Potential for Supercritical Carbon Sequestration in the Offshore Bedrock Formations of the Baltimore Canyon Trough*

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Abstract

Although geologists continue to find terrestrial rock formations that have the capacity to hold moderate amounts of carbon dioxide, the greatest potential for carbon sequestration in North Eastern United States lies in the offshore geologic formations that make up the continental shelf.

The Baltimore Canyon Trough is a portion of the continental shelf which lies approximately 100 miles south of Long Island and over 50 miles southeast of New Jersey. It is over 7,500 square miles in size and consists of Mesozoic and Cenozoic limestones, dolomites, sandstones, and shales. A number of oil and gas companies as well as the Continental Offshore Stratigraphic Test (COST), the Offshore Drilling Project (ODP), and the Deep Sea Drilling Project (DSDP) have explored this area. A large amount of data including wireline logs, cores, and seismic surveys has been collected and much of it is available for additional study. Previous work indicates that there are several sandstone beds in this region having porosities greater than 25% and permeabilities over 100 md This suggests an extremely large capacity for potential storage of supercritical CO2.

Offshore sequestration also avoids the issues associated with individual landowners'' mineral rights and public concerns over leaks or drinking water contamination. Offshore sequestration also offers the benefit of additional trapping mechanisms such as density inversion and formation of hydrates.

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September 28, 2010

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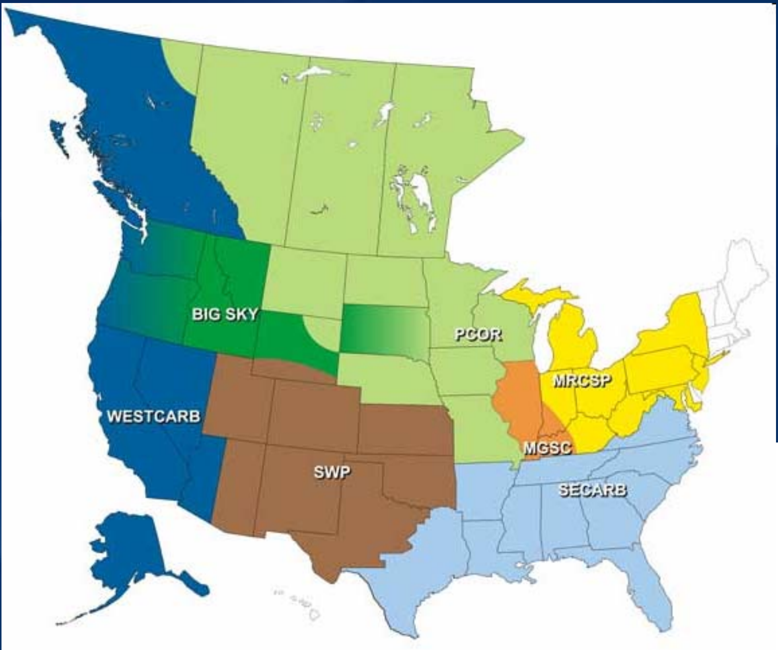
MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

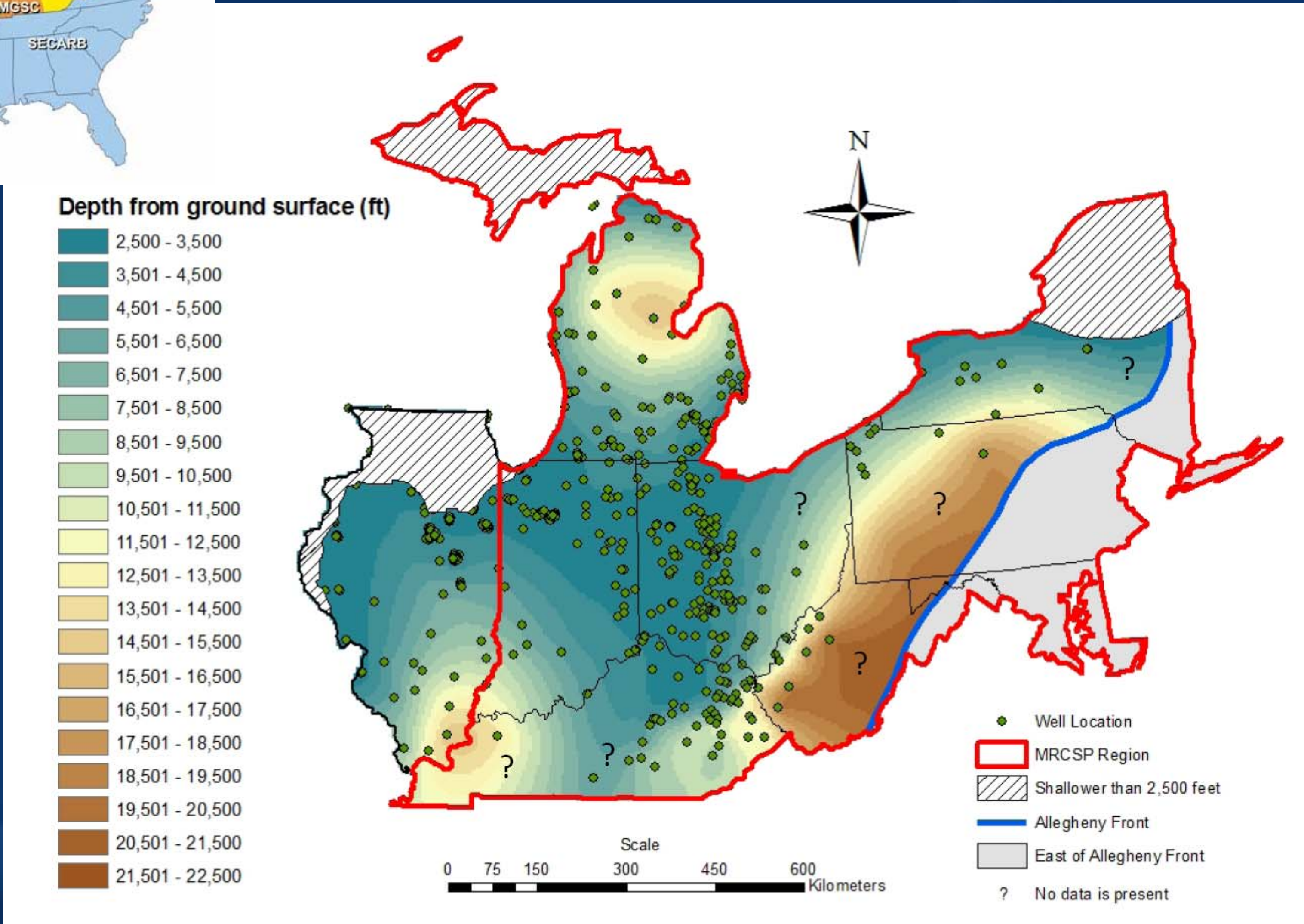
Overview

- Introduction
- Why Offshore?
- Basic geology of the Baltimore Canyon
- Available Data
- Potential
- Work Plan
- Conclusions

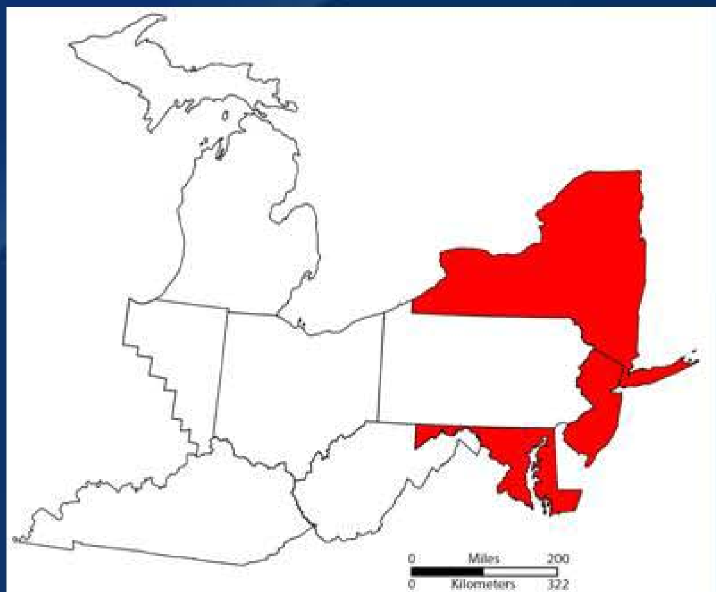
Midwest Region Carbon Sequestration Partnership



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



Phase III: Offshore Component



More than 450 miles of coastline

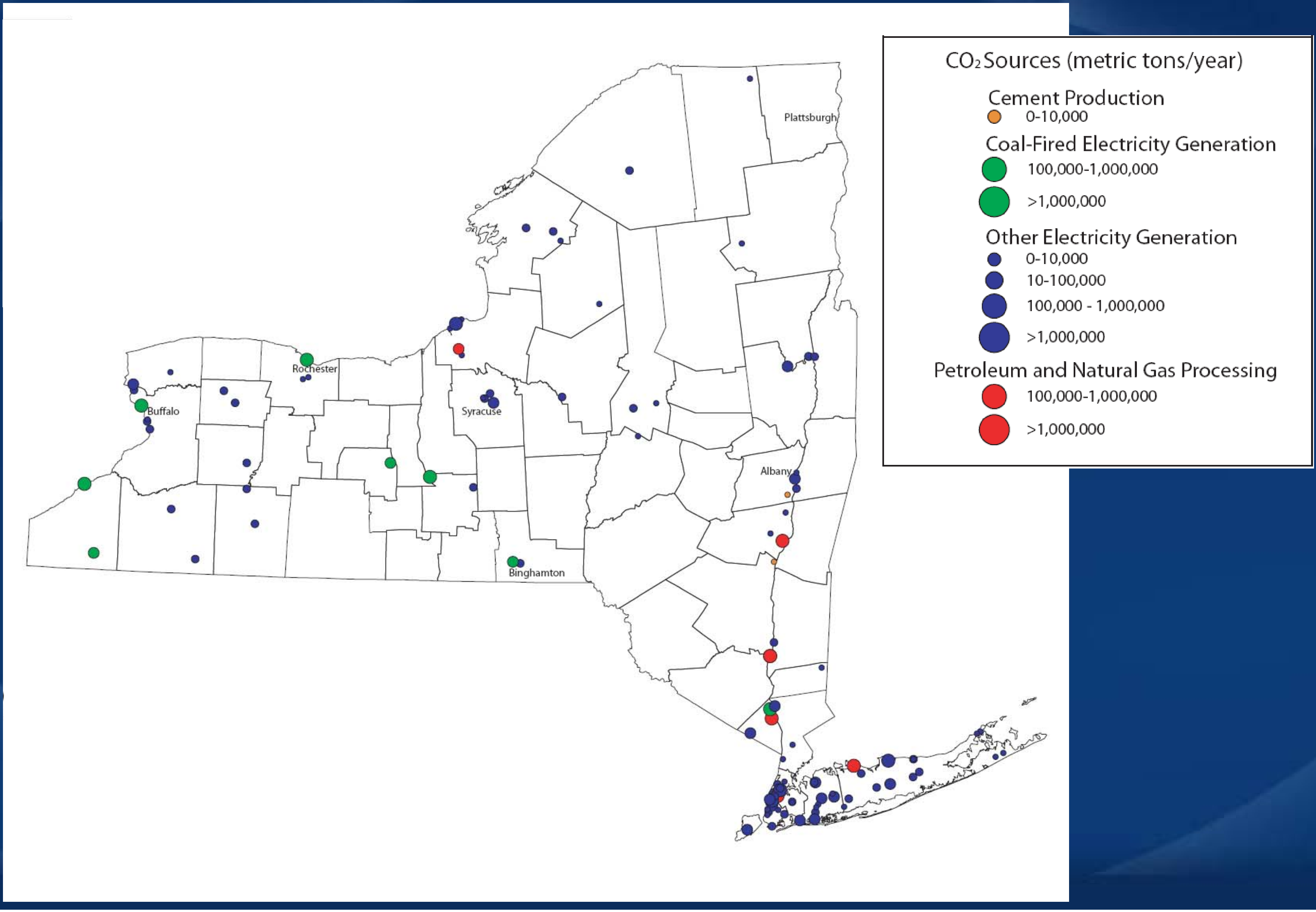
Notes by presenter: Not only has the MRCSP been working over the last 7 years, it has also been growing. New York joined the partnership in 2005 and just last year New Jersey joined as well. Along with Maryland, these states have a combined coastline of over 450 miles. This has inspired a portion of Phase III to be dedicated toward offshore research.

Why Offshore?

- Proximity to point sources
- None of the on land leasing and legal issues
- No NIMBY’s

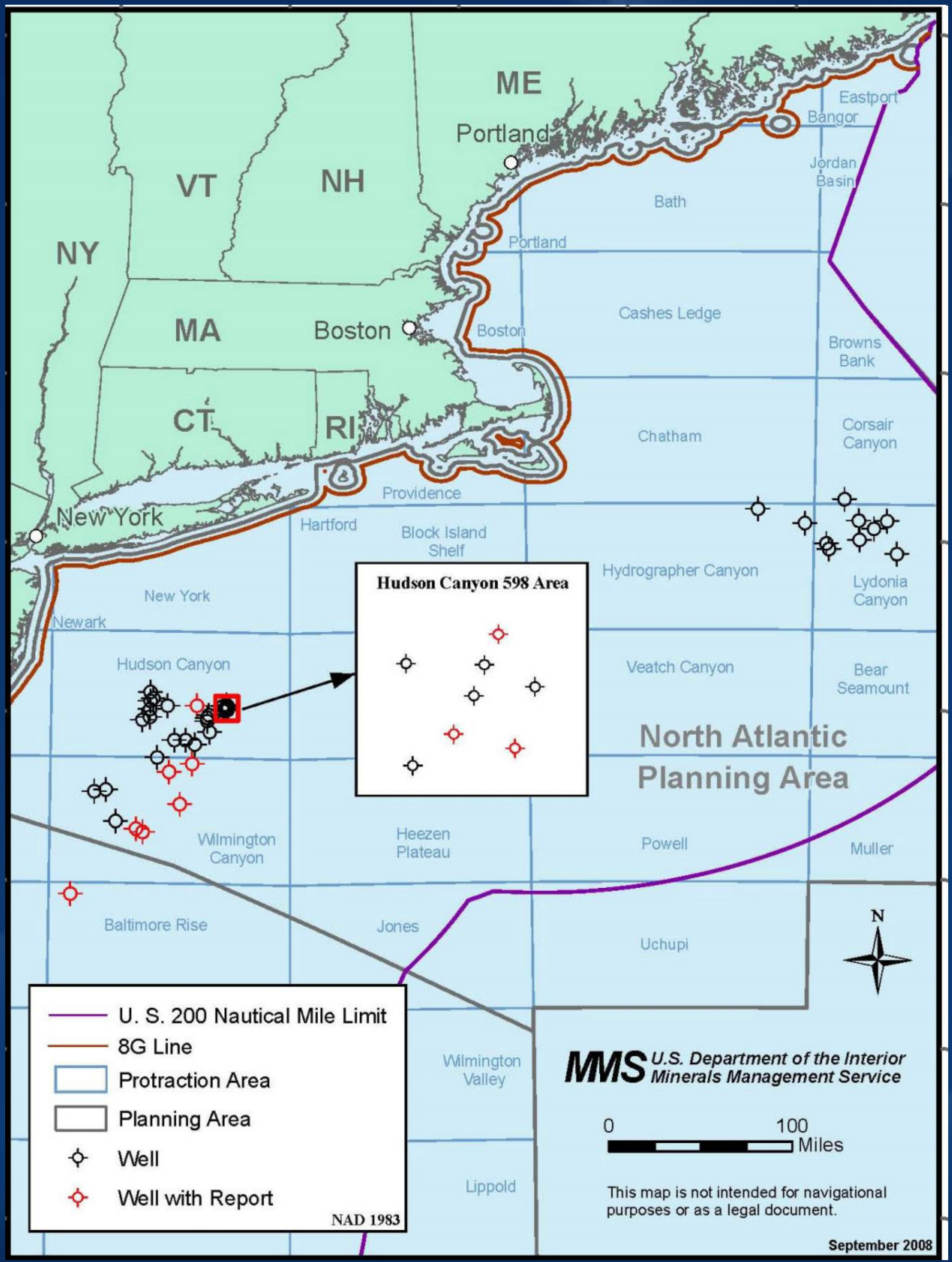
  (Though there will be environmental opposition)
- Possibility of enormous capacity
- Density inversion
- Low salinity formation water
- Hydrate formation?
- Pressure management

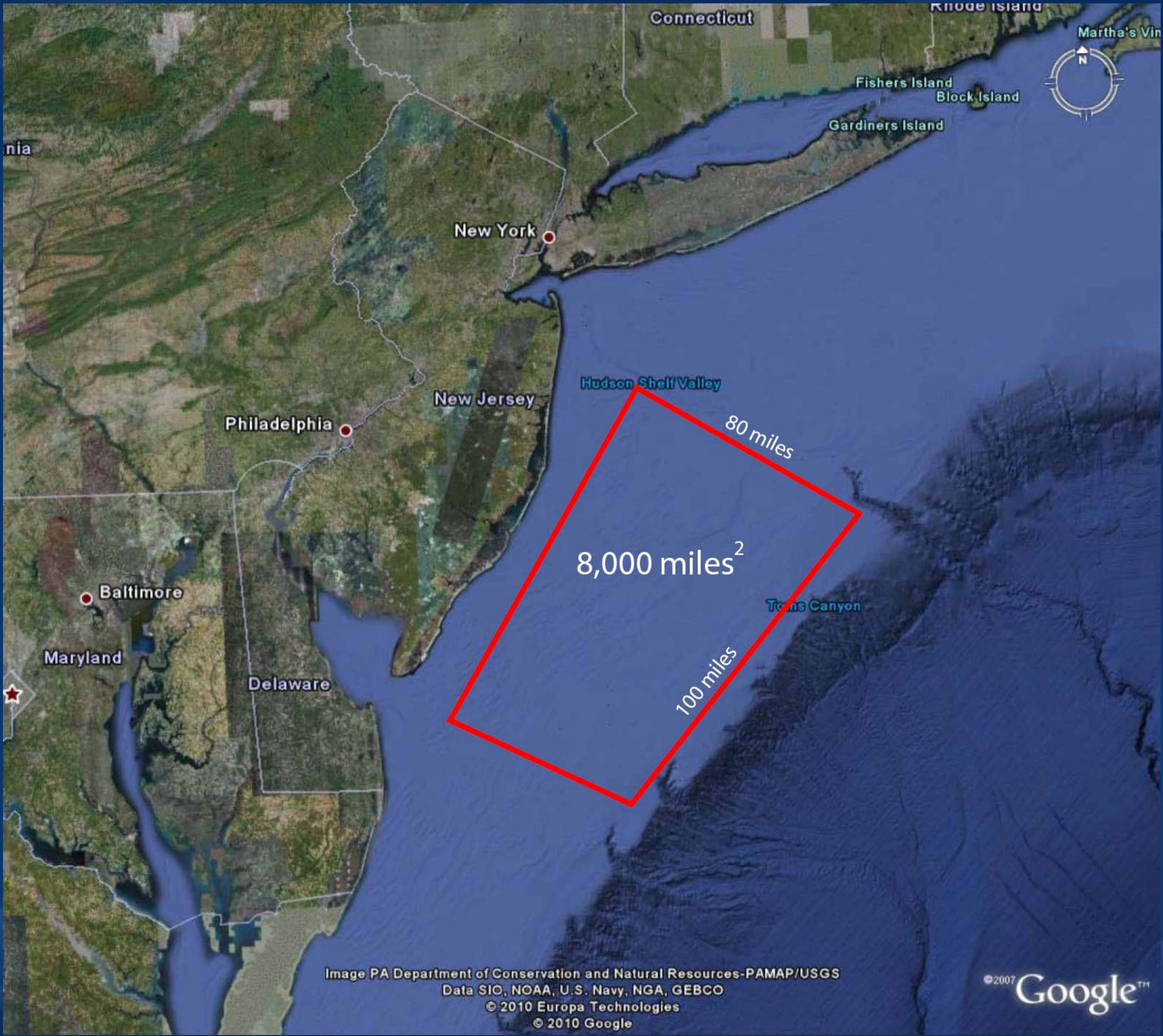
Proximity to CO_2 Point Sources



Leasing

- State waters extend 3 miles from shore
- Federal waters extend from 3 to 200 miles from shore
- 51 exploratory wells drilled between 1947 and the early 1980's
- No production, however 5 wells tested gas flows as high as 18.9 mcf / day
- All leases have reverted back to government
- Leasing of wells through the MMS





Connecticut
Rhode Island
Martha's Vin
Fishers Island
Block Island
Gardiners Island
New York
New Jersey
Philadelphia
Baltimore
Maryland
Delaware
Hudson Shelf Valley
80 miles
8,000 miles^2
100 miles
Toms Canyon
Image PA Department of Conservation and Natural Resources-PAMAP/USGS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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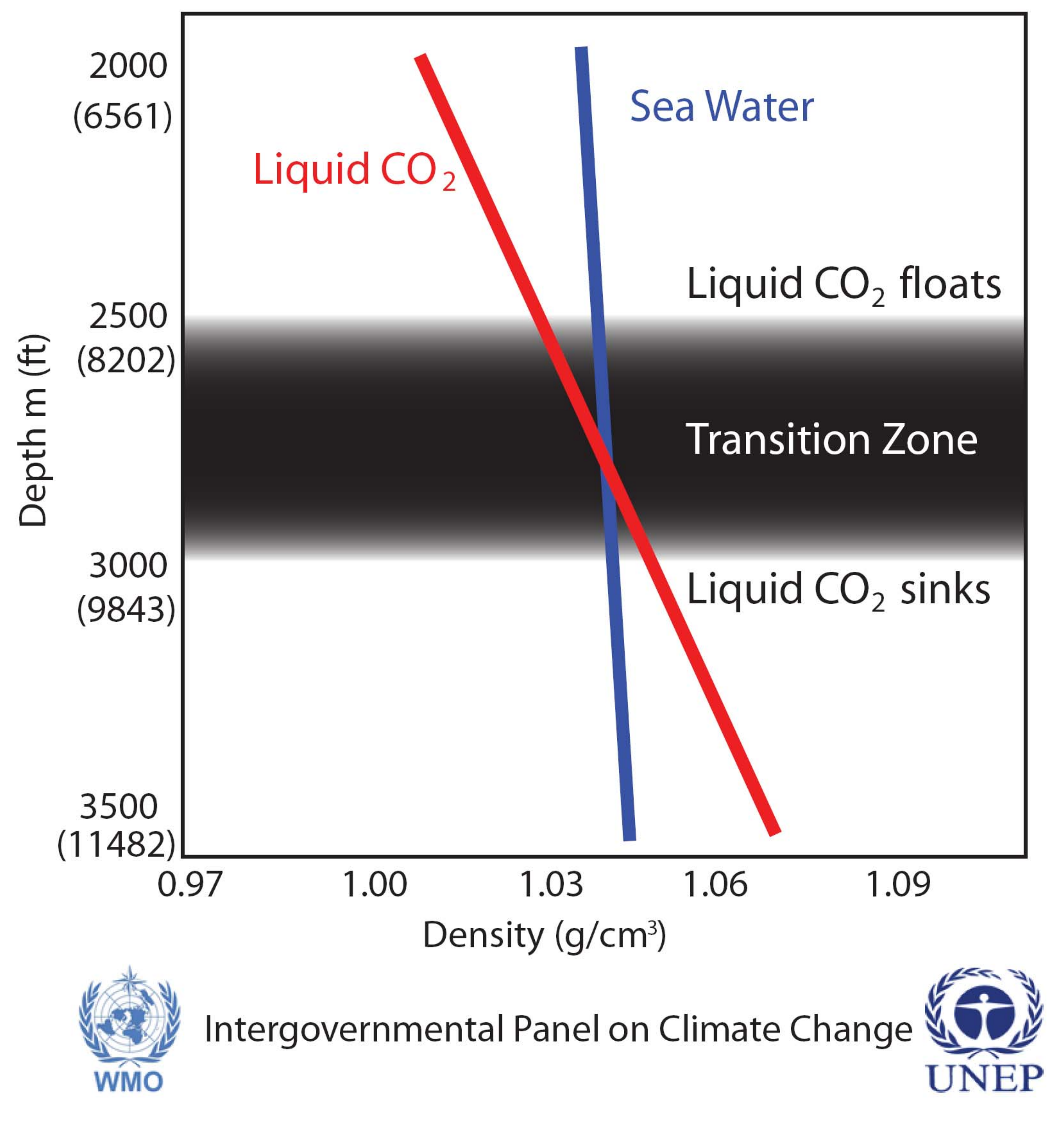
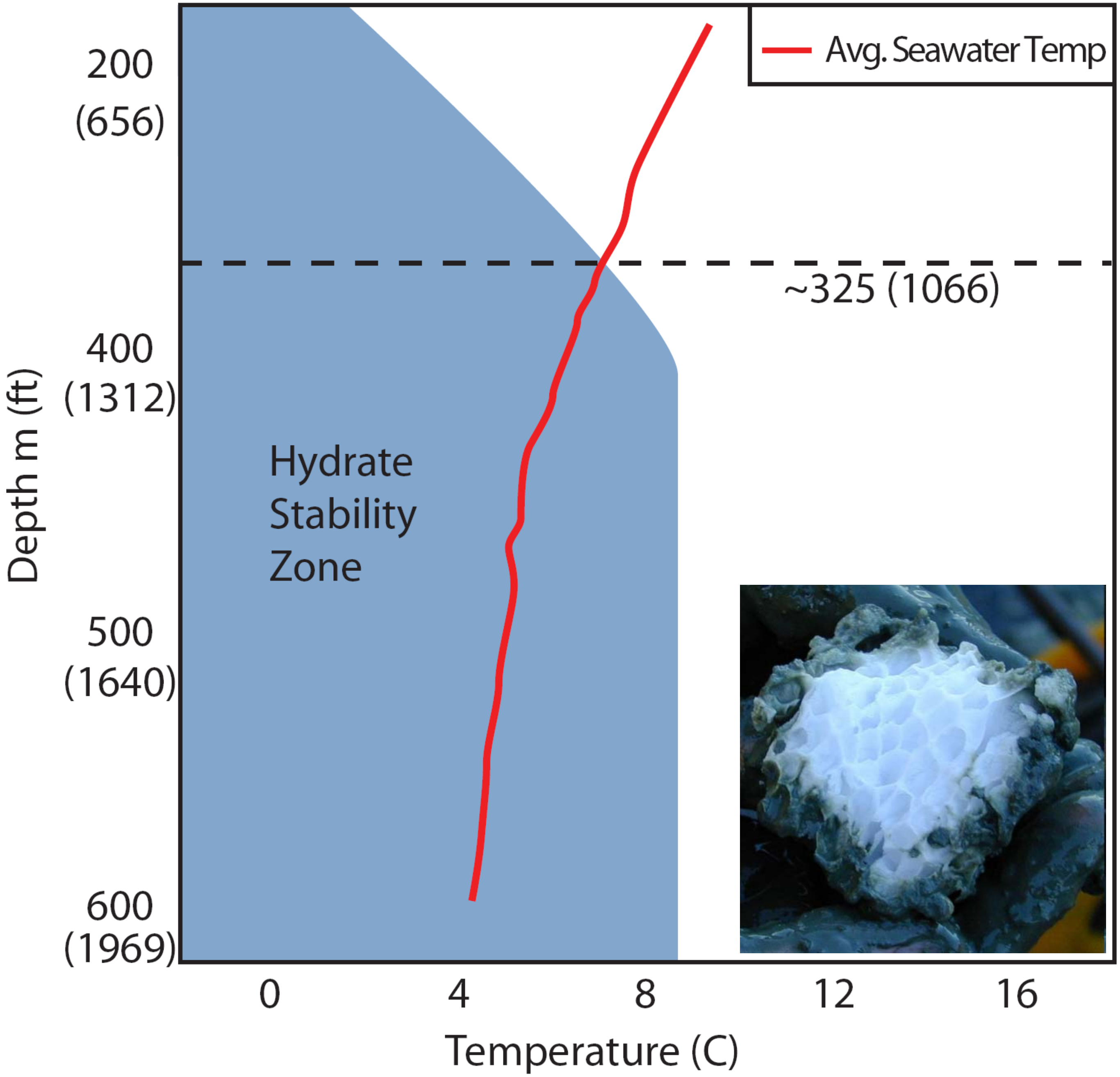
Density Inversion



The increase in density with depth is greater with CO_2 than with sea water, so that between 8,000 and 10,000 feet liquid CO2 becomes more dense than seawater and will sink rather than float.

This may prove to be a factor in both trapping mechanisms and additional safety in the event of a leak.



Intergovernmental Panel on Climate Change

WMO

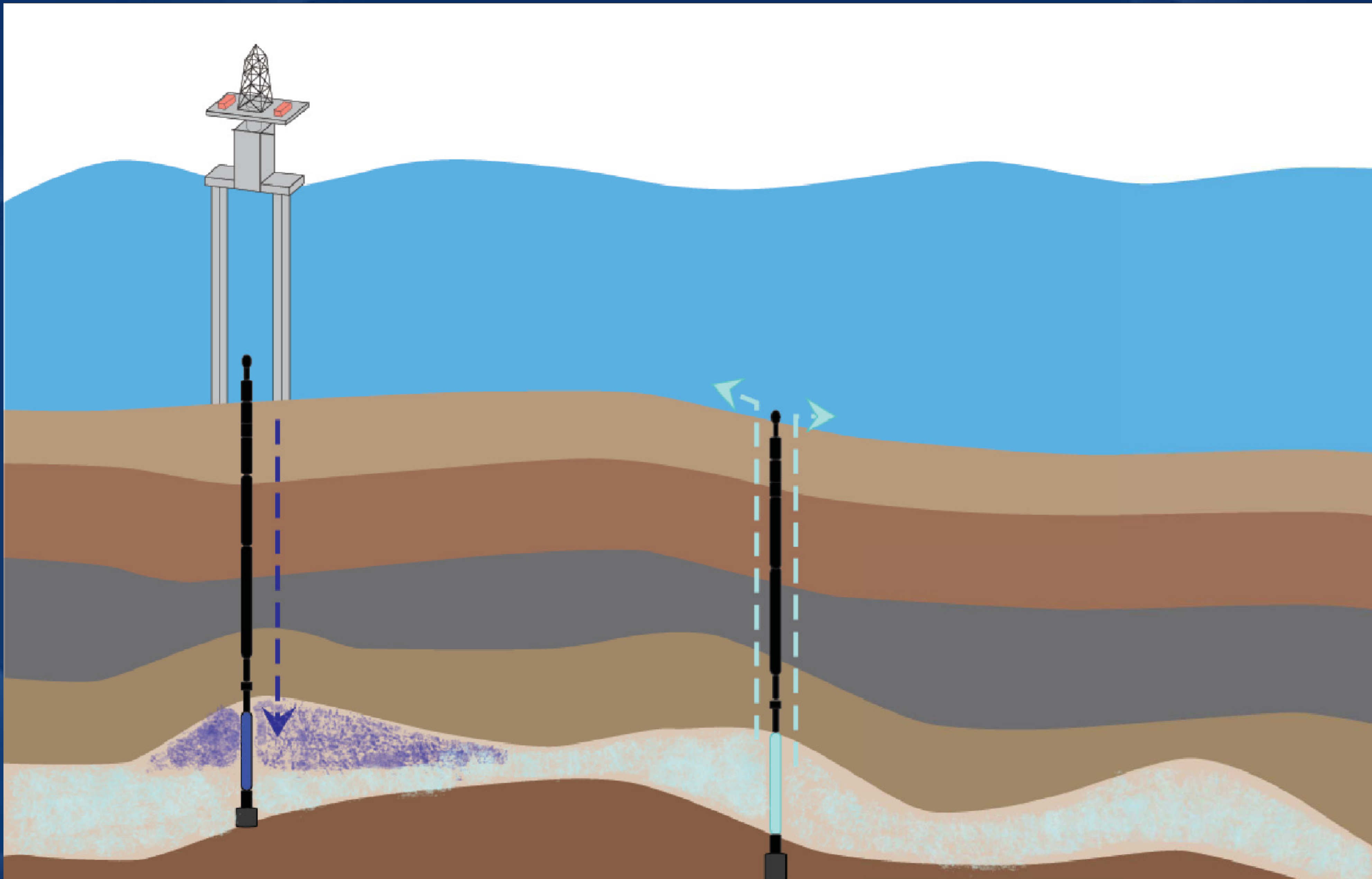
UNEP

CO_2 Hydrate Formation

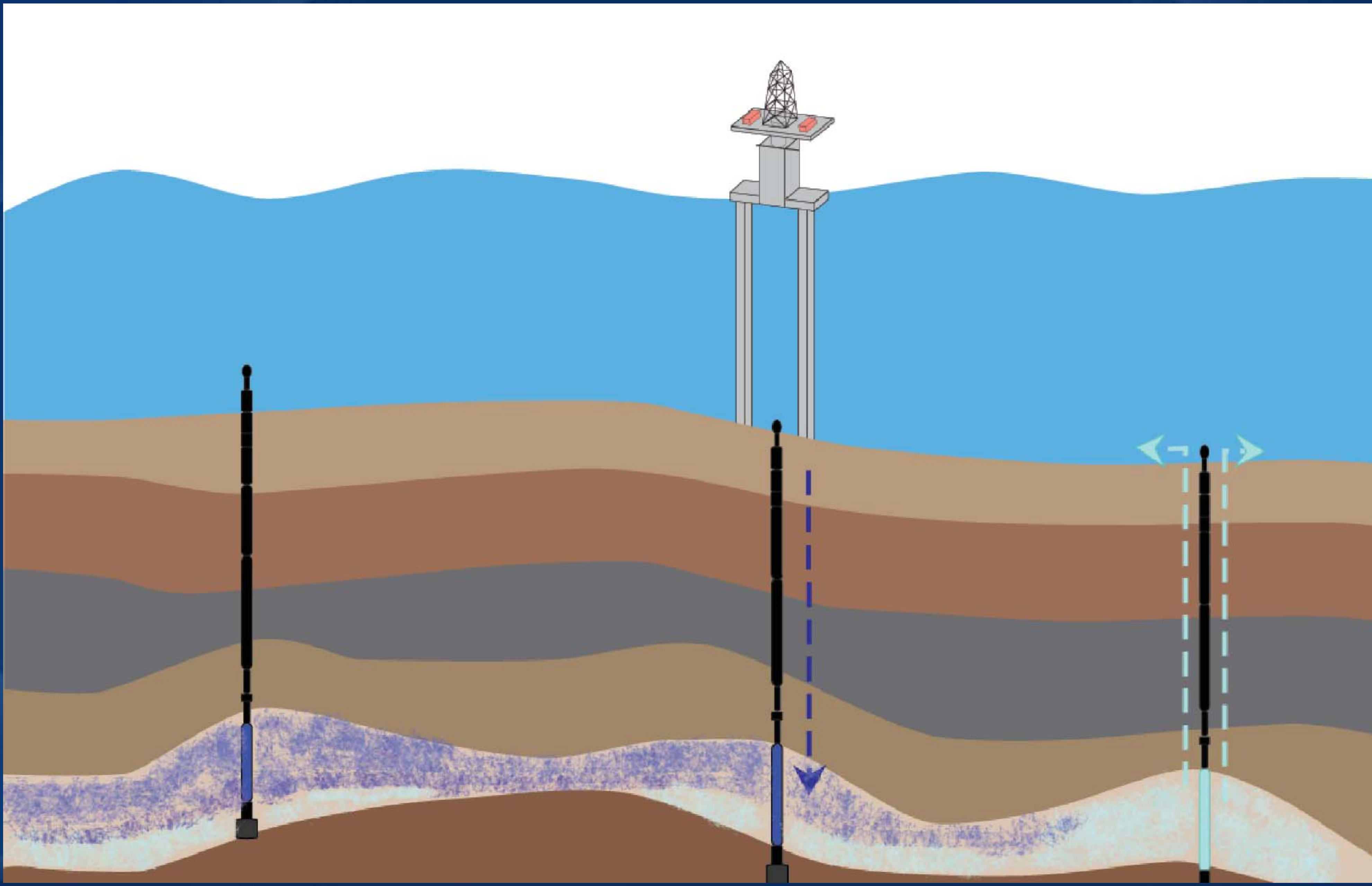
In high pressure, low temperature conditions CO_2 will form a clathrate (aka hydrate) which is a crystalline water-based solid in which CO_2 molecules are trapped in a "cage" of hydrogen bonded water molecules.

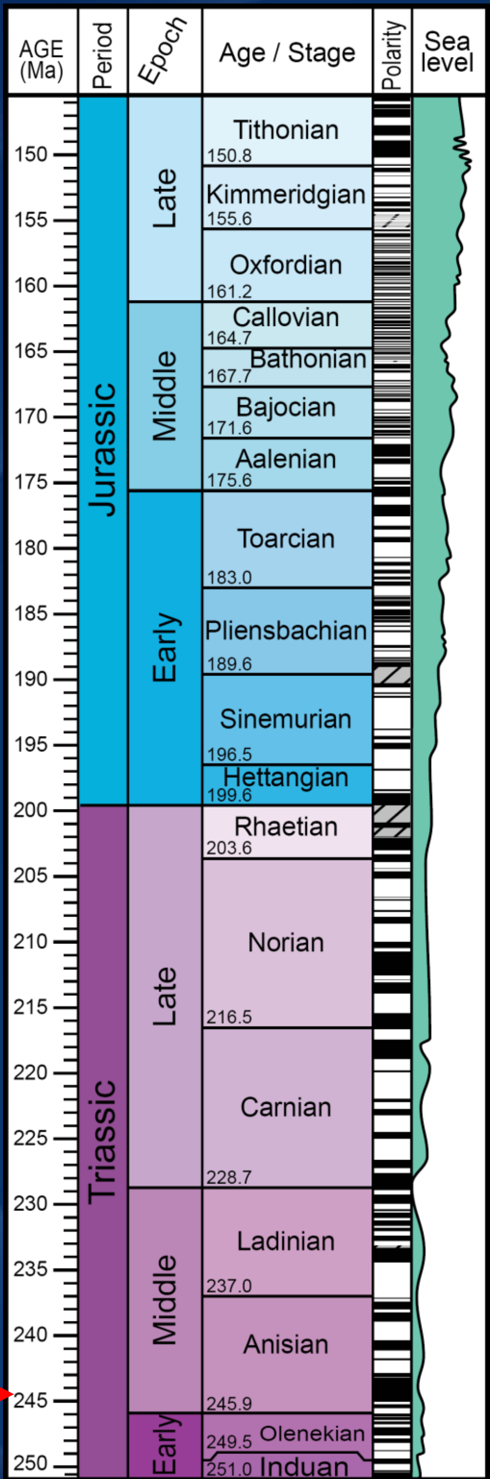
Formation of CO_2 hydrate in its stability zone may form a solid cap that can serve as a secondary seal for sequestered CO_2 below.

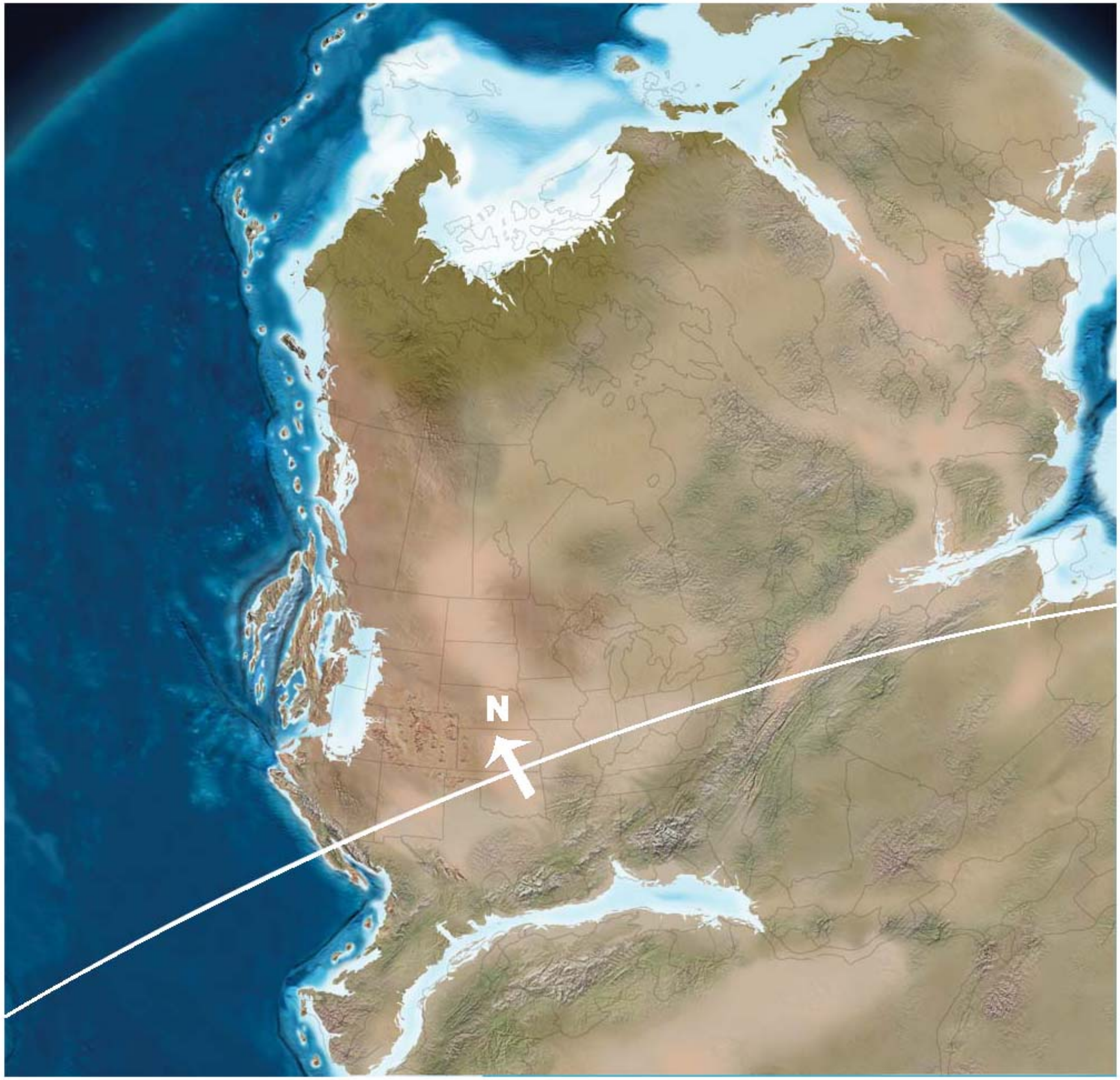
Pressure Management



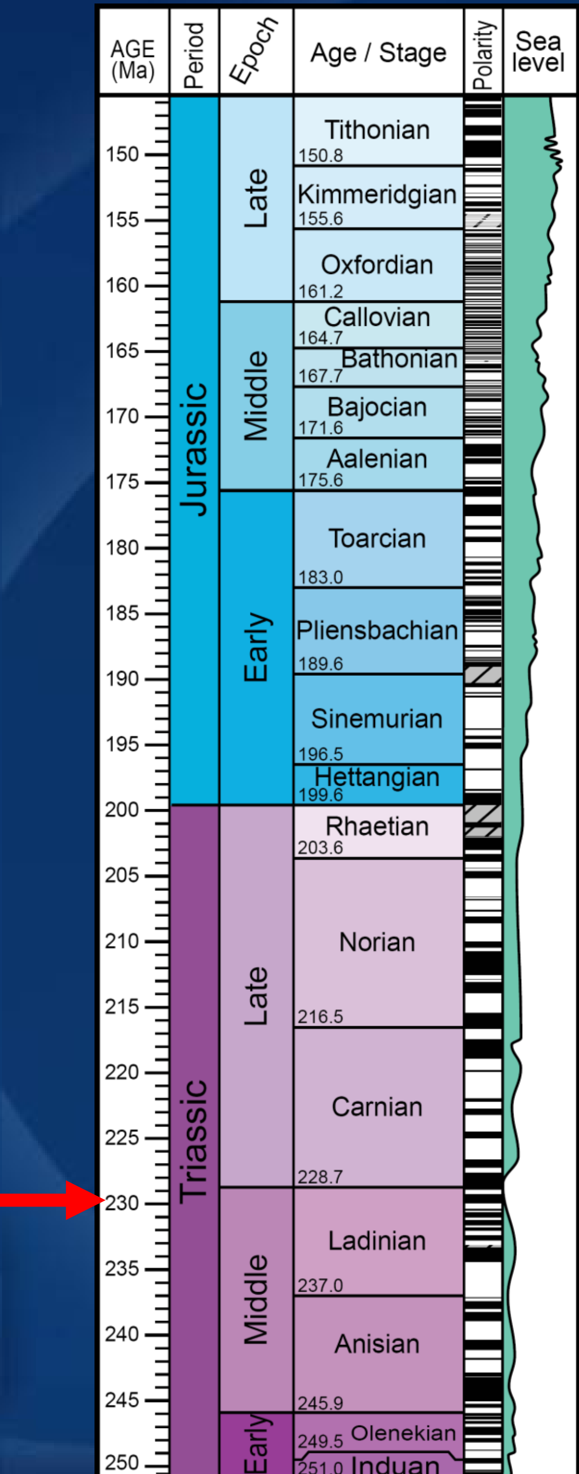
Pressure Management

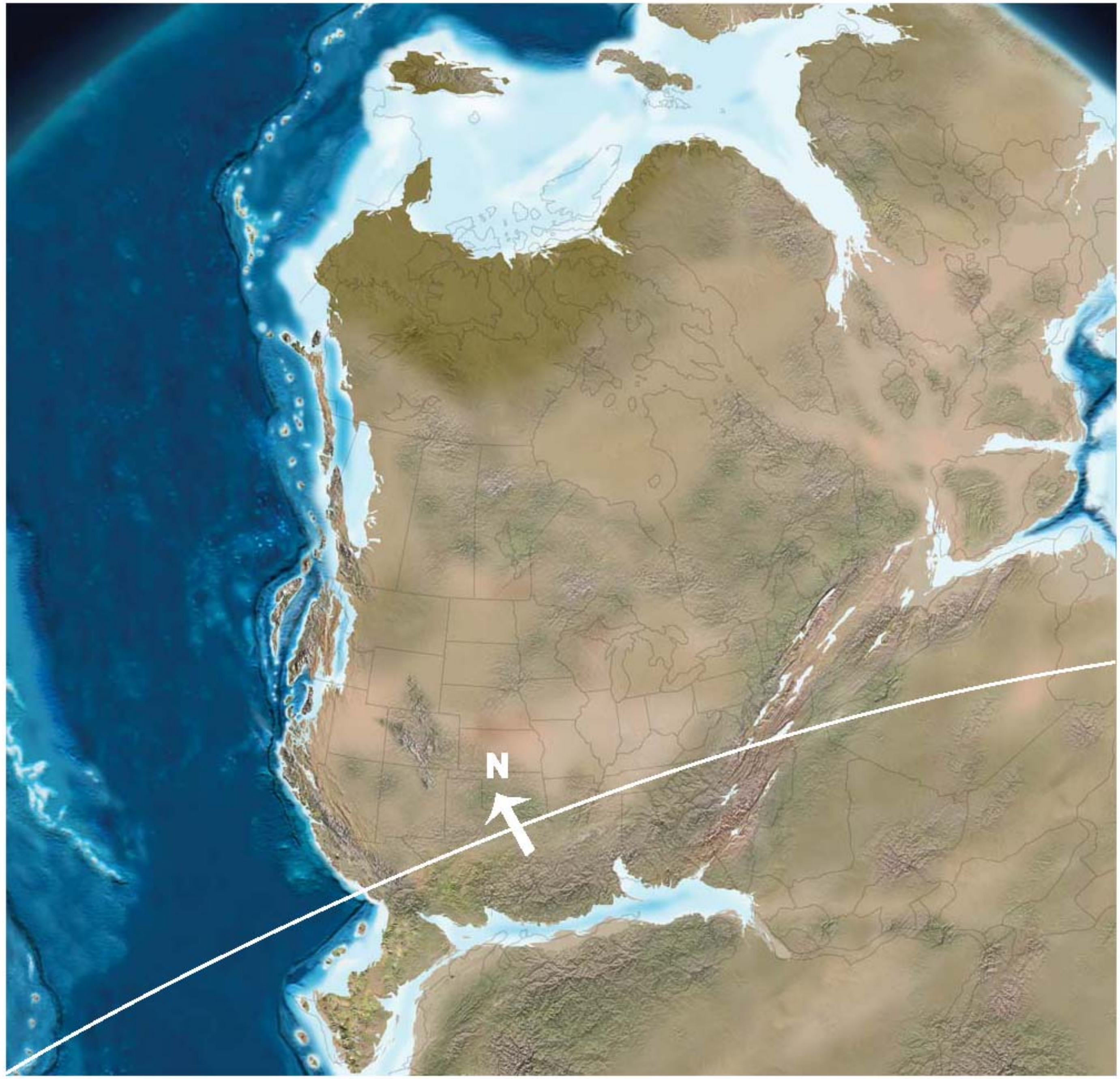






(From Ron Blakey website)





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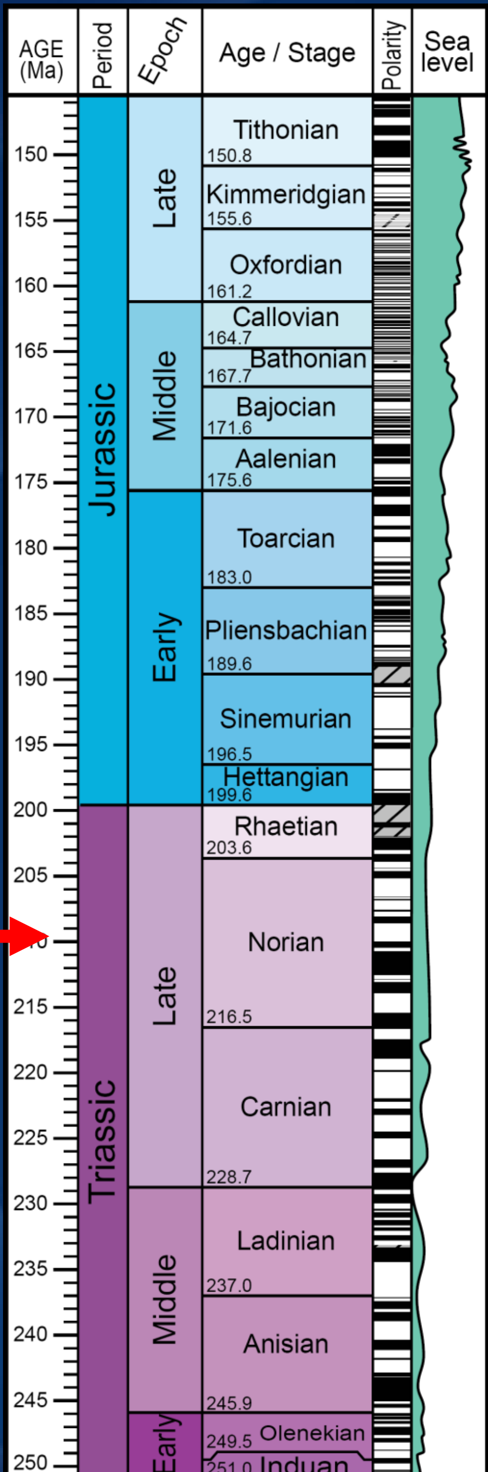

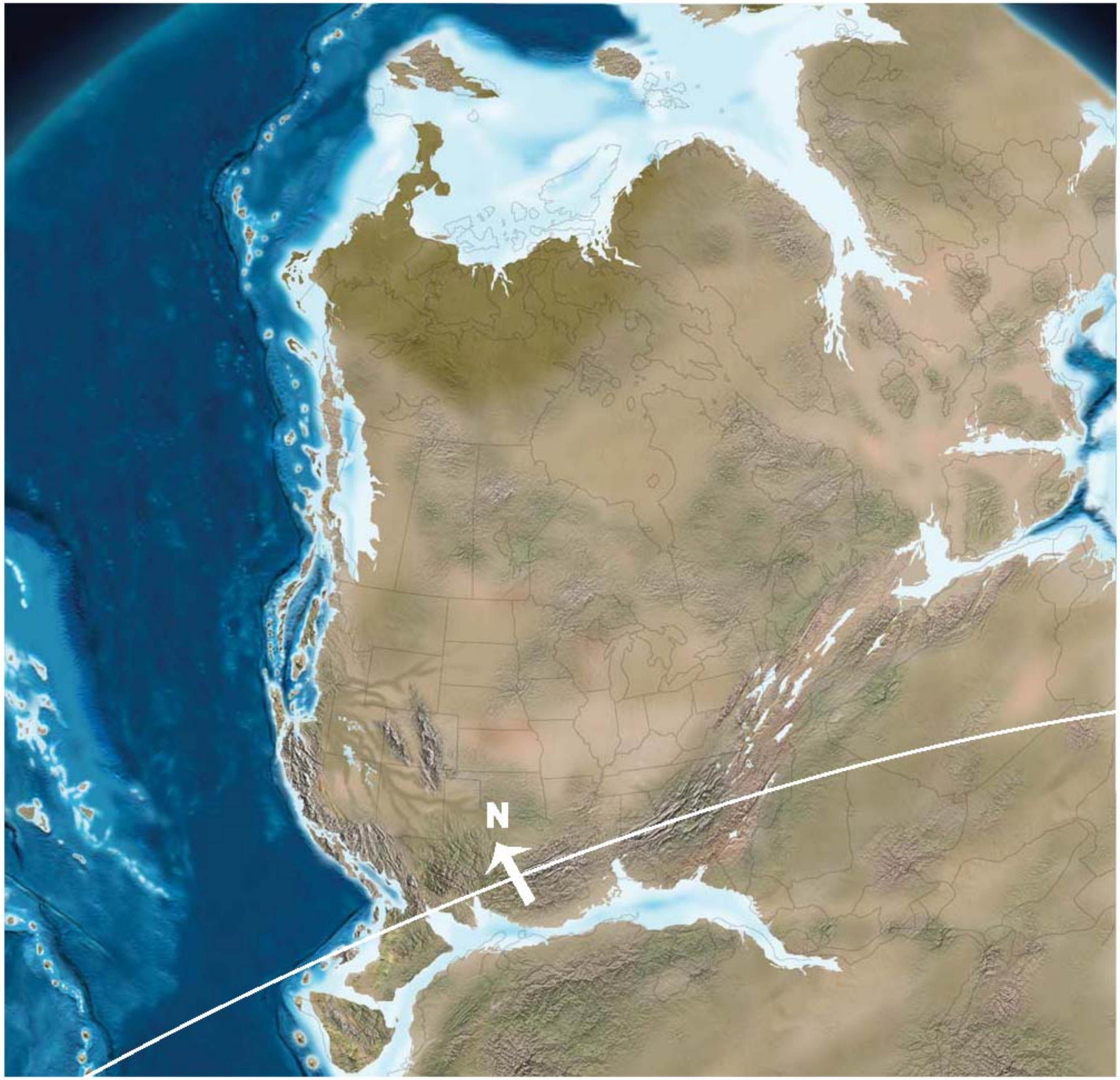

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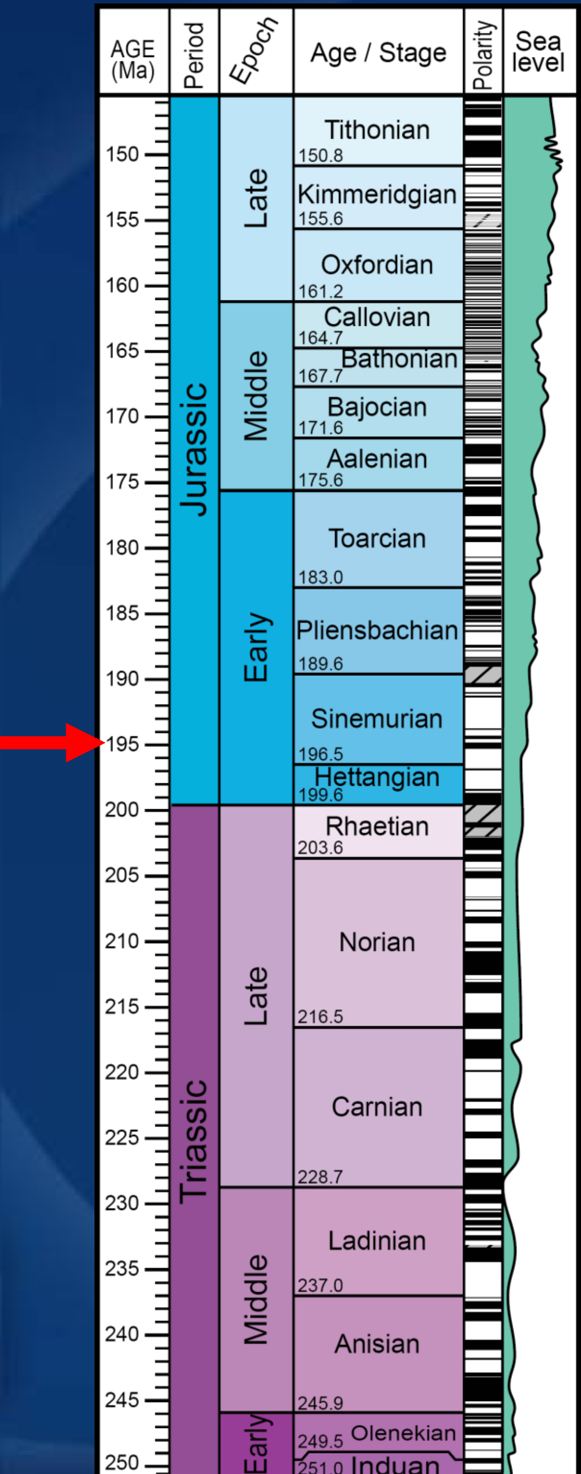

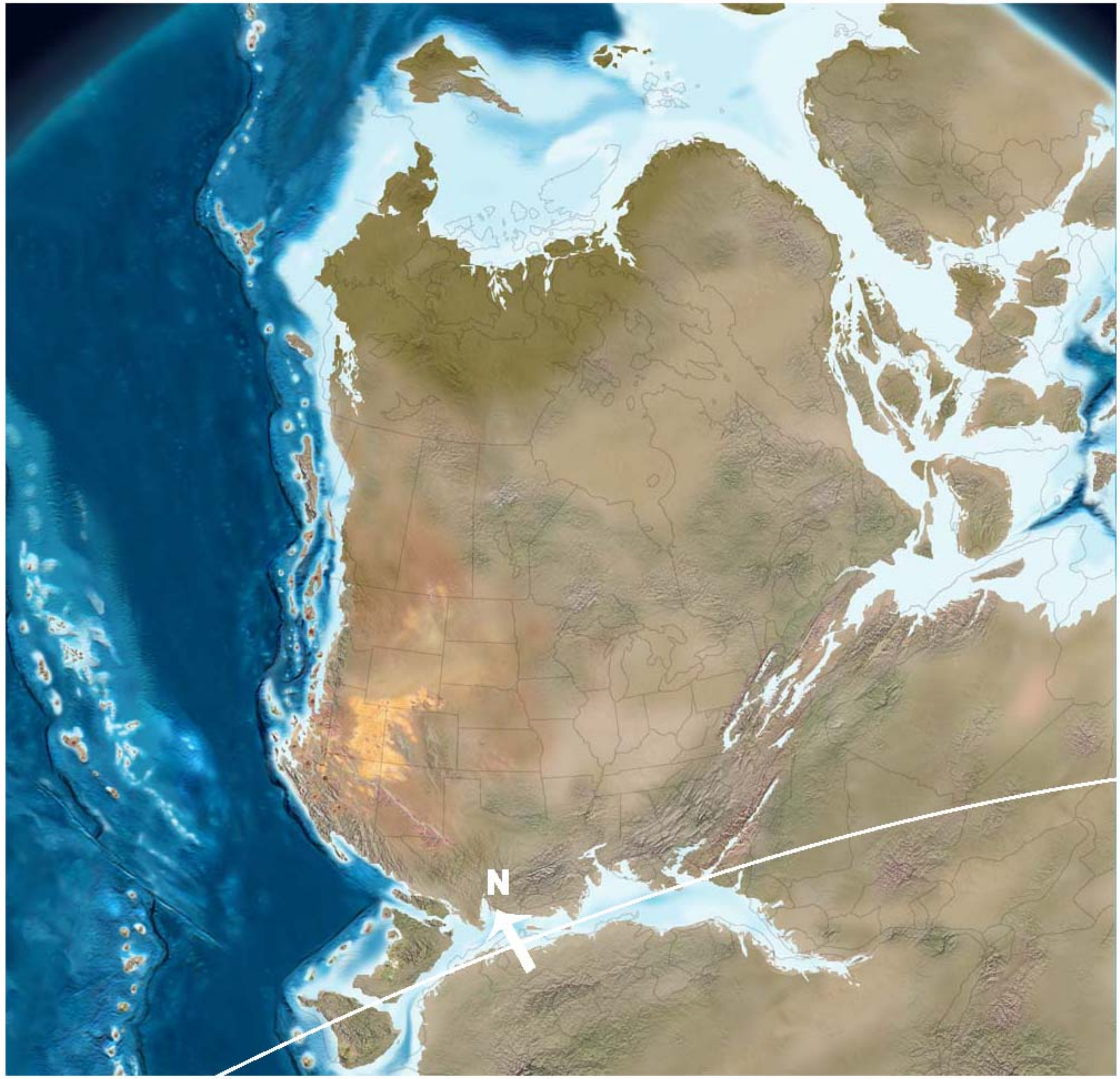

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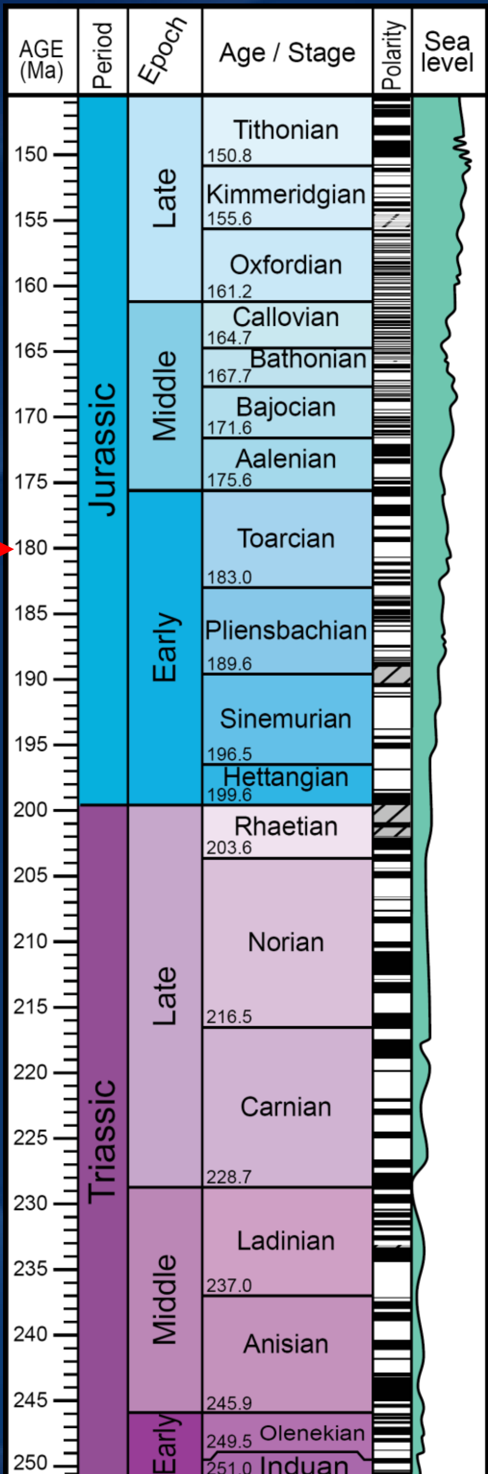

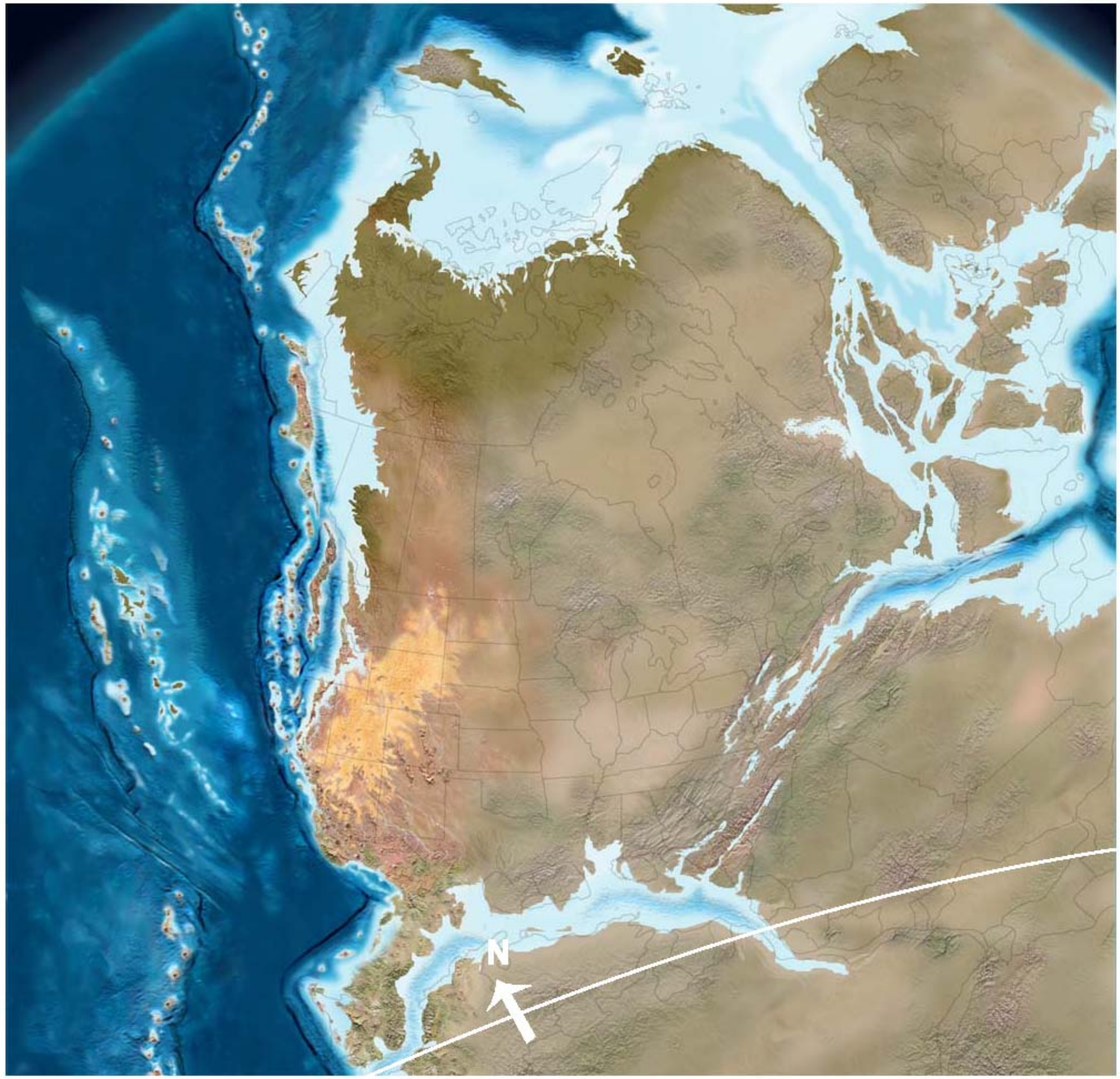

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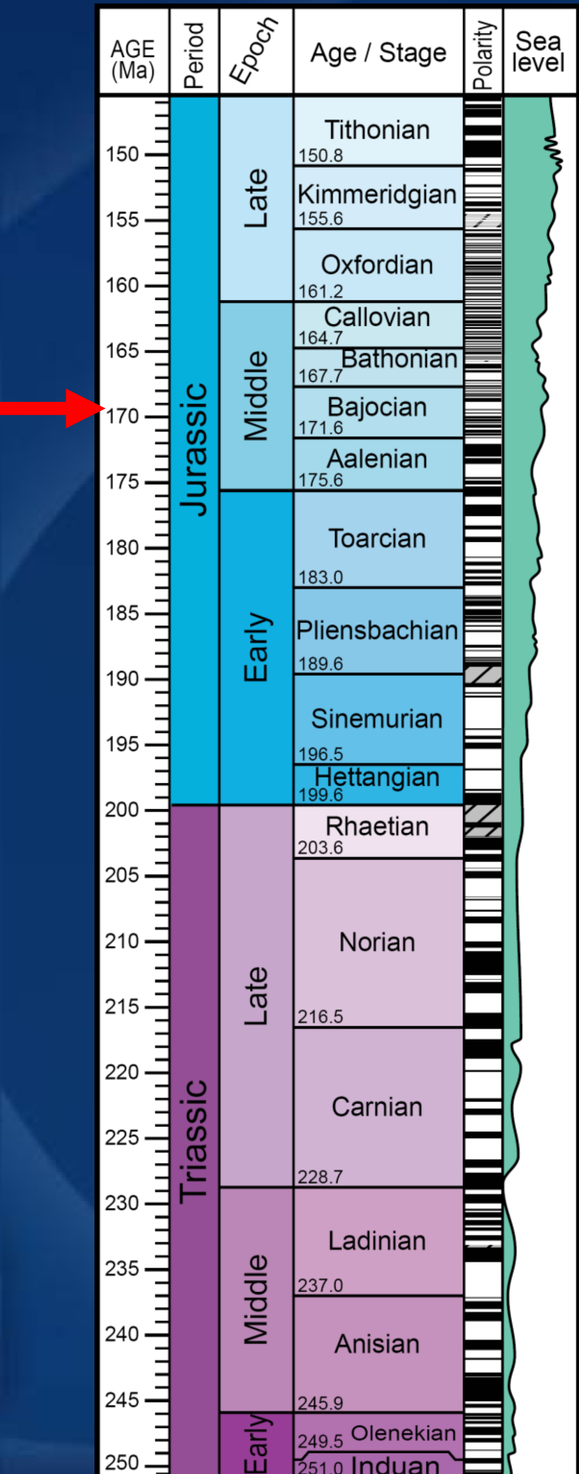

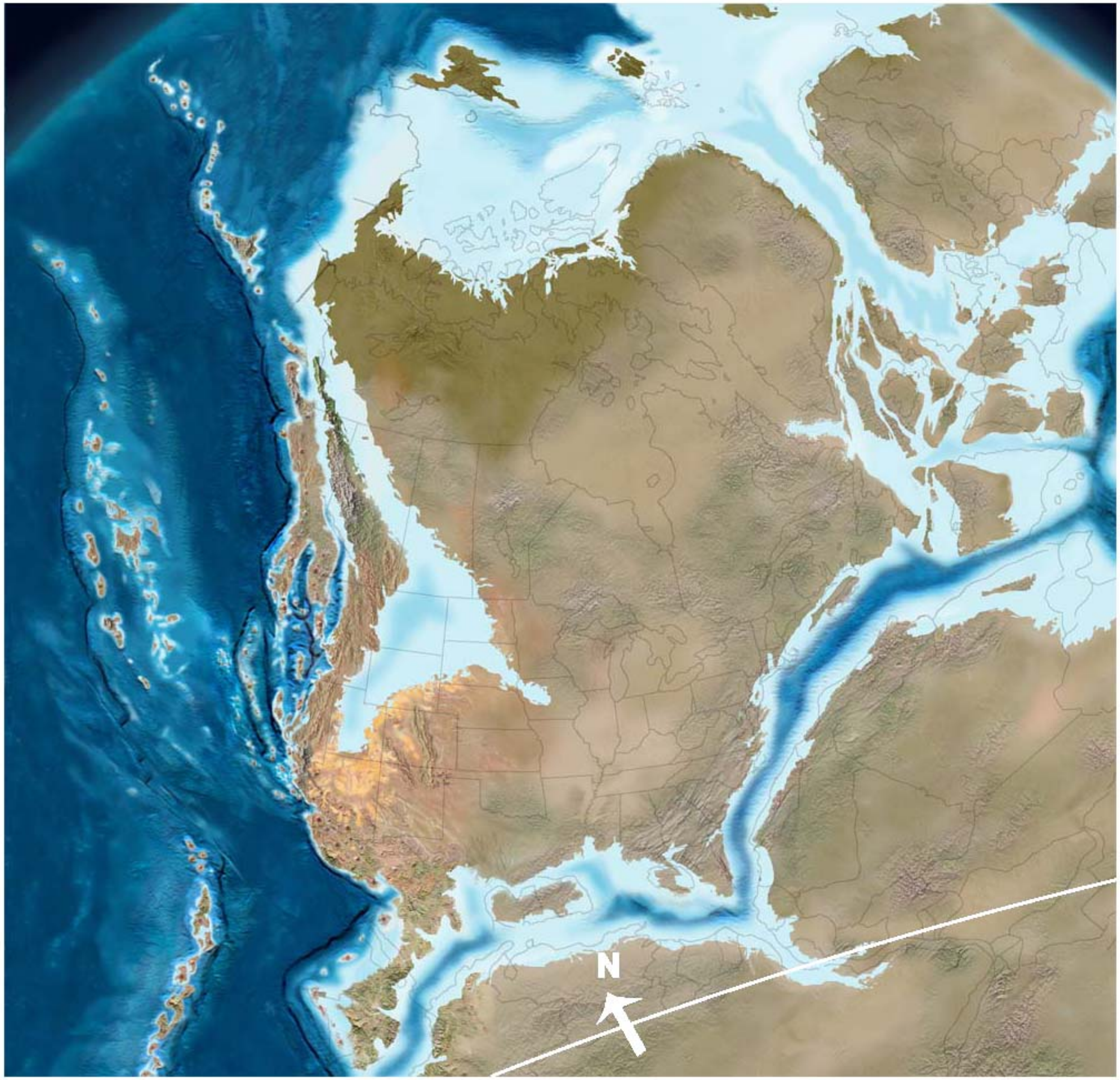

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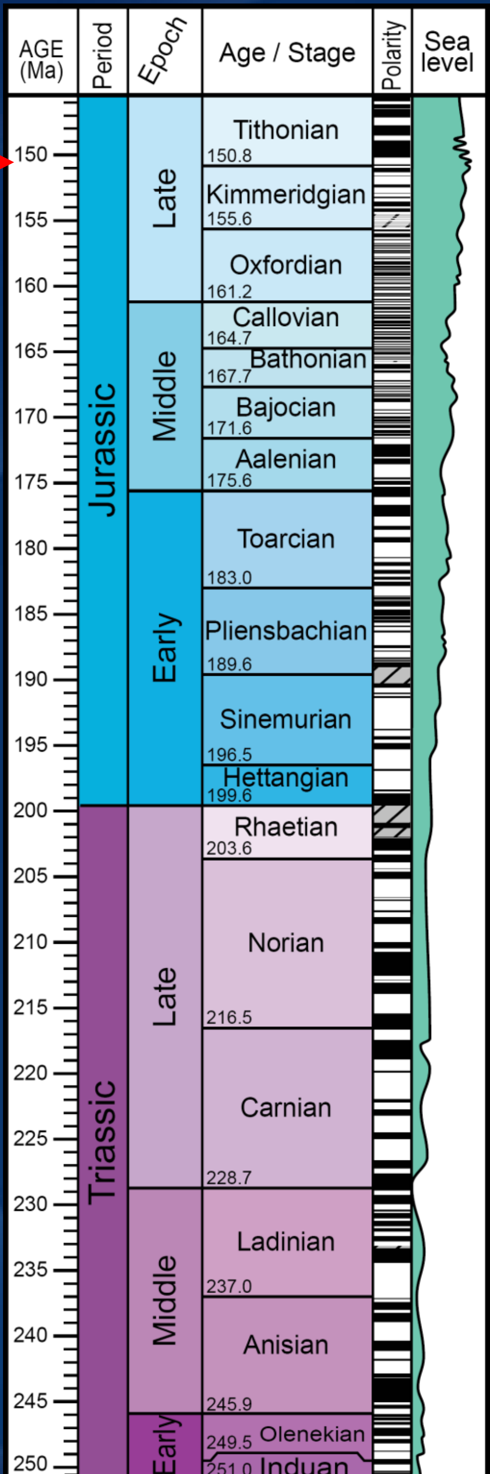

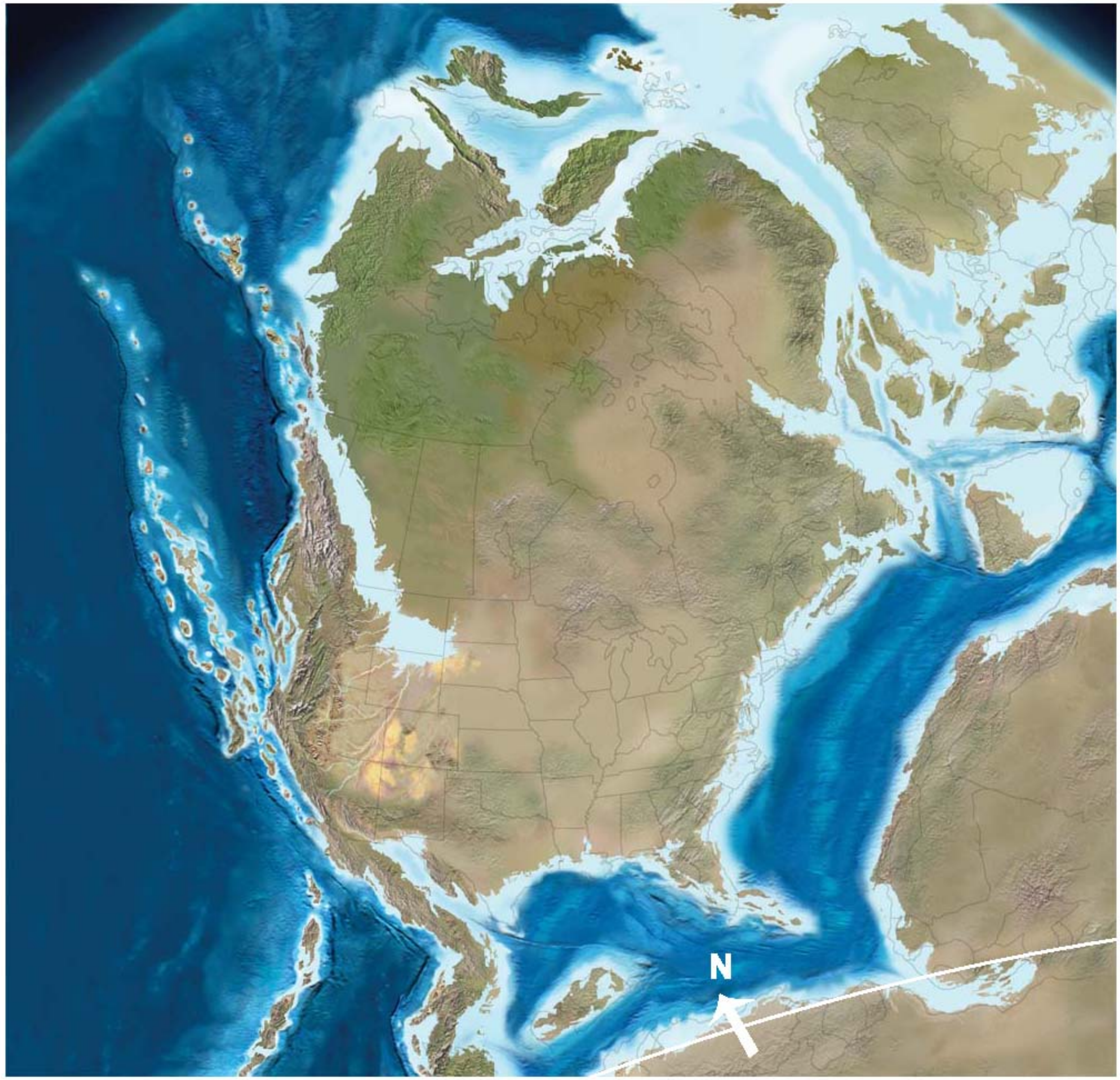

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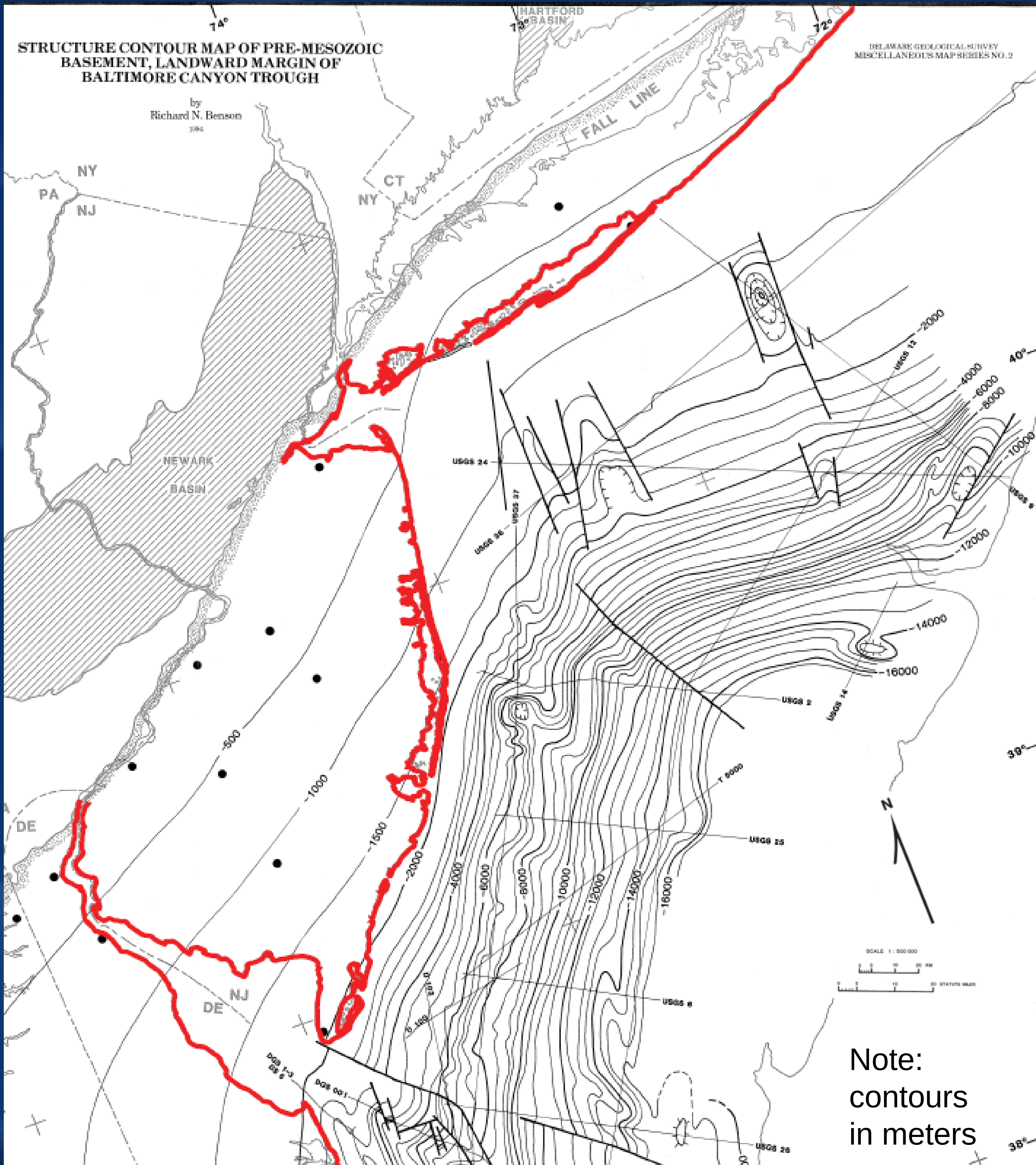
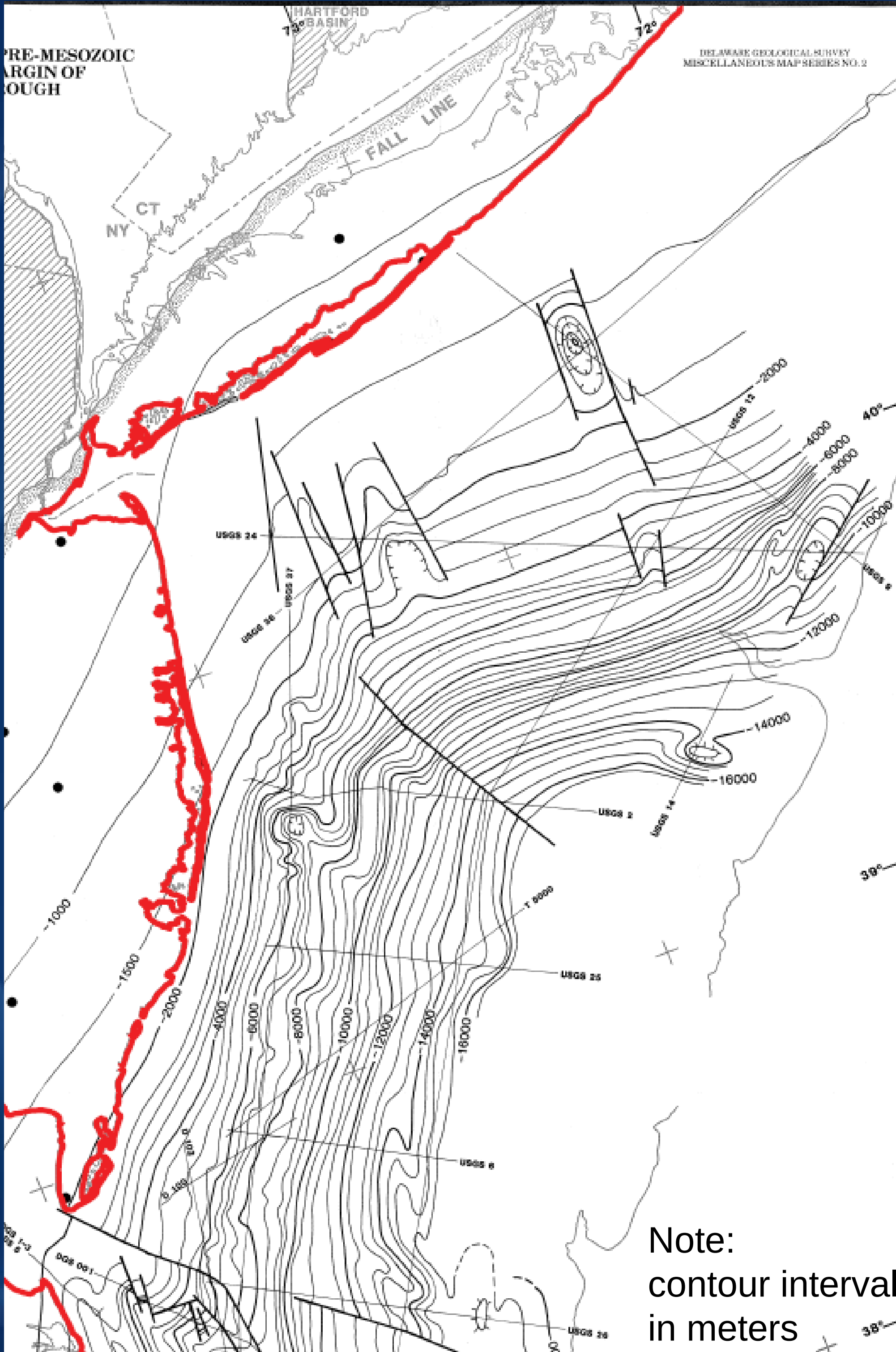
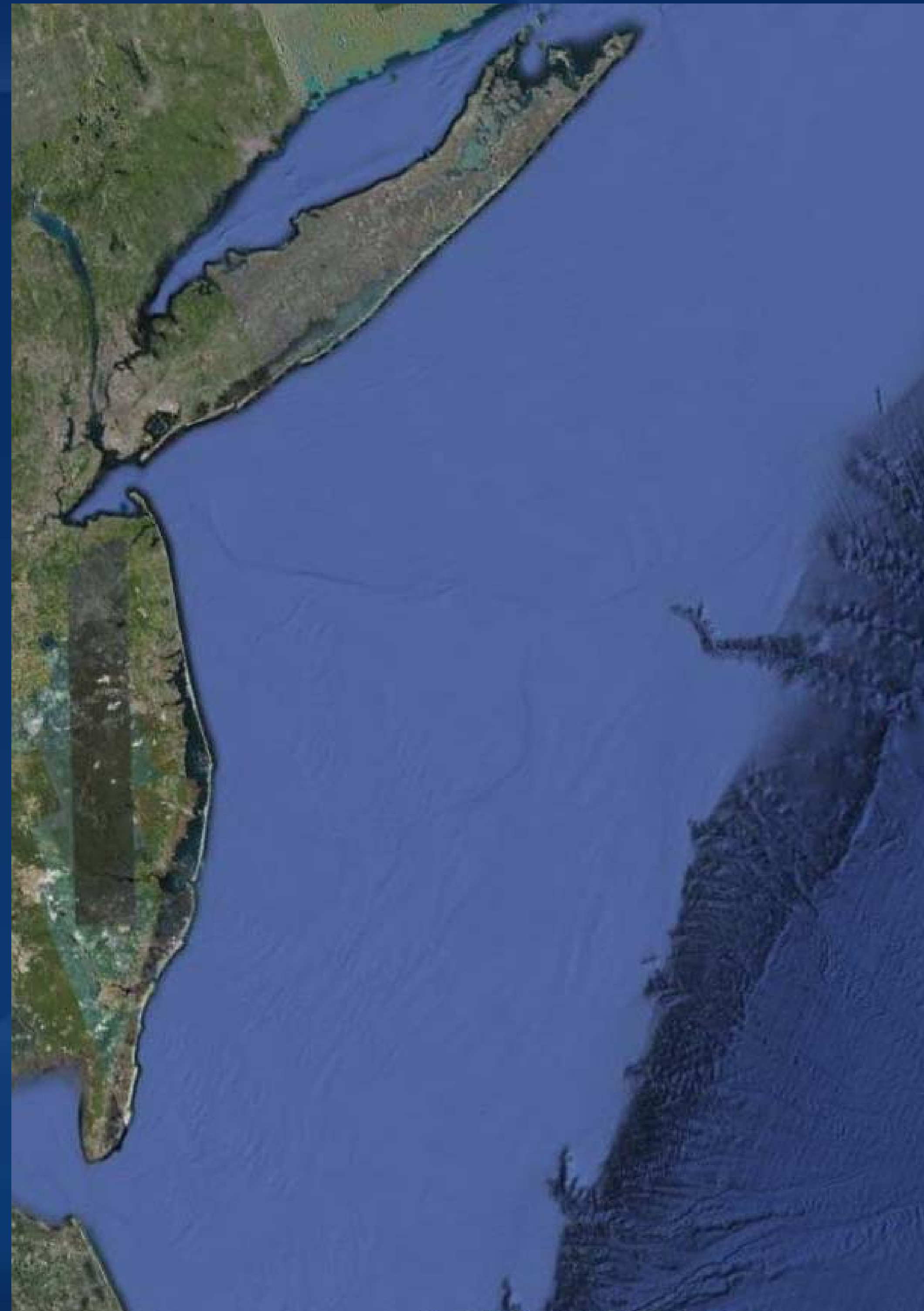


Depth to Basement

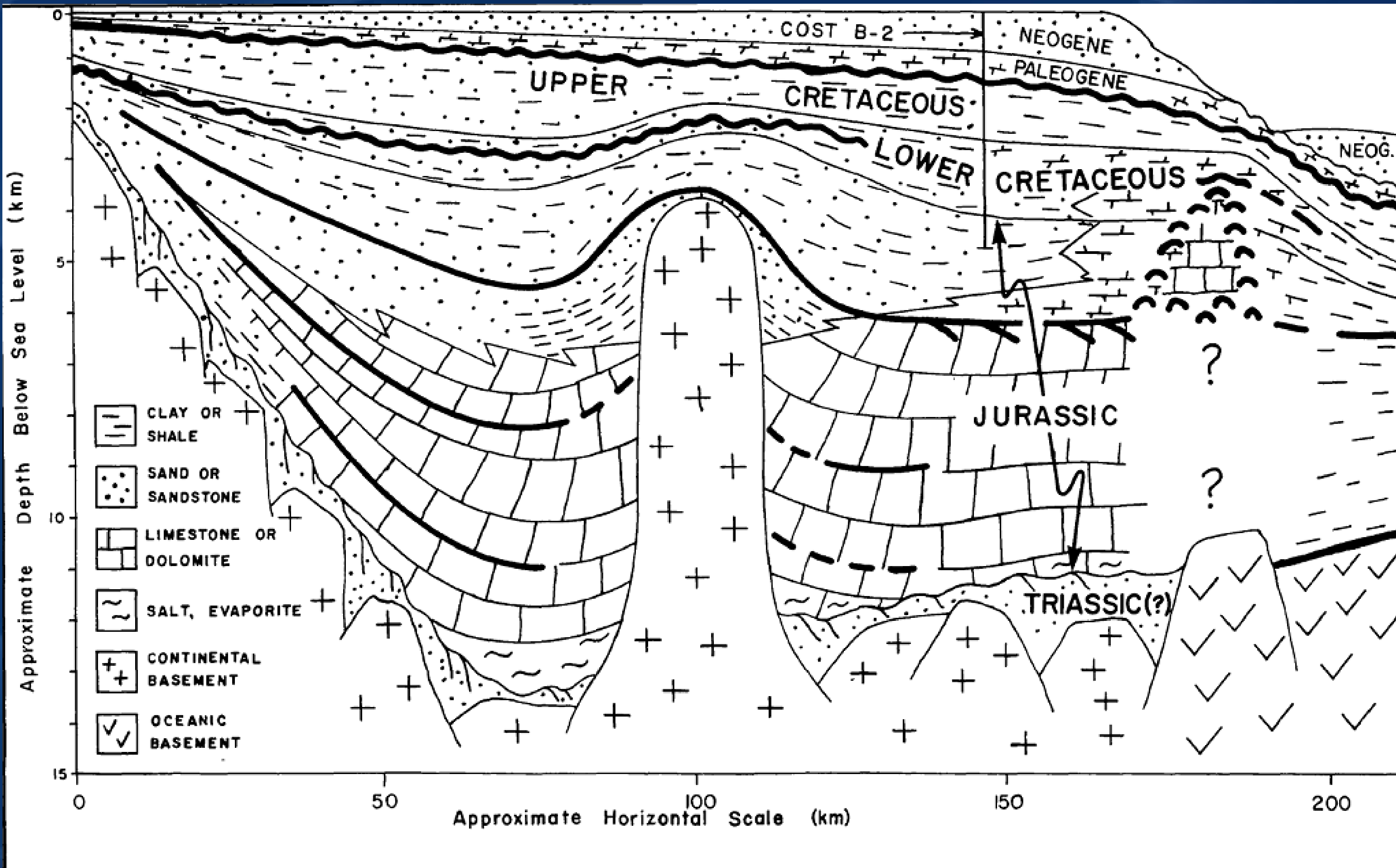
The metamorphic basement dips steeply from 6,500 feet on the coast of New Jersey to 46,000 feet just 75 miles east. This contour represents the “bottom of the bowl” in which our potential sequestration reservoir lie.



Note:
contour interval
in meters

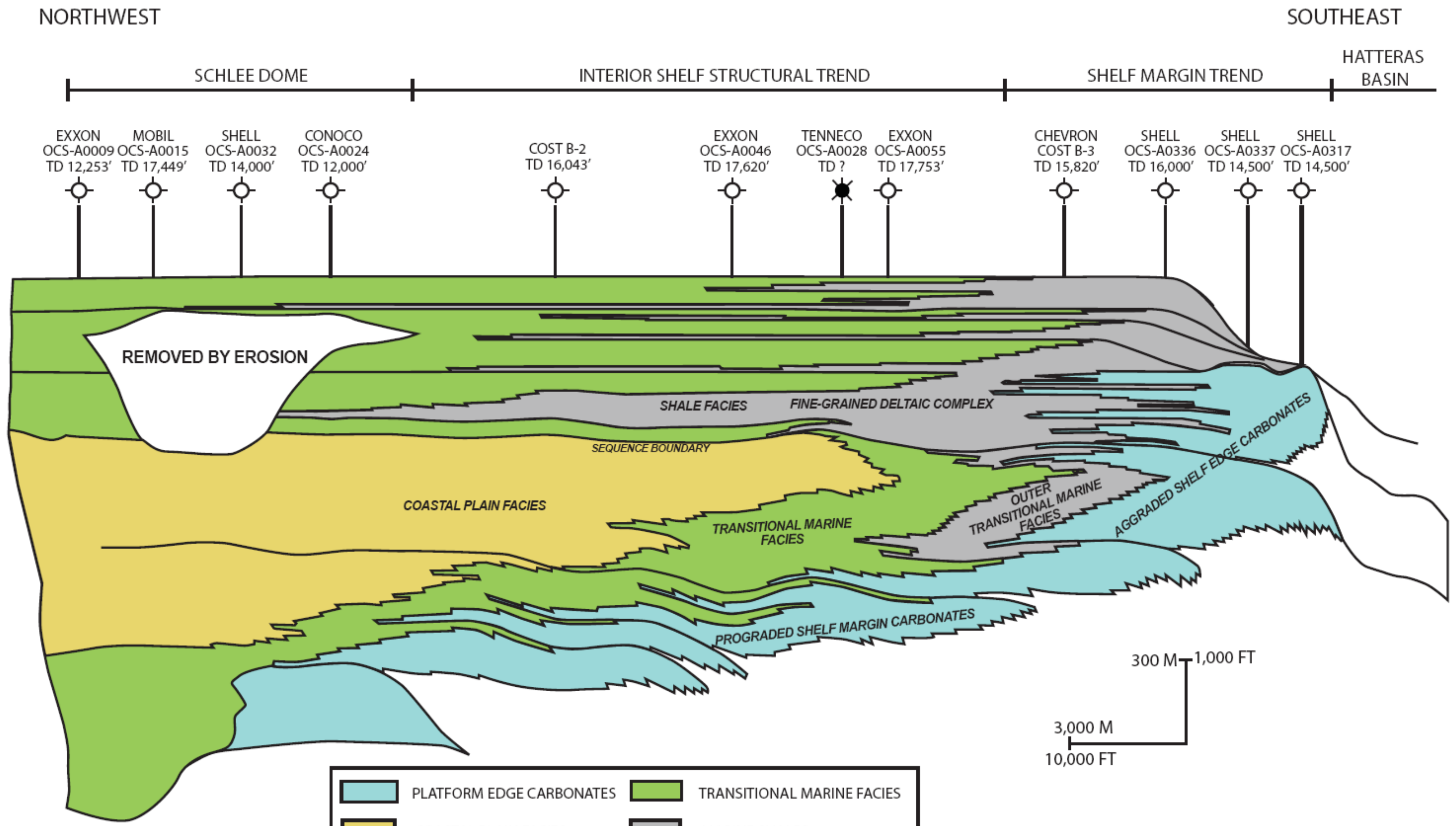


Baltimore Canyon Trough Cross Section



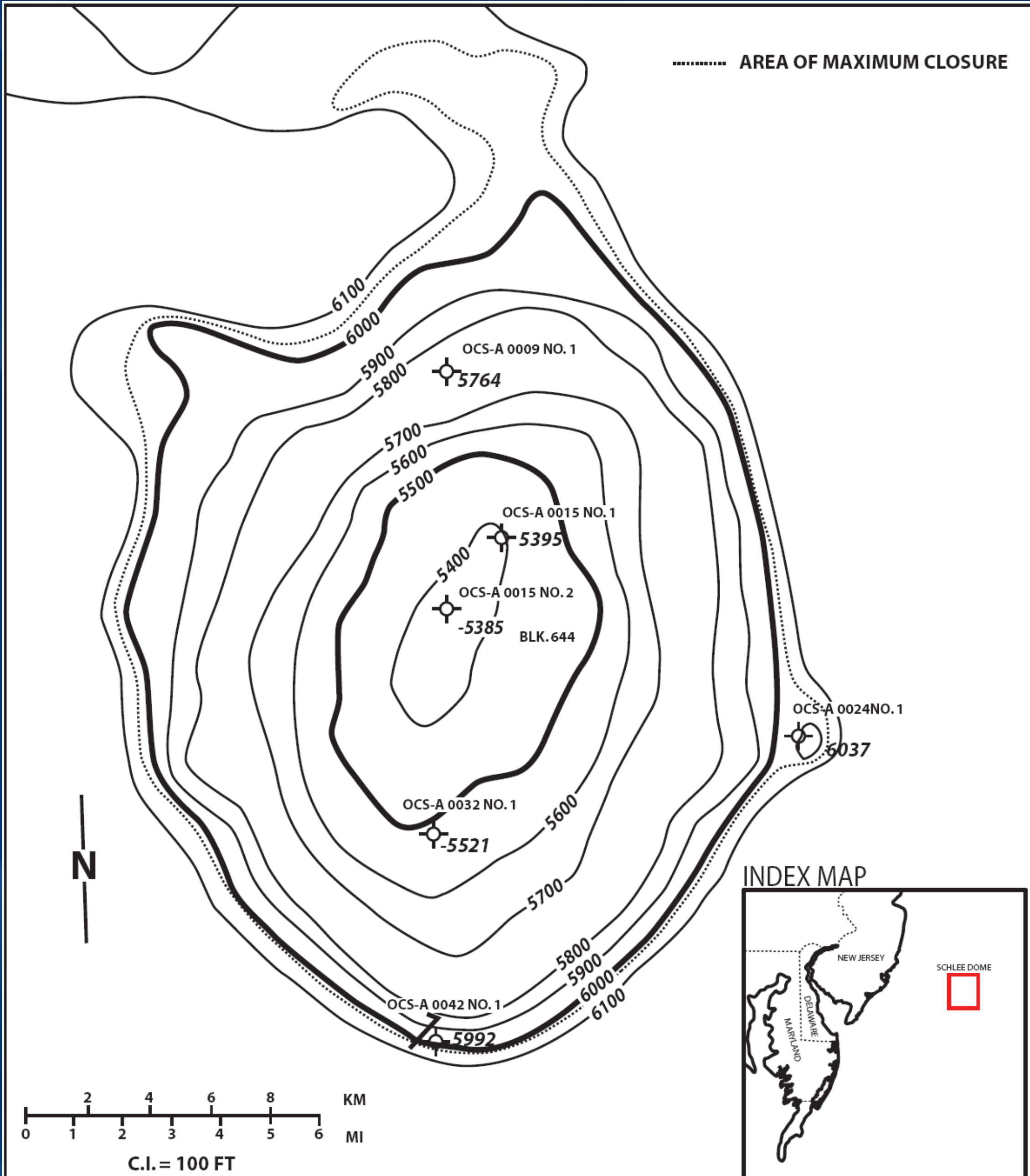
(From Poag, 1978)

Regional Composite Stratigraphic Cross Section



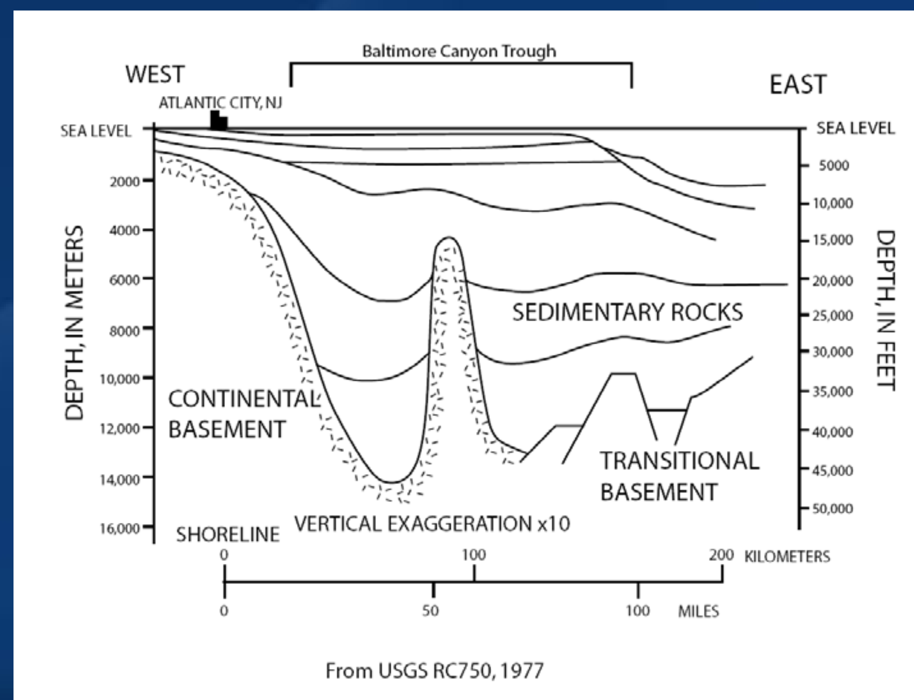
(Digitized from Prather ,1991)

Schlee Dome

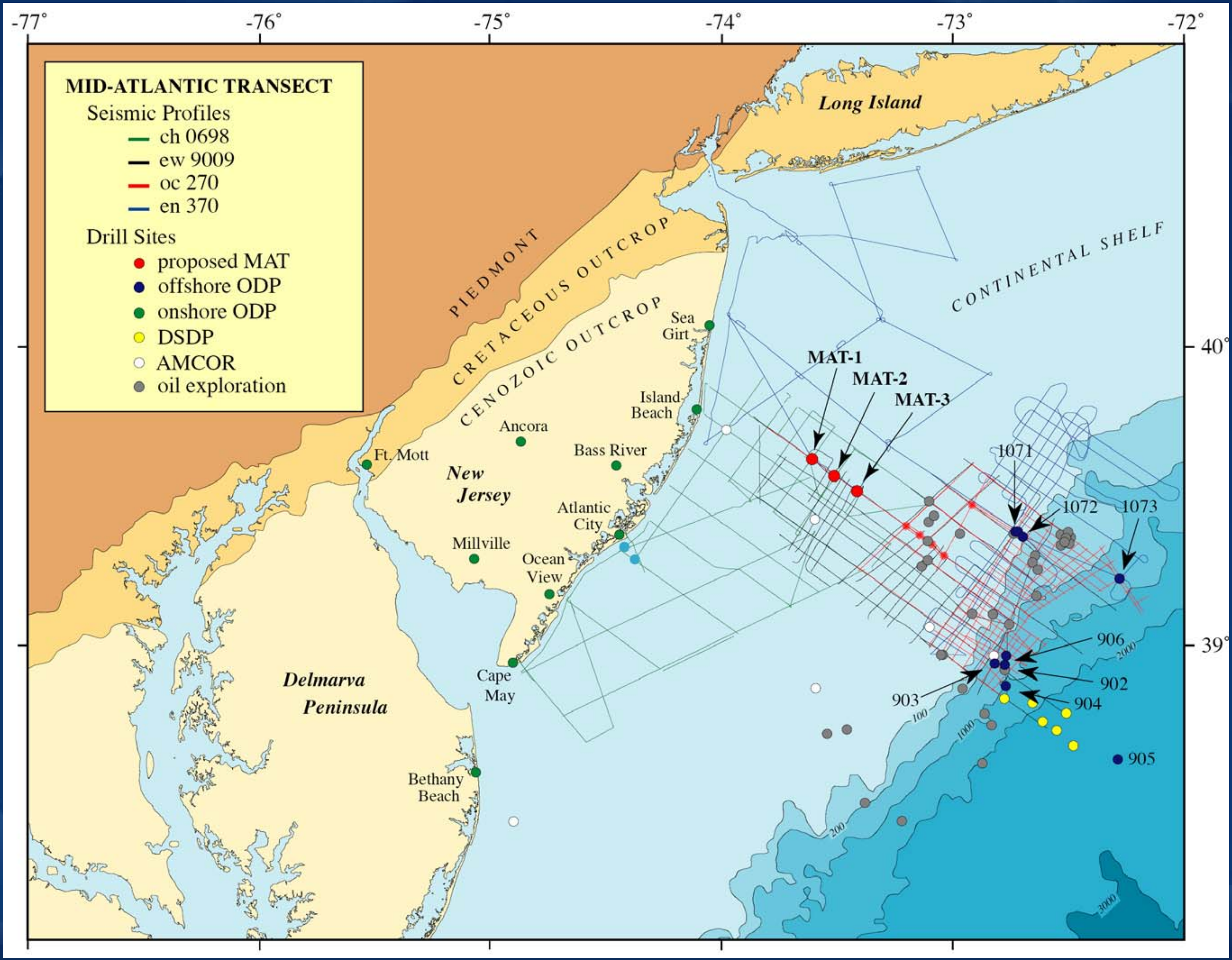


From Prather, 1991

"The most significant structural closure in this area is the large domal anticline known as Schlee Dome. Uplift of the dome is interpreted to be associated with emplacement of an igneous intrusive dike swarm during the Late Jurassic. The resulting 2-km-high topographic feature produced on the coastal plain (Lippert, 1983; Jansa and Pe-Piper, 1988) was later eroded flat prior to the end of the Barremian, exposing Upper Jurassic rocks at the crest of the dome (Crutcher, 1983; Lippert, 1983; Amato and Giordano, 1985)." – Prather, 1991



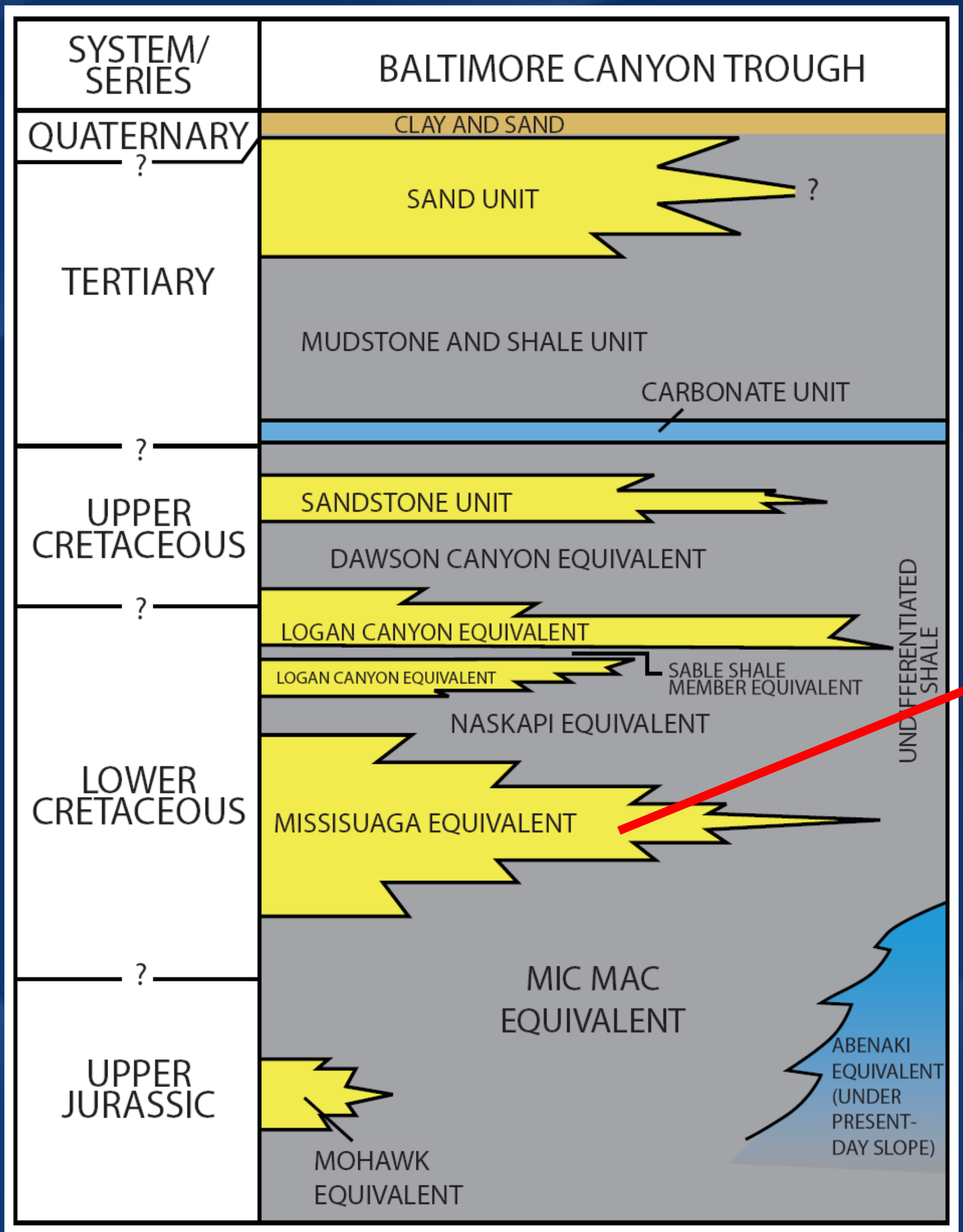
Available Data



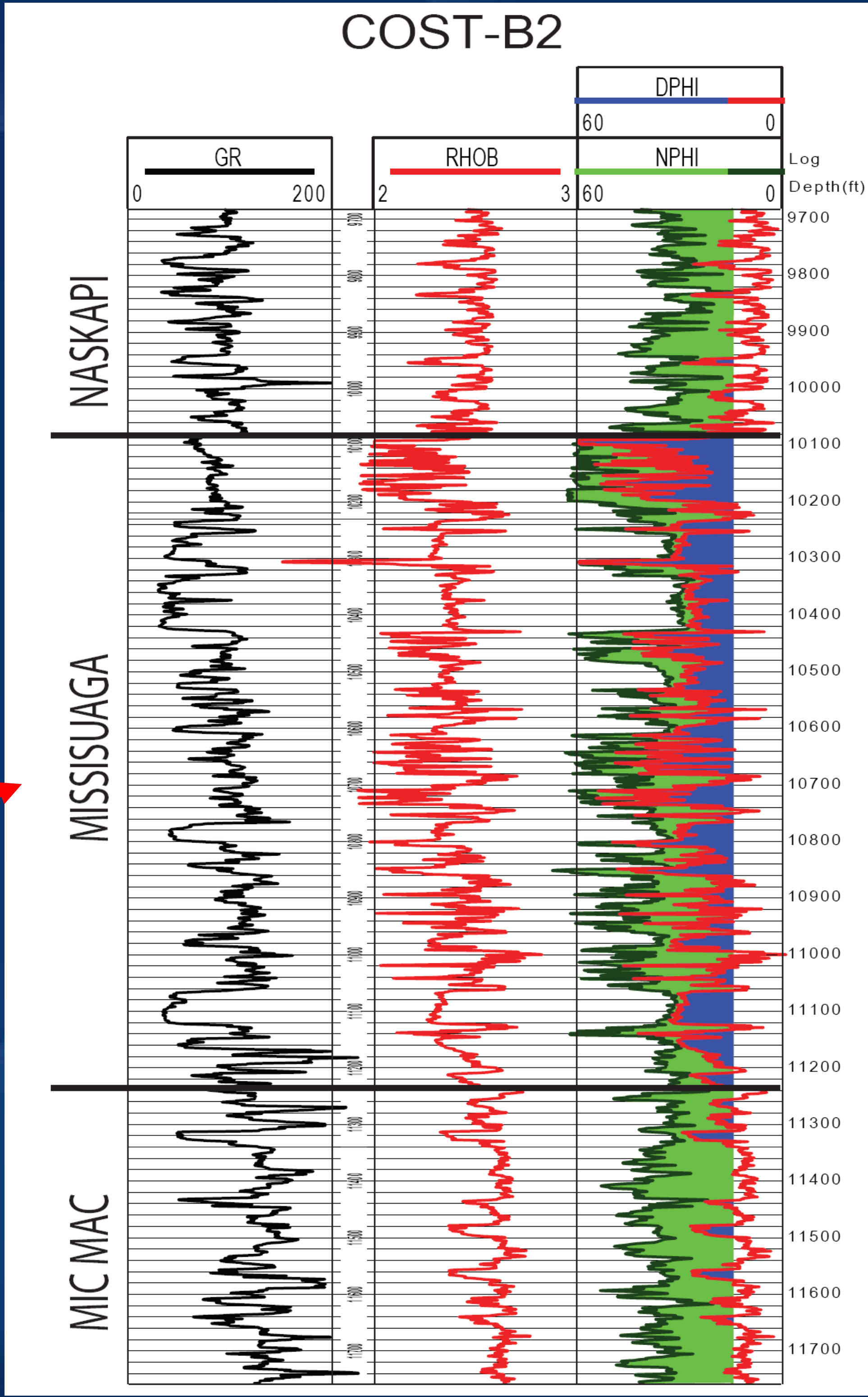
Well Data

API Number	Lease No.	OPD Name	Block No.	Operator	Lat (dec deg)	Long (dec deg)	Water Depth (ft)	KB (ft)	TD (ft)	Completion Date
61-105-00016	OCS-A0009	Hudson Canyon	500	Exxon	39.49722	-73.10556	204	79	12253	9/28/1979
61-105-00003	OCS-A0015	Hudson Canyon	544	Mobil	39.55556	-73.11111	220	84	17449	12/29/1978
61-105-00023	OCS-A0015	Hudson Canyon	544	Mobil	39.45556	-73.19444	220	47	8312	10/1/1981
61-105-00007	OCS-A0024	Hudson Canyon	590	Conoco	39.46111	-72.97222	242	73	12000	6/7/1978
61-105-00001	----	Hudson Canyon	594	Ocean Prod	39.45556	-72.74444	298	90	16043	2/28/1976
61-105-00004	OCS-A0028	Hudson Canyon	598	Texaco	39.41944	-72.55278	432	82	15025	8/26/1978
61-105-00011	OCS-A0028	Hudson Canyon	598	Texaco	39.41944	-72.65833	421	82	17708	3/20/1979
61-105-00017	OCS-A0028	Hudson Canyon	598	Texaco	39.51667	-72.64722	425	78	16103	5/25/1980
61-105-00021	OCS-A0028	Hudson Canyon	598	Texaco	39.46111	-72.58056	435	78	16050	3/24/1981
61-105-00019	OCS-A0029	Hudson Canyon	599	Exxon	39.49167	-72.52222	442	82	17121	11/2/1980
61-105-00009	OCS-A0032	Hudson Canyon	632	Shell	39.49722	-73.15278	205	84	14000	7/14/1978
61-105-00015	OCS-A0038	Hudson Canyon	642	Texaco	39.48056	-72.64722	450	82	17807	12/1/1979
61-105-00014	OCS-A0038	Hudson Canyon	642	Tenneco	39.43056	-72.59167	443	88	18400	6/10/1979
61-105-00018	OCS-A0038	Hudson Canyon	642	Tenneco	39.37222	-72.63611	446	80	16475	10/14/1980
61-105-00006	OCS-A0042	Hudson Canyon	676	Houston O&M	39.32778	-73.16667	220	96	12500	9/22/1978
61-105-00002	OCS-A0046	Hudson Canyon	684	Exxon	39.32778	-72.71667	399	38	17620	12/23/1978
61-105-00010	OCS-A0046	Hudson Canyon	684	Exxon	39.39167	-72.67778	417	78	16800	7/15/1979
61-105-00005	OCS-A0048	Hudson Canyon	718	Gulf	39.40833	-73.30833	204	74	12813	3/31/1979
61-105-00022	OCS-A0052	Hudson Canyon	728	Exxon	39.29722	-72.68056	433	83	15205	7/5/1981
61-105-00020	OCS-A0055	Hudson Canyon	816	Exxon	39.17500	-72.65278	461	82	17753	5/7/1981
61-105-00012	OCS-A0057	Hudson Canyon	855	Houston O&M	39.15556	-73.03889	290	100	17505	2/8/1979
61-105-00008	OCS-A0059	Hudson Canyon	857	Gulf	39.15278	-72.89167	349	73	18554	1/29/1979
61-105-00013	OCS-A0065	Hudson Canyon	902	Exxon	39.10278	-72.79167	433	72	15968	4/15/1979
61-104-00004	OCS-A0075	Wilmington Canyon	17	Mobil	38.97778	-73.18889	260	83	1200	1/24/1979
61-104-00005	OCS-A0075	Wilmington Canyon	17	Mobil	38.98056	-73.19167	260	83	13992	5/14/1979
61-104-00002	----	Wilmington Canyon	66	Chevron	38.91944	-72.82778	2686	42	15820	1/24/1979
61-104-00008	OCS-A0081	Wilmington Canyon	106	Murphy	38.88333	-73.00278	412	98	18405	5/29/1980
61-104-00003	OCS-A0096	Wilmington Canyon	272	Shell	38.71667	-73.60278	217	84	13500	2/19/1979
61-104-00001	OCS-A0097	Wilmington Canyon	273	Shell	38.86111	-73.50556	235	84	17500	12/16/1978
61-104-00011	OCS-A0317	Wilmington Canyon	372	Shell	38.60278	-72.96944	6952	48	11631	7/9/1984
61-104-00007	OCS-A0131	Wilmington Canyon	495	Tenneco	38.61389	-73.47500	355	88	18300	10/11/1979
61-104-00010	OCS-A0336	Wilmington Canyon	586	Shell	38.45278	-73.22500	5838	48	16000	5/22/1984
61-104-00009	OCS-A0337	Wilmington Canyon	587	Shell	38.51111	-73.29444	6448	48	14500	12/21/1983

Wireline Logs

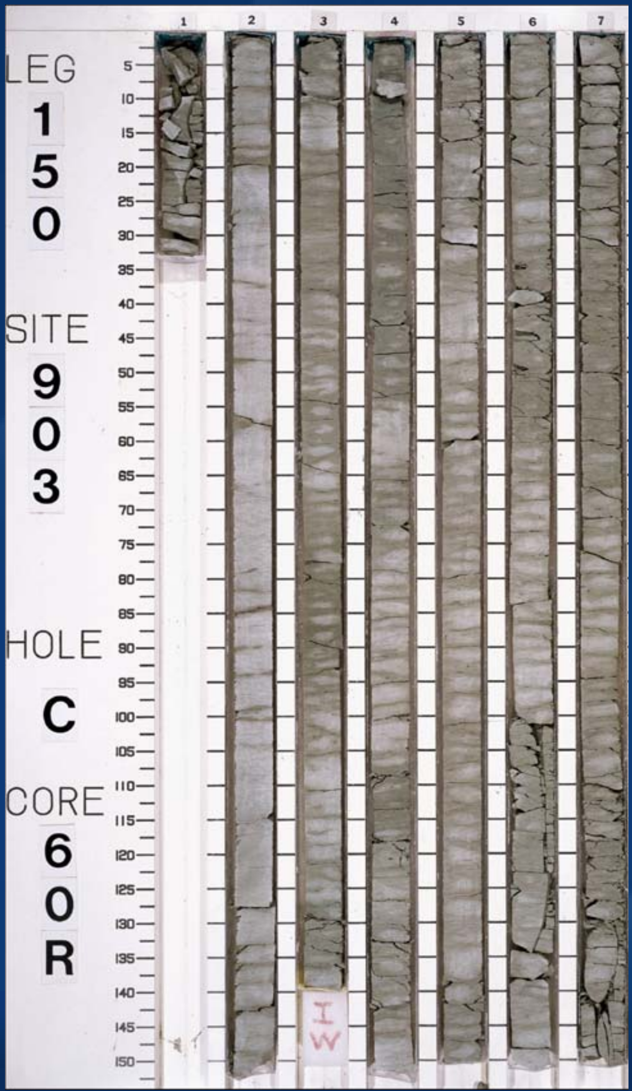


(From Libby-French, 1984)



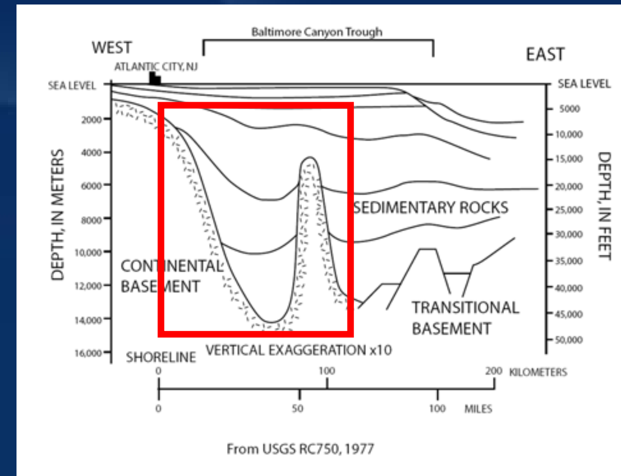
Core & Cuttings

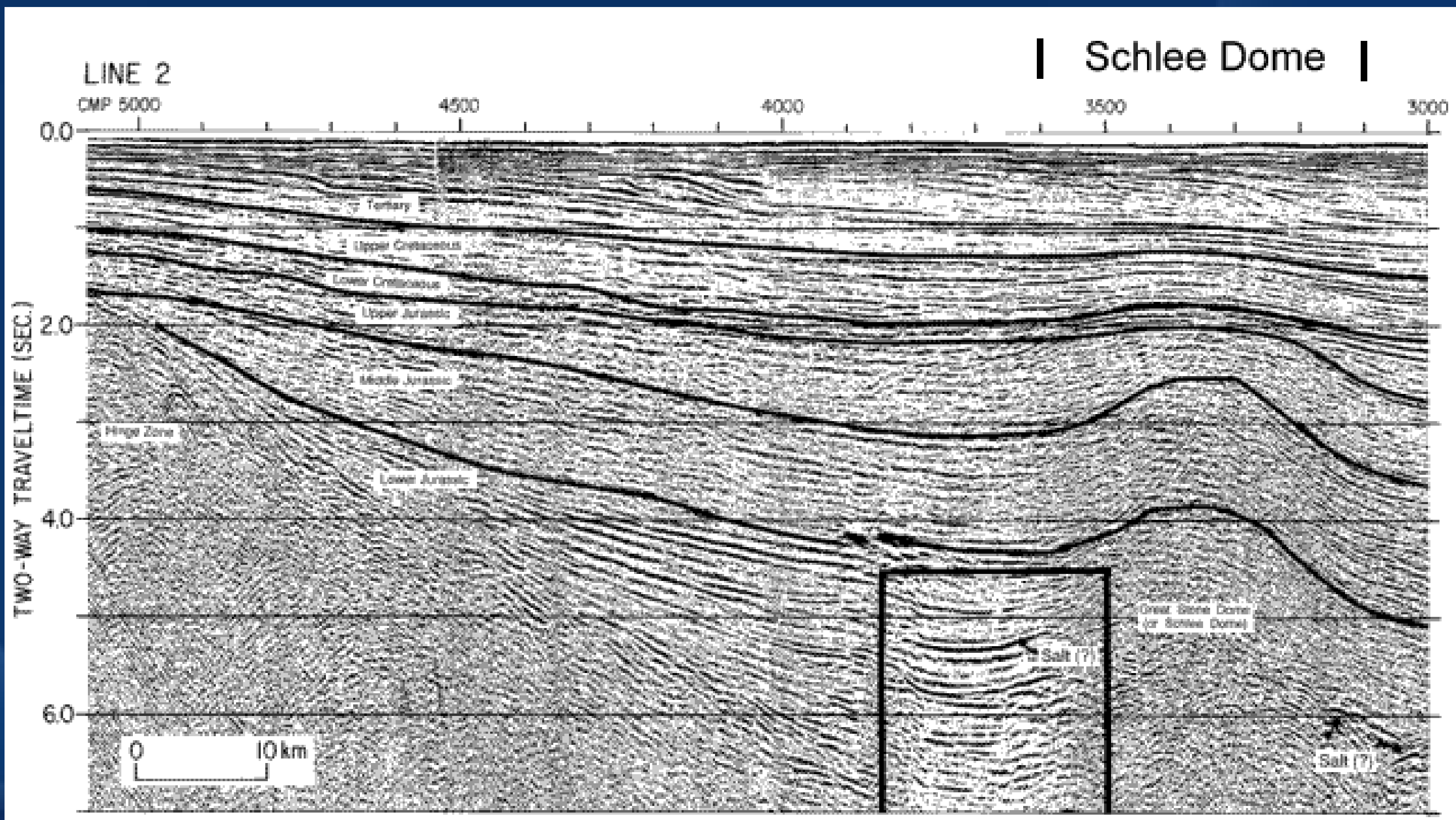
- 465 Boxes of core material
  (including COST-B2 & COST-B3)
- 245 boxes of unwashed cuttings
  (~5,000 individual samples)
- 1959 boxes of washed cuttings
  (~40,000 individual samples)
- 32 Boxes of vials
  (~6,500 individual samples)
- 88 boxes of thin sections
  (~6,300 slides)
- Geophysical logs, micropaleontology summary, and other data from many of the wells

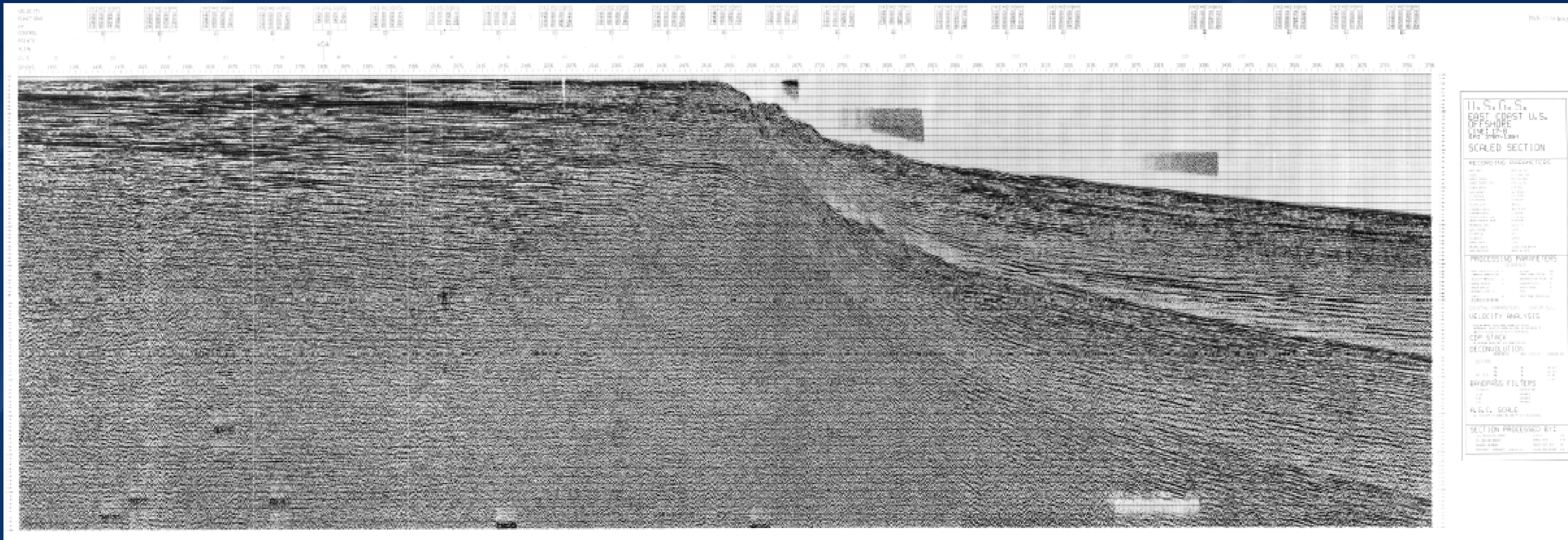


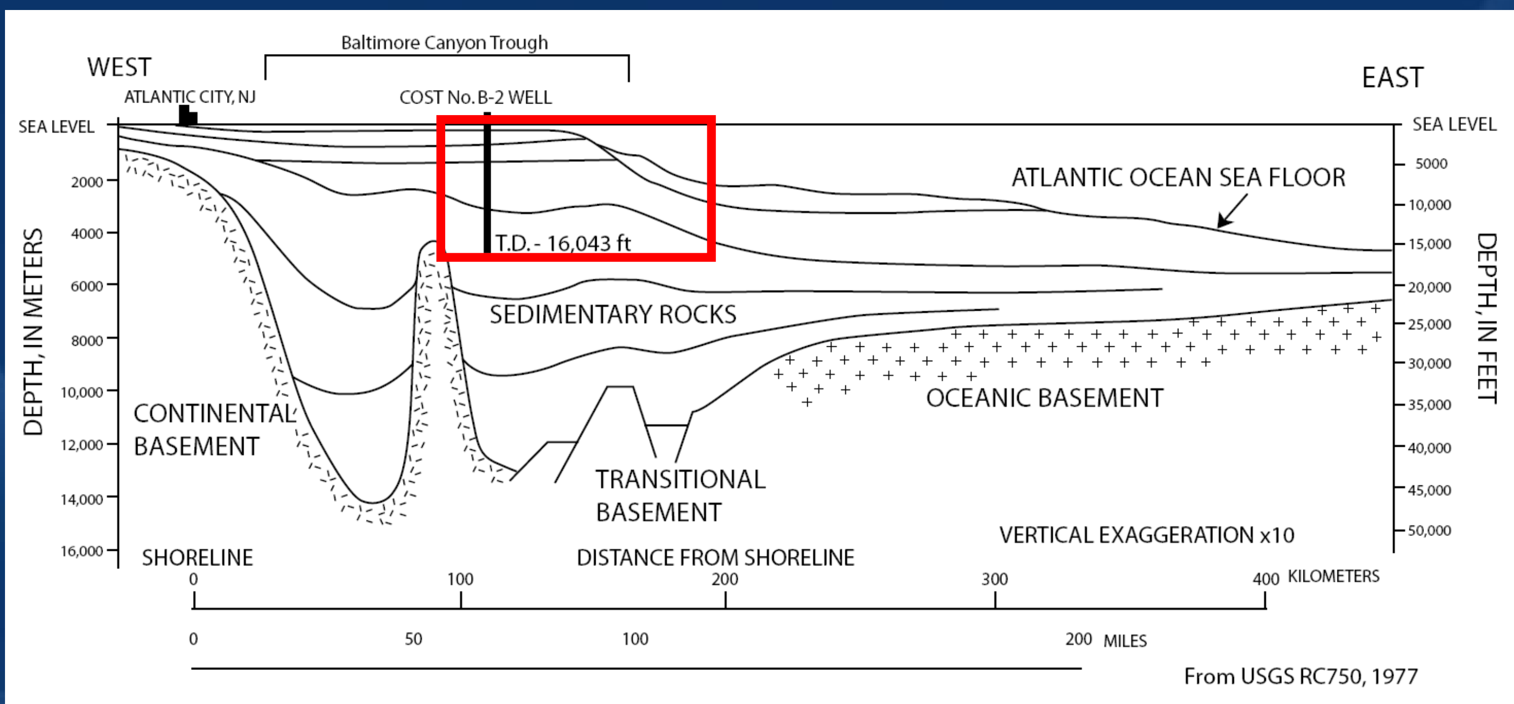
Seismic Surveys

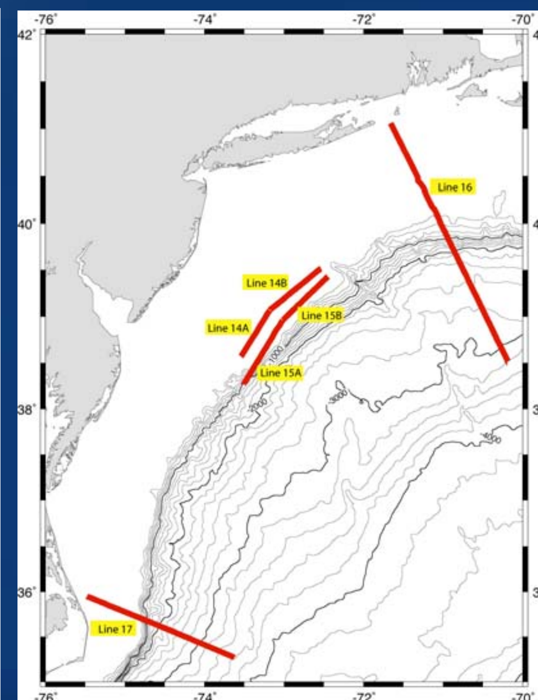
There is a significant amount of seismic data available at little or no charge through the USGS and other institutions



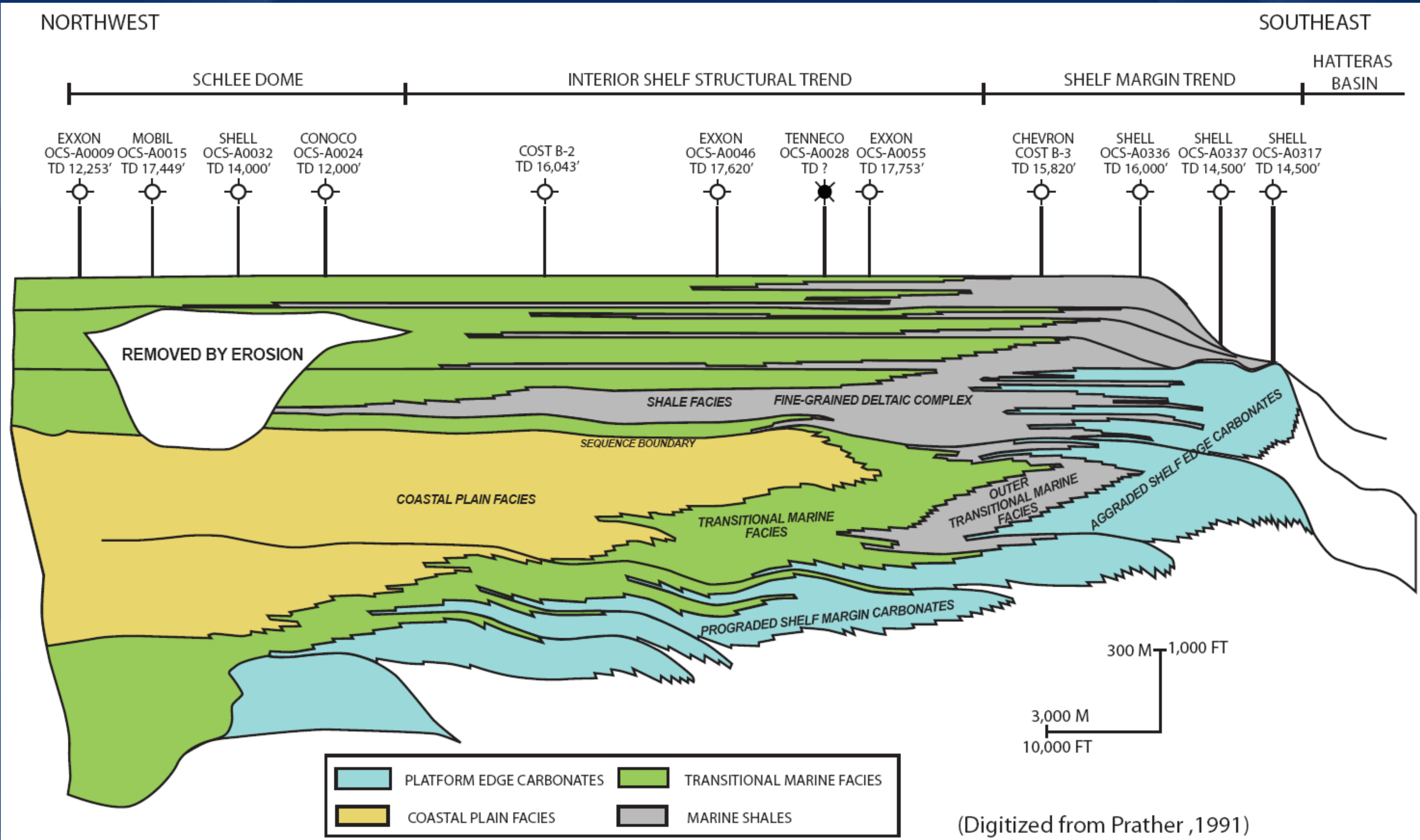



U.S.G.S.
EAST COAST U.S.
OFFSHORE
SCALED SECTION

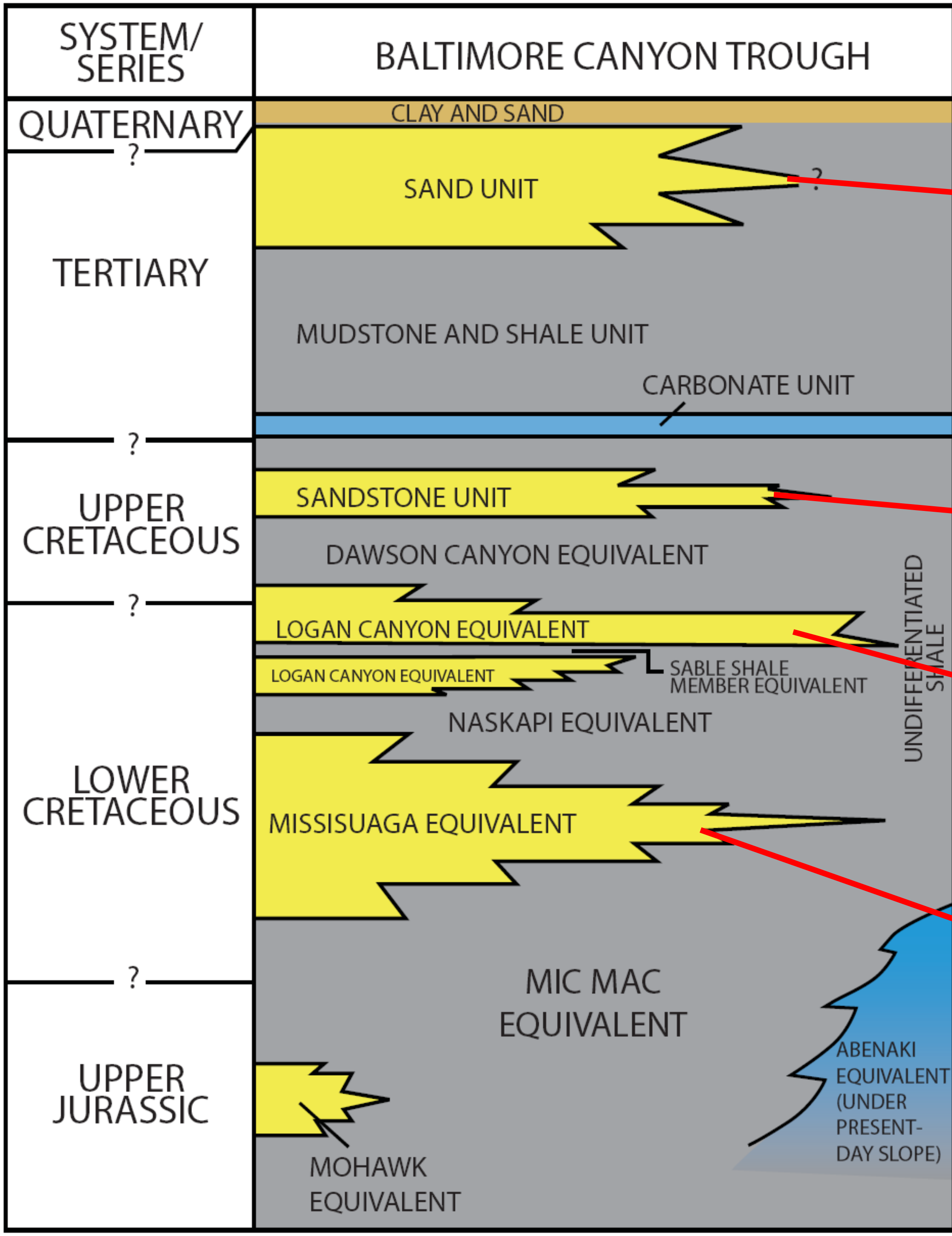

Baltimore Canyon Trough
WEST
EAST
ATLANTIC CITY, NJ
COST No. B-2 WELL
SEA LEVEL
SEA LEVEL
ATLANTIC OCEAN SEA FLOOR
T.D. - 16,043 ft
SEDIMENTARY ROCKS
OCEANIC BASEMENT
CONTINENTAL BASEMENT
TRANSITIONAL BASEMENT
DEPTH, IN METERS
2000
4000
6000
8000
10,000
12,000
14,000
16,000
DEPTH, IN FEET
5000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
VERTICAL EXAGGERATION x10
SHORELINE
DISTANCE FROM SHORELINE
0
100
200
300
400 KILOMETERS
0
50
100
200 MILES
From USGS RC750, 1977


-76˚
-74˚
-72˚
-70˚
42˚
40˚
38˚
36˚
Line 16
Line 14B
Line 14A
Line 15B
Line 15A
Line 17

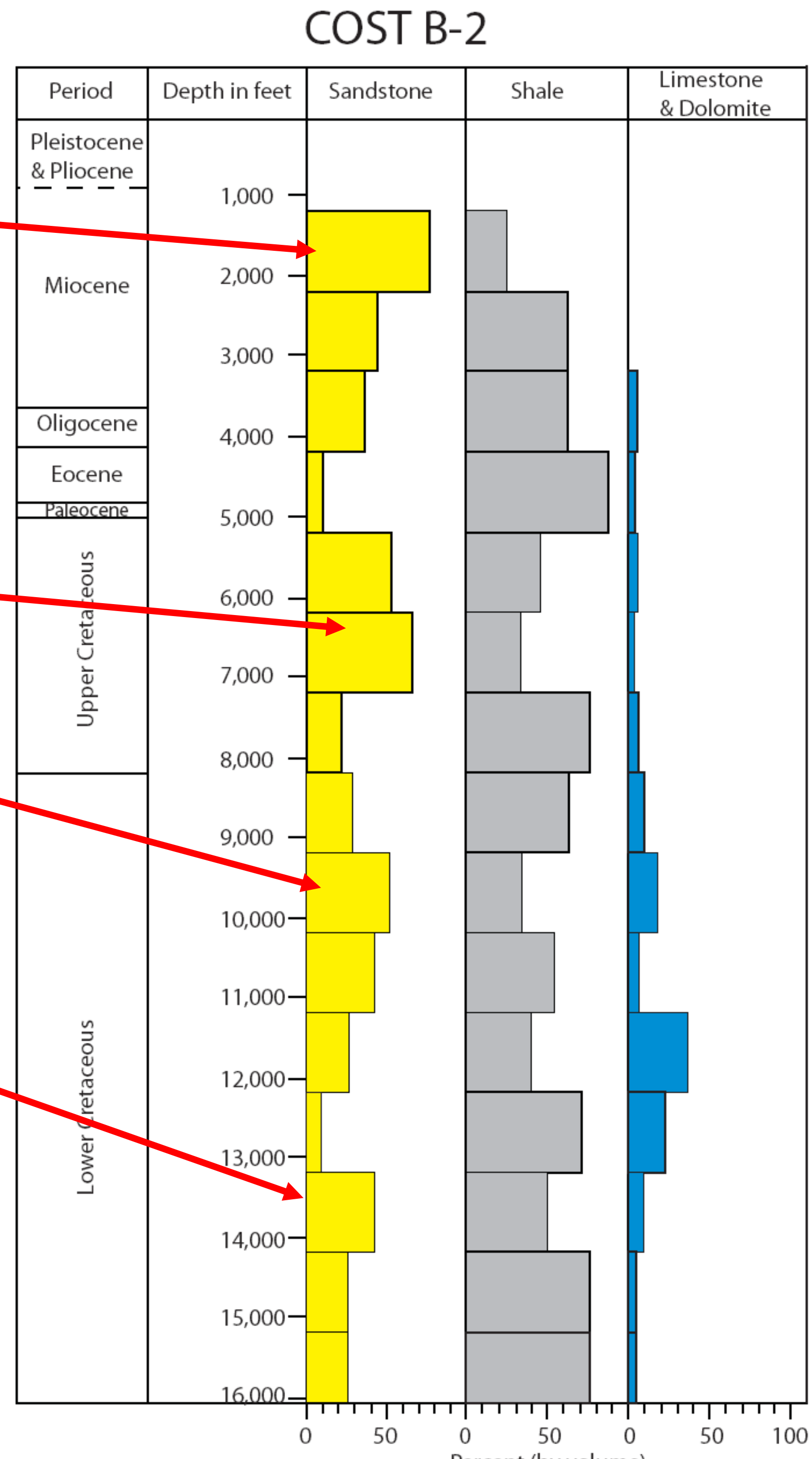
Sequestration Potential in Sandstone Units



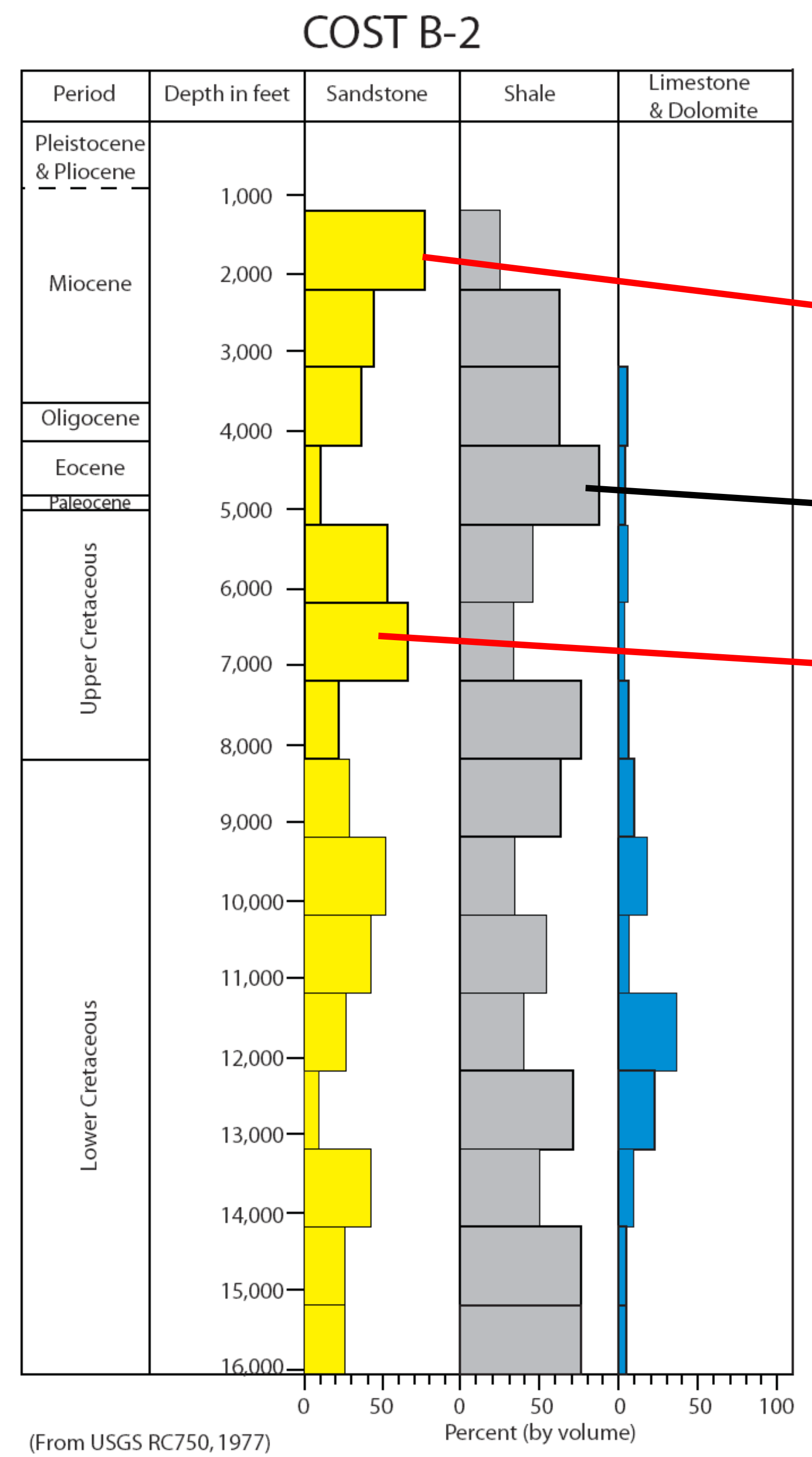
(Digitized from Prather ,1991)



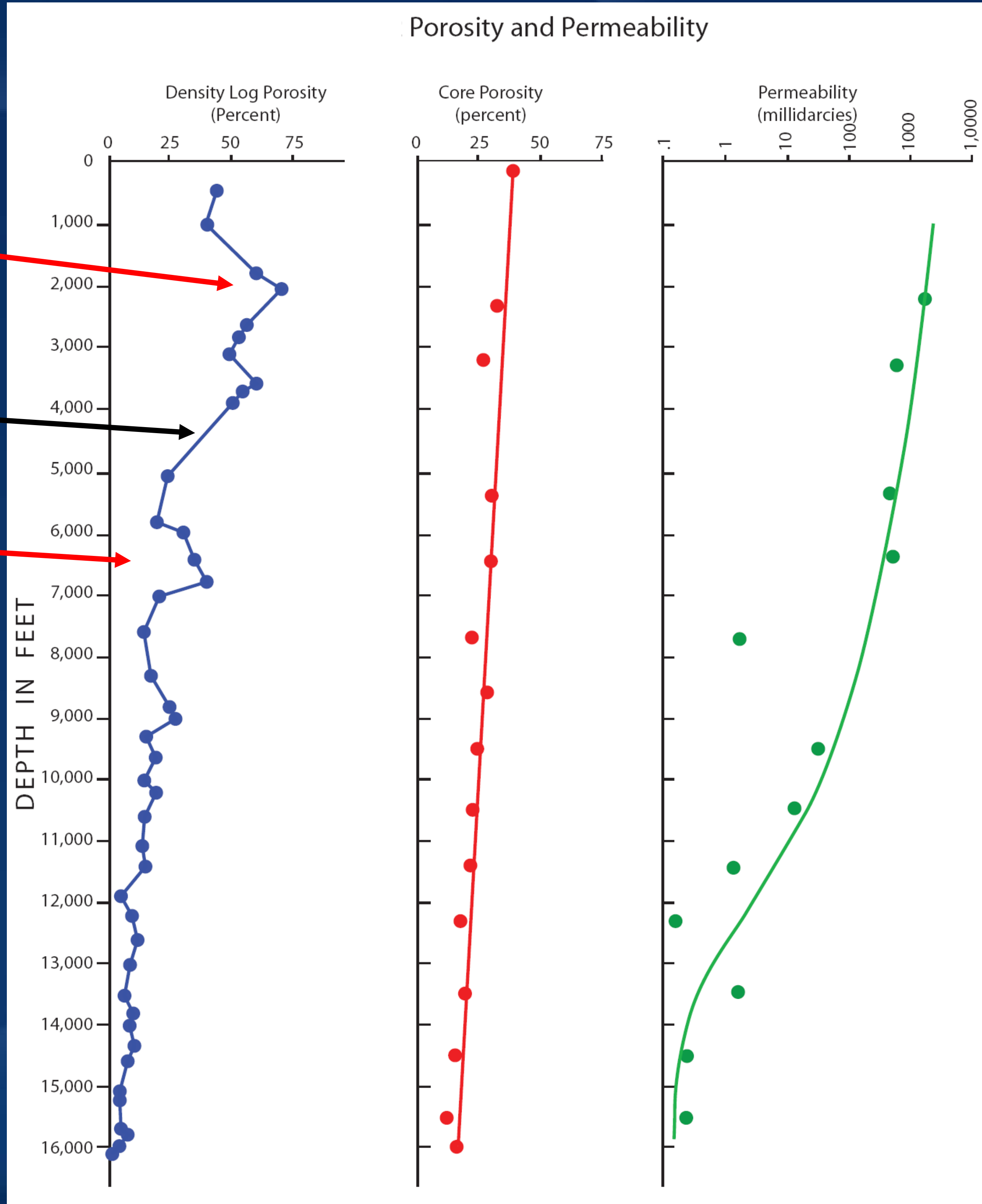
(From Libby-French, 1984)



(From USGS RC750, 1977)

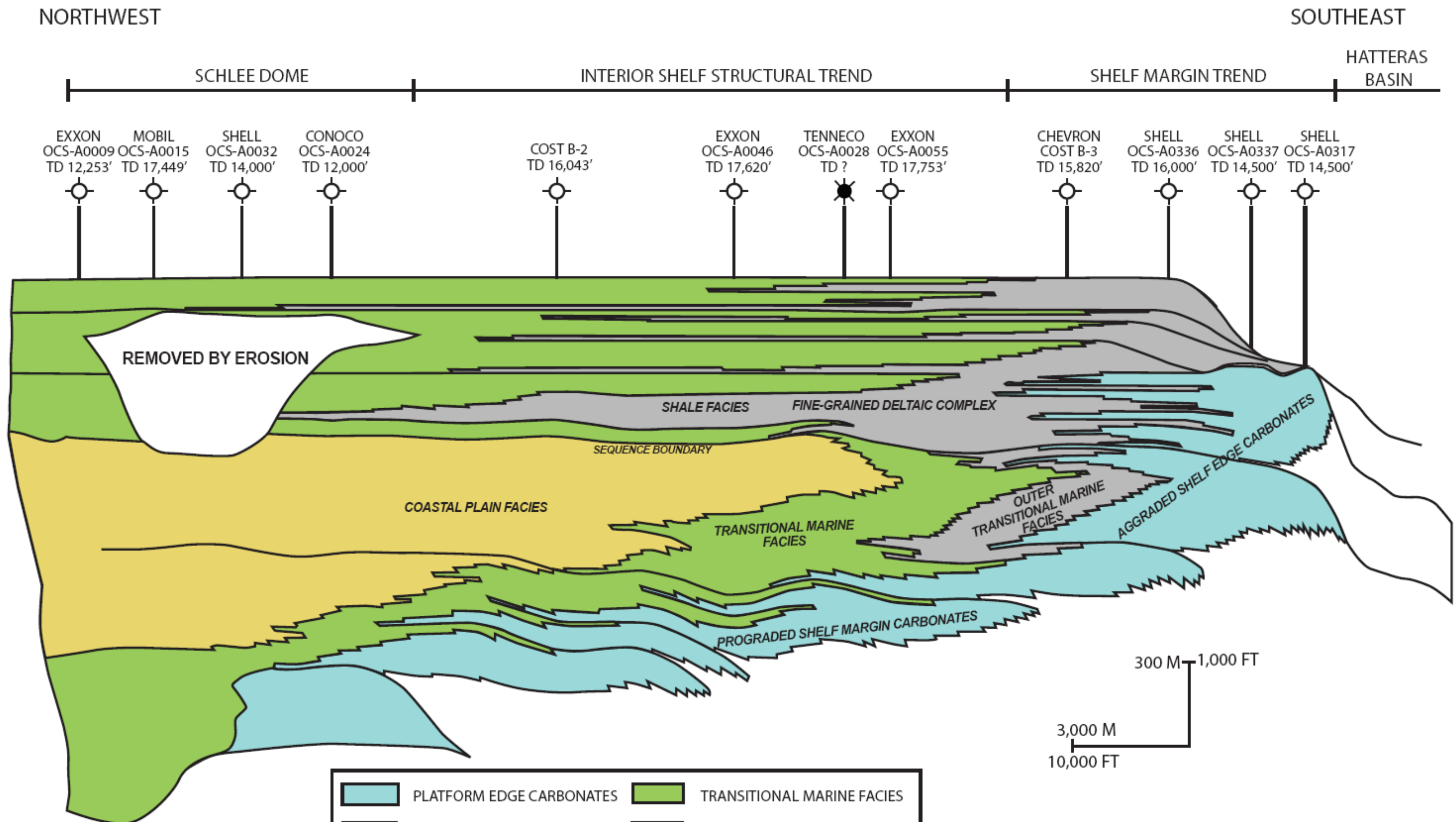


COST B-2
Period
Depth in feet
Sandstone
Shale
Limestone & Dolomite
Pleistocene & Pliocene
Miocene
Oligocene
Eocene
Paleocene
Upper Cretaceous
Lower Cretaceous
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
13,000
14,000
15,000
16,000
0 50 0 50 0 50 100
Percent (by volume)
(From USGS RC750, 1977)

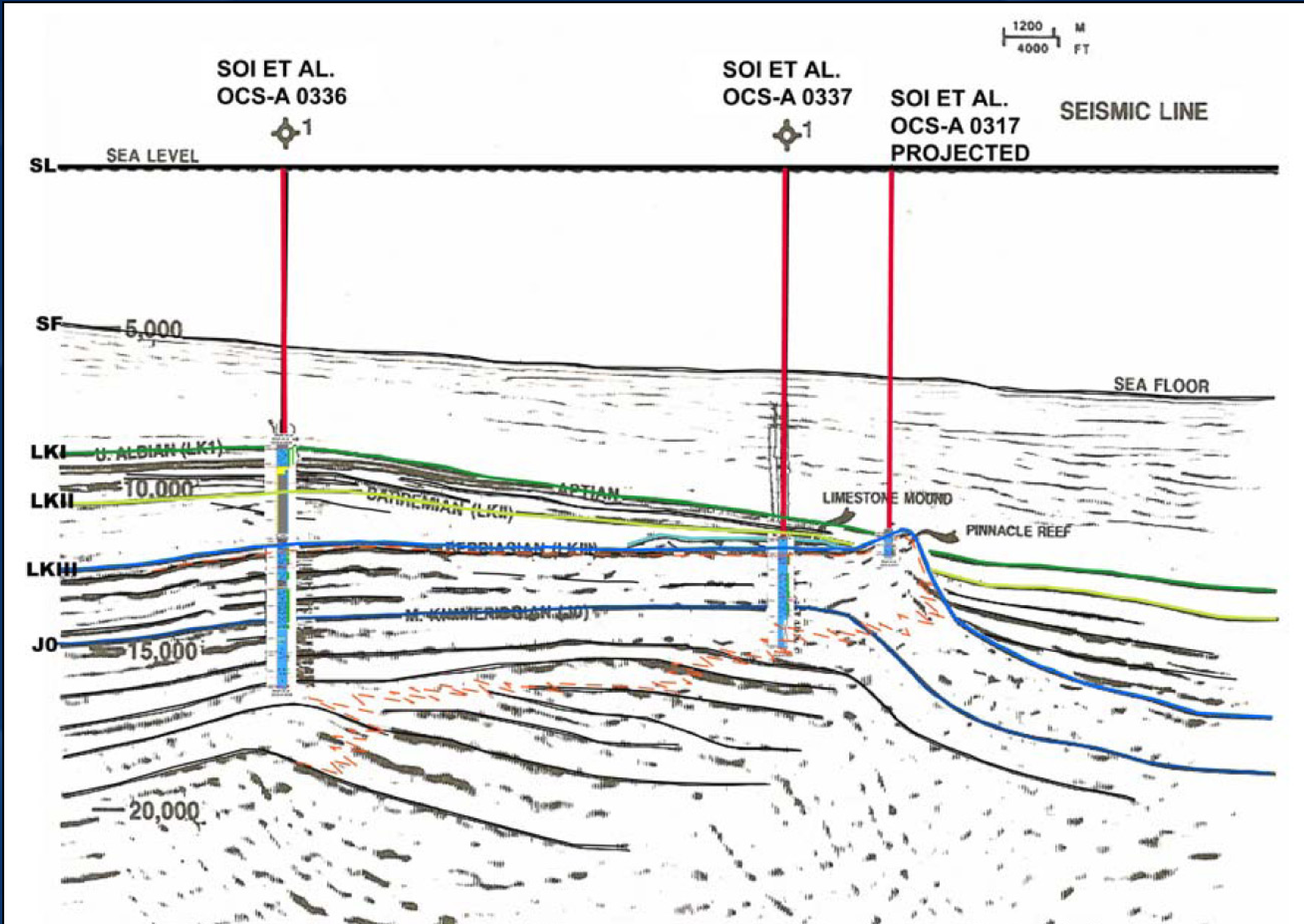


Porosity and Permeability
Density Log Porosity (Percent)
0 25 50 75
Core Porosity (percent)
0 25 50 75
Permeability (millidarcies)
.1 1 10 100 1000 1,0000
DEPTH IN FEET
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
13,000
14,000
15,000
16,000

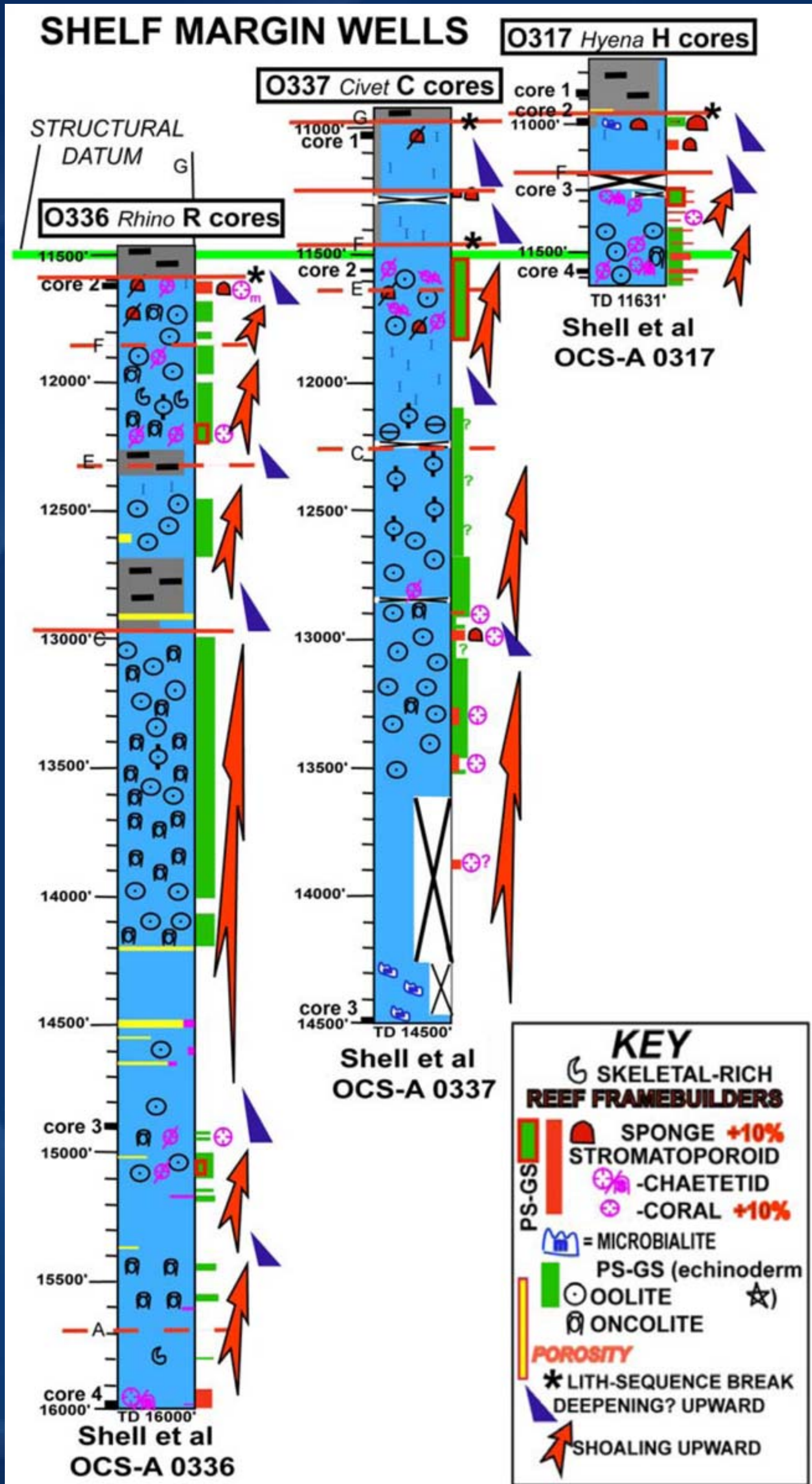
Sequestration Potential in Limestone Units

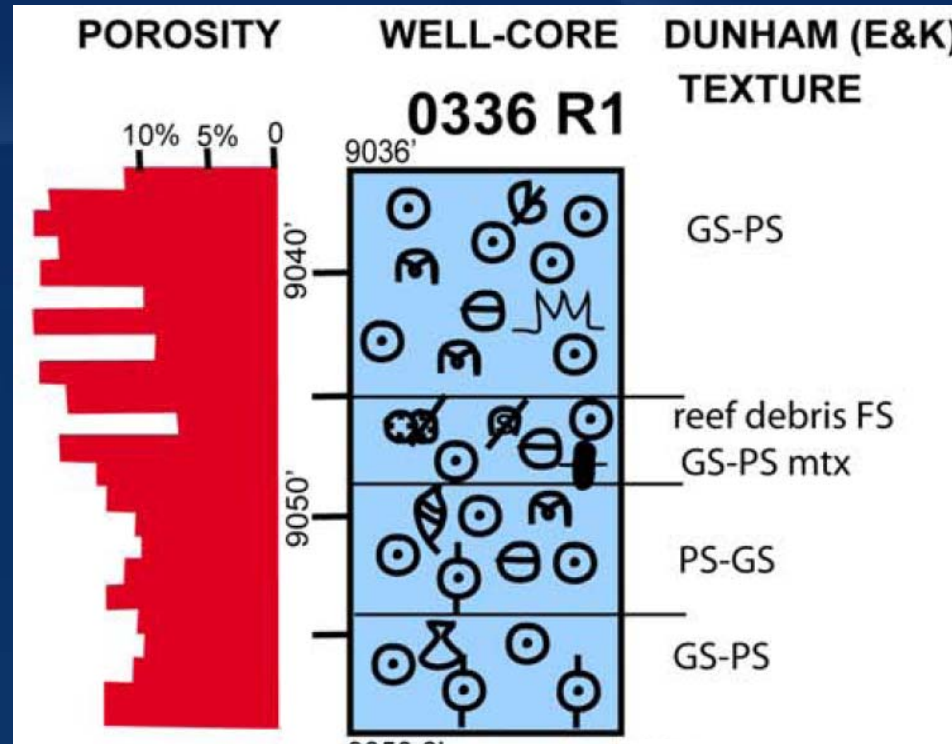


(Digitized from Prather ,1991)



modified from Prather 1991





(From Eliuk & Prather, 2008)

Facies / Lithology	n*	Porosity Ave. Φ (%)	Range
Prograded shelf margin limestones	277	2.4	0.0 - 17.0
Transitional marine sandstones	619	6.1	0.0 - 29.0
Coastal Plain sandstones	1391	8.7	0.0 - 33.0
Fine-grained deltaic sandstones	729	9.2	0.0 - 28.0
Aggradded shelf-margin limetsones	189	8.5	0.0 - 26.0
Limestone buildups	3	12.2	0.0 - 13.0
Chalky *Tubiphytes* packstone	84	6.3	0.0 - 31.1
Shoal-water oolite grainstone	53	17	0.0 - 36.0
Shelf-margin deltaic sandstones	163	18.2	0.0 - 30.0

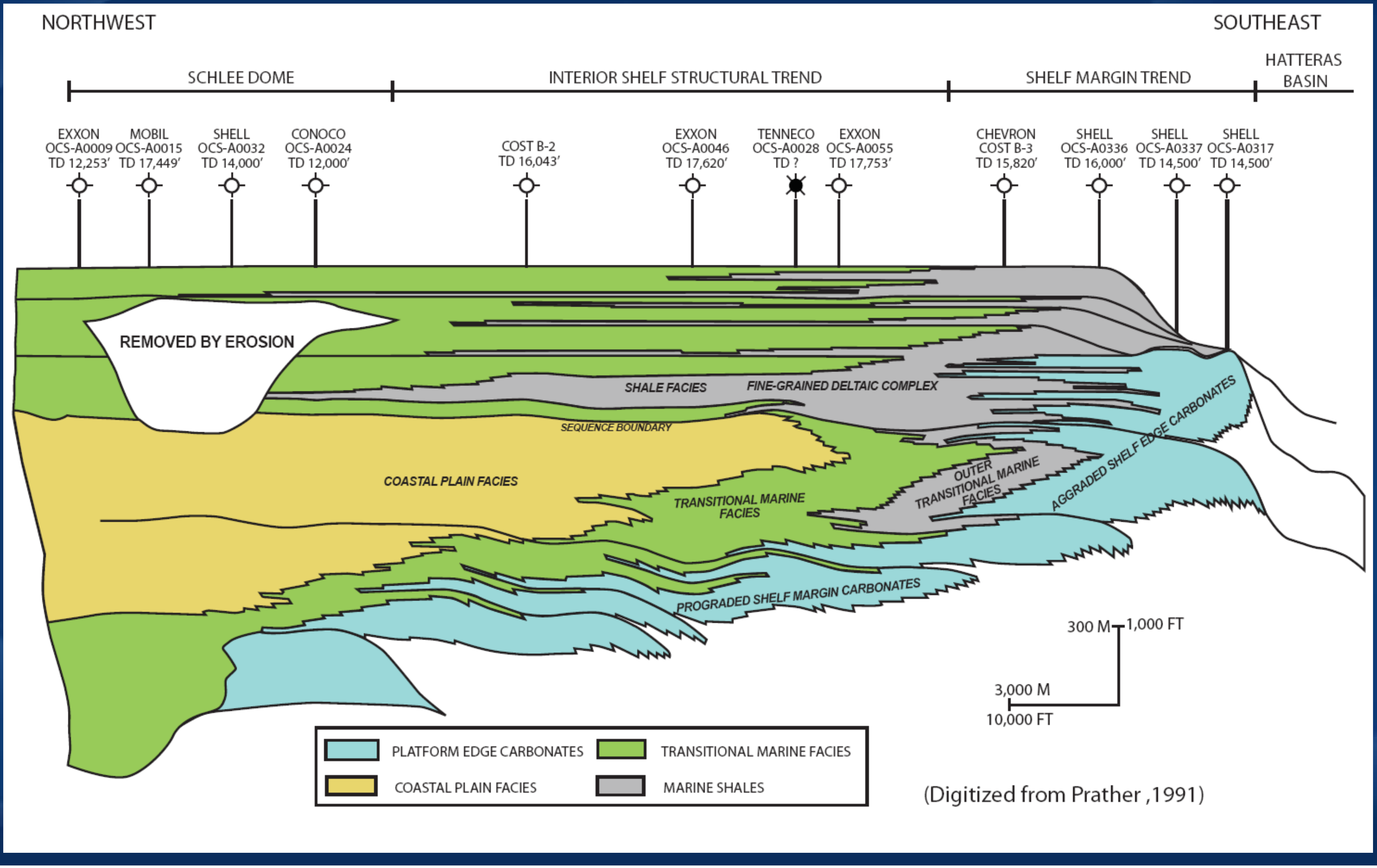
Facies / Lithology	n	Permeability Ave. K (md)**	Range
Prograded shelf margin limestones	148	0.34	< 0.01 - 17
Transitional marine sandstones	351	0.71	< 0.01 - 46
Coastal Plain sandstones	650	26.19	< 0.01 - 349
Fine-grained deltaic sandstones	189	71.11	< 0.01 - 195
Aggradded shelf-margin limetsones	43	5.1	< 0.01 - 156
Limestone buildups	---	---	---
Chalky *Tubiphytes* packstone	84	0.47	< 0.01 - 12.6
Shoal-water oolite grainstone	23	2.45	< 0.01 - 12.2
Shelf-margin deltaic sandstones			

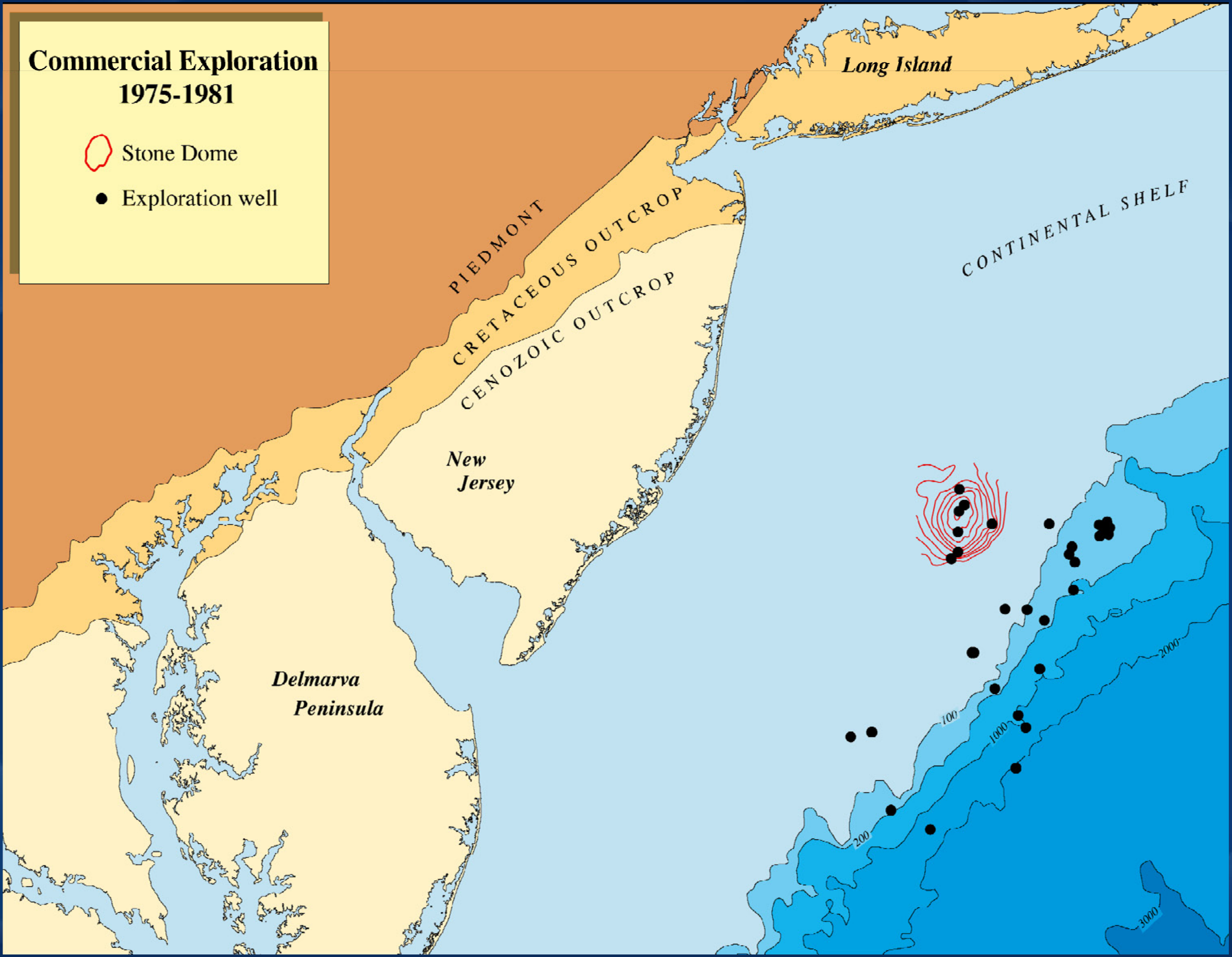
(From Prather, 1991)

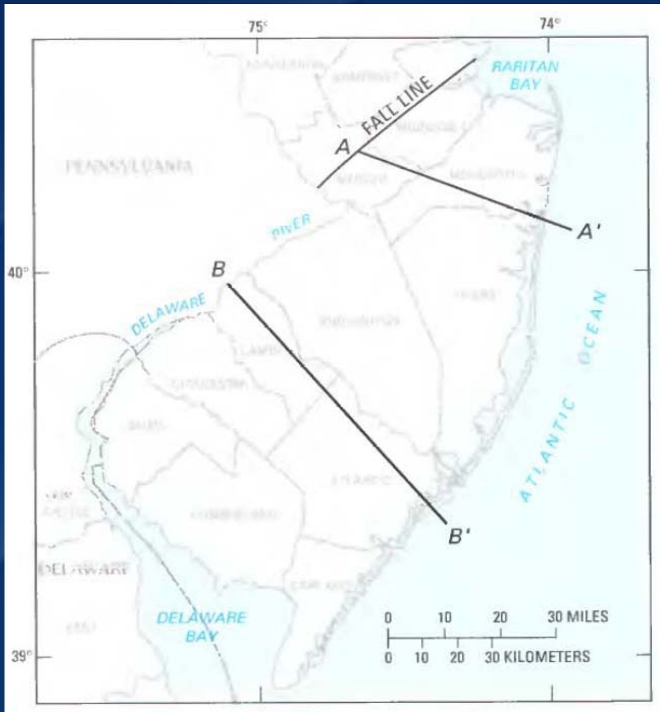
*n = number of beds, **based on perm plug measurements

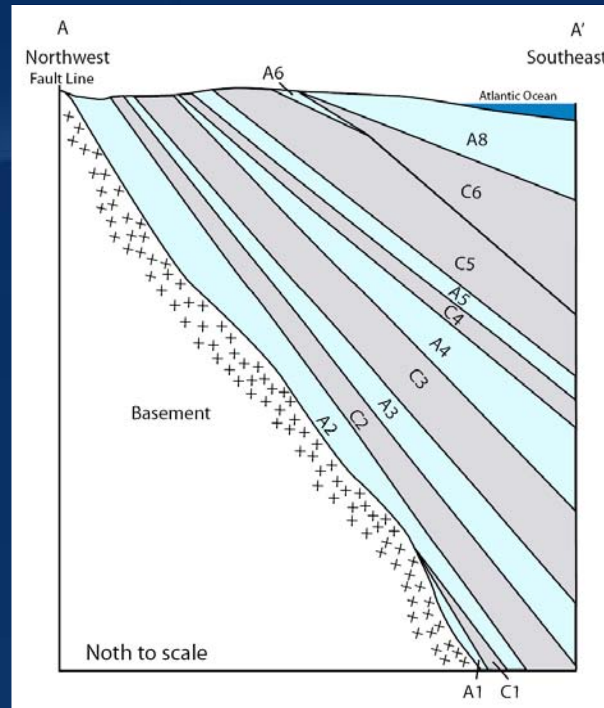
Porosity and permeability data from 3 exploratory wells in the study area show high porosity, high permeability beds in both sandstone and limestone units.

"The coastal-plain and transitional-marine facies are overlain by a fine-grained deltaic complex dominated by delta-plain shales which collectively form a regionally extensive top seal unit." – Prather, 1991

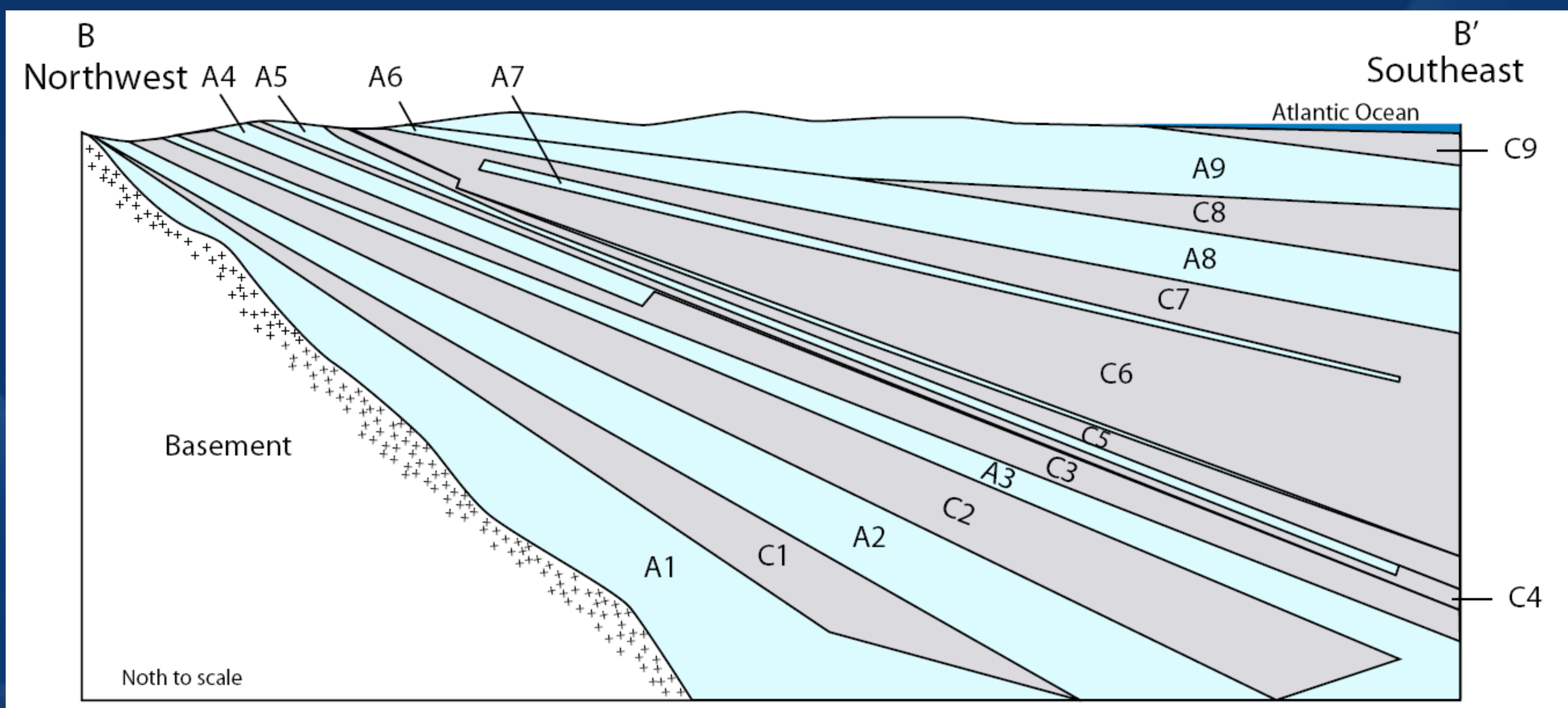



Commercial Exploration
1975-1981
Stone Dome
Exploration well
Long Island
PIEDMONT
CRETACEOUS OUTCROP
CENOZOIC OUTCROP
CONTINENTAL SHELF
New Jersey
Delmarva Peninsula
100
200
1000
2000
3000





Hydrogeologic studies of Cretaceous and Cenozoic rocks in New Jersey have indicated these formations may be relatively continuous causing some concern when considering potential migration paths of sequestered CO_2.



(digitized from Martin, 1998)

PRM Sequences (Potomac, Raritan, Magothy)

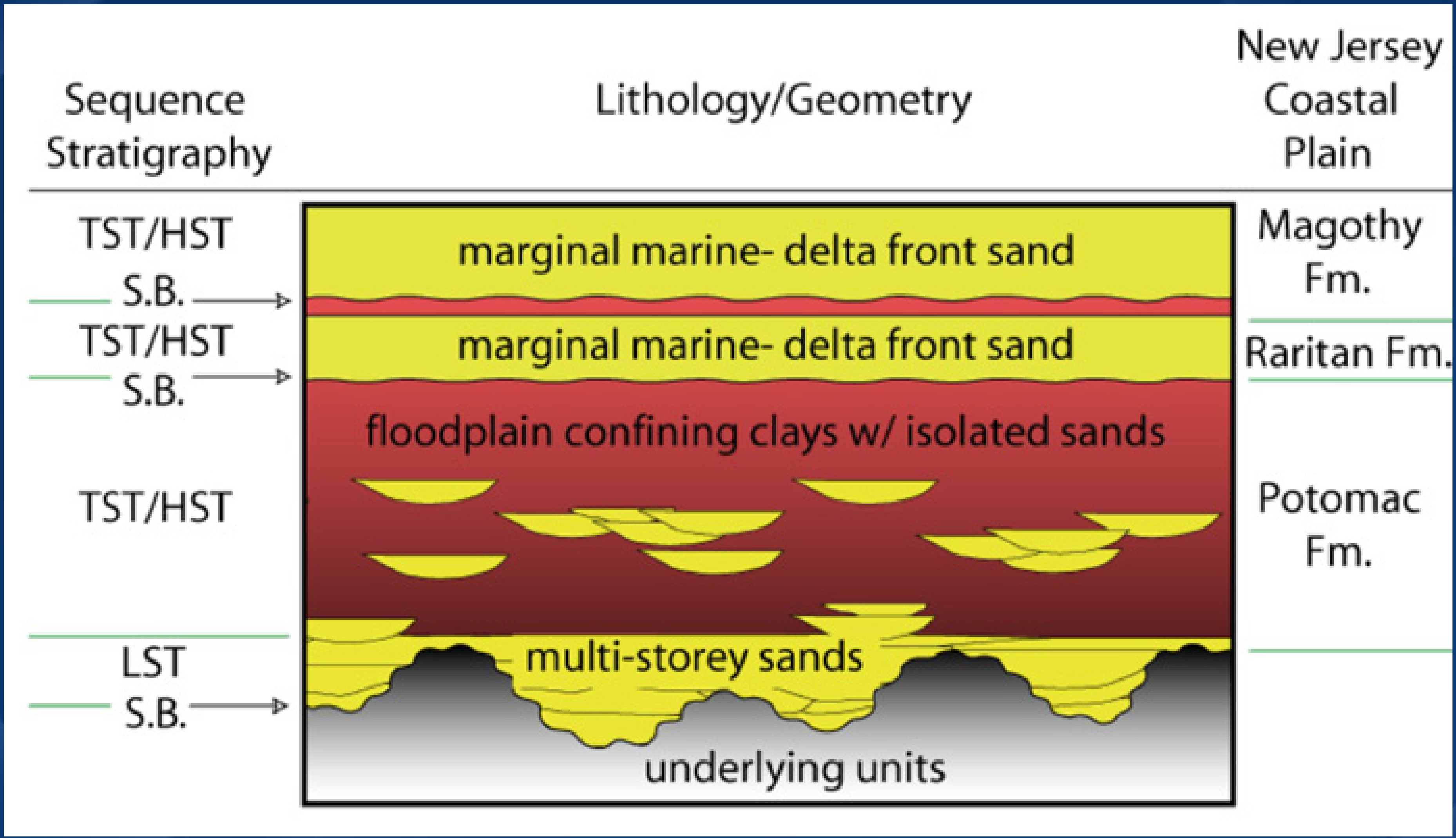


Figure Courtesy of Ken Miller (Rutger's University)

Recent geologic cross sections based on well logs depict isolated "pockets" of Potomac Sands. This contradicts the earlier interpretations of continuous aquifers. If this scenario is correct and extends offshore, it is likely to reduce storage capacity but also reduce risk of long distance plume migration.

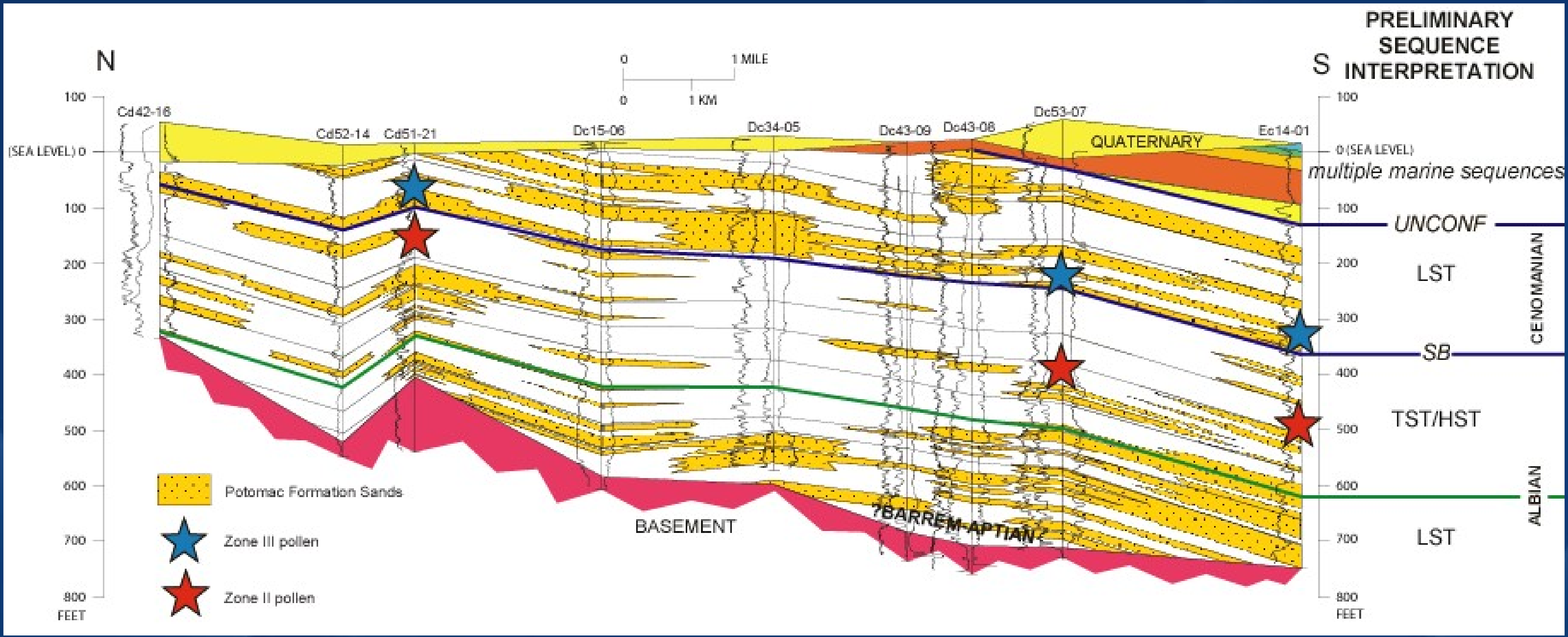
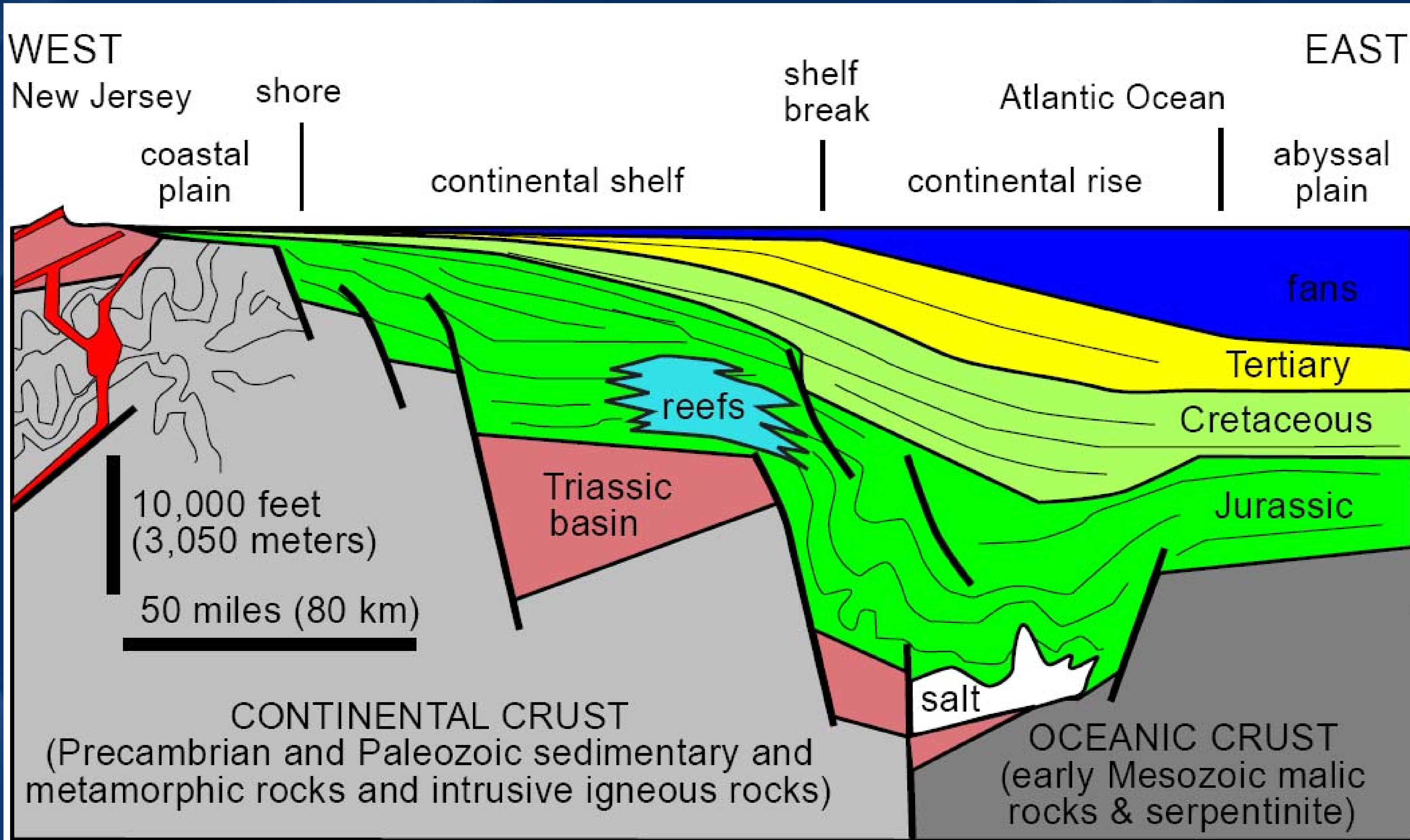
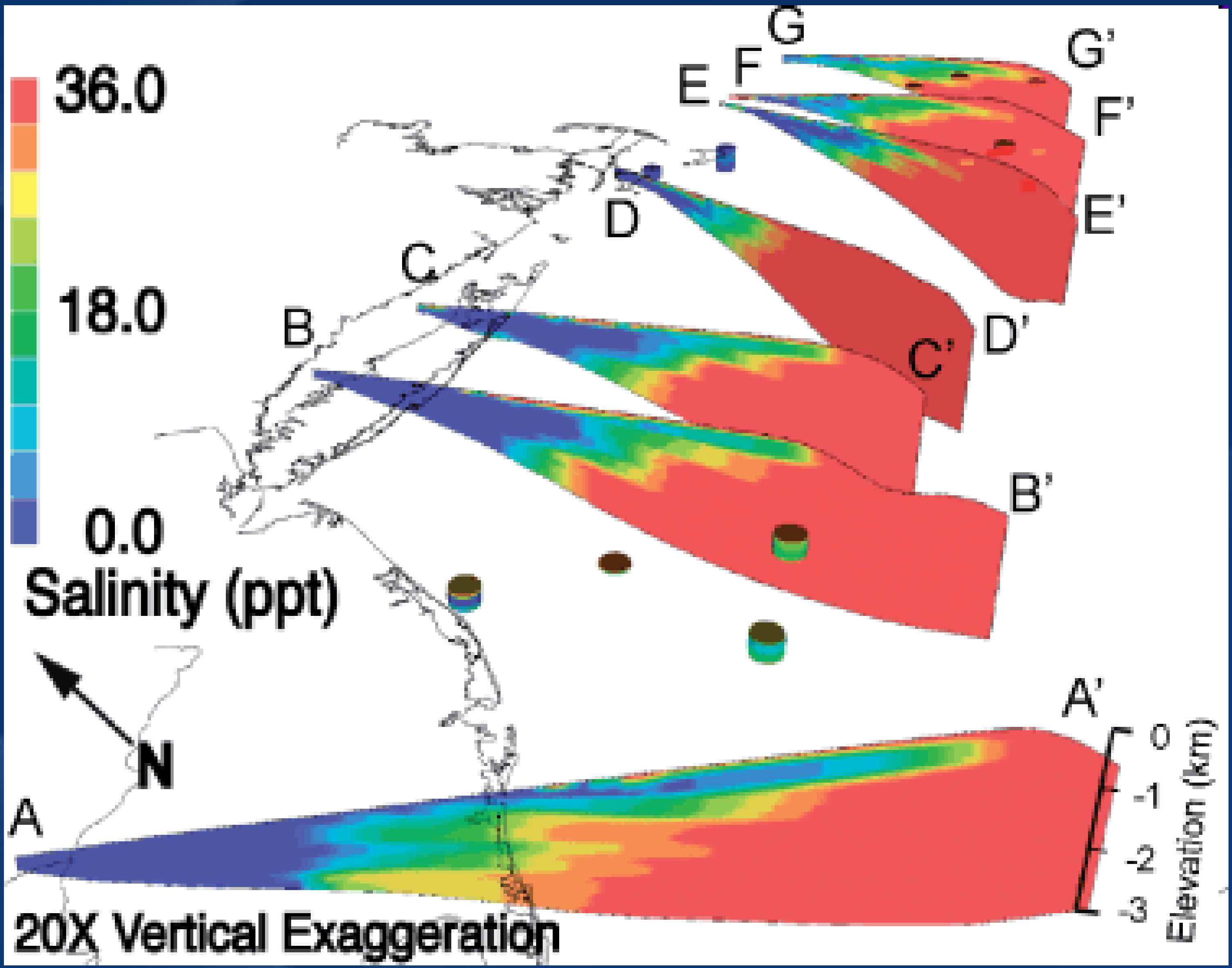


Figure Courtesy of Ken Miller (Rutger's University)



From USGS (after Sheridan 1989)

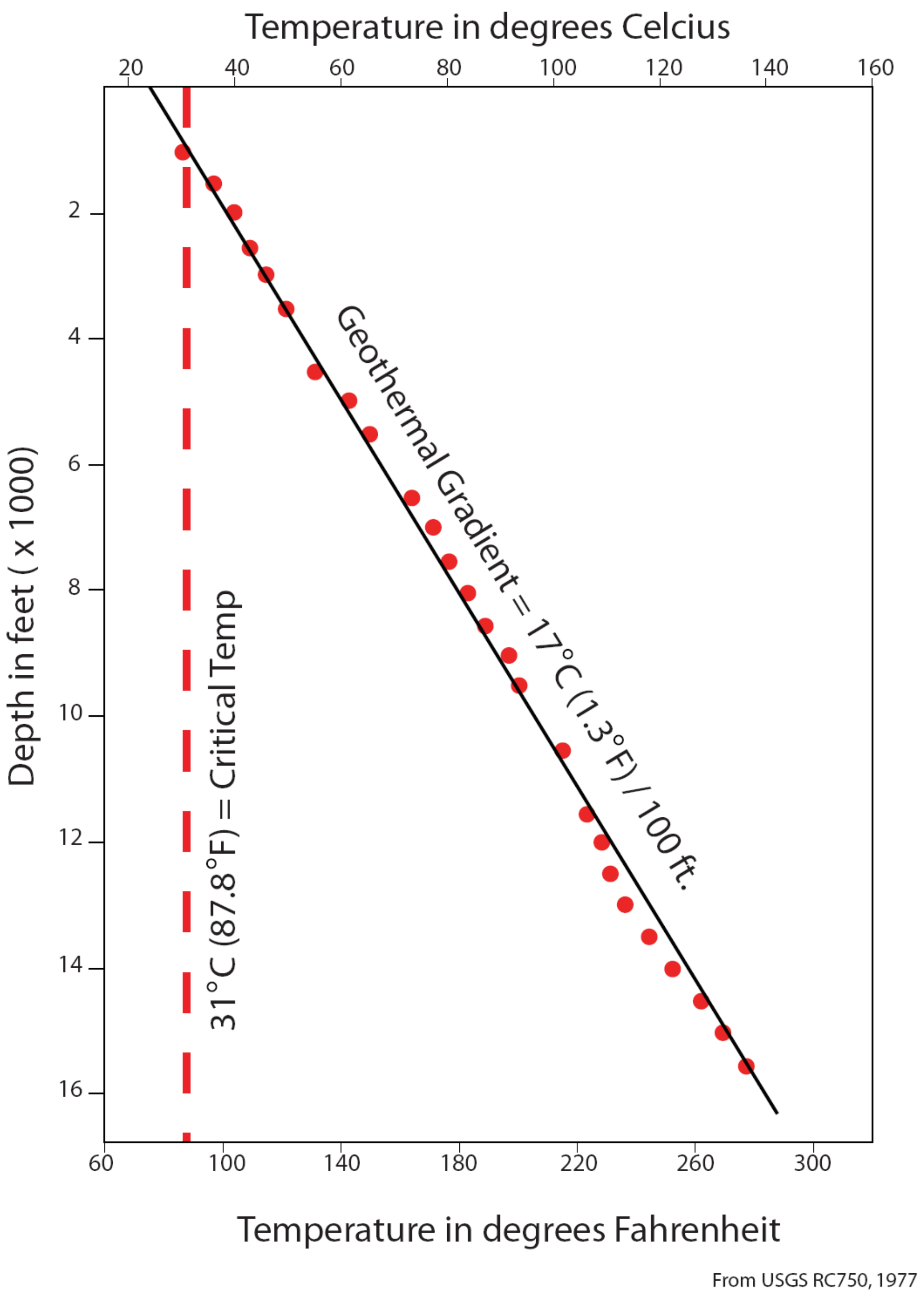
Coastal Hydraulic Head



(From Cohen et al, 2010)

Current research shows that the hydraulic head along the coast of NJ and NY is oriented such that fresh water is pushing outward into the ocean. This flow may prevent, or inhibit, the migration of sequestered CO_2 toward terrestrial regions where these reservoirs outcrop.

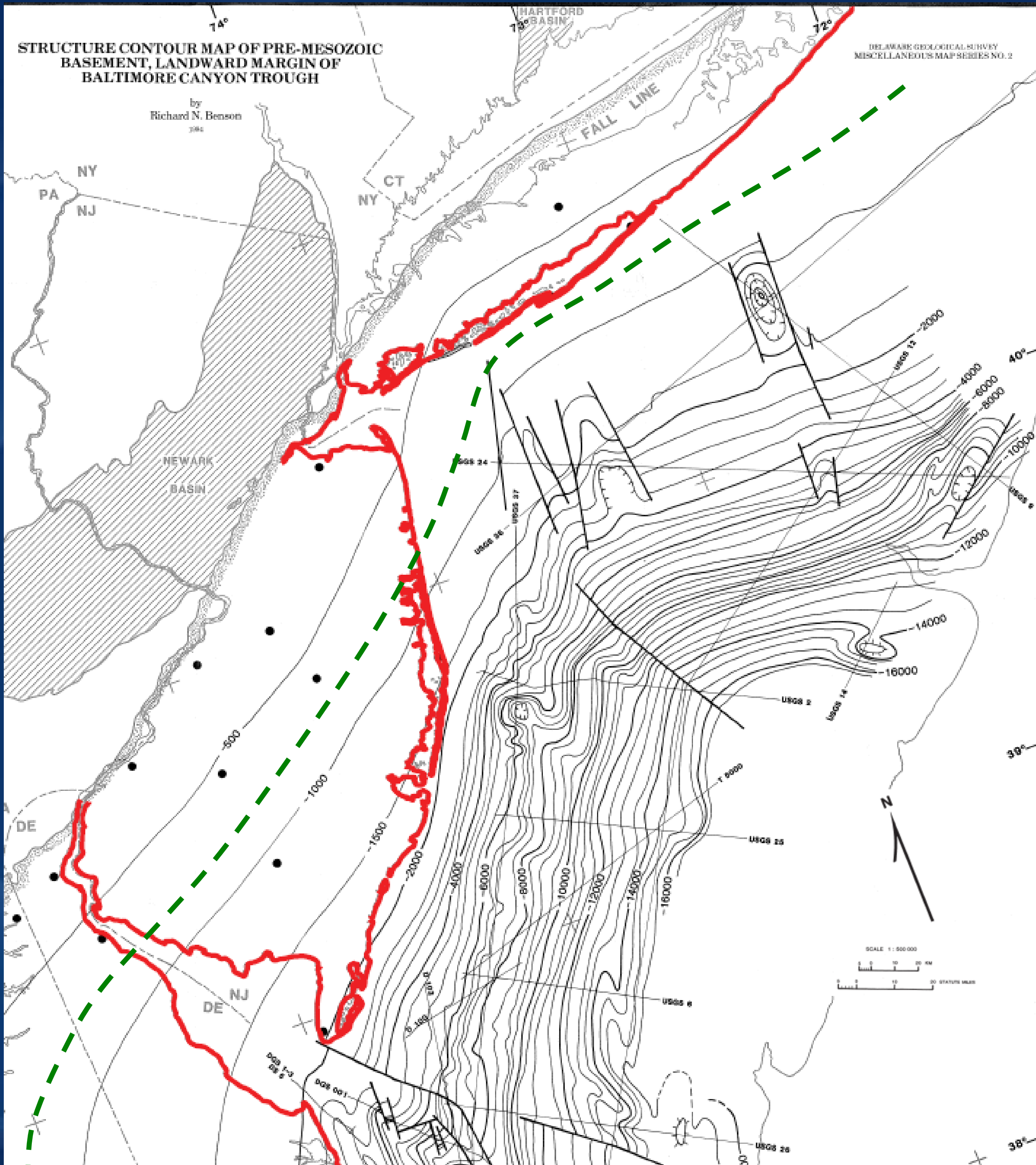
Decrease in salinity as the CO_2 plume migrates eastward would also encourge increased dissolution



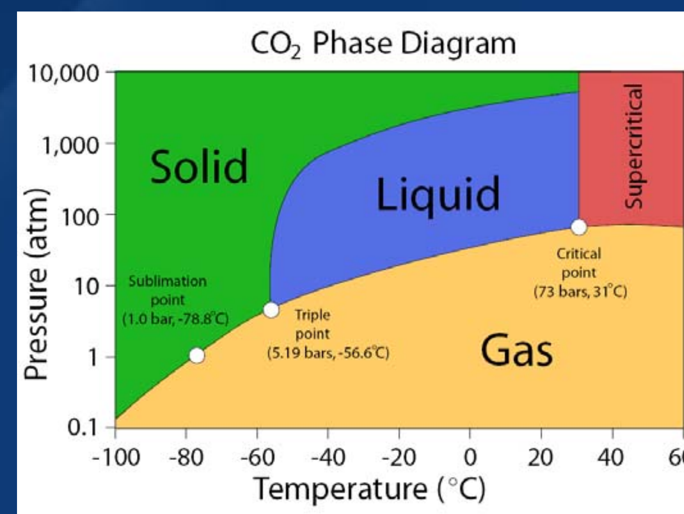
Temperature

Based on data from the COST-B2 well, reaching the critical temperature of 31°C will require a reservoir depth of at least 1,000 feet. This should not be an issue since reaching the target pressure will require a depth of at least 2,500 feet to sequester CO_2 as a supercritical fluid.

Pressure

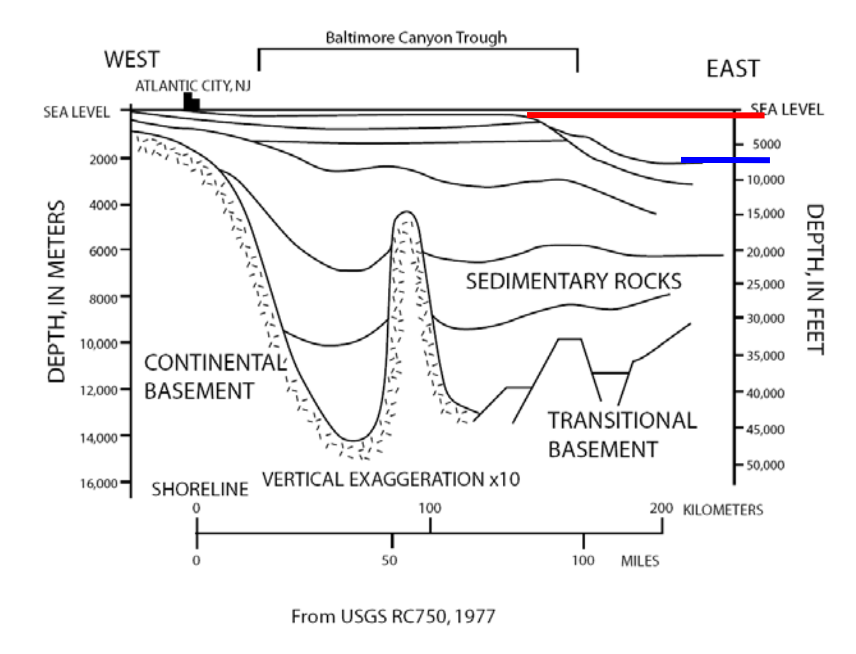


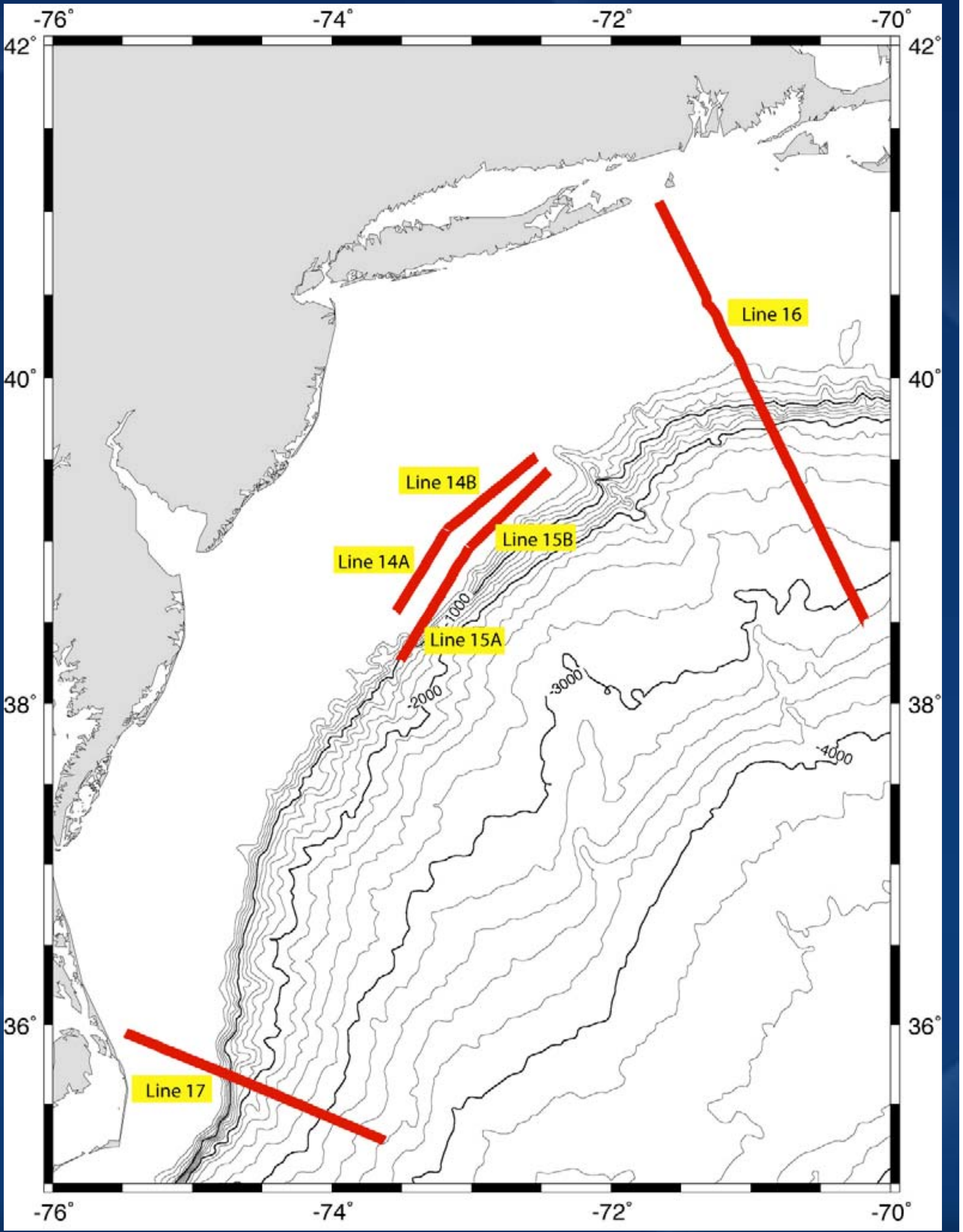
Just as with onshore sequestration, a reservoir depth greater than 2500 feet will be necessary to sequester CO_2 in a supercritical state.



Bathymetry

The cost of drilling an offshore well increases dramatically as you get into deeper waters. It is in our best interest to find target reservoirs in areas where the sea floor is relatively shallow (not beyond the shelf break)





Work Plan

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

- Correlation of Offshore terminology and onshore unit names
- Detailed analysis of shale facies and other potential sealing units
- Establish porosity cutoffs and calculate net thickness of high porosity – permeability zones for each facies association
- Plume migration simulations that account for hydraulic head
- Take a closer look at Schlee Dome
- Investigate the effects of offshore factors such as hydrate formation and density inversion
- Digitize and analyze wireline logs
- Seismic Interpretation
- Capacity Calculations

Preliminary Correlation Chart

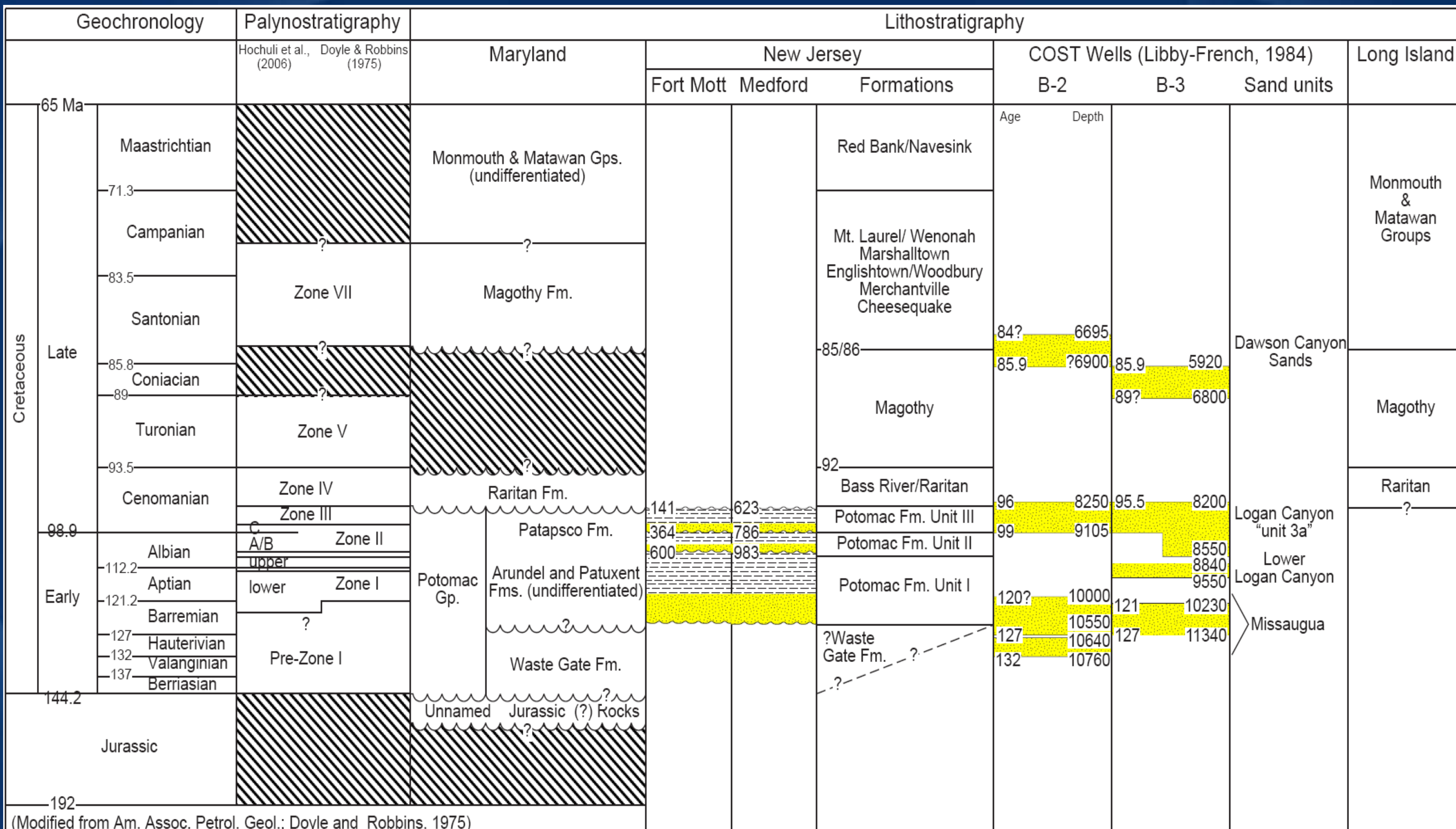


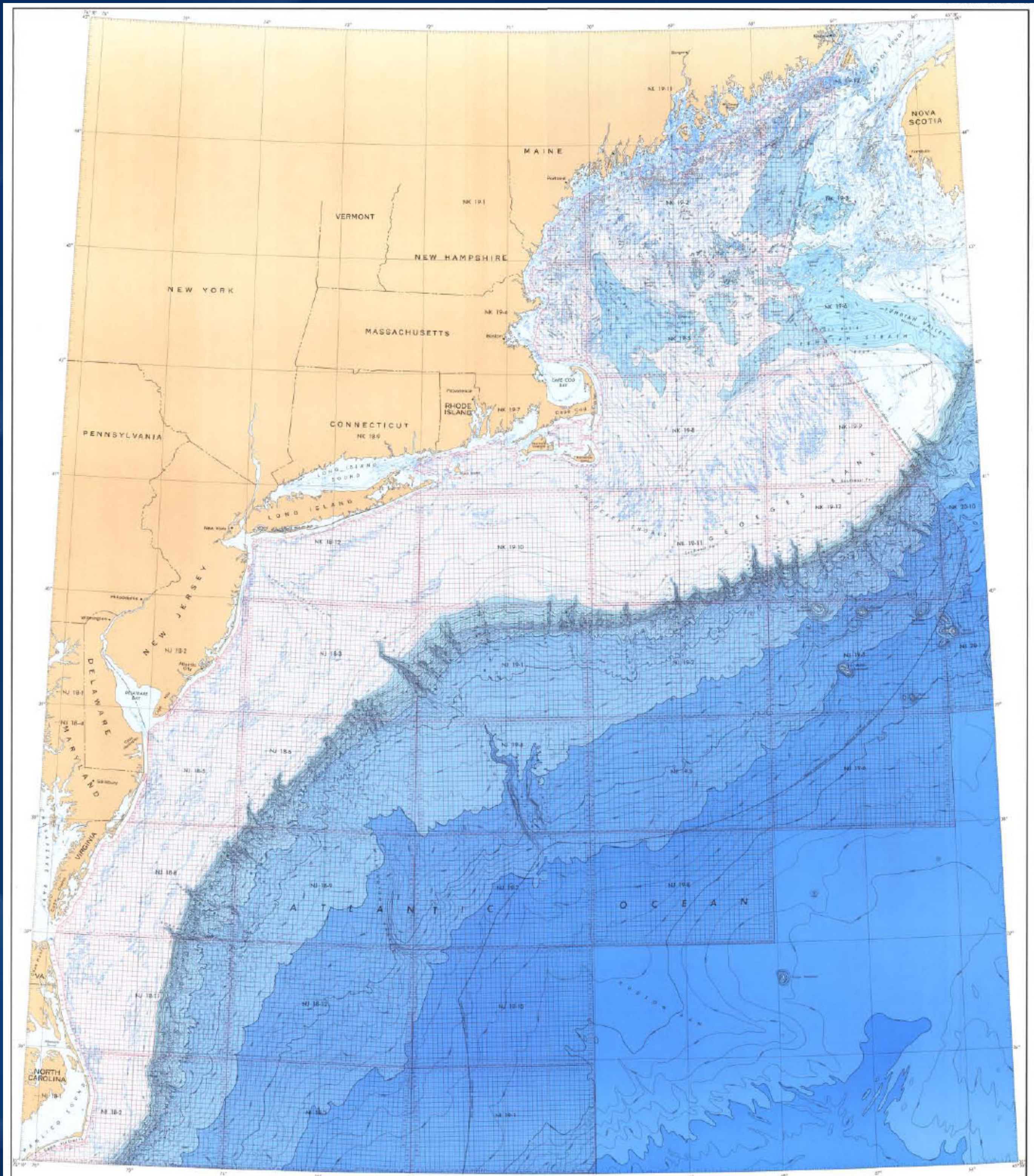
Figure Courtesy of Pete Sugarman (NJGS)

Conclusions

- Advantages to sequestering carbon dioxide in the sedimentary units of the Baltimore Canyon Trough, offshore Atlantic Coast include ease of leasing, additional trapping mechanisms, and large potential capacity.
- A wide variety of data is already available and a significant amount of analysis as already been done by previous studies.
- There are numerous sandstone and limestone formations with high porosities and permeabilities making them excellent potential sequestration reservoirs.
- Migration pathways and confining units such as shales require more attention, but appear to be sufficient for containing sequestered CO_2.

Long Term Future Work

Although this project is part of the MRCSP's Phase III, the work being done is more comparable to the onshore characterization that was done in Phase I. Collection of new data such as a 3-D seismic survey may become an option in subsequent phases of the project.



More opportunities to the north east in the Georges Bank region and to the south off the coast of Virginia and North Carolina.

"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