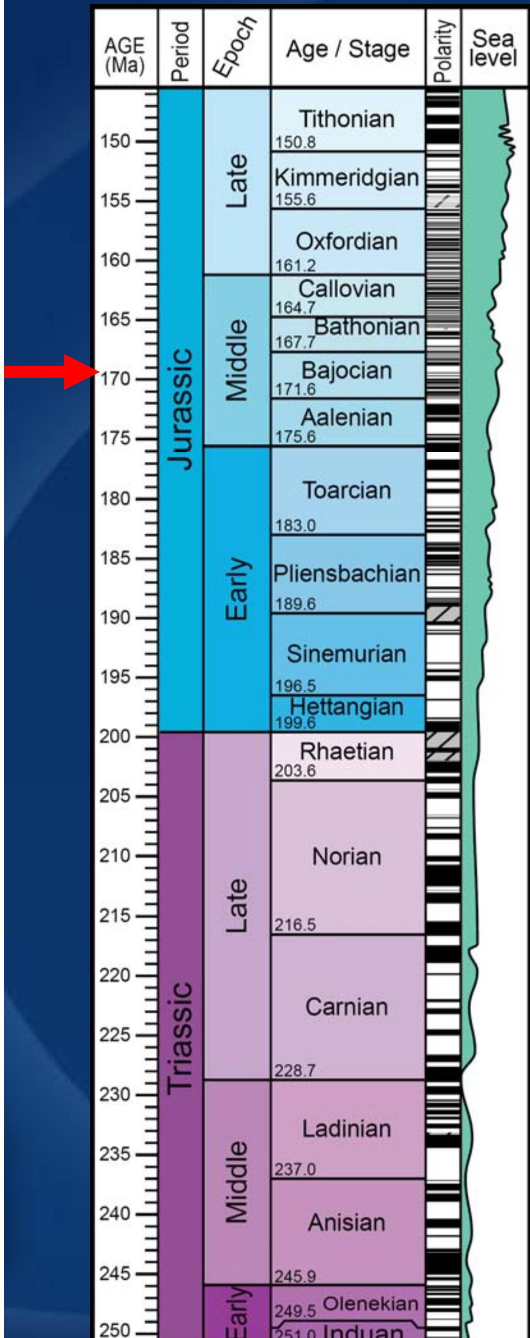

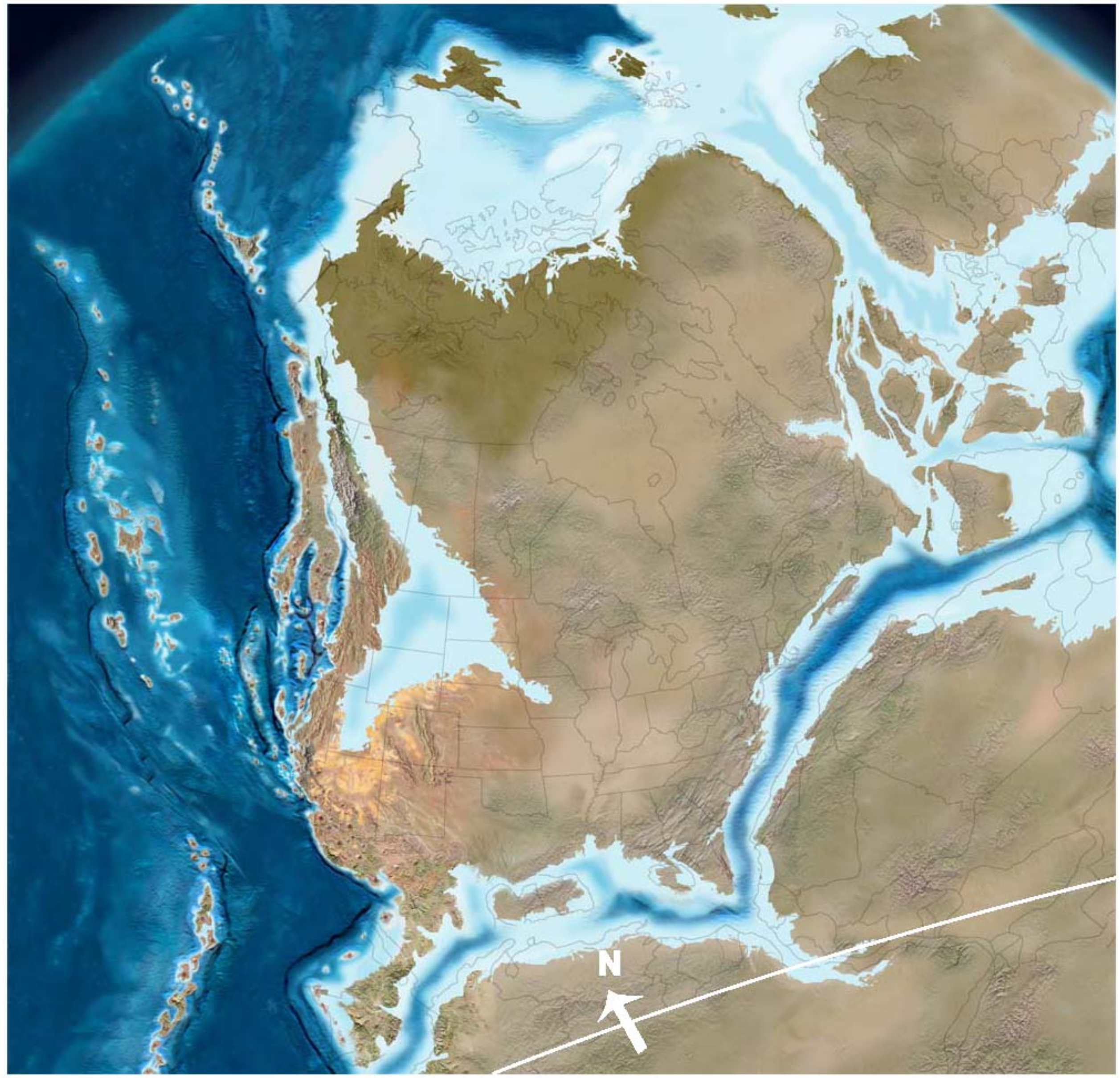

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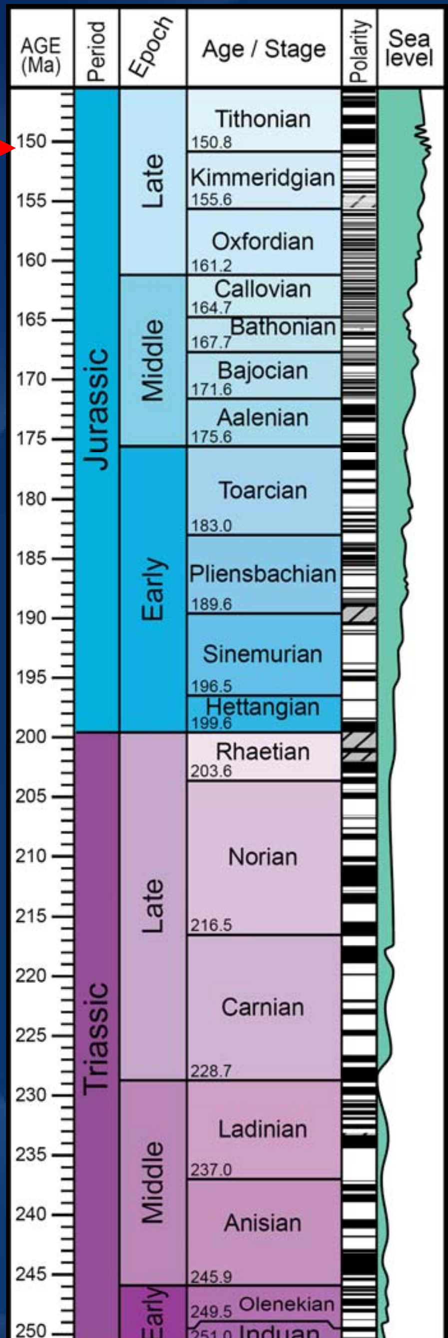
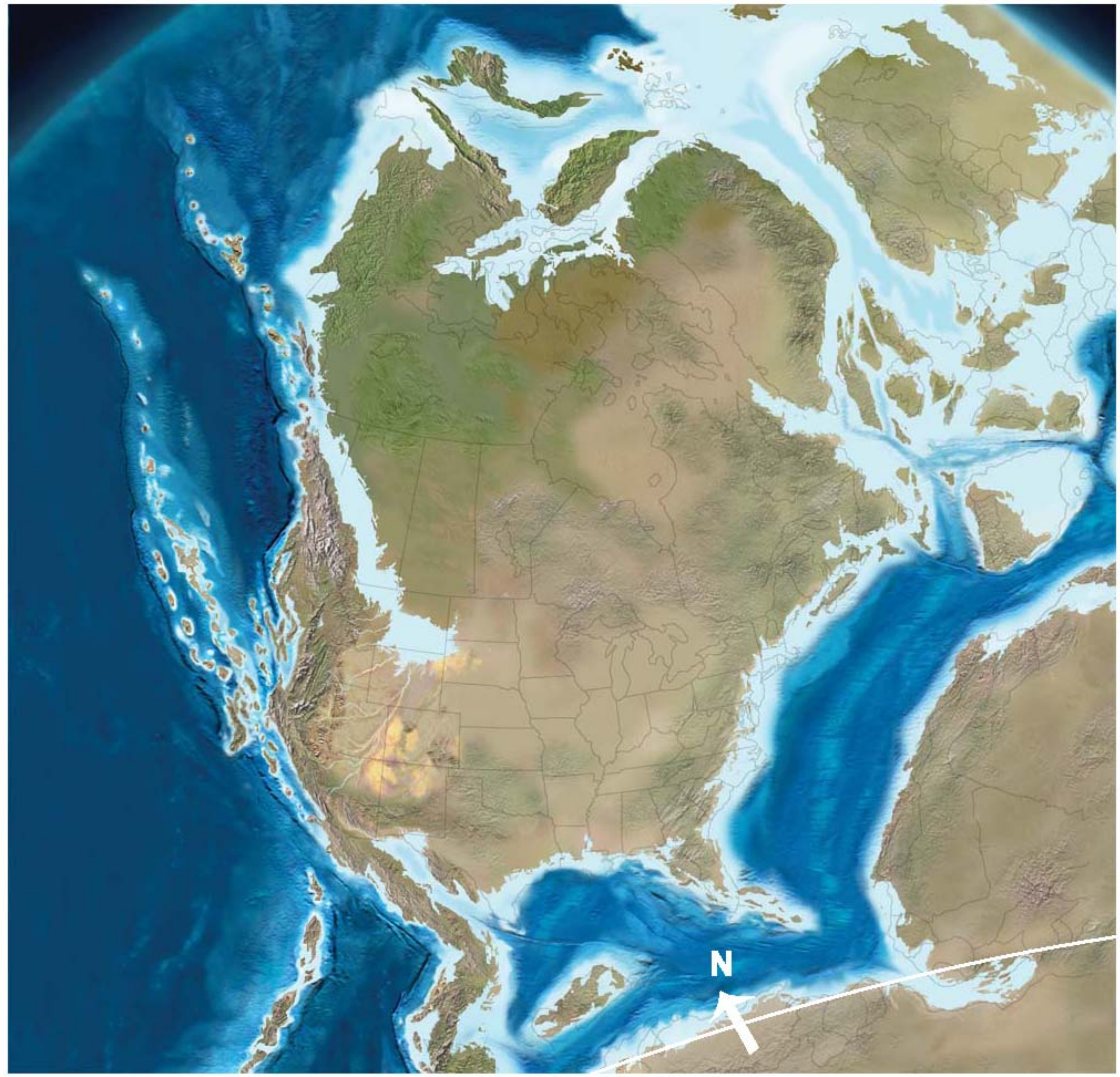
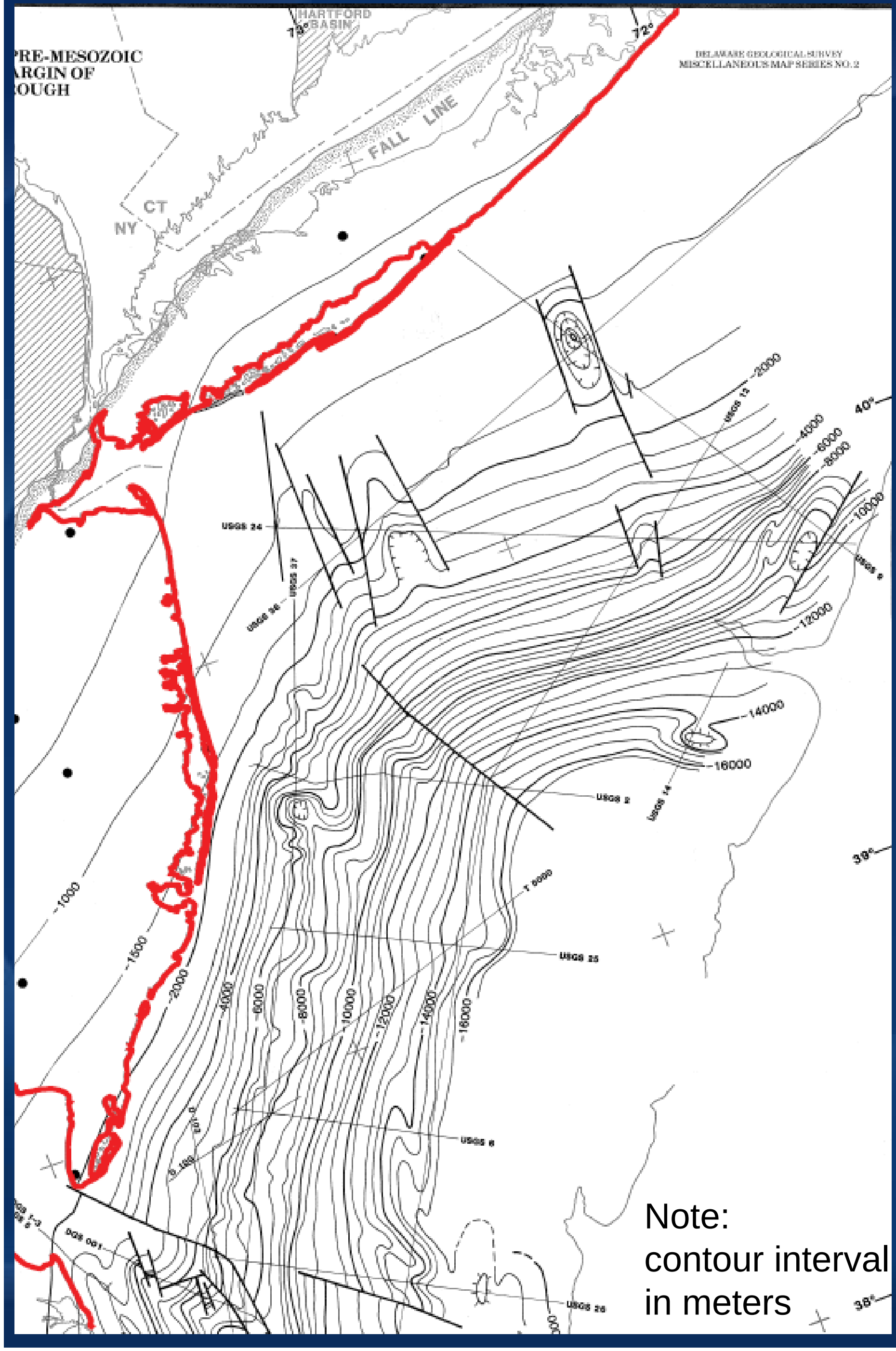
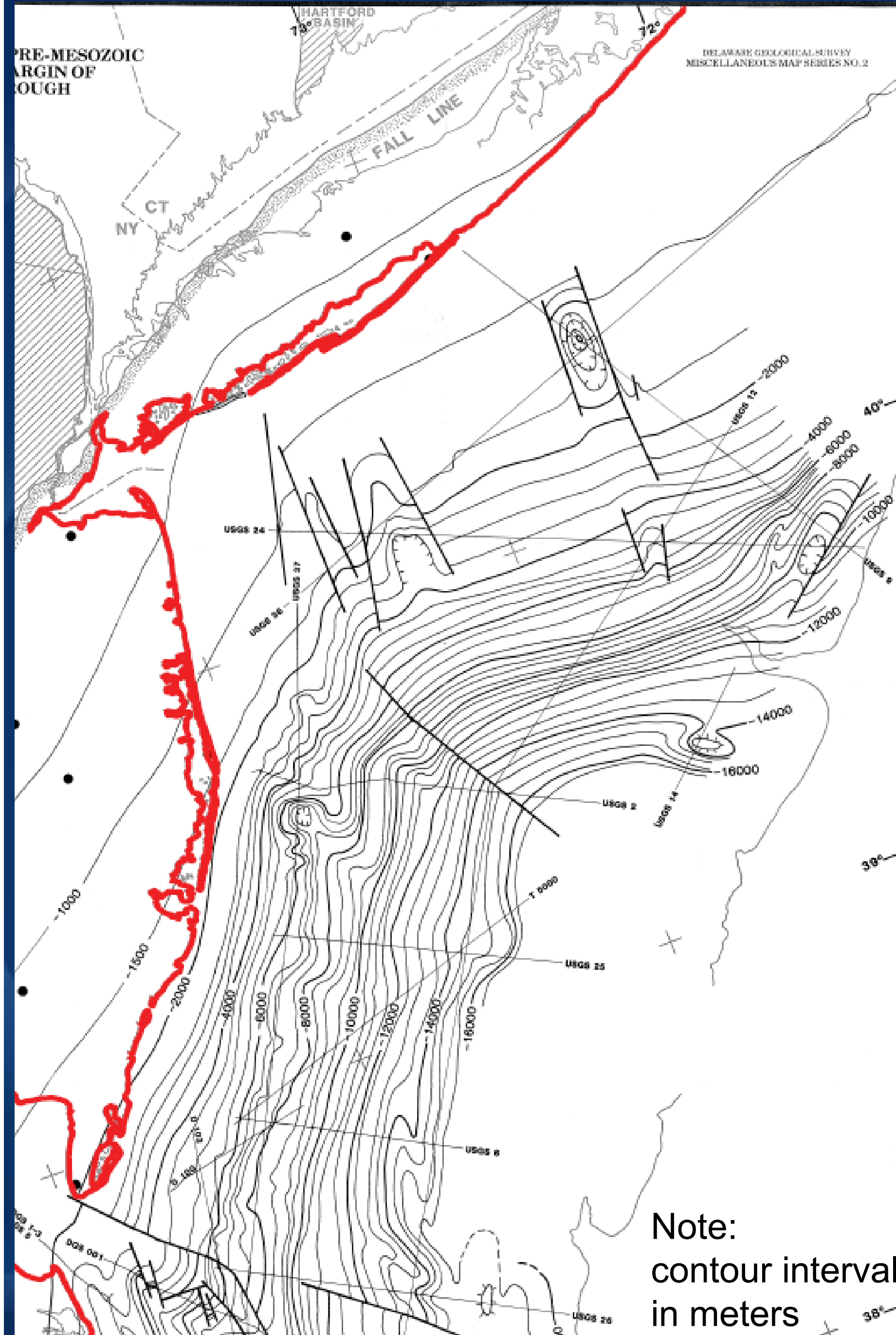


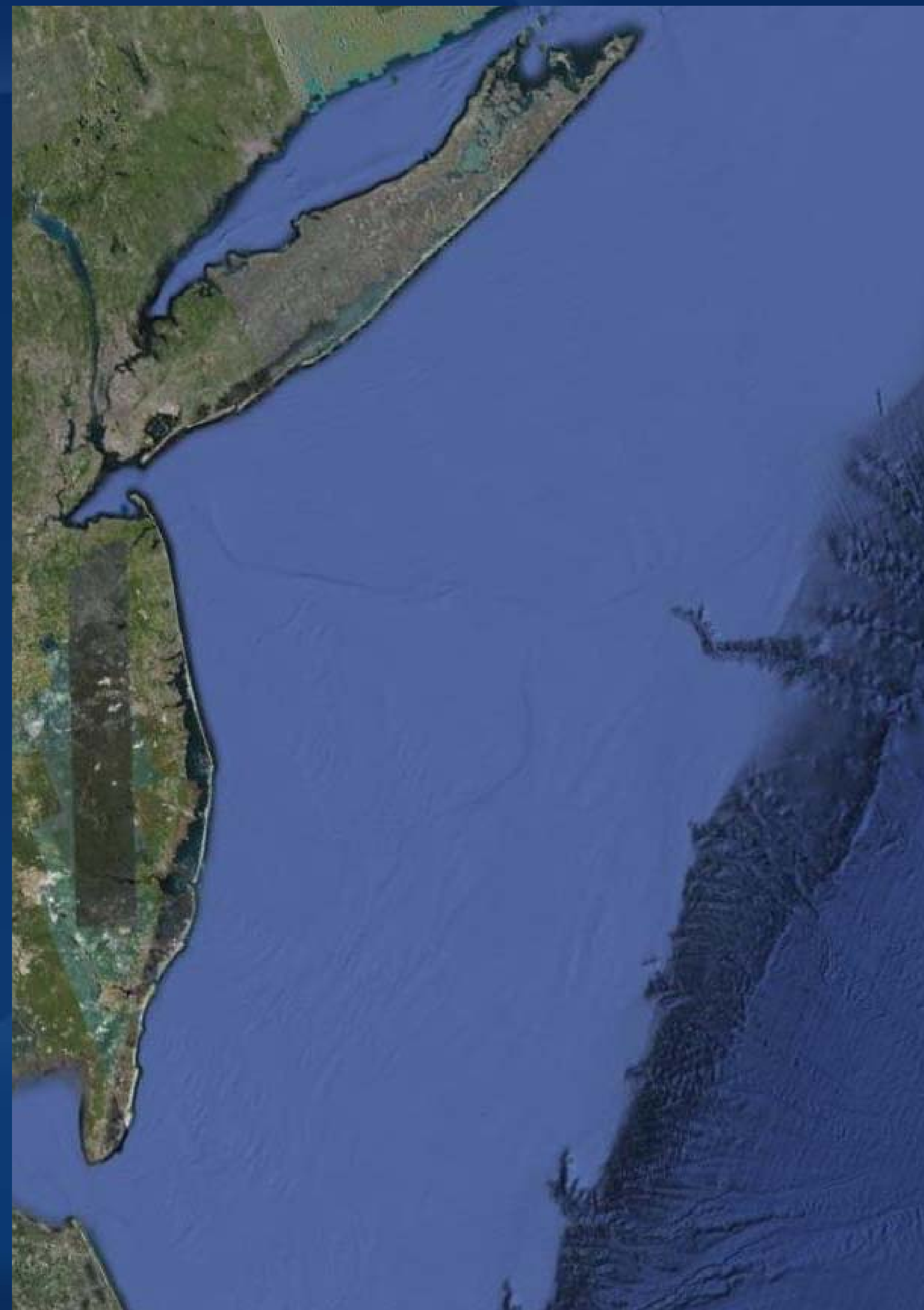


(From Ron Blakey website)

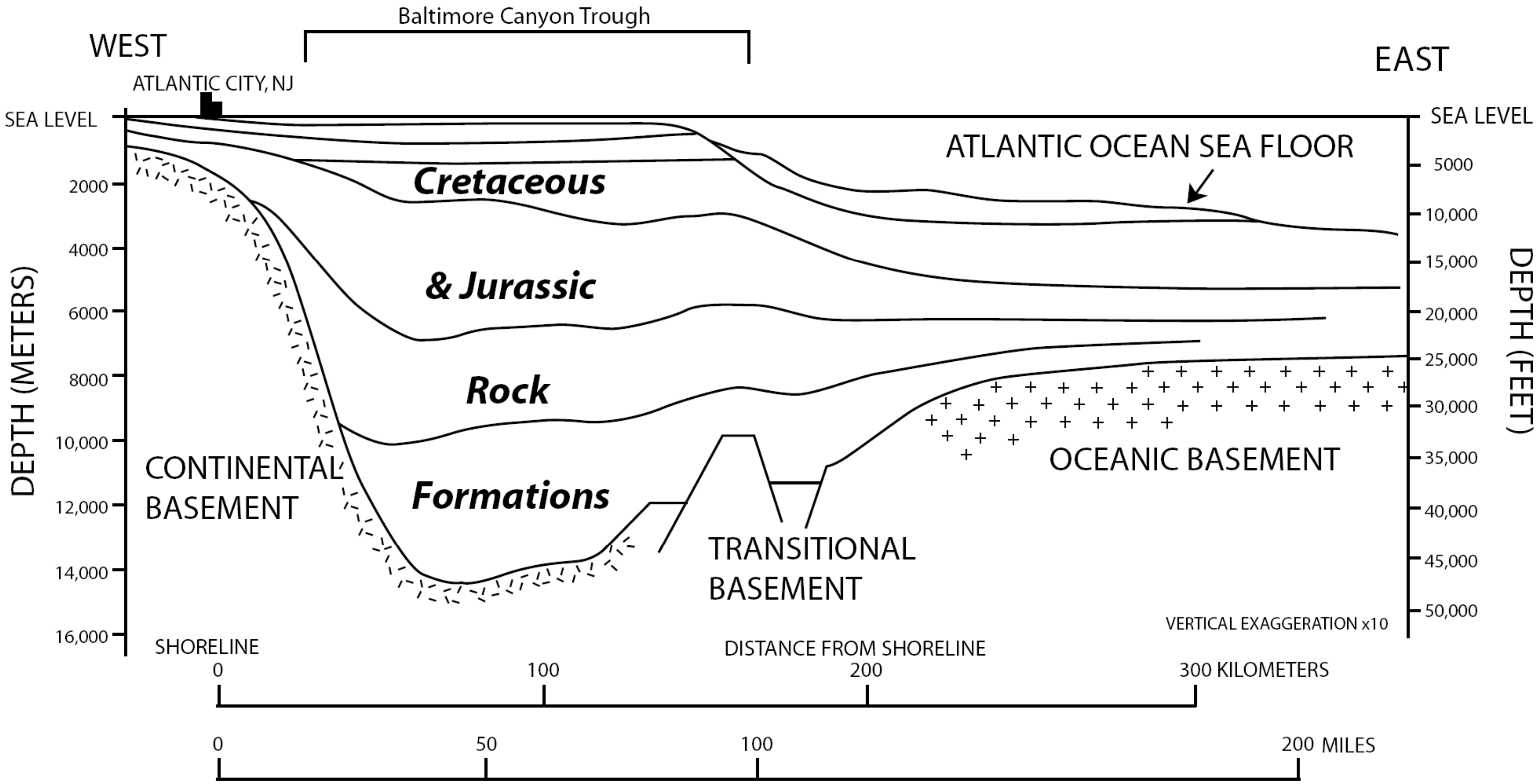

PRE-MESOZOIC
ARGIN OF
OUGH
HARTFORD
BASIN
73°
72°
DELAWARE GEOLOGICAL SURVEY
MISCELLANEOUS MAP SERIES NO. 2
FALL LINE
NY
CT
40°
39°
38°
-1000
-1500
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
USGS 24
USGS 2
USGS 25
USGS 6
USGS 26
USGS 13
USGS 14
Note:
contour interval
in meters



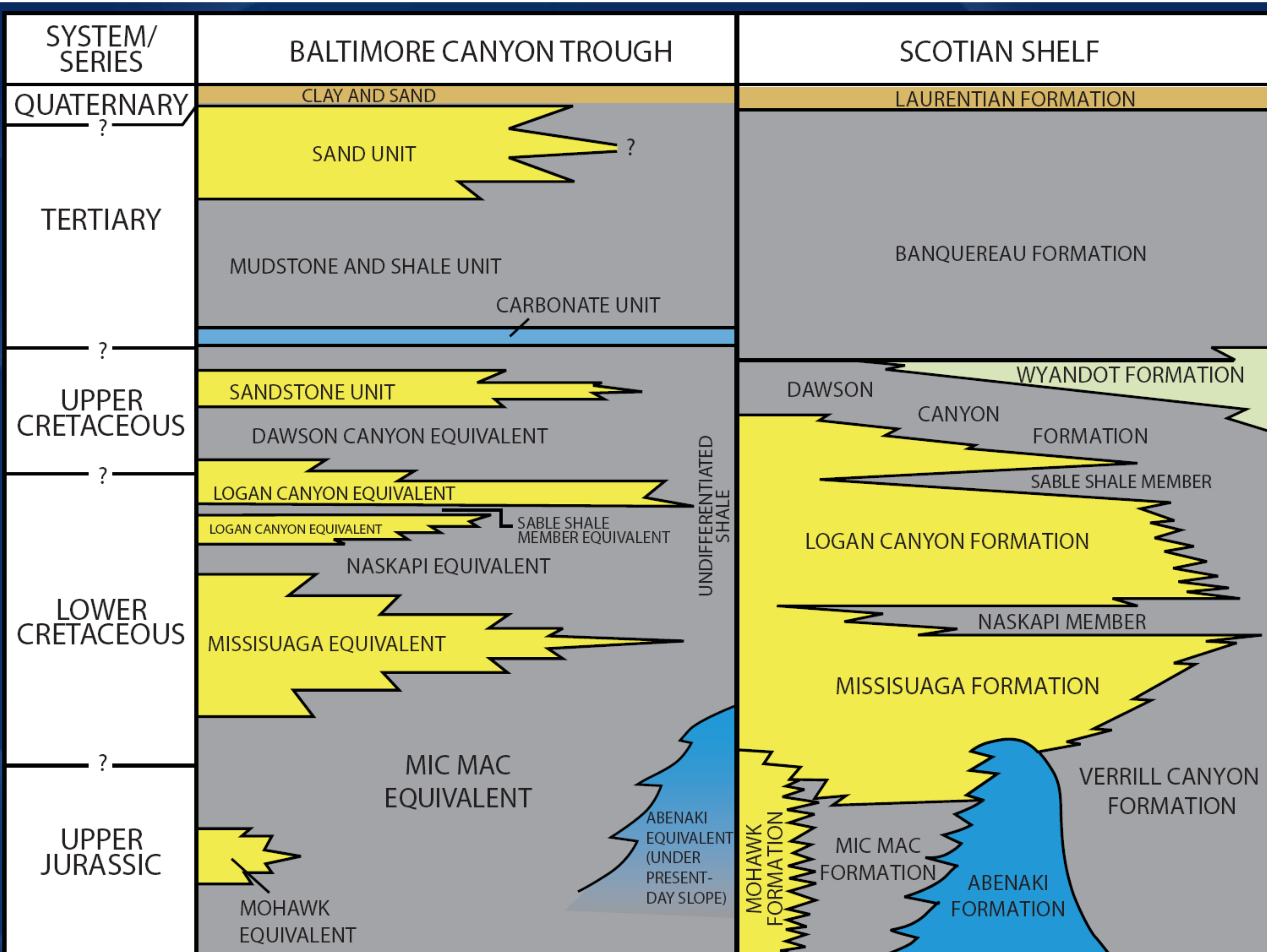
Note:
contour interval
in meters



Baltimore Canyon Trough Cross Section

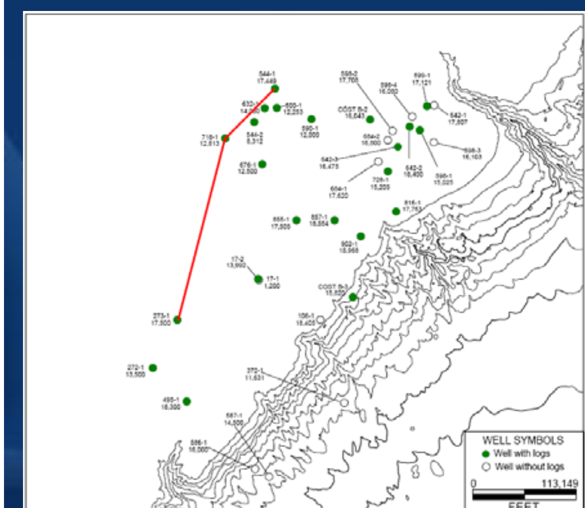


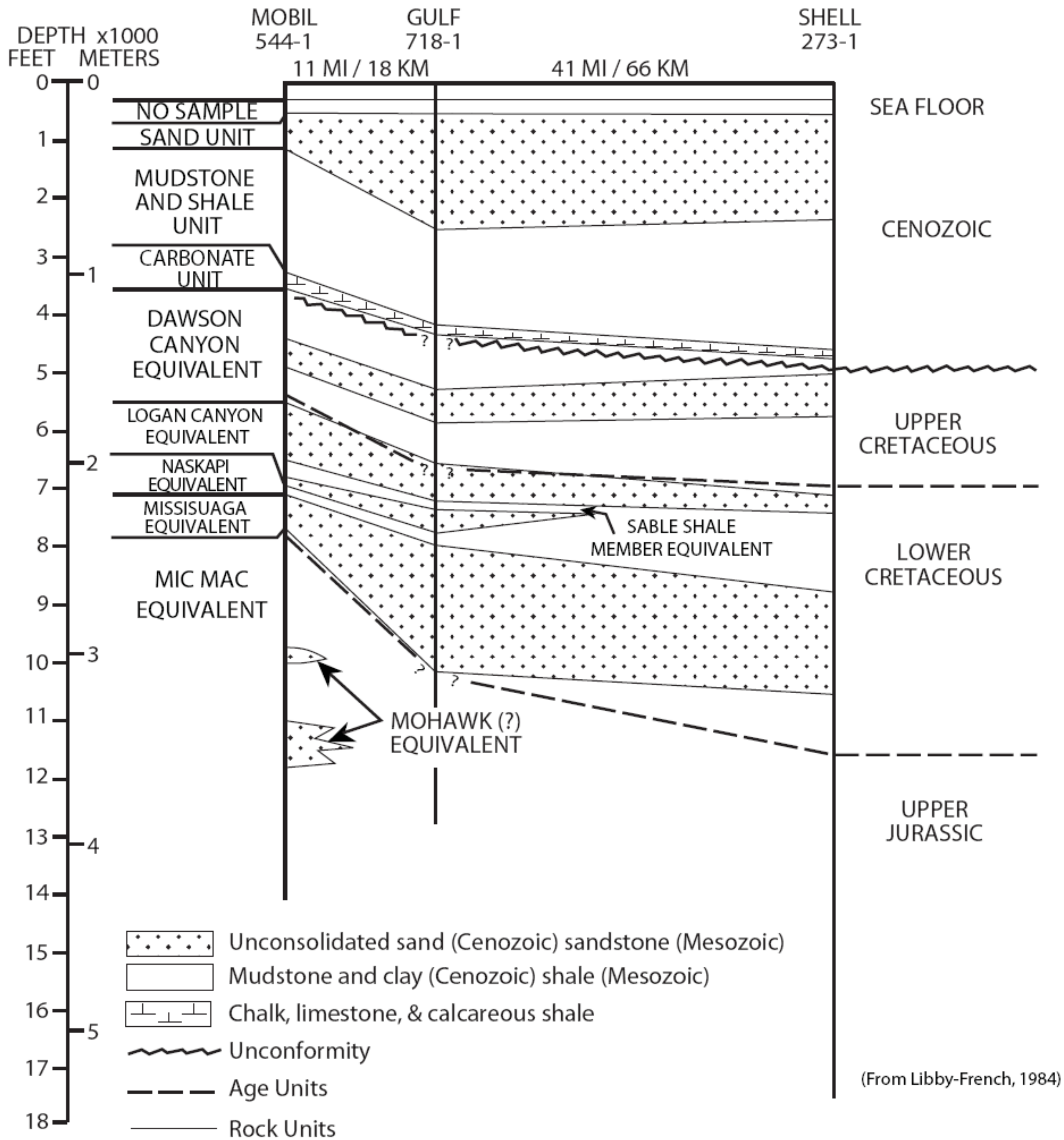
Modified From USGS RC750, 1977



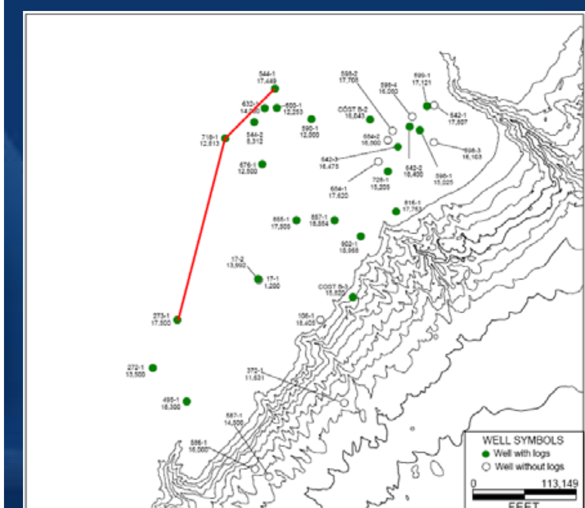
(From Libby-French, 1984)

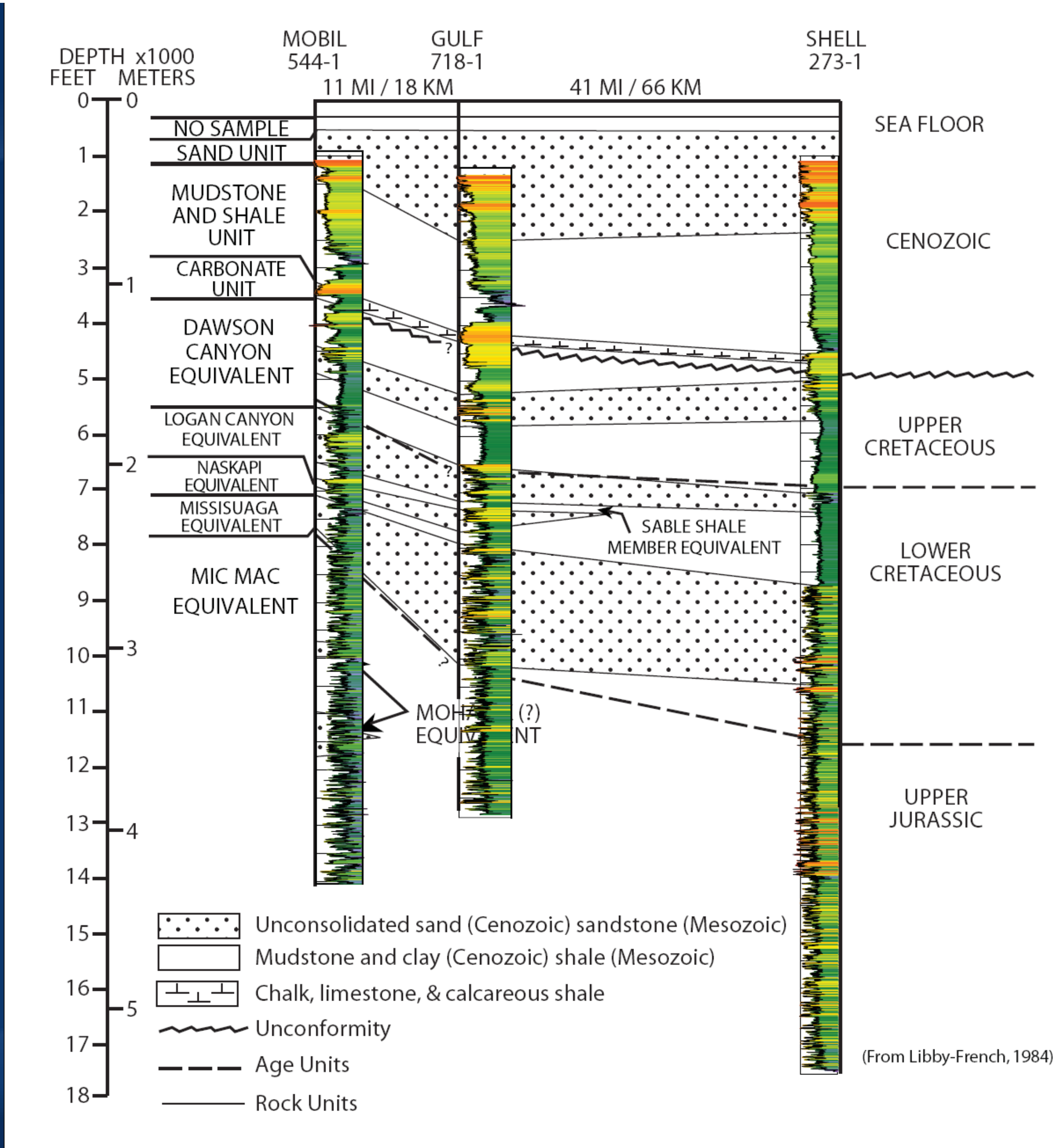
Well log cross sections from Libby-French, 1984 support her correlation between the Scotian Shelf and Baltimore Canyon Trough.



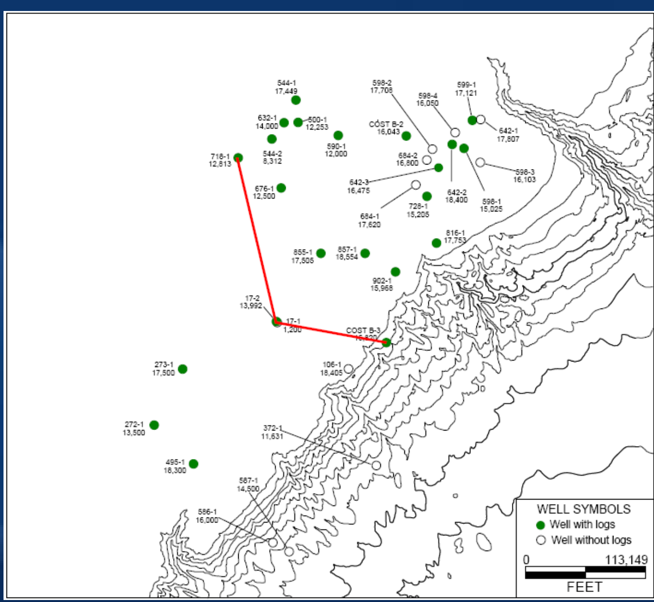


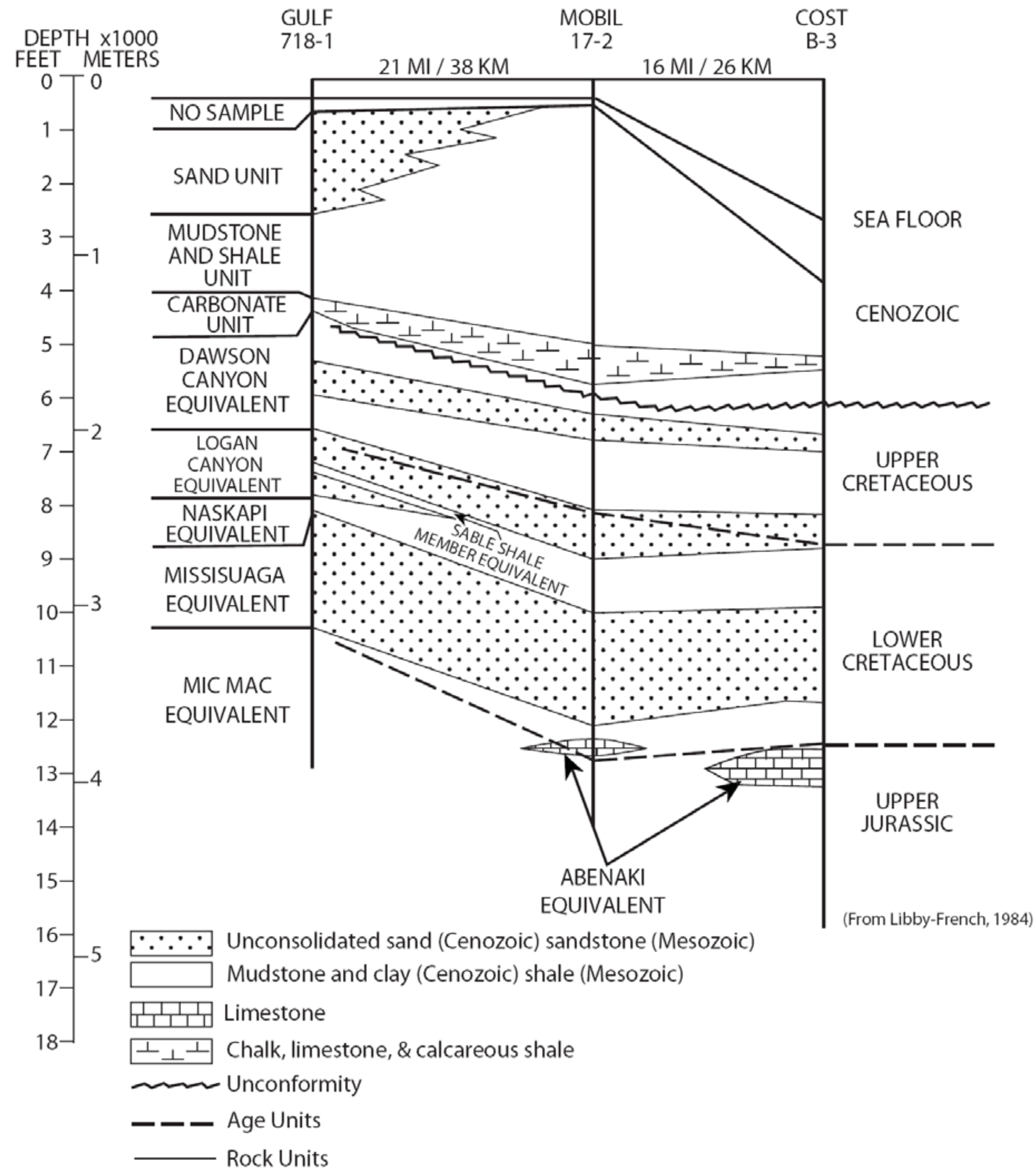
By overlying the gamma ray curves from these wells, it becomes quite clear how Libby-French picked her tops and correlated these units.



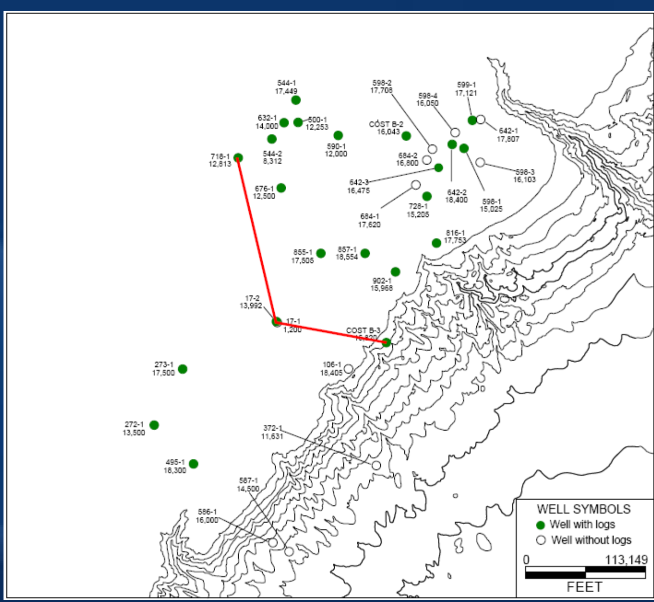


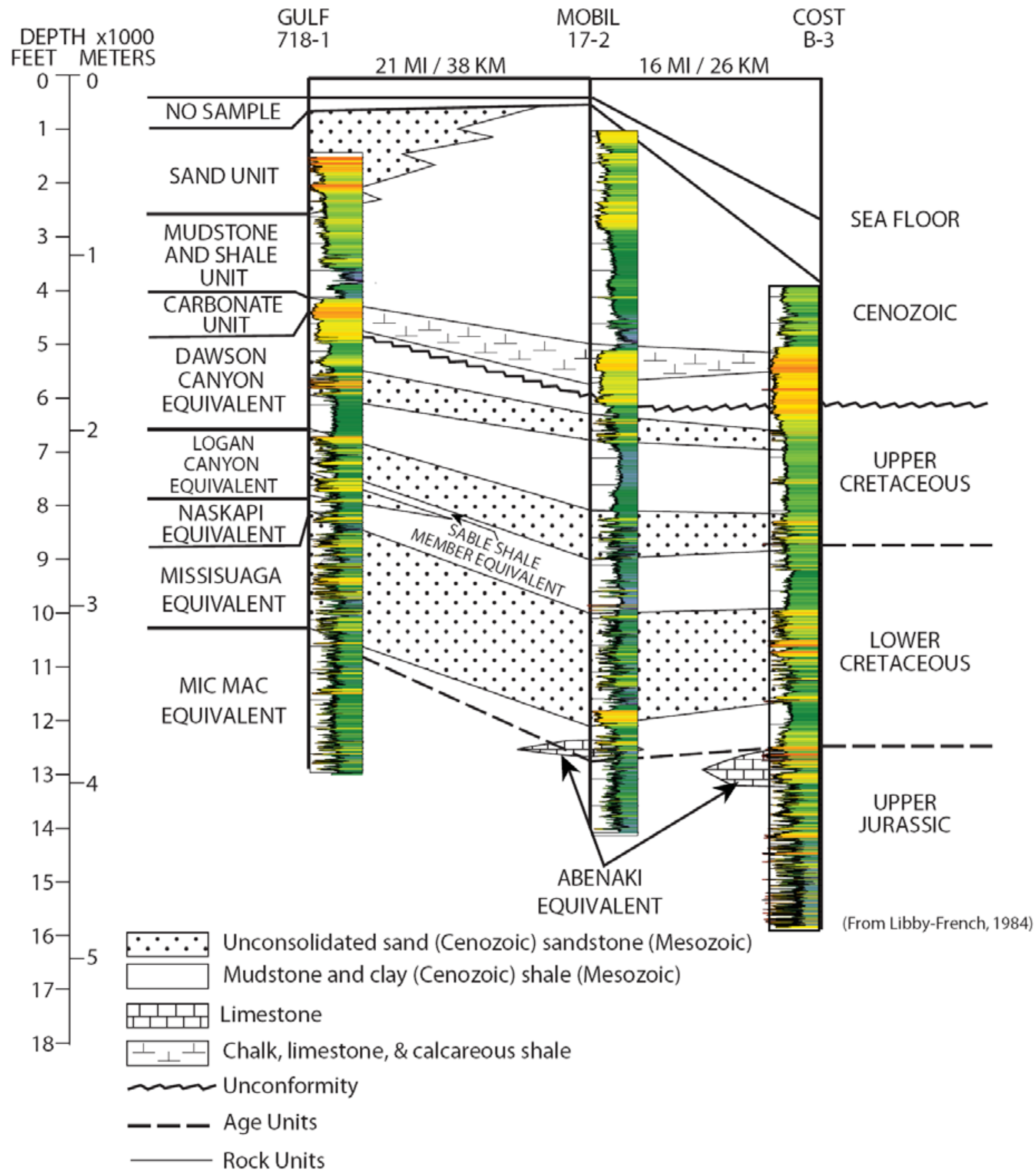
Here again, a cross sections published by Libby-French, 1984 shows the Scotian Shelf names applied to the BCT, and the formations appear to be continuous



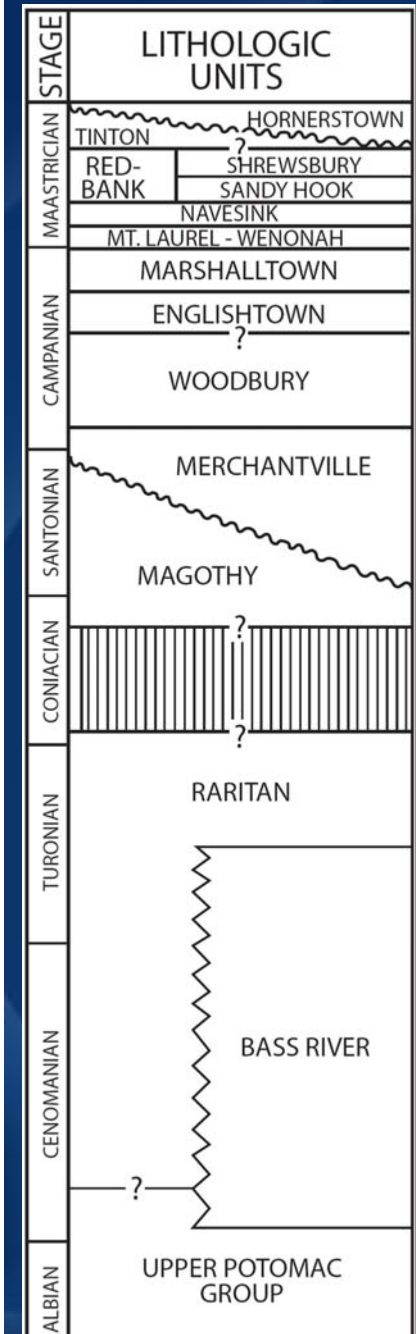


Overlying the gamma ray curves clearly illustrates how these units were picked and correlated across the region.

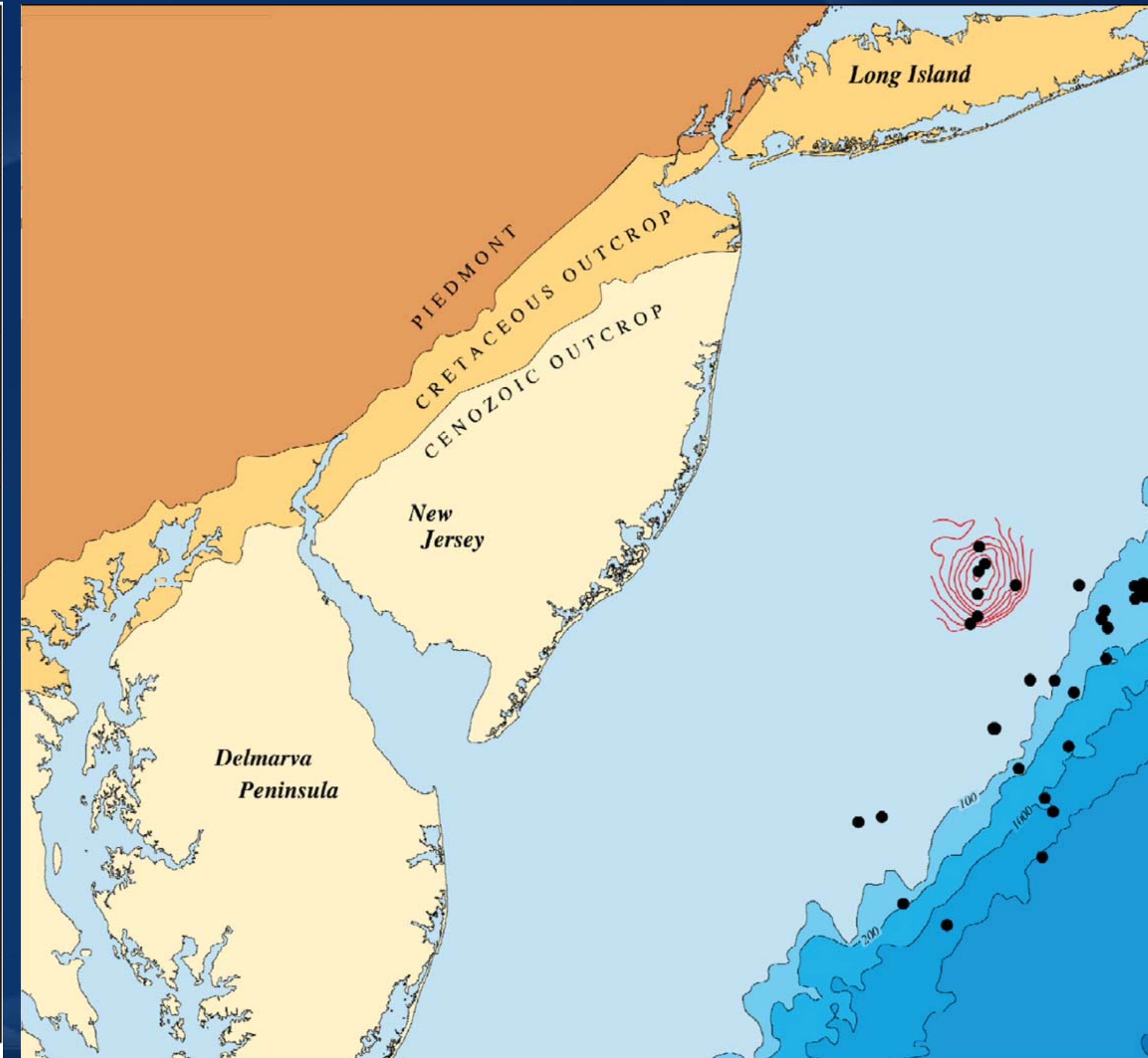




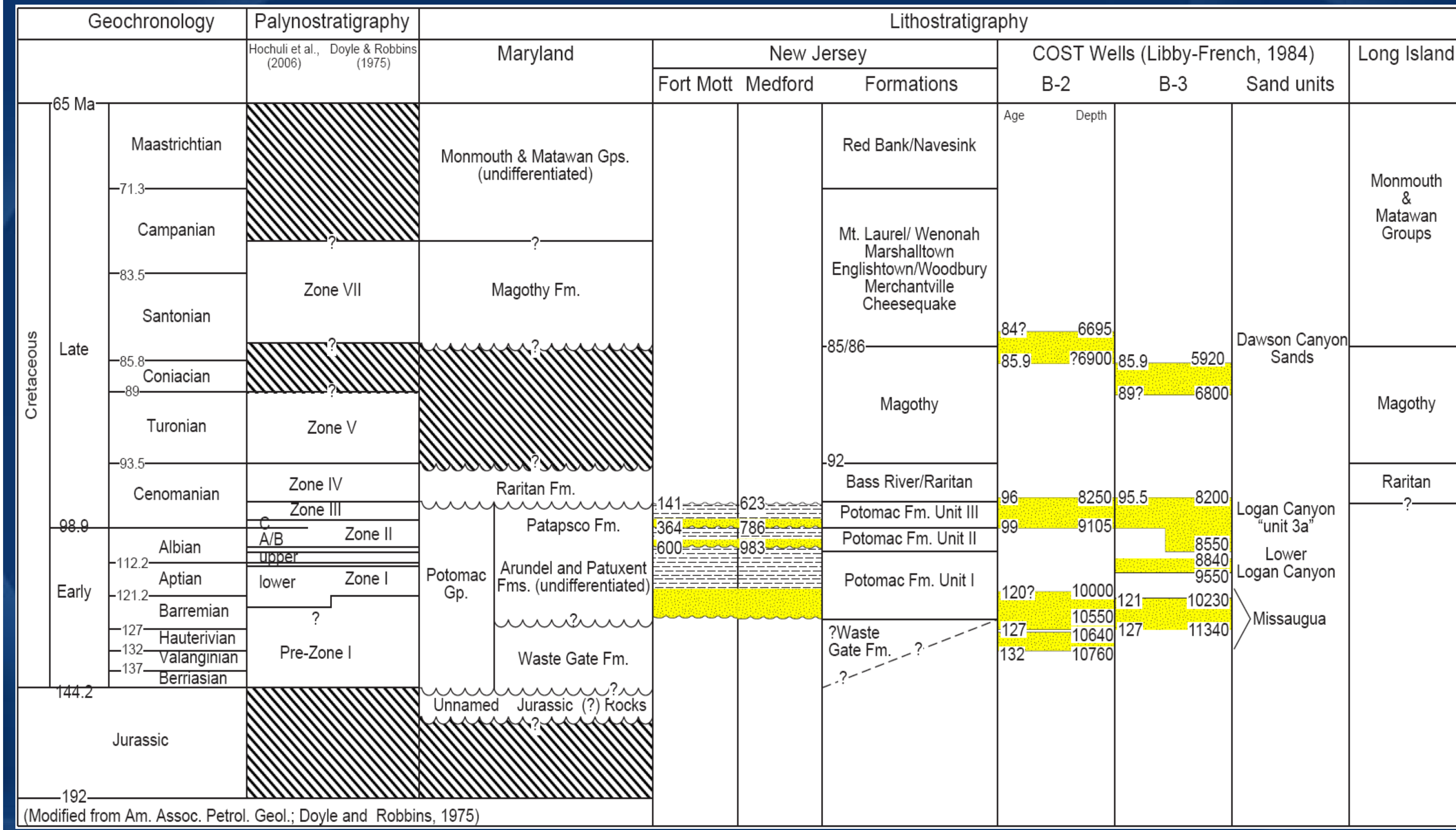
(From Libby-French, 1984)



From Petters, 1976

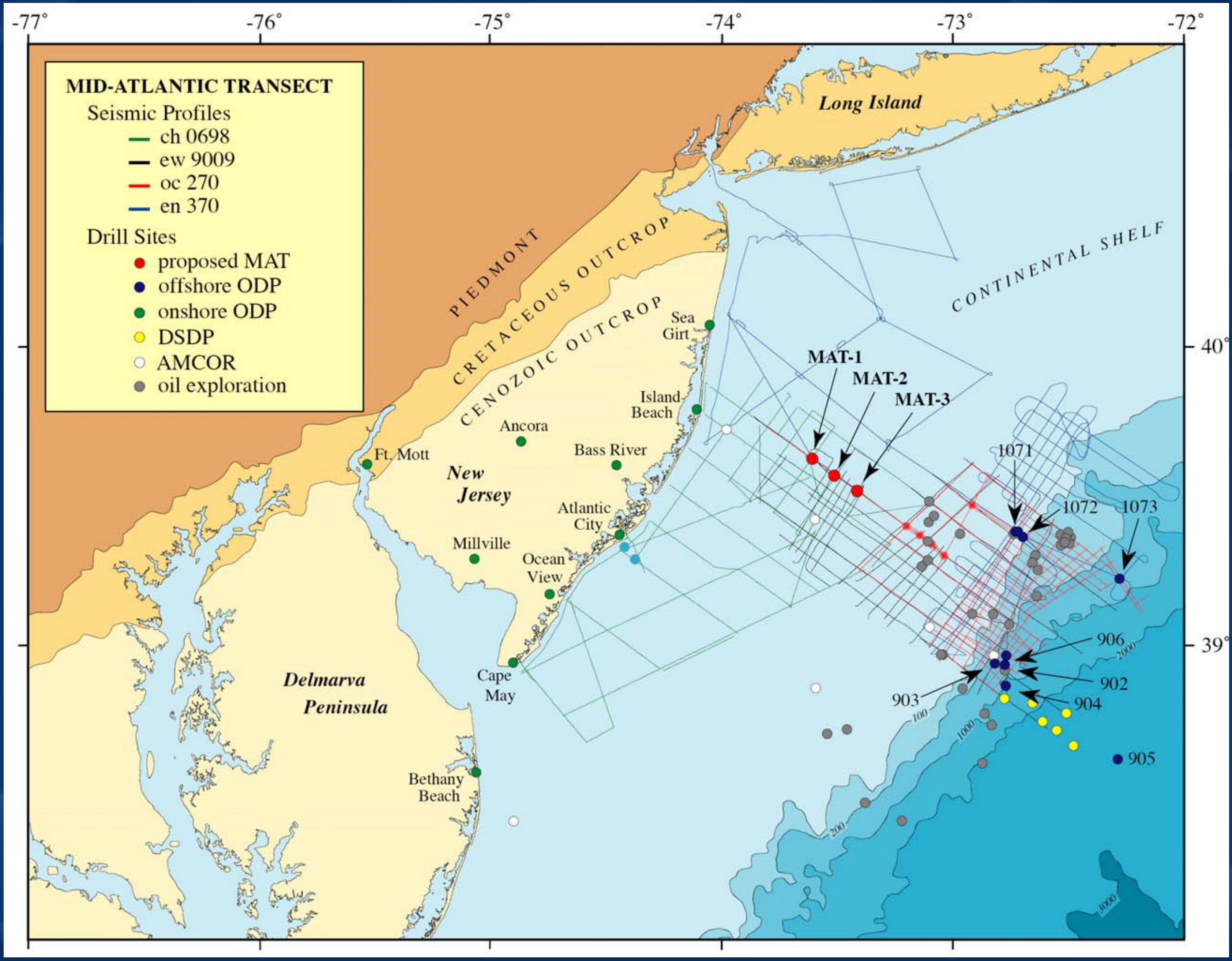


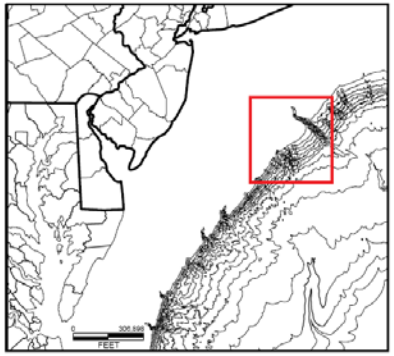
Scotian Shelf - NJ, MD, NY bedrock nomenclature correlation



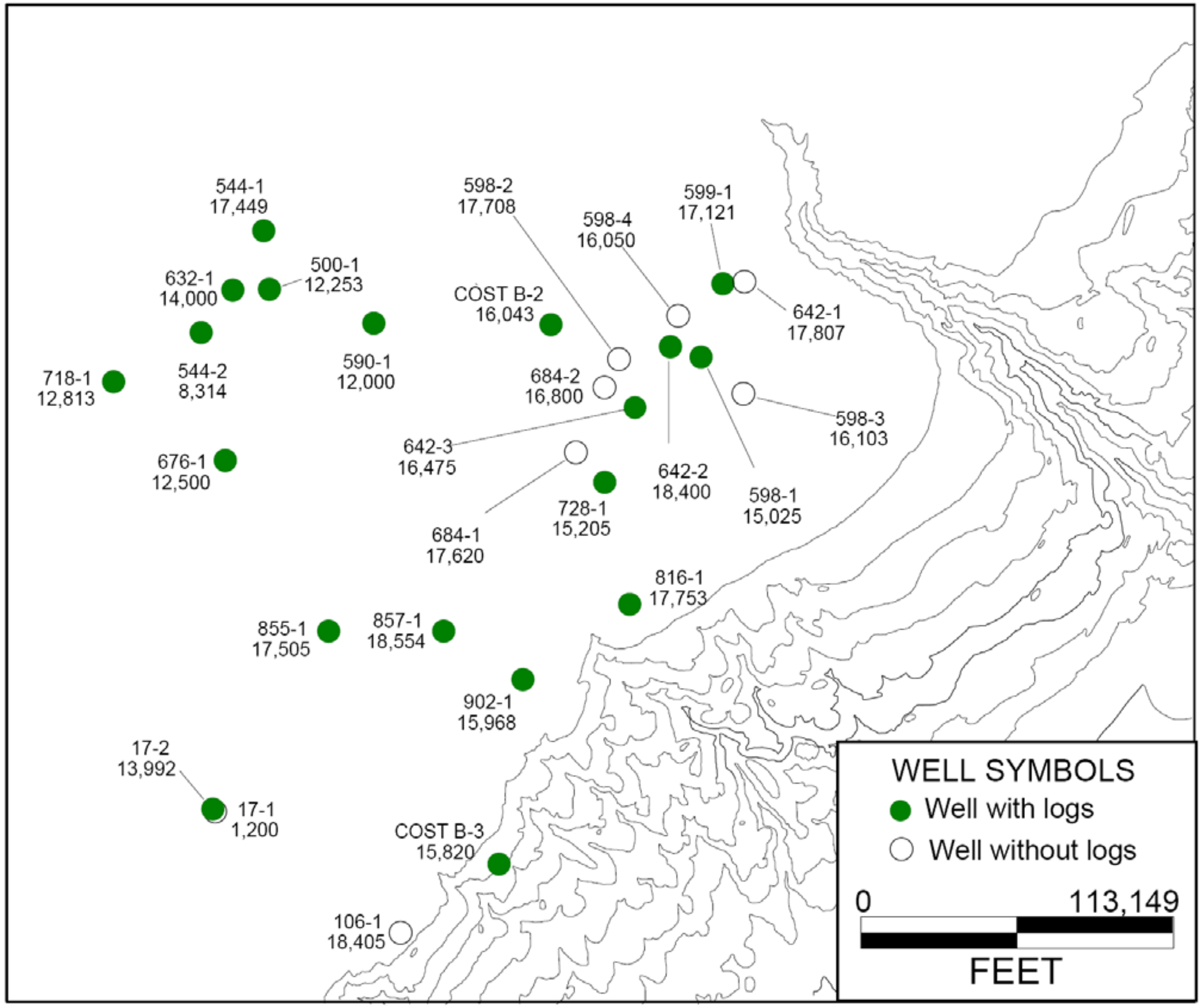
Pete Sugarman, NJGS

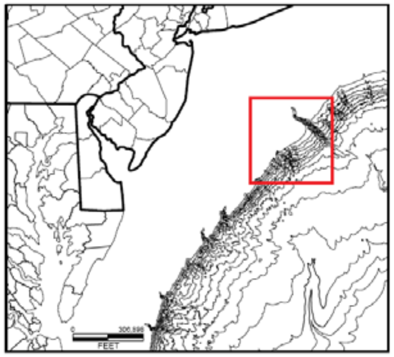
Available Data





Company	Well name
----------	COST B-2
Exxon	728-1
Exxon	816-1
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





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Exxon	728-1
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Mobil	544-1
Exxon	684-2
Texaco	598-4
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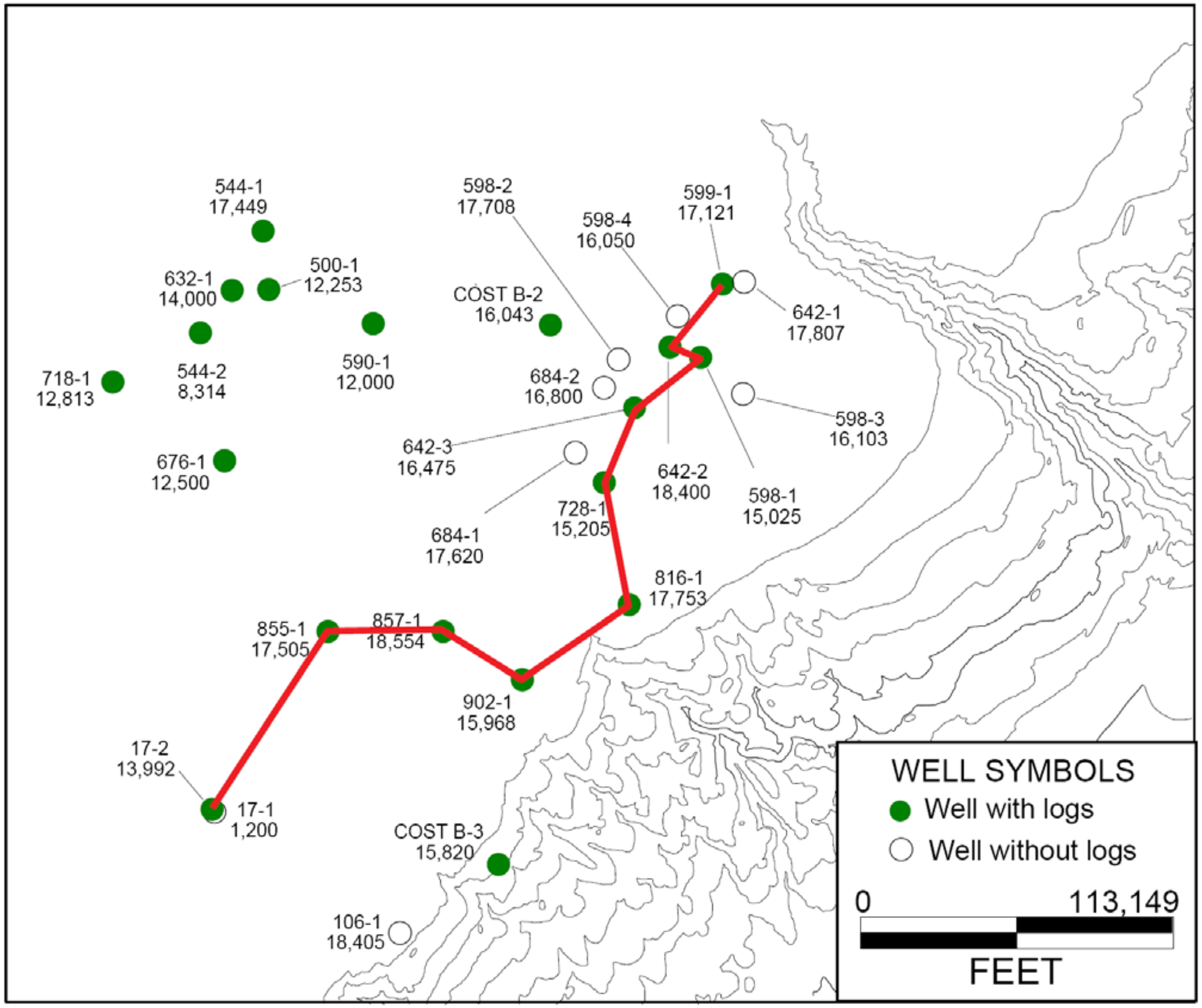
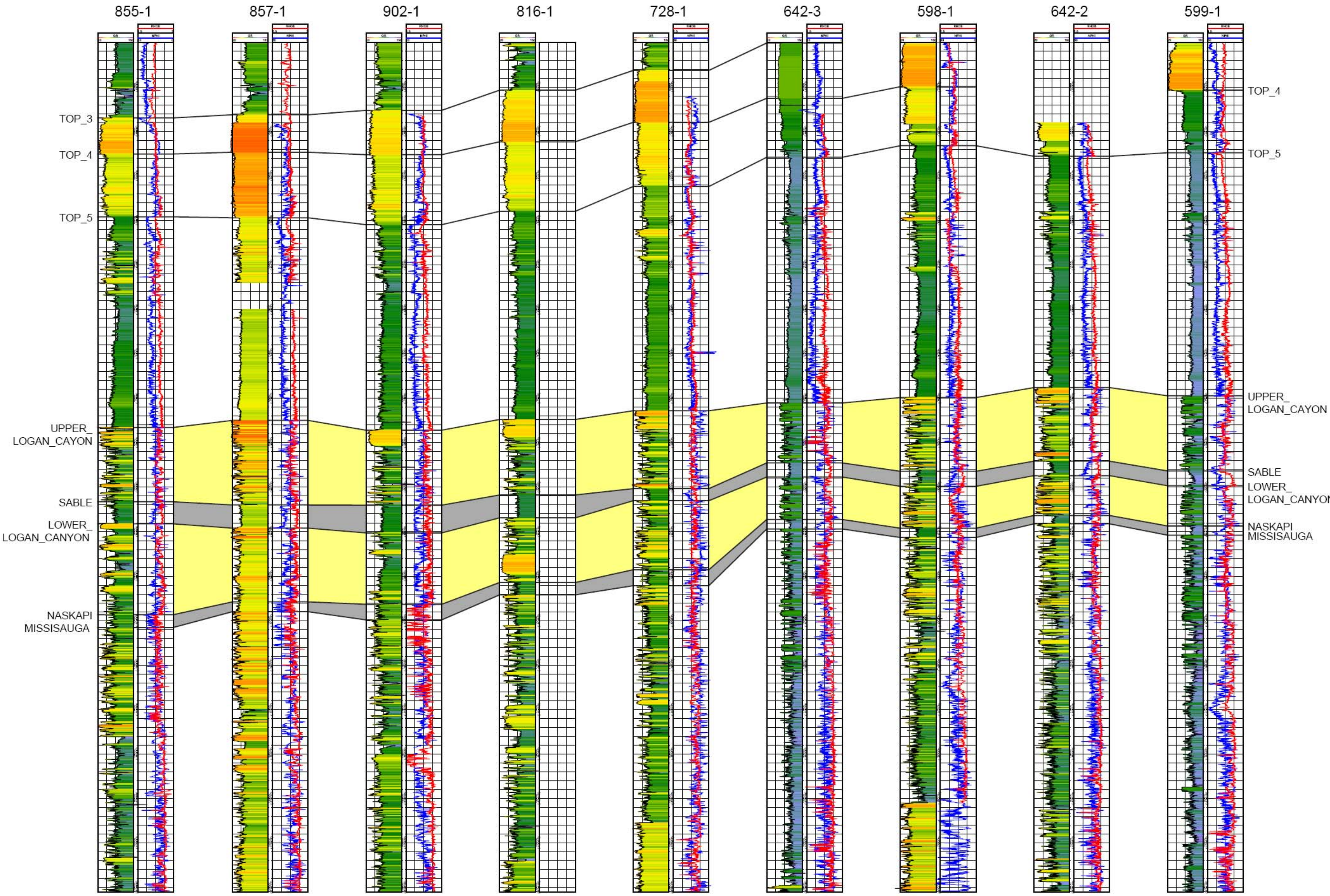
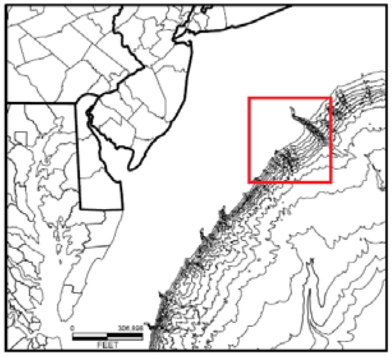
Houston	676-1
Exxon	684-1
Mobil	17-1
Houston	855-1
Exxon	599-1
Gulf	718-1
Exxon	902-1
Tenneco	642-2
Exxon	500-1
Texaco	642-1
Murphy	106-1
Tenneco	642-3
Mobil	544-2





855-1
857-1
902-1
816-1
728-1
642-3
598-1
642-2
599-1
TOP_3
TOP_4
TOP_5
UPPER_
LOGAN_CAYON
SABLE
LOWER_
LOGAN_CANYON
NASKAPI
MISSISAUGA



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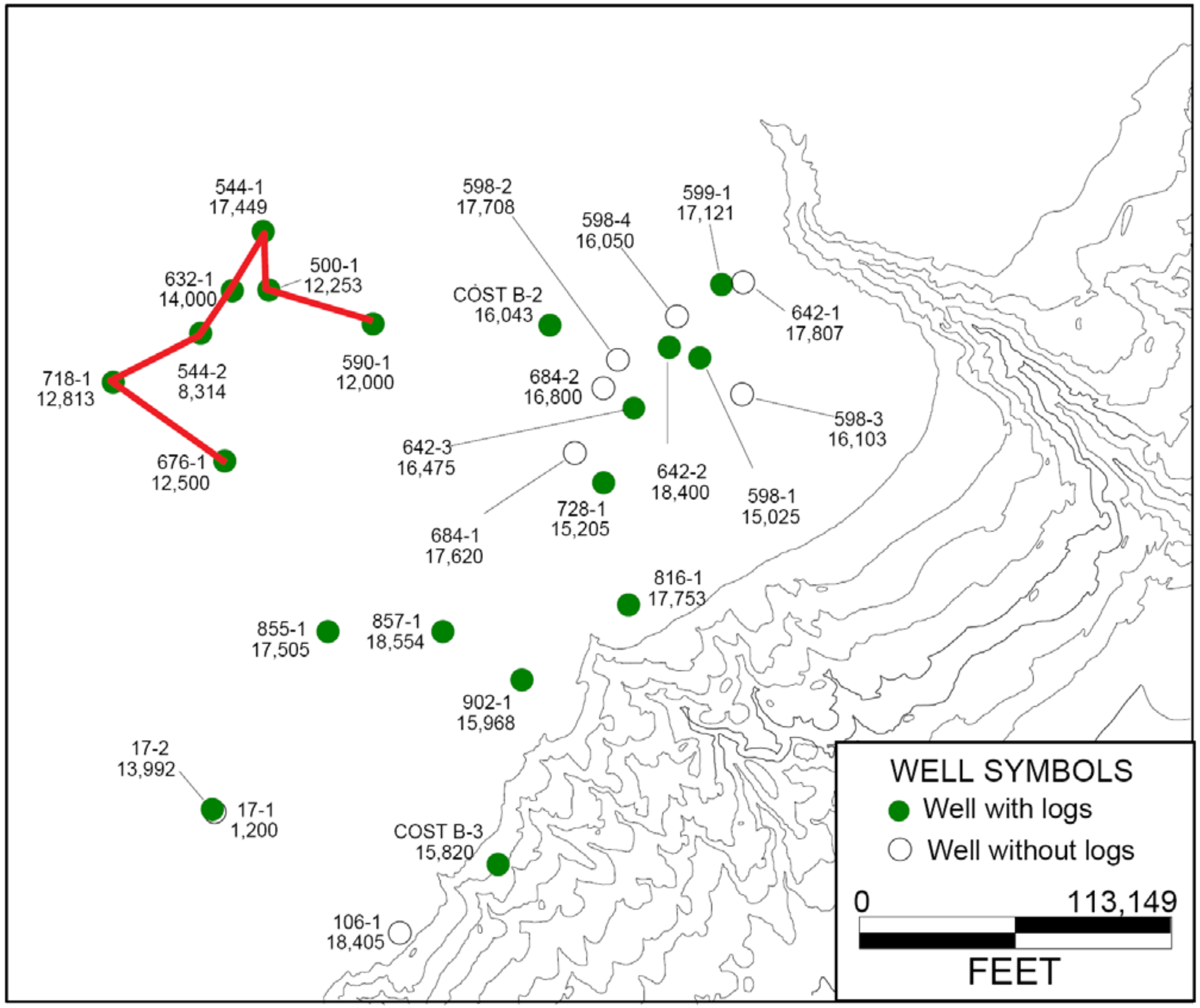
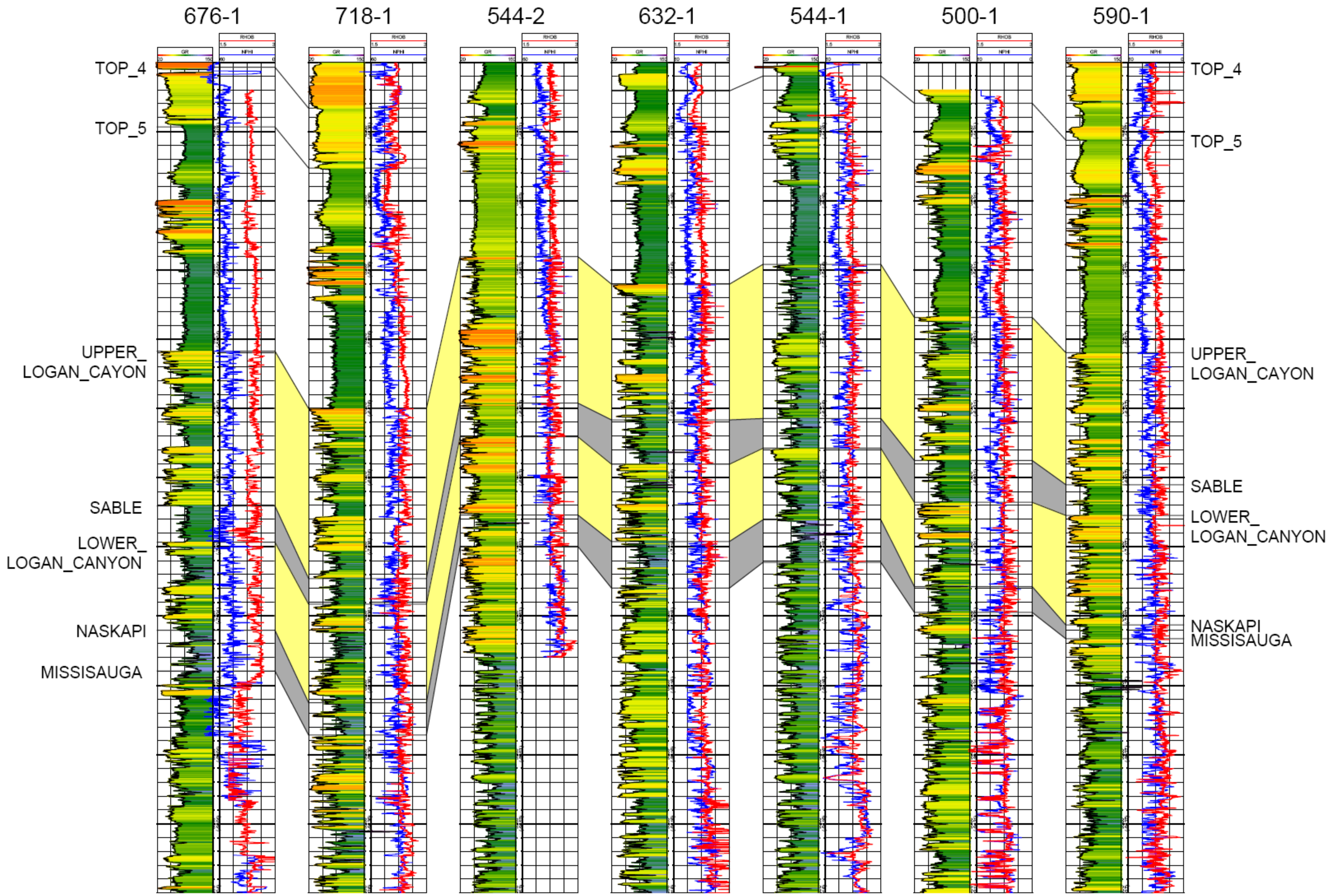
Exxon	728-1
Exxon	816-1
Shell	93-1
Gulf	857-1
Texaco	598-2
Mobil	17-2
Mobil	544-1
Exxon	684-2
Texaco	598-4
----------	COST B-3
Conoco	590-1
Shell	632-1
Texaco	598-1
Houston	676-1
Exxon	684-1
Mobil	17-1
Houston	855-1
Exxon	599-1
Gulf	718-1
Exxon	902-1
Tenneco	642-2
Exxon	500-1
Texaco	642-1
Murphy	106-1
Tenneco	642-3
Mobil	544-2




676-1
718-1
544-2
632-1
544-1
500-1
590-1
TOP_4
TOP_5
UPPER_
LOGAN_CAYON
SABLE
LOWER_
LOGAN_CANYON
NASKAPI
MISSISAUGA
TOP_4
TOP_5
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LOGAN_CAYON
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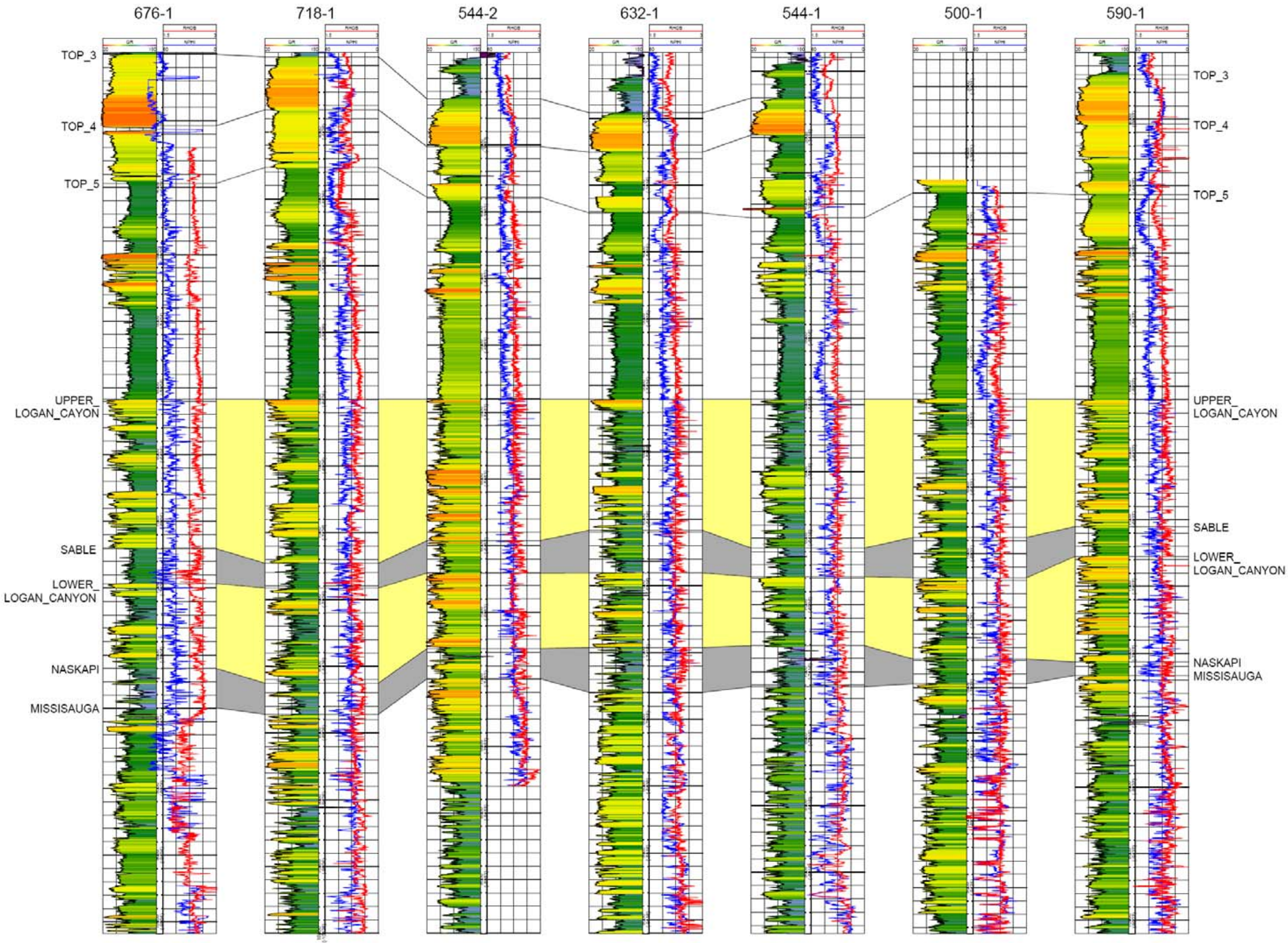
LOWER_
LOGAN_CANYON
NASKAPI
MISSISAUGA



676-1
718-1
544-2
632-1
544-1
500-1
590-1
TOP_3
TOP_4
TOP_5
UPPER_ LOGAN_CAYON
SABLE
LOWER_ LOGAN_CANYON
NASKAPI
MISSISAUGA
TOP_3
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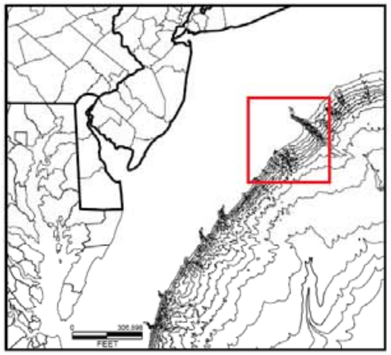

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Tenneco	642-2
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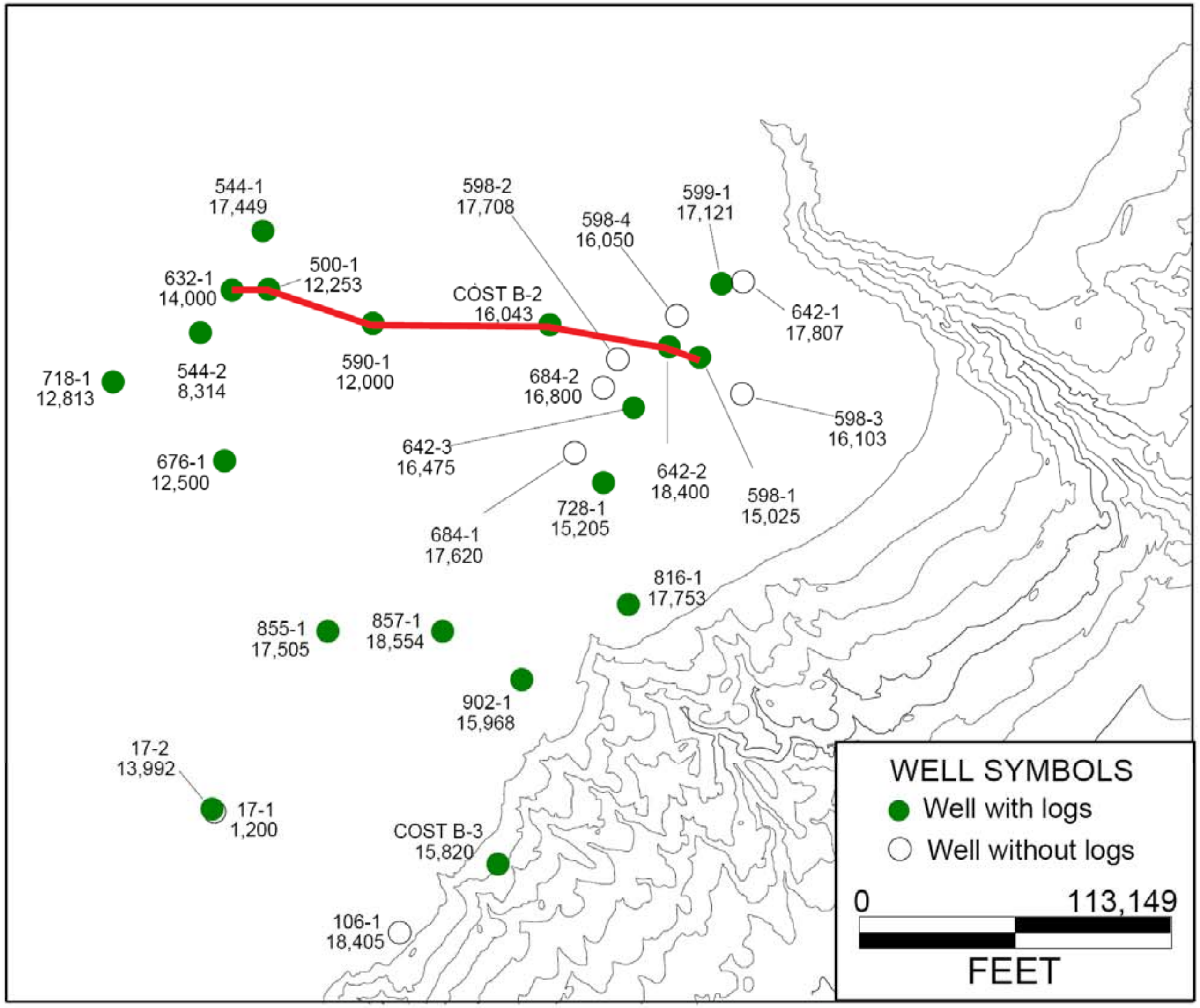
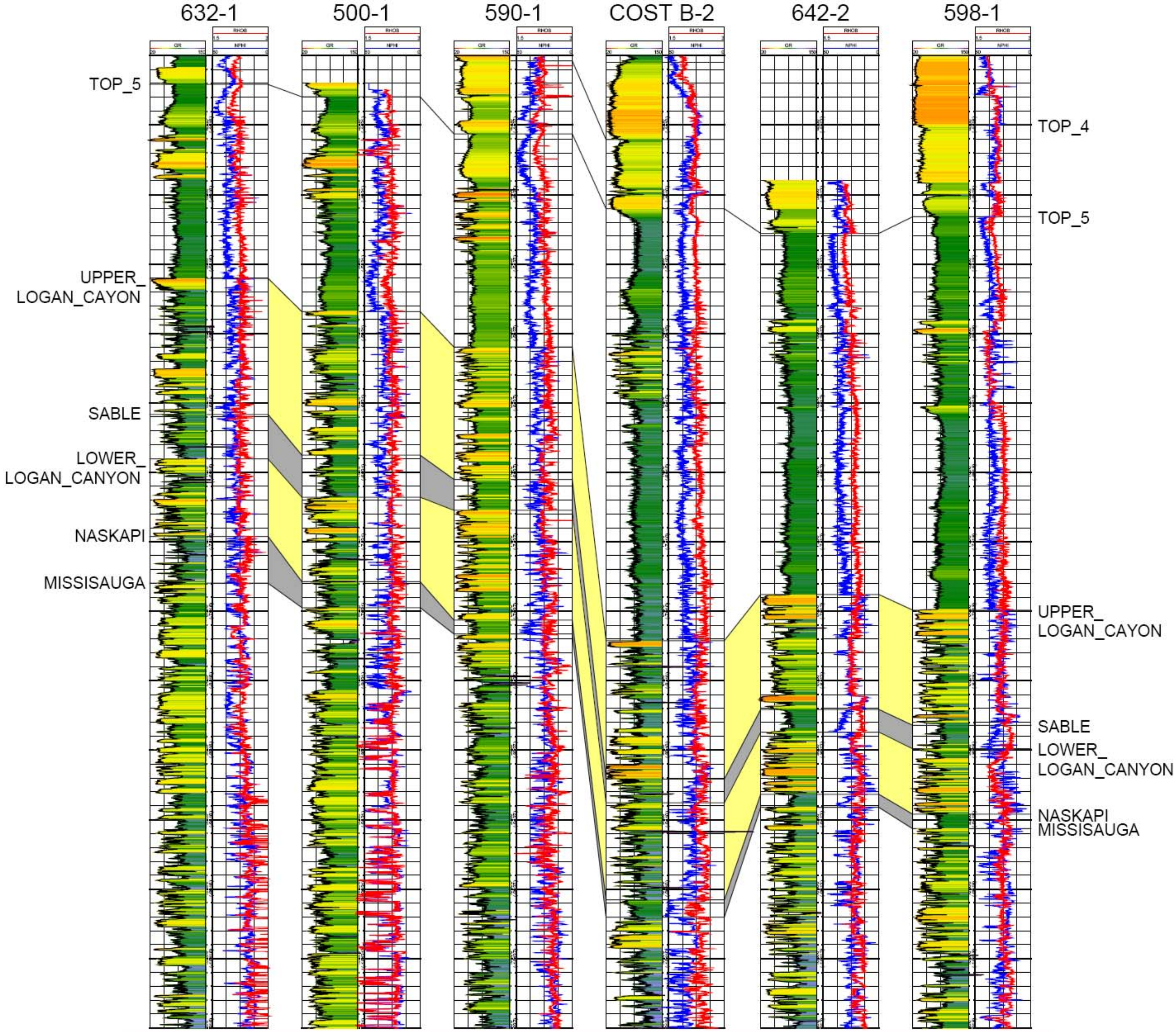
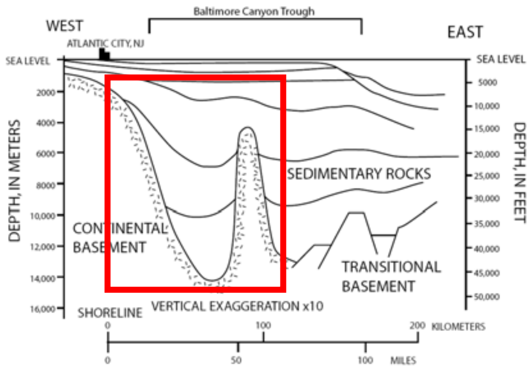
Texaco	642-1
Murphy	106-1
Tenneco	642-3
Mobil	544-2

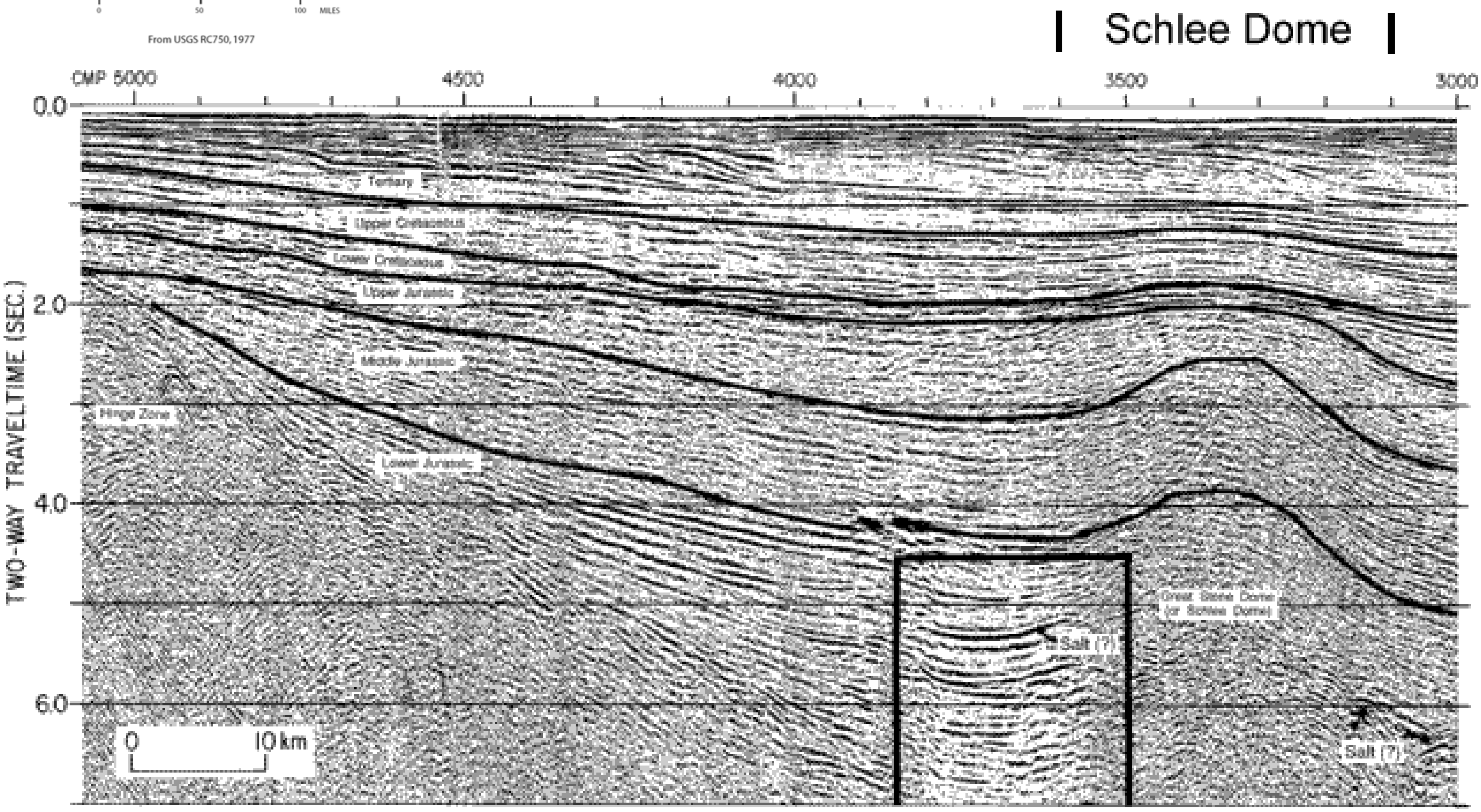


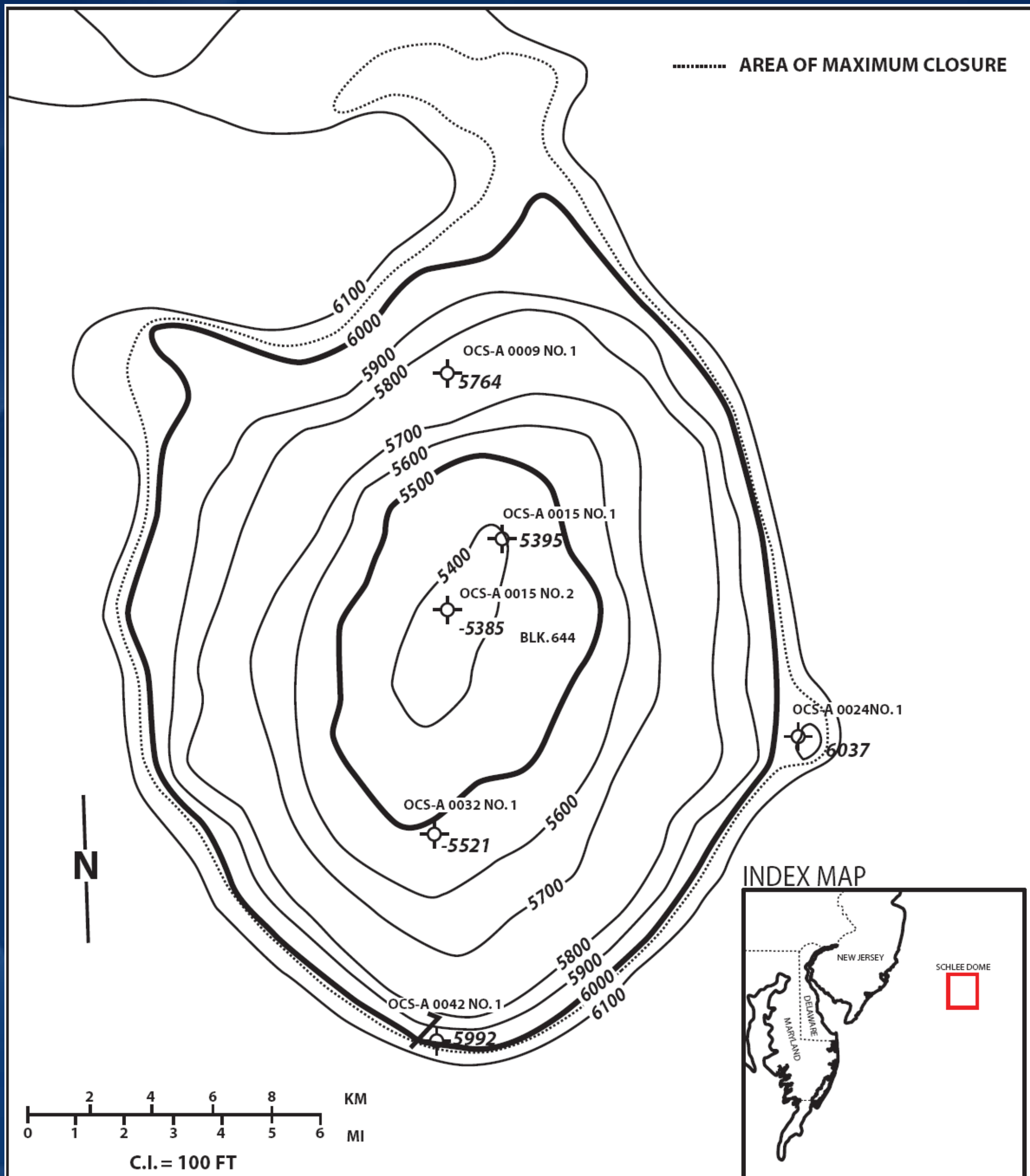

632-1
500-1
590-1
COST B-2
642-2
598-1
TOP_5
UPPER_
LOGAN_CAYON
SABLE
LOWER_
LOGAN_CANYON
NASKAPI
MISSISAUGA
TOP_4
TOP_5
UPPER_
LOGAN_CAYON
SABLE
LOWER_
LOGAN_CANYON
NASKAPI
MISSISAUGA

Great Stone Dome (a.k.a Schlee Dome)



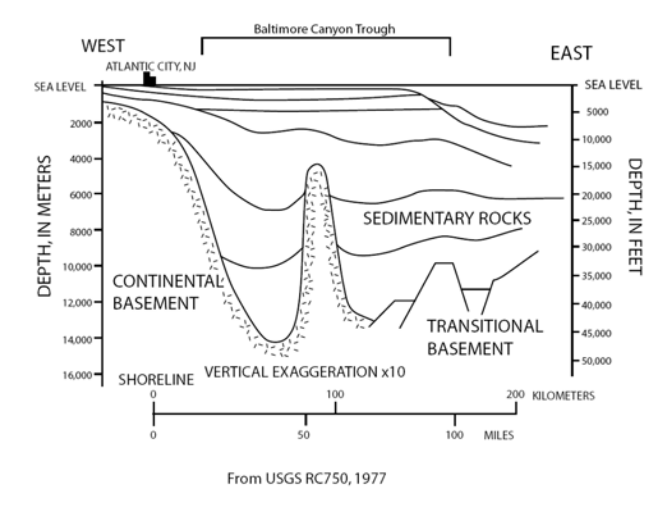
From USGS RC750, 1977



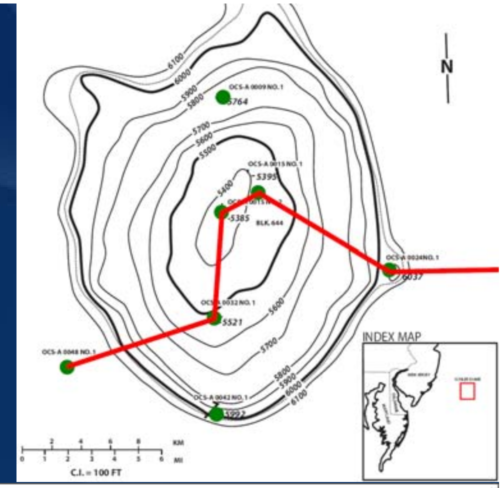


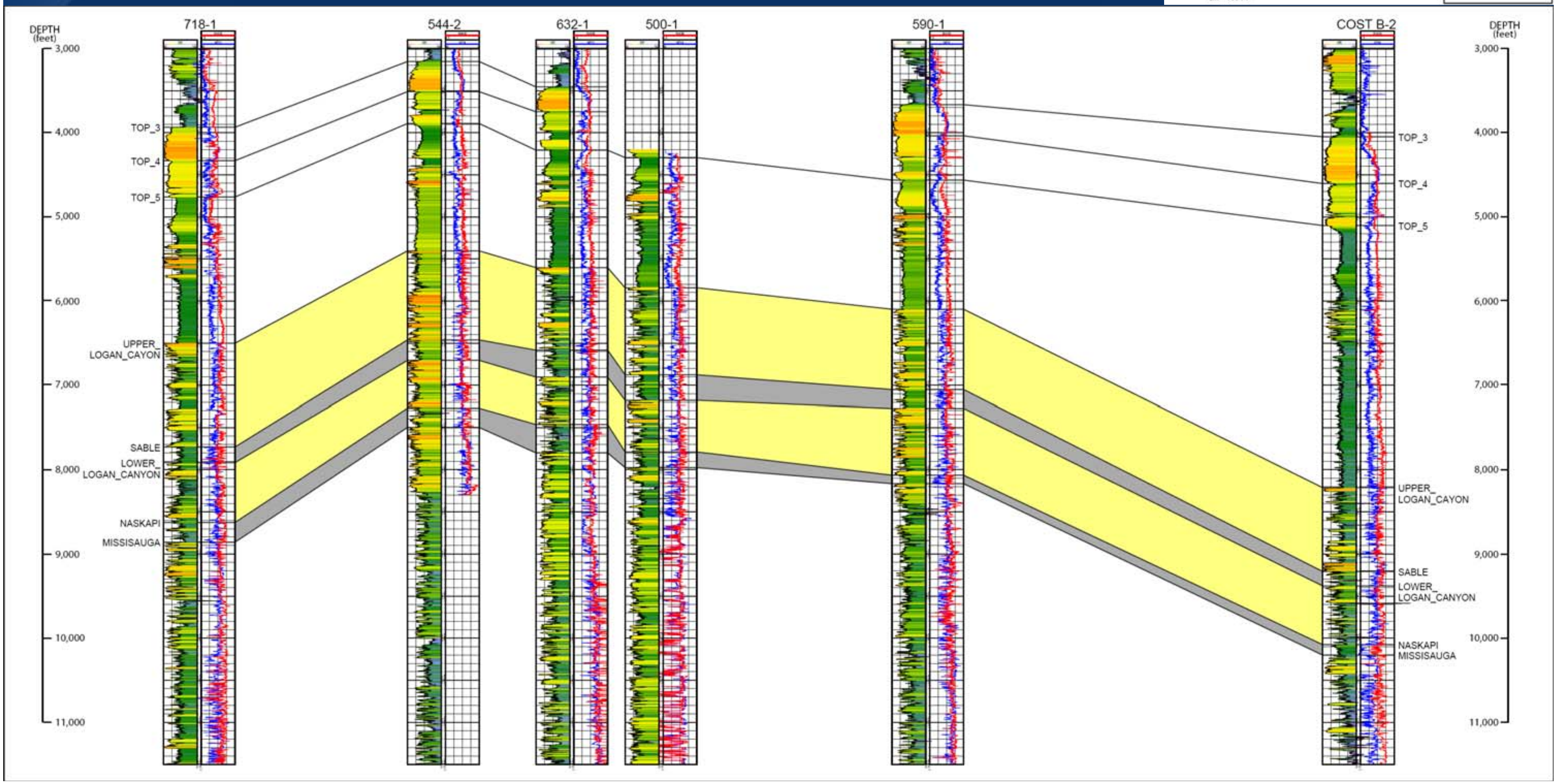
From Prather, 1991

"Uplift of the dome is interpreted to be associated with emplacement of an igneous intrusive dike swarm during the Late Jurassic." – Prather, 1991



"The most significant structural closure in this area is the large domal anticline known as Schlee Dome." – Prather, 1991





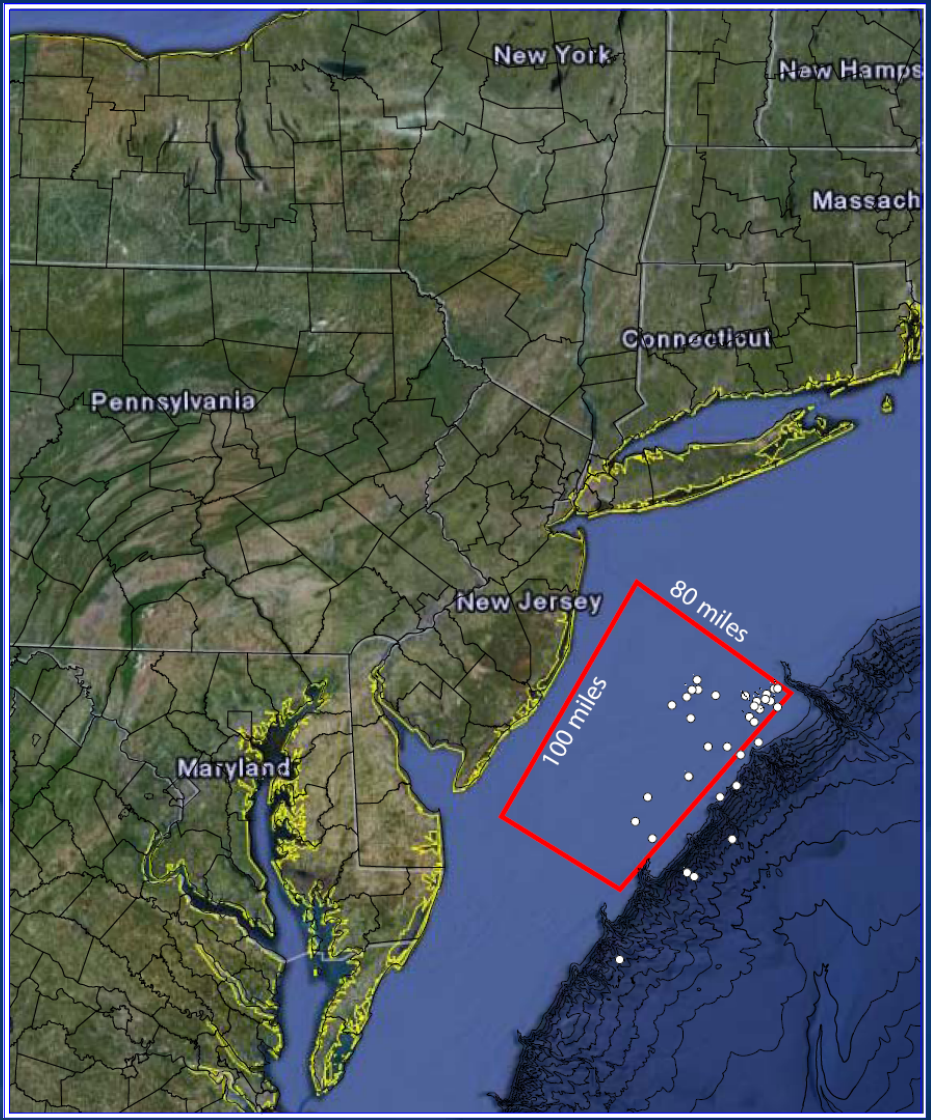
Logan Canyon Sands

UWI(API)	FORMATION NAME	MD VALUE	WELL NAME	OPERATOR	TD	ULC thickness	LLC thickness
61-104-00002	UPPER_LOGAN_CAYON	8199.4	COST B-3	Chevron	15820	908.6	
	SABLE	9108.0	COST B-3	Chevron	15820		
	LOWER_LOGAN_CANYON	9273.6	COST B-3	Chevron	15820		582.6
	NASKAPI	9856.2	COST B-3	Chevron	15820		
61-104-00005	UPPER_LOGAN_CAYON	8134.7	17-2	Mobil	13992	797.7	
	SABLE	8932.3	17-2	Mobil	13992		
	LOWER_LOGAN_CANYON	9289.0	17-2	Mobil	13992		670.0
	NASKAPI	9959.0	17-2	Mobil	13992		
61-105-00003	UPPER_LOGAN_CAYON	5460.0	544-1	Mobil	17449	1112.8	
	SABLE	6572.8	544-1	Mobil	17449		
	LOWER_LOGAN_CANYON	6787.7	544-1	Mobil	17449		516.6
	NASKAPI	7304.3	544-1	Mobil	17449		
61-105-00004	UPPER_LOGAN_CAYON	7991.8	598-1	Texaco	15025	829.0	
	SABLE	8820.8	598-1	Texaco	15025		
	LOWER_LOGAN_CANYON	8989.8	598-1	Texaco	15025		470.8
	NASKAPI	9460.6	598-1	Texaco	15025		
61-105-00005	UPPER_LOGAN_CAYON	6501.3	718-1	Gulf	12813	1227.3	
	SABLE	7728.6	718-1	Gulf	12813		
	LOWER_LOGAN_CANYON	7913.7	718-1	Gulf	12813		712.2
	NASKAPI	8625.9	718-1	Gulf	12813		
61-105-00006	UPPER_LOGAN_CAYON	6086.6	676-1	Houston O&M	12500	1118.7	
	SABLE	7205.2	676-1	Houston O&M	12500		
	LOWER_LOGAN_CANYON	7466.1	676-1	Houston O&M	12500		636.4
	NASKAPI	8102.5	676-1	Houston O&M	12500		
61-105-00007	UPPER_LOGAN_CAYON	6098.2	590-1	Conoco	12000	952.8	
	SABLE	7050.9	590-1	Conoco	12000		
	LOWER_LOGAN_CANYON	7273.4	590-1	Conoco	12000		790.6
	NASKAPI	8064.0	590-1	Conoco	12000		
61-105-00008	UPPER_LOGAN_CAYON	8248.5	857-1	Gulf	18554	950.7	
	SABLE	9199.1	857-1	Gulf	18554		
	LOWER_LOGAN_CANYON	9459.5	857-1	Gulf	18554		829.3
	NASKAPI	10288.8	857-1	Gulf	18554		
61-105-00009	UPPER_LOGAN_CAYON	5603.5	632-1	Shell	14000	980.5	
	SABLE	6584.0	632-1	Shell	14000		
	LOWER_LOGAN_CANYON	6903.7	632-1	Shell	14000		558.5
	NASKAPI	7462.1	632-1	Shell	14000		
61-105-00012	UPPER_LOGAN_CAYON	8327.5	855-1	Houston O&M	17505	836.0	
	SABLE	9163.5	855-1	Houston O&M	17505		
	LOWER_LOGAN_CANYON	9411.5	855-1	Houston O&M	17505		1020.9
	NASKAPI	10432.4	855-1	Houston O&M	17505		

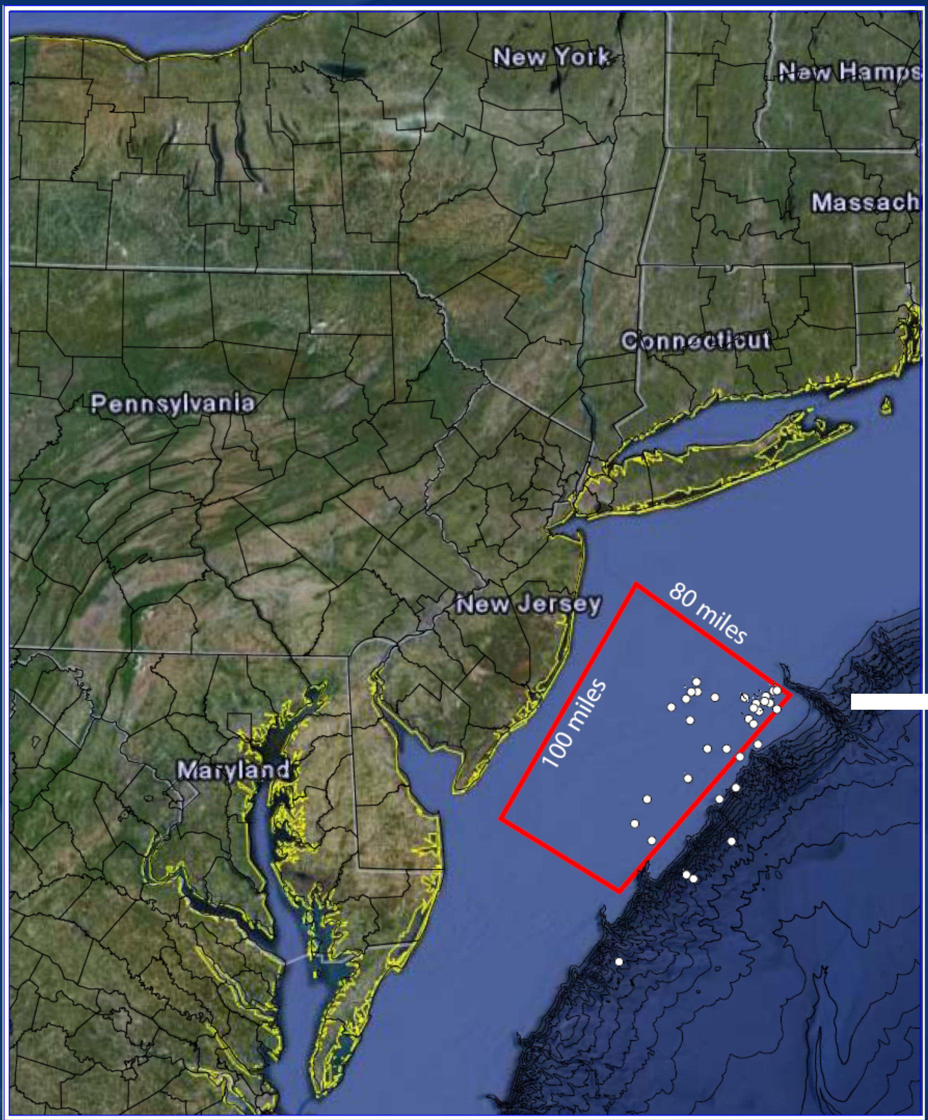
UWI(API)	FORMATION NAME	MD VALUE	WELL NAME	OPERATOR	TD	ULC thickness	LLC thickness
61-105-00013	UPPER_LOGAN_CAYON	8358.6	902-1	Exxon	15968	843.3	
	SABLE	9201.9	902-1	Exxon	15968		
	LOWER_LOGAN_CANYON	9513.5	902-1	Exxon	15968		802.5
	NASKAPI	10316.0	902-1	Exxon	15968		
61-105-00014	UPPER_LOGAN_CAYON	7880.0	642-2	Tenneco	18400	827.3	
	SABLE	8707.3	642-2	Tenneco	18400		
	LOWER_LOGAN_CANYON	8869.9	642-2	Tenneco	18400		448.1
	NASKAPI	9318.0	642-2	Tenneco	18400		
61-105-00016	UPPER_LOGAN_CAYON	5843.3	500-1	Exxon	12253	1033.3	
	SABLE	6876.6	500-1	Exxon	12253		
	LOWER_LOGAN_CANYON	7178.4	500-1	Exxon	12253		609.2
	NASKAPI	7787.6	500-1	Exxon	12253		
61-105-00018	UPPER_LOGAN_CAYON	8053.0	642-3	Tenneco	16475	673.7	
	SABLE	8726.7	642-3	Tenneco	16475		
	LOWER_LOGAN_CANYON	8885.4	642-3	Tenneco	16475		477.1
	NASKAPI	9362.5	642-3	Tenneco	16475		
61-105-00019	UPPER_LOGAN_CAYON	7971.7	599-1	Exxon	17121	845.1	
	SABLE	8816.8	599-1	Exxon	17121		
	LOWER_LOGAN_CANYON	8983.2	599-1	Exxon	17121		452.2
	NASKAPI	9435.4	599-1	Exxon	17121		
61-105-00020	UPPER_LOGAN_CAYON	8237.7	816-1	Exxon	17753	849.1	
	SABLE	9086.8	816-1	Exxon	17753		
	LOWER_LOGAN_CANYON	9344.3	816-1	Exxon	17753		727.1
	NASKAPI	10071.4	816-1	Exxon	17753		
61-105-00022	UPPER_LOGAN_CAYON	8140.1	728-1	Exxon	15205	875.6	
	SABLE	9015.7	728-1	Exxon	15205		
	LOWER_LOGAN_CANYON	9151.6	728-1	Exxon	15205		776.0
	NASKAPI	9927.5	728-1	Exxon	15205		
61-105-00023	UPPER_LOGAN_CAYON	5404.6	544-2	Mobil	8312	1057.7	
	SABLE	6462.2	544-2	Mobil	8312		
	LOWER_LOGAN_CANYON	6705.0	544-2	Mobil	8312		565.3
	NASKAPI	7270.3	544-2	Mobil	8312		
61-105-00001	UPPER_LOGAN_CAYON	8211.8	COST B-2	Ocean	16043	995.7	
	SABLE	9207.6	COST B-2	Ocean	16043		
	LOWER_LOGAN_CANYON	9379.2	COST B-2	Ocean	16043		698.4
	NASKAPI	10077.6	COST B-2	Ocean	16043		

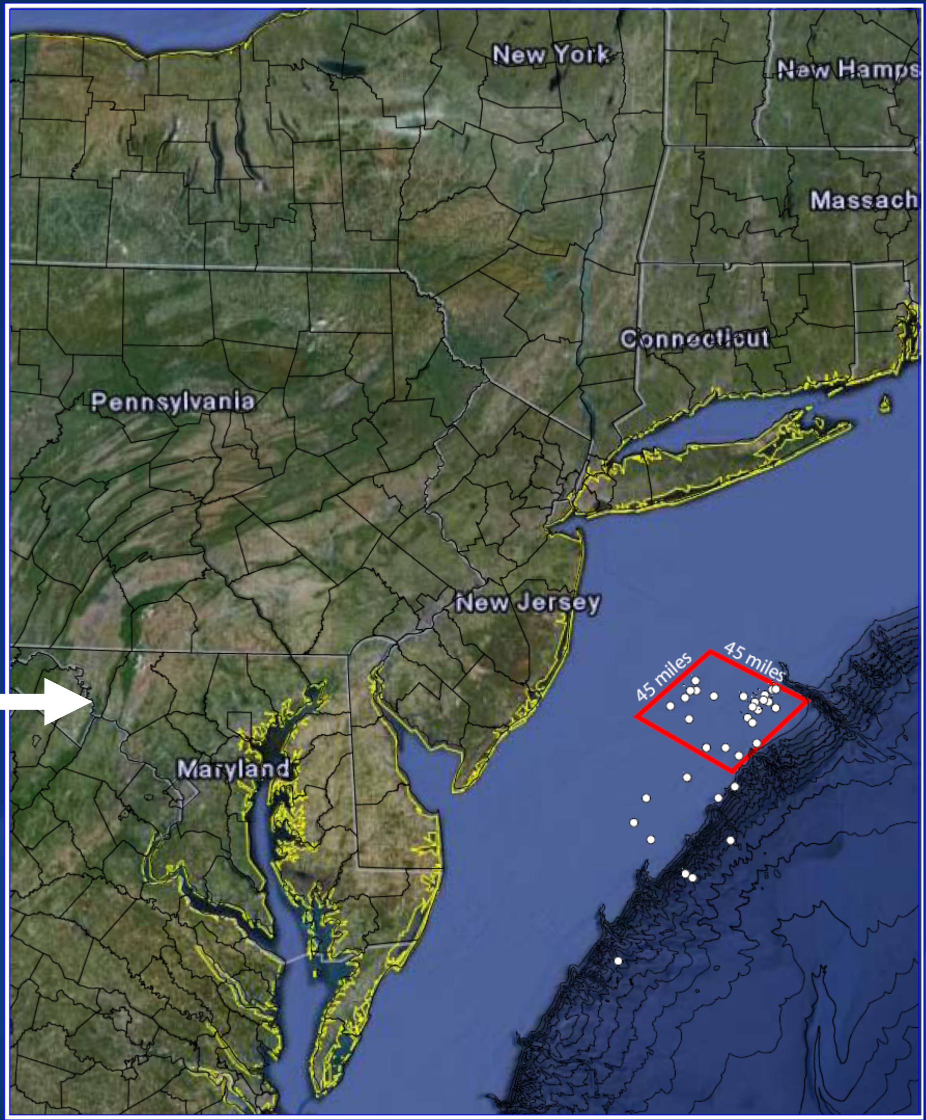
Average Upper Logan Canyon Thickness = 932.4 feet
Average Lower Logan Canyon Thickness = 649.7 feet
TOTAL = 1582.0 feet

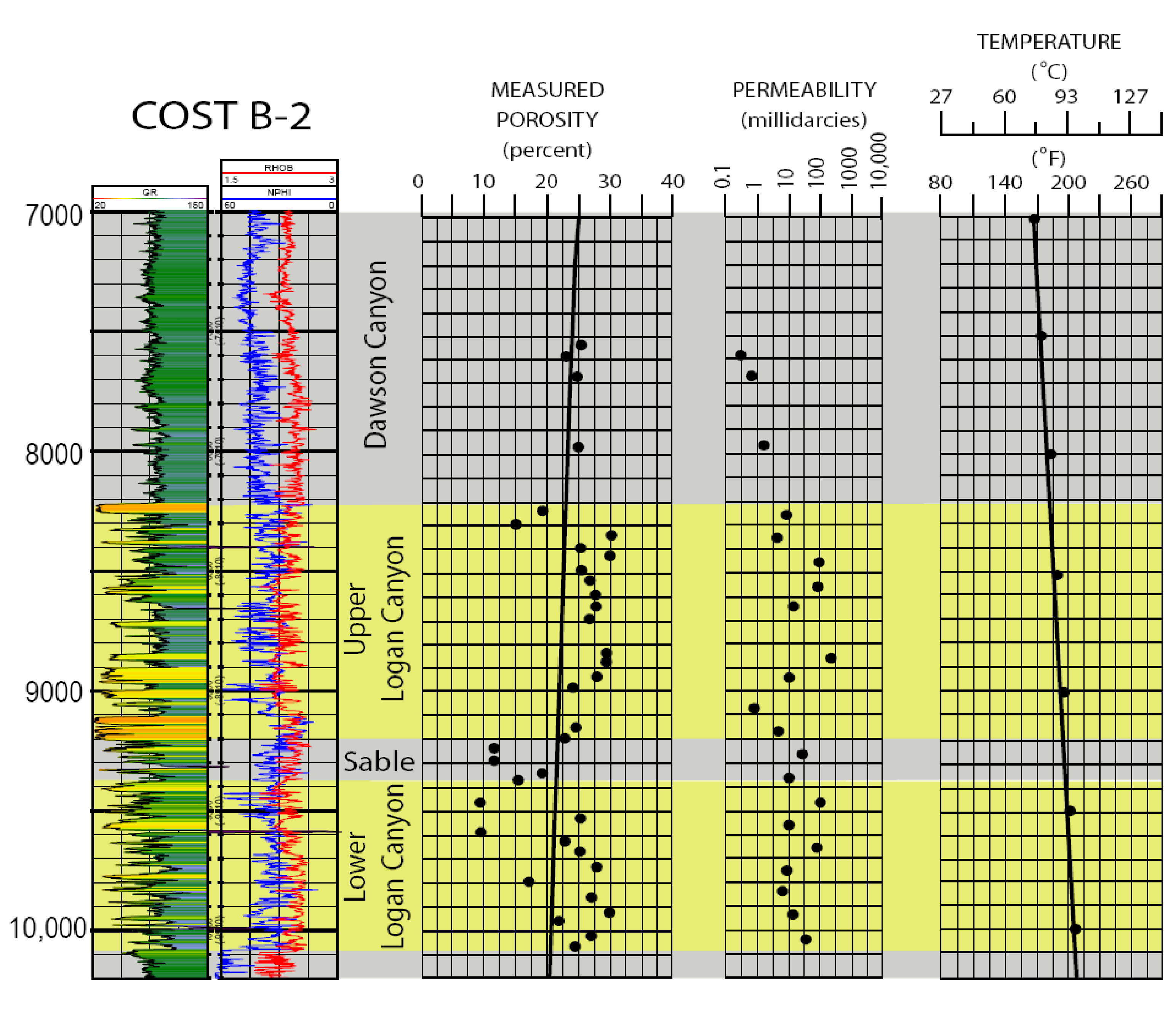
Sequestration Area



Sequestration Area

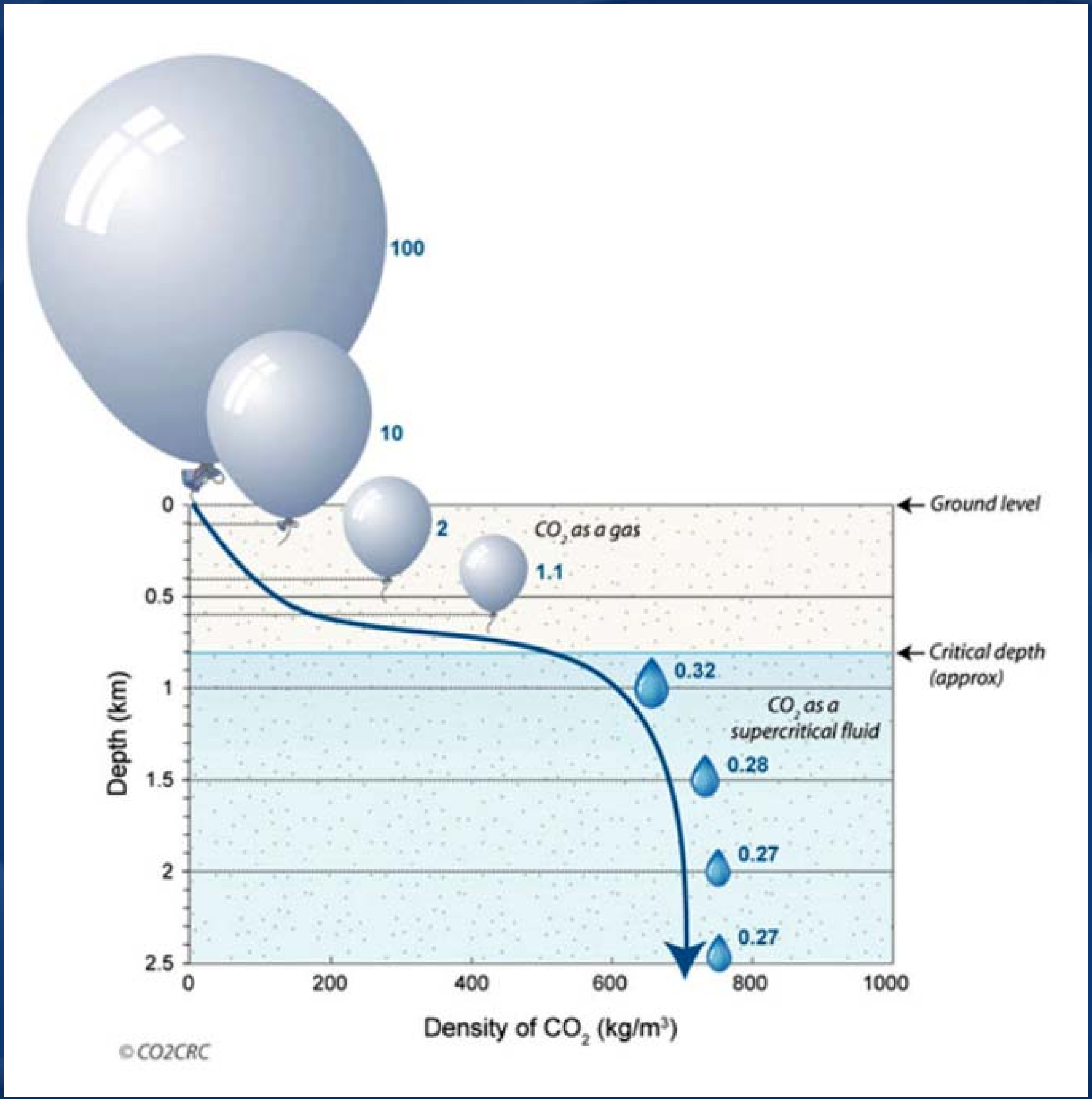






COST B-2
MEASURED POROSITY (percent)
PERMEABILITY (millidarcies)
TEMPERATURE (°C)
27
60
93
127
(°F)
80
140
200
260
0
10
20
30
40
0.1
1
10
100
1000
10,000
GR
RHOB
NPHI
7000
8000
9000
10,000
Dawson Canyon
Upper Logan Canyon
Sable
Lower Logan Canyon

Pressure and Density



The density of CO_2 "tops out" at approximately 700 kg/mg^3 (43.7 lbs/ft^3). This occurs at a depth of approximately 2.5km, or 8,200 feet. Since the Upper Logan Canyon occurs at or below that depth, a density 43.7 lbs/ft^3 was used in all capacity equations.

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

Capacities for the 8,000 square mile target area

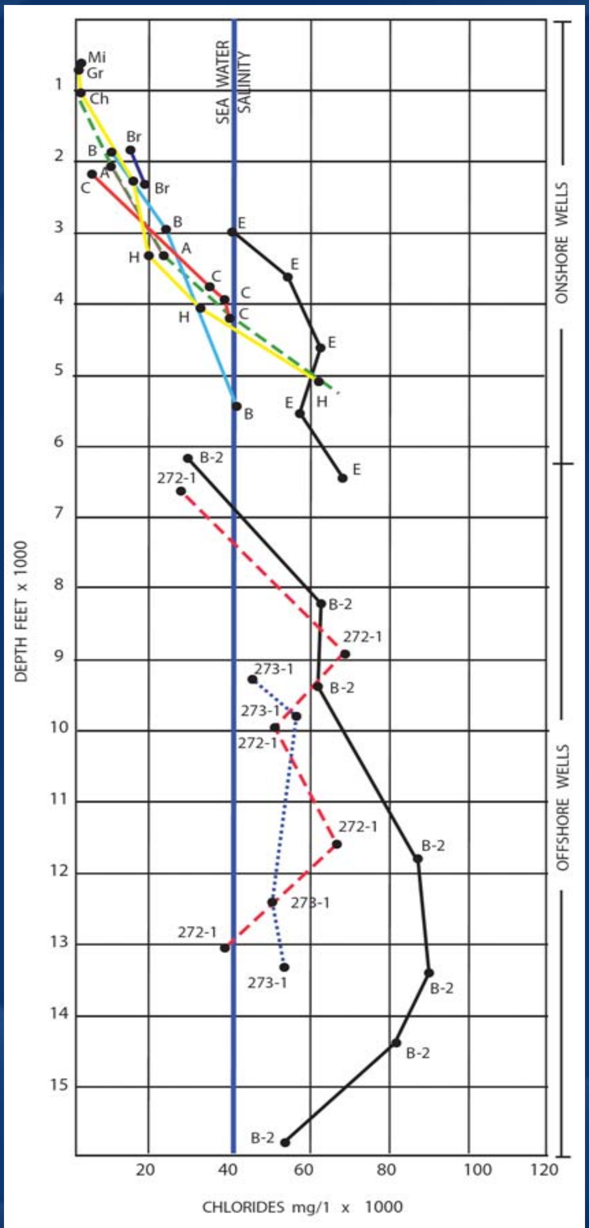
Reservoir Unit	Reservoir Depth	Reservoir Temperature	Resevoir Pressure	Reservoir Thickness	Reservoir Area	CO2 Mass Storage Capacity (in MMT) @ 20% Porosity		
	feet	deg F	psi	feet	acre	displace 1%	displace 2.5%	displace 4%
Upper Logan Canyon	8,000	160	3,300	932	5,120,000 (8,000 mi^2)	8,263	20,659	33,054
Lower Logan Canyon	8,900	180	3,600	650	5,120,000 (8,000 mi^2)	5,531	13,828	22,125
Total				1,582		13,794	34,487	55,179

2010 CO_2 Emissions (Million Metric Tonnes, MMT)

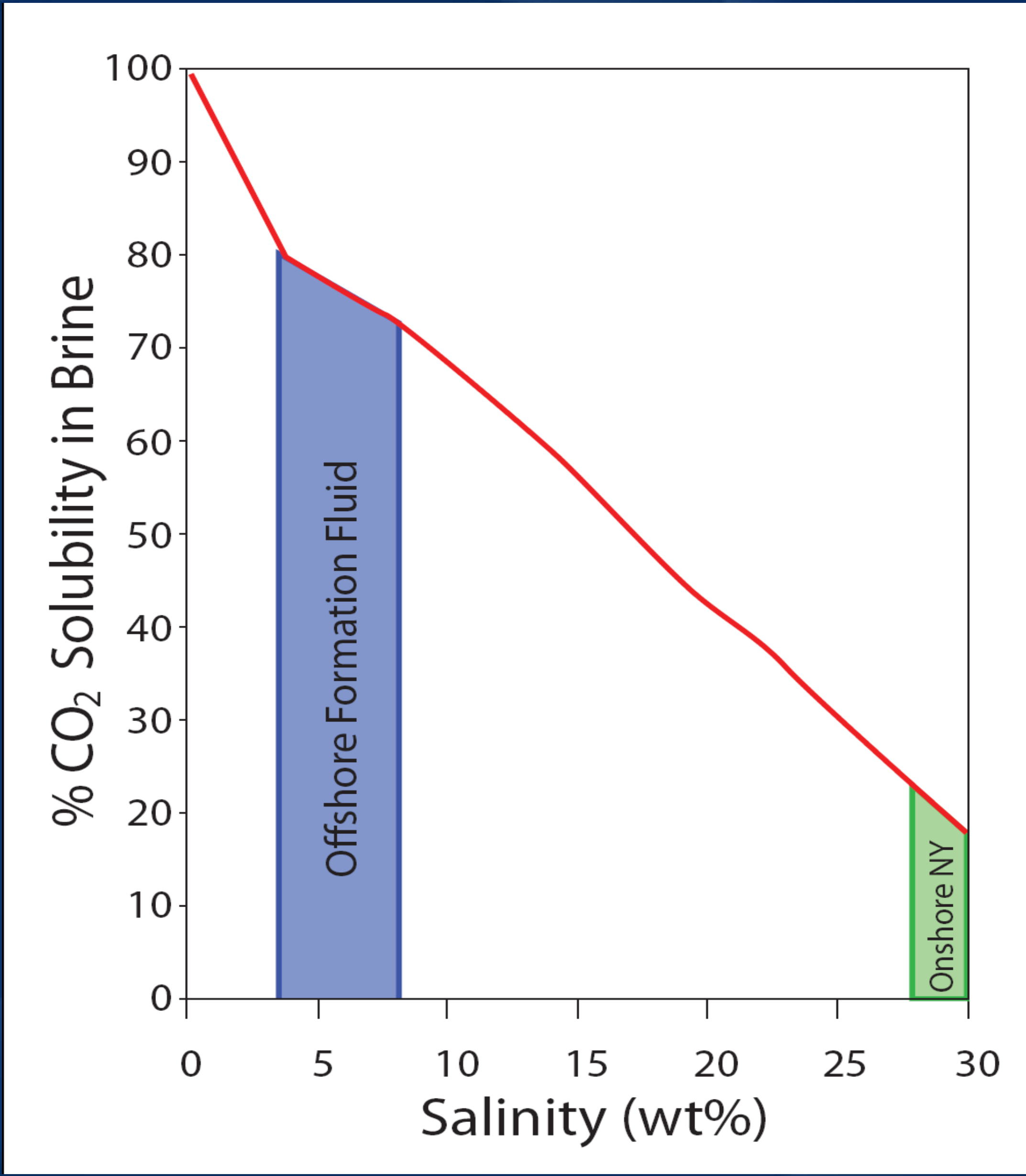
State	Electric Power	Industrial	
Pennsylvania	116.58	39.20	
New York	37.76	10.29	
Maryland	24.52	4.57	
Massachusetts	17.99	3.62	
New Jersey	17.62	9.18	
Connecticut	7.62	1.99	
Delaware	4.17	1.55	
TOTAL	109.68	70.4	**180.08**

Capacity ranges from 77 - 307 years of storage at current emission levels

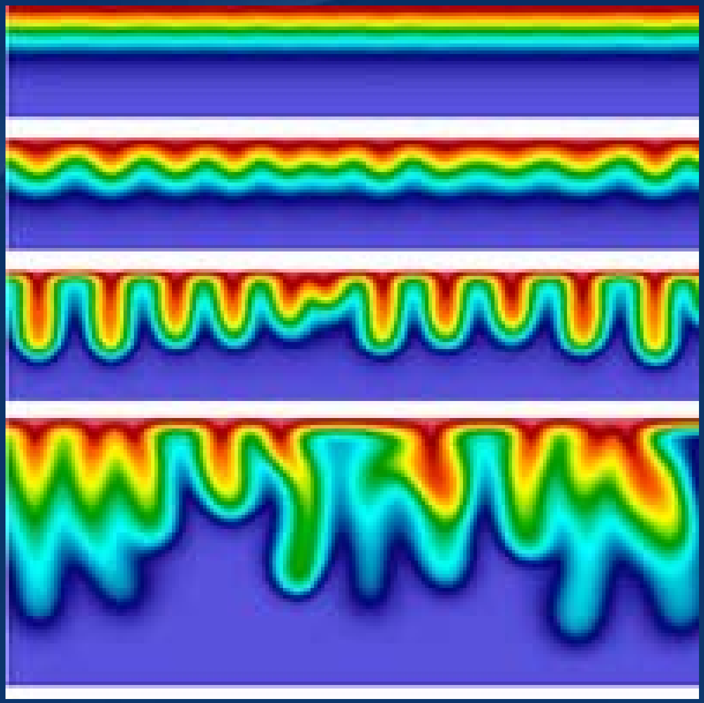
Salinity and Its Affect on Sequestration

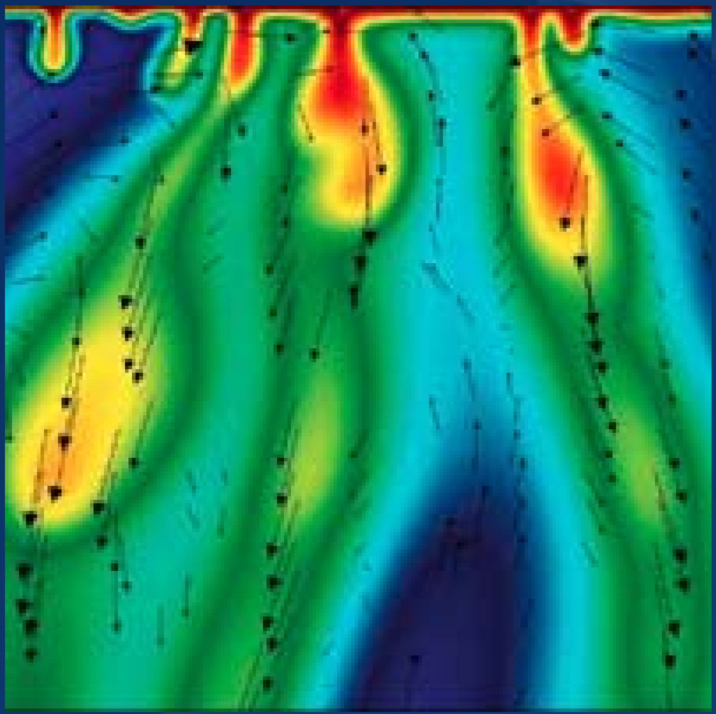


From Groot, 1983

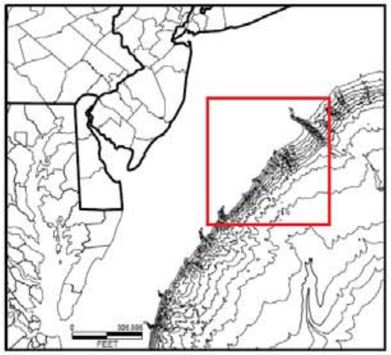


Dissolution and Convection Research

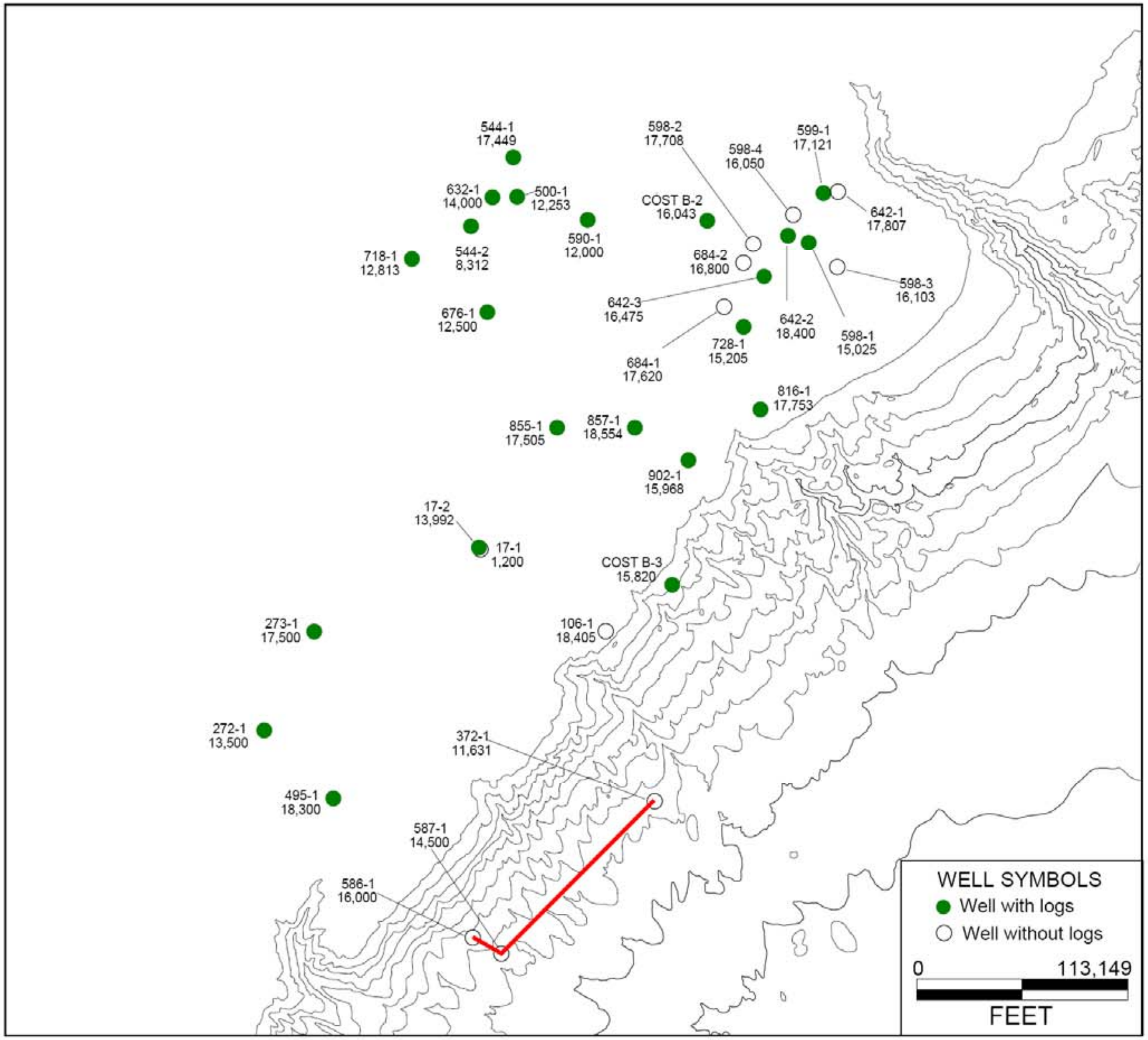


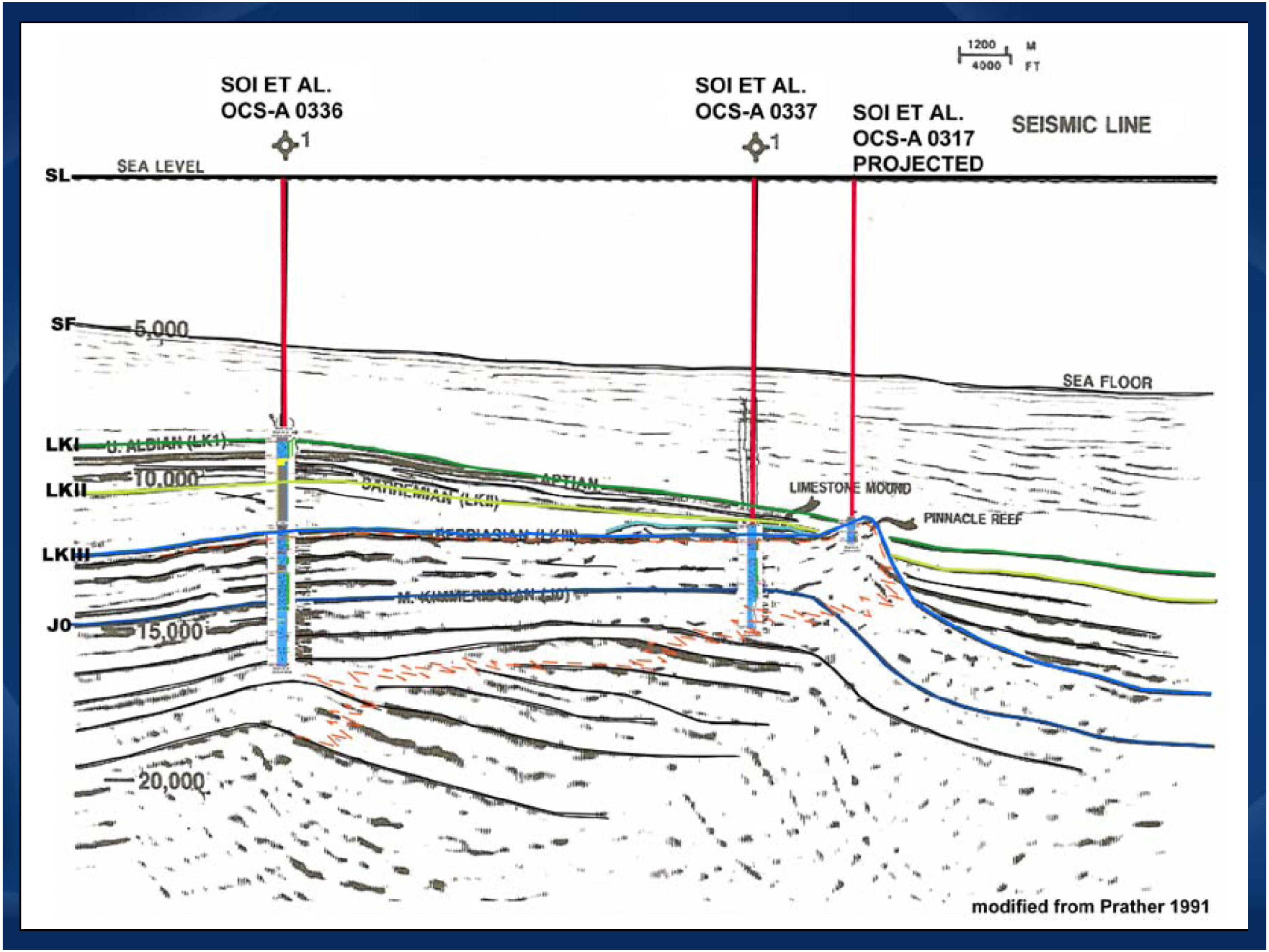


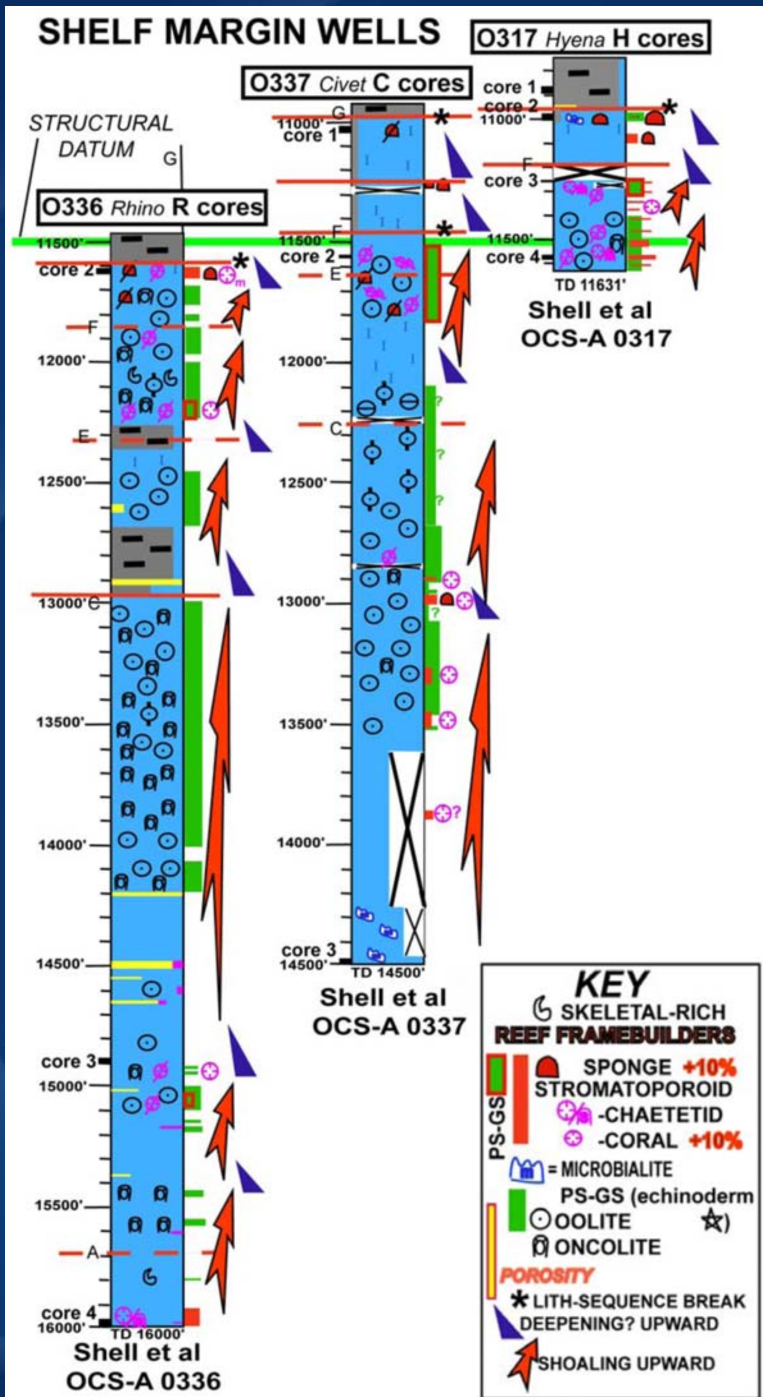
According to Pruess, when CO2 is first injected into an aquifer, it forms a separate layer, a bubble of sorts, above the saline. Over time, some CO2 will diffuse into the brine, causing the brine density to increase slightly. As more of the CO2 diffuses into the water, the resulting layer of carbonic acid (now less buoyant than the water below it) sinks. This churns up fresh brine, and a convective process kicks in which dramatically increases the rate of CO_2 uptake, compared to diffusion alone.

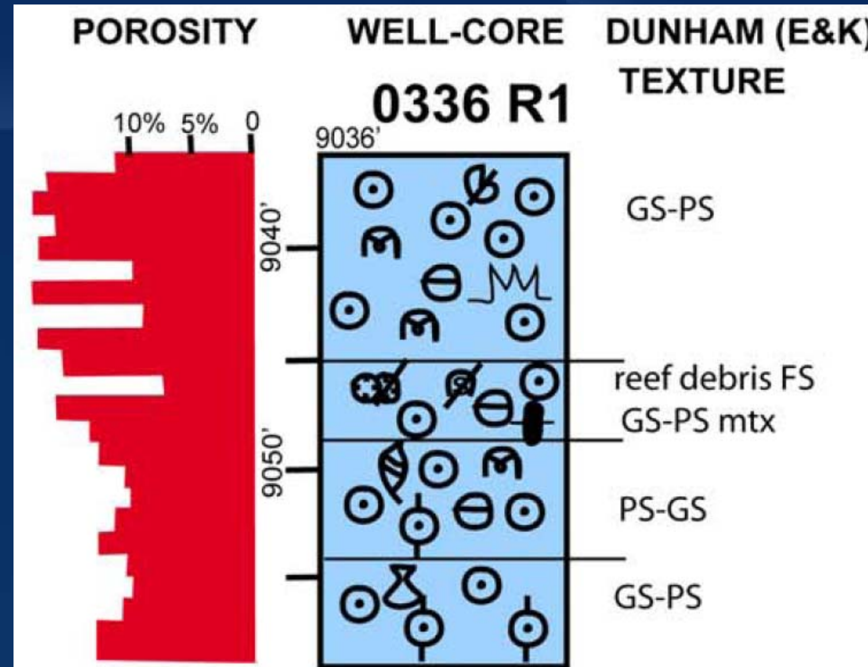


Company	Well name
----------	COST B-2
Shell	273-1
Shell	587-1
Shell	586-1
Shell	93-1
Gulf	857-1
Texaco	598-2
Mobil	17-2
Mobil	544-1
Exxon	684-2
Tenneco	495-1
----------	COST B-3
Conoco	590-1
Shell	632-1
Texaco	598-1
Houston	676-1
Exxon	684-1
Mobil	17-1
Houston	855-1
Shell	272-1
Gulf	718-1
Exxon	902-1
Tenneco	642-2
Exxon	500-1
Texaco	642-1
Murphy	106-1
Tenneco	642-3
Exxon	599-1
Texaco	598-4
Exxon	816-1
Exxon	728-1
Shell	372-1




1200 M
4000 FT
SOI ET AL.
OCS-A 0336
1
SOI ET AL.
OCS-A 0337
1
SOI ET AL.
OCS-A 0317
PROJECTED
SEISMIC LINE
SL
SEA LEVEL
SF
5,000
SEA FLOOR
LKI
U. ALBIAN (LK1)
10,000
LKII
BARREMIAN (LKII)
APTIAN
LIMESTONE MOUND
PINNACLE REEF
LKIII
BERRIASIAN (LKIII)
M. KIMMERIDGIAN (J0)
J0
15,000
20,000
modified from Prather 1991





(From Eliuk & Prather, 2008)

Conclusions

- Advantages of offshore sequestration in the sedimentary units of the Baltimore Canyon Trough include (but are not limited to) close proximity to large point sources, a vast area of potential reservoir, and lower salinity formation fluids may drastically increase storage capacity
- The application of Scotian Shelf nomenclature to the Baltimore Canyon Trough rock formations appears to be an easy and effective way to divide the
- Correlation of wireline logs from previous hydrocarbon exploration shows the Upper and Lower Logan Canyon equivalents to be continuous over the 2,000 mi^2 study area.
- Porosity and permeability data from previous studies indicate that the Logan Canyon equivalents have porosities (>25%) and permeabilities (≥ 10mD) that are favorable for sequestration of supercritical CO_2.
- Preliminary capacity estimates range from 3,449 to 55,179 MMT of CO_2.
- Features such as the Schlee Dome and carbonate reef (Abenaki Equivalent) represent additional traps and potential reservoirs.

Work Plan

(A lot has been done, but there's much more left to do!)

- Detailed analysis of shale facies and other sealing units
- Plume migration modeling
- Take a closer look at Schlee Dome
- Take a closer look at the Abenaki Equivalent carbonates
- Calibrate / Normalize NPHI curves to lab measured porosities
- Seismic Interpretation

"Exploration wells have penetrated at least four of the largest structural culminations in the Baltimore Canyon Trough. These wells show that sealing and reservoir facies are present in both the interior-shelf and shelf margin trends." – Prather, 1991

Thank You