Carbon Dioxide Storage Resource Assessment of the Mid-Atlantic Ocean Seaboard: Analysis of Geological and Geophysical Vintage Data

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SOSRA

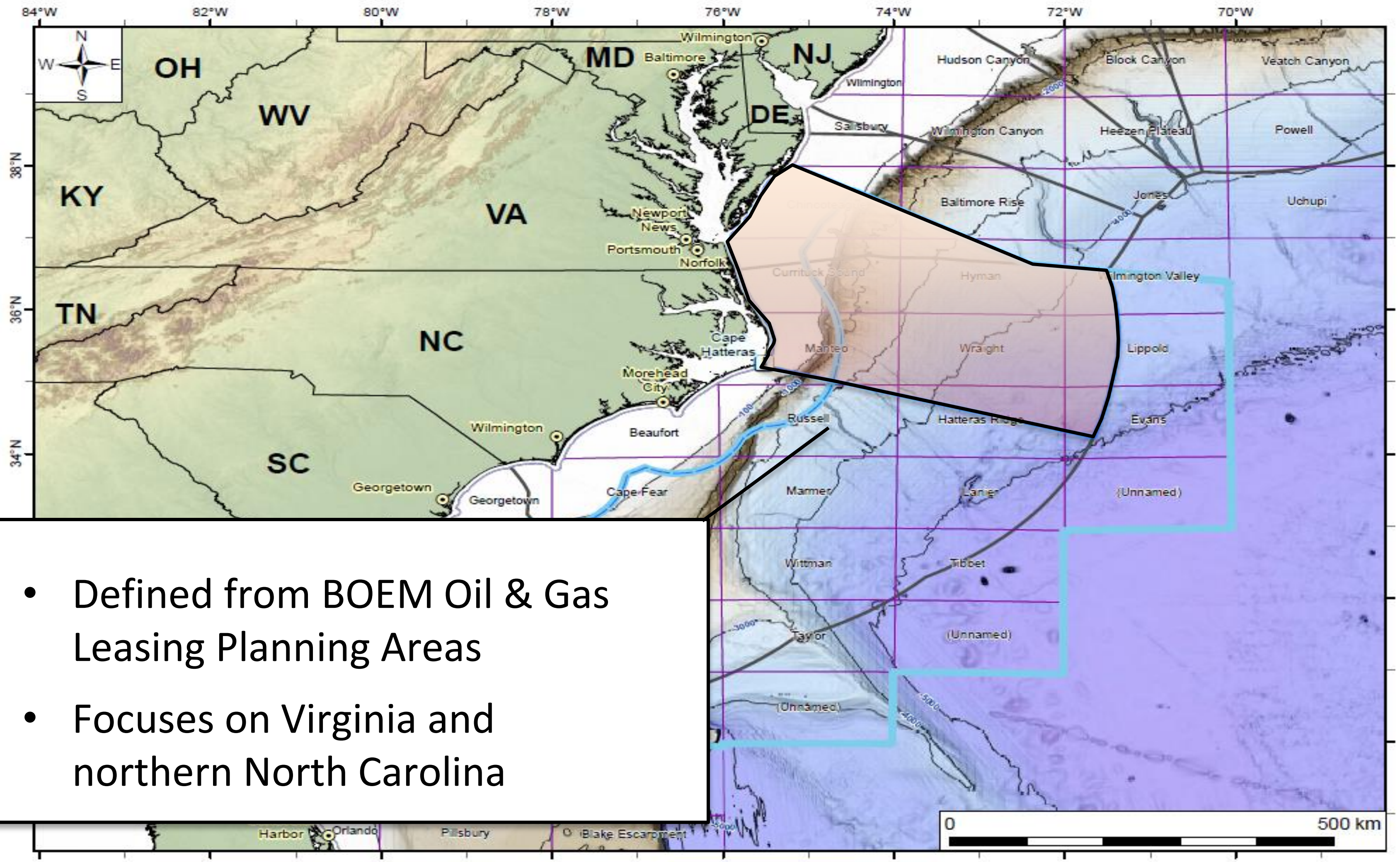
Southeast Offshore Storage Resource Assessment

- Founded by the Department of Energy
- Managed by the Southern States Energy Board (SSEB)
- SSEB appointed three planning area managers to each offshore region (defined by BOEM)
- Mid-Atlantic Seaboard Planning Area management was awarded to researchers at Virginia Tech's Virginia Center for Coal and Energy Research (VCCER)

Mid-Atlantic: Team

- Virginia Tech
- Virginia Center for Coal and Energy Research (VCCER)
- VA DMME
- Advisors and Consultants

SOSRA Mid-Atlantic Study Area



- Defined from BOEM Oil & Gas Leasing Planning Areas
- Focuses on Virginia and northern North Carolina

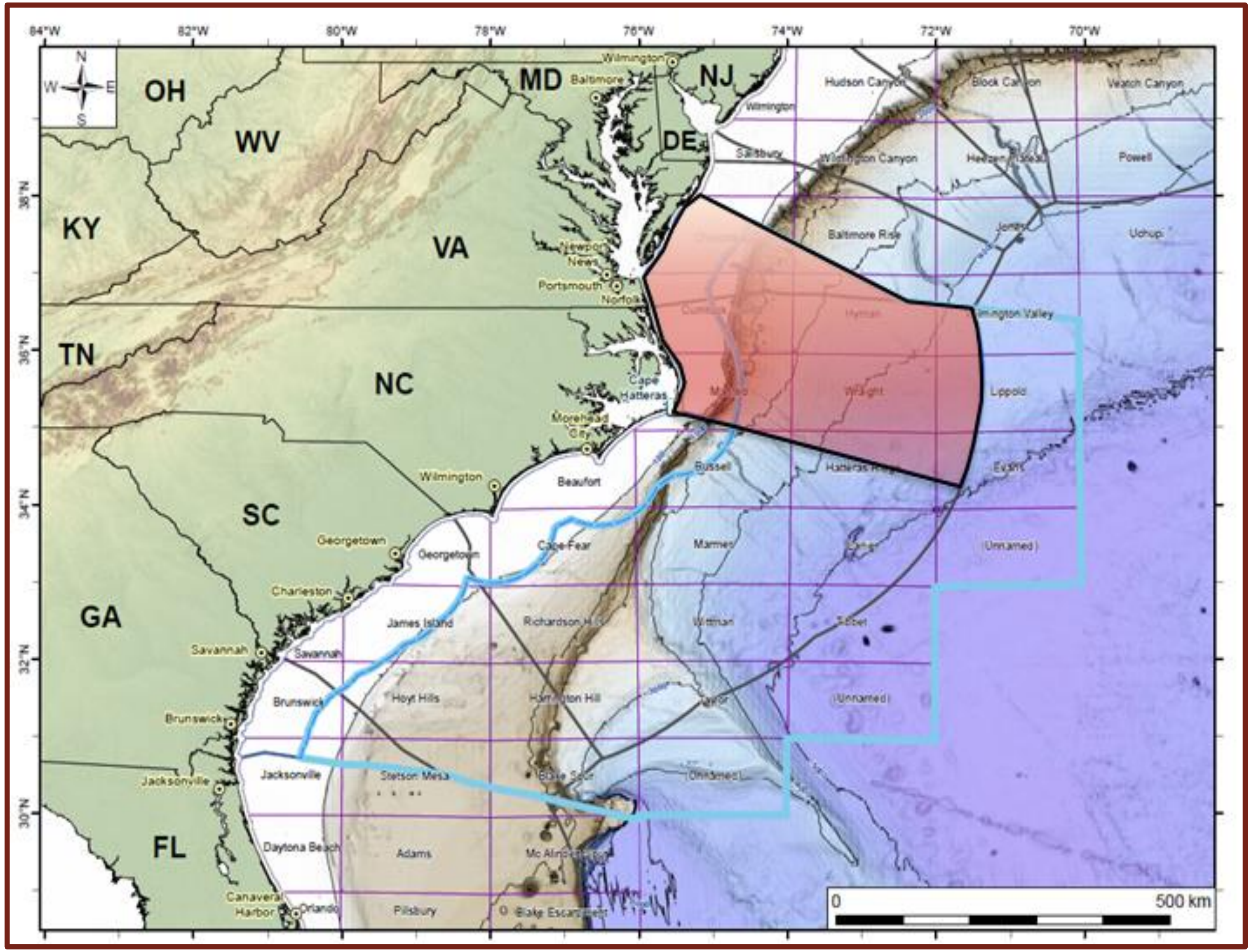
Summary

- SOSRA's Objectives
- Phase I Objectives
- Identify Potential Geological Target for the Storage of CO2
- Data Collection
- Preliminary Results
- Conclusion

SOSRA: Objectives

Southeast Offshore Storage Resource Assessment

- Provide a high quality prospective carbon dioxide storage resource assessment of the Atlantic ocean and the eastern part of the Gulf of Mexico
- Predicting storage capacity to within ± 30%
- Provide a pathway toward commercialization



Phase I: Objectives

- Data Collection
- Basic Geological Framework: Based on Publications
- Data Analysis
  - Quality assessment
  - Coverage assessment
  - Well ties
- Seismic Interpretation

Identification of Geological Targets

- Reservoir Parameters

➢ High Porosity (up to 30%)

➢ Permeability (1 to 10^{-5} Darcy)

(Ideally Sandstone and Limestone)

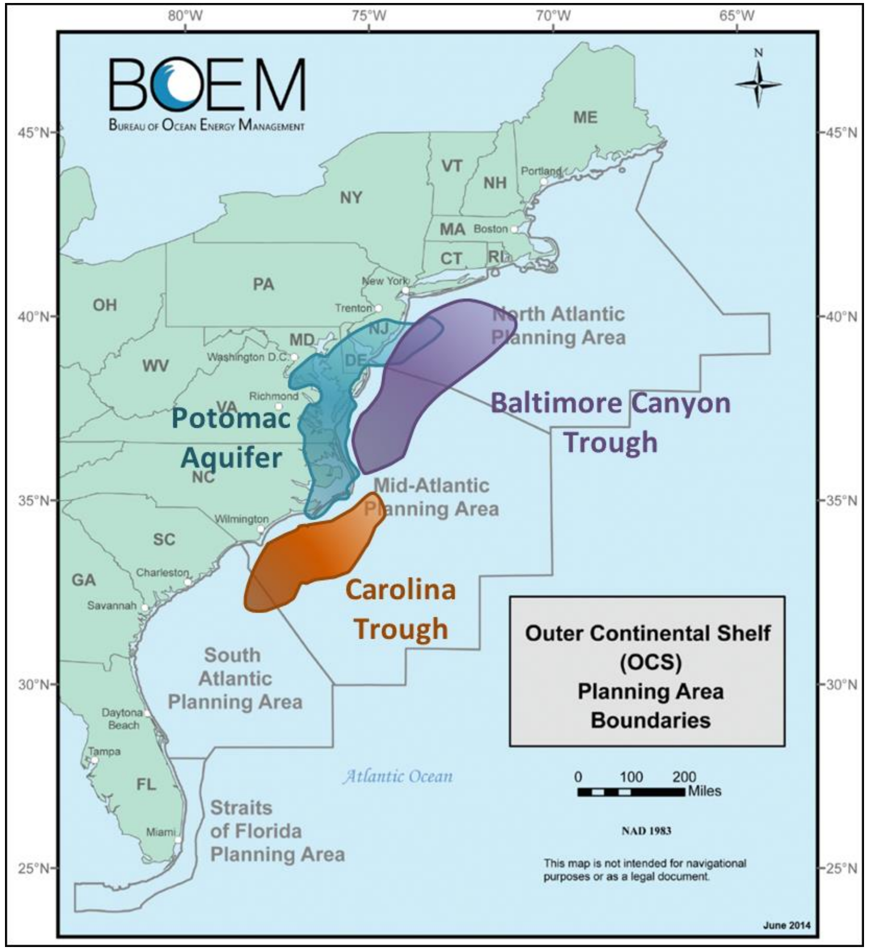
- Presence of a Seal

➢ Low permeability layer above the porous rock

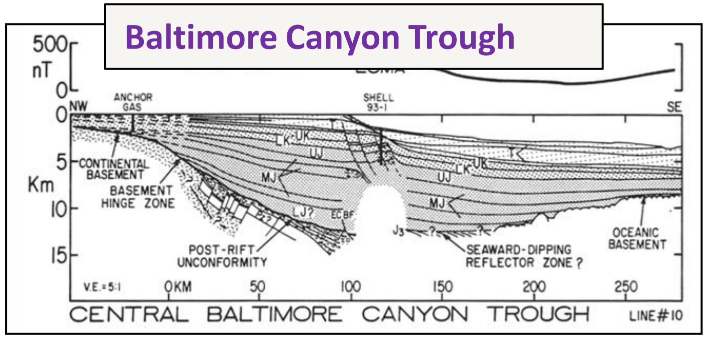
(Shale: 10^{-5} to 10^{-9} Darcy, Clay…)

- Thickness of Reservoir Large Enough

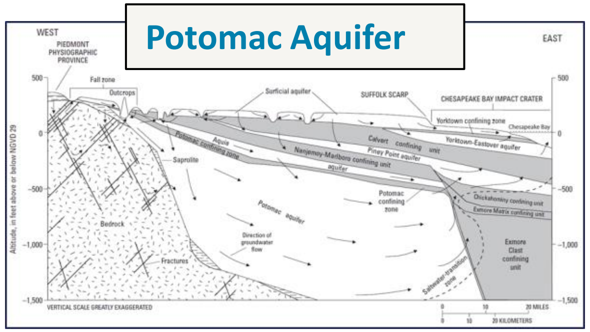
Initial Geologic Characterization



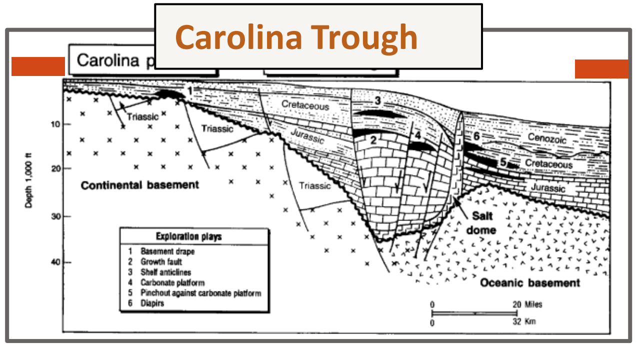
Modified from BOEM, USGS, GCCC, and Bayer and Milici,1987.



From Klitgord, 1988.



From USGS, 2013.



From Carpenter and Amato, 1992.

Data Overview

Wells

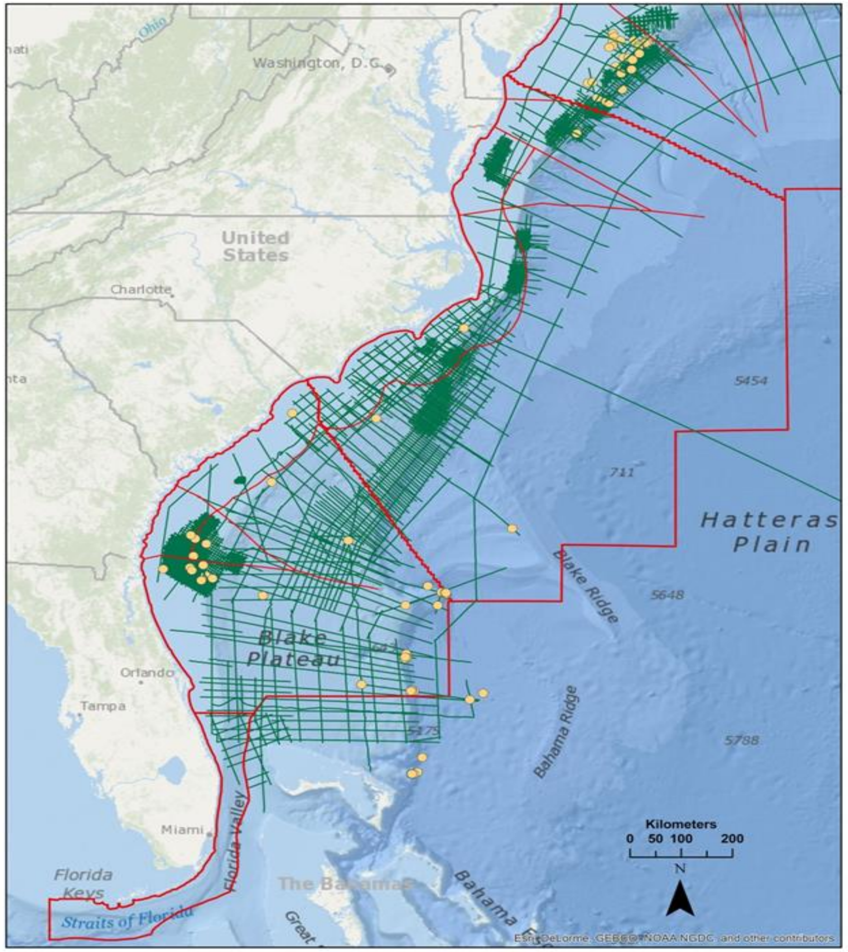
- Atlantic Slope Project (1967): 13
- Atlantic Margin Coring (1976): 3
- Ocean Drilling Program (1987): 2
- Shell Oil and Gas Exploration (1984): 1

30 Surveys: 2D multi-channel seismic (vintage)

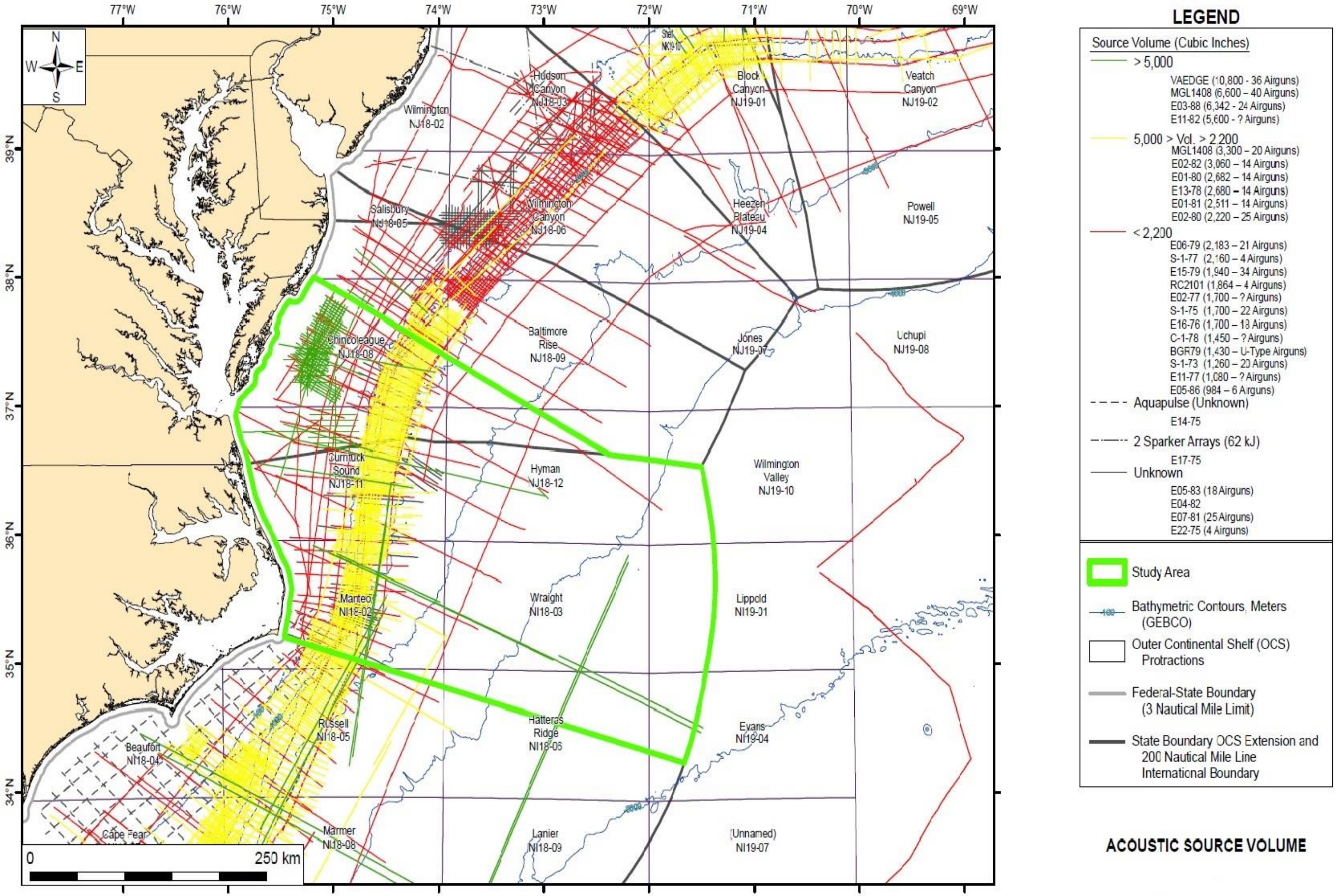
- Over 1,000 lines collected

Publications

Main Issue: Lack of <u>Well Control</u>



Quality Assessment



❖ **Acoustic Source Volume**
Much smaller than modern air gun volumes
Limits Depth Penetration

❖ **Streamer Length**
For most less than 4km
Can't go deeper than 4km and therefore not recommend for exploration purposes

❖ **CDP Fold**
For most 48 or less so S/N ratio not ideal

This parameters decrease the quality of the legacy surveys compared to modern 2-D surveys

Coverage

Critical Parameter: Line Spacing between Dip line and Strike Line

Surveys divided into 3 categories based on their line-spacing:

- **Regional**: greater than 8 nautical miles (15km)

Gives basic overview of the basin of interest

- **Semi-Regional**: between 3 and 8 nautical miles (5 to 15km)

To identify potential area of interest within a basin

- **Exploration Scale**: less than 3 nautical miles (5km)

To characterize a potential reservoir

30 Surveys provide a <u>good coverage</u> of the Mid-Atlantic region.
However, not enough wells in the region to establish good ties (1 well).

Seismic Line Spacing for Surveys Acquired in Virginia and Northern North Carolina Waters*

Permit or Survey	Specific OCS Area Tabulated[1]	Survey Scope[2]	Seismic Data Type Available	Number of Dip Lines	Typical Spacing Between Dip Lines	Number of Strike Lines	Typical Spacing Between Strike Lines
All four 1973-1978 USGS surveys in study area	Lines extending into VA and Northern NC waters	Regional	Demux & Stacked	6	22-27 nmi (40-50 km)	2	92 nmi (170 km)
E14-75	Cape Hatteras, NC to Northern SC	Semi-Regional	Stacked	25	5-11 nmi (10-20 km)	Variable, 3 to 7	5-11 nmi (10-20 km)
E16-76	Cape Hatteras, NC to MD	Semi-Regional	Stacked & Migrated	35	2-8 nmi (4-15 km)	6	5-14 nmi (10-25 km)
BGR 79	Lines extending into VA waters	Regional	Stacked & Migrated	0	NA	4	7-14 nmi (12-25 km)
E01-80	Currituck Sound Protraction	Exploration	Stacked & Migrated	16	1-2 nmi (2-3 km)	6	1-3 nmi (2-5 km)
	Manteo Protraction	Exploration	Stacked & Migrated	23	1-3 nmi (2-5 km)	7	1.5-2 nmi (3-4 km)
E02-80	Currituck Sound Protraction	Exploration	Stacked, Migrated & Depth	8	1-3 nmi (2-5 km)	2	4 nmi (7 km)
	Manteo Protraction	Exploration	Stack, Migrated & Depth	22	1-3 nmi (2-5 km)	2	5-11 nmi (10-20 km)
E01-81	Northern NC and VA	Regional	Stacked & Migrated	7	14 nmi (26 km)	2	10 nmi (18 km)
E07-81	Manteo Protraction	Exploration	Migrated & Depth	11	1.5-3 nmi (2.5-5 km)	1	NA
E02-82	Northern NC to Southern MD	Exploration	Stack, Migrated, Depth	104	1 nmi (1.5 km)	4	7 nmi (13 km)
E04-82	Northern NC and VA	Regional	Migrated & Depth	9	5-16 nmi (9-30 km)	0	NA
E11-82	Norfolk Basin, VA	Exploration	Migrated	33	1.5 nmi (2.5 km)	11	2 nmi (3 km)
	Northern NC to Southern MD	Regional	Migrated	5	14-34 nmi (25-63 km)	3	4-15 nmi (7-27 km)
E05-83	Northern NC slope	Exploration	Migrated & Depth	6	1-3 nmi (2-5 km)	0	NA
E03-88	Currituck Sound Protraction	Exploration	Migrated	8	3 nmi (5 km)	1	NA
	Norfolk Basin, VA	Exploration	Stacked	7	3 nmi (5 km)	1	NA

Well Ties

- Seismic lines passing as close as possible to the wells
- Most are in the Northern part of the Mid-Atlantic
- Starting point for interpretation
- Will allow calibration of geological model and insure consistency of the interpretation
- For each well collected:

One or more lines passes as close as 1km and at the most 3km.

Wells	Permit	Line	Orientatic	Type	Approximate distance from well
AMCOR 6006	E02-77	BP-102	Dip	Depth	3 km
AMCOR 6006	E02-82	pr92-225	Dip	Migrated	3 km
AMCOR 6006	E14-75	we-011-2	Strike	Stack	2 km
AMCOR 6006	E14-75	we-011-2	Dip	Stack	3 km
AMCOR 6007	E04-82	18079	Dip	Migrated or Depth	2 km
AMCOR 6007	E16-76	ma-22	Dip	Migrated	3 km
AMCOR 6007	E16-76	ma-7-2	Strike	Migrated	1 km
ASP 10	E01-81	pp81-324b	Strike	Migrated	1 km
ASP 10	E02-82	pr82-121	Dip	Migrated or Depth	< 1 km
ASP 10	E02-82	pr82-122a	Dip	Migrated or Depth	< 1 km
ASP 13	C-1-78	25	Dip	Stack	1.5 km
ASP 13	E11-77	MA-104 D/E	Strike	Migrated	< 1 km
ASP 14	E11-77	MA-108B	Strike	Migrated	1 km
ASP 14	E11-77	MA-129	Dip	Migrated	2 km
ASP 15	C-1-78	25	Strike	Stack	1 km
ASP 15	E11-77	MA-112A	Strike	Migrated	1 km
ASP 15	E11-77	MA-131	Dip	Migrated or Depth	2 km
ASP 22	E01-81	pp81-324b	Strike	Migrated	< 1 km
ASP 22	E02-82	pr82-124	Dip	Migrated or Depth	< 1 km
ASP 23	E02-82	pr82-099	Dip	Migrated or Depth	< 1 km
ASP 23	E02-82	pr82-230-1	Strike	Migrated or Depth	1.5 km
ASP 7	E01-80	56-059	Strike	Migrated	< 1 km
ASP 7	E02-80	sa1048	Dip	Migrated	< 1 km
ASP 8	E01-80	56-088	Dip	Migrated	< 1 km
ASP 8	E07-81	csa81-12b	Strike	Migrated	< 1 km
ASP 8	E07-81	csa81-9	Dip	Migrated	< 1 km
Shell 372-1	E11-77	MA-116A	Strike	Migrated	< 1 km
Shell 372-1	E11-77	MA-139	Dip	Migrated or Depth	< 1 km
Shell 586-1	BGR-79	203	Strike	Migrated	1.5 km
Shell 586-1	E11-77	MA-112B	Strike	Migrated	1 km
Shell 586-1	E11-77	MA-151	Dip	Migrated or Depth	2.5 km
Shell 587-1	E11-77	MA-116A	Strike	Migrated	< 1 km
Shell 587-1	E11-77	MA-151	Dip	Migrated or Depth	1.5 km
Shell 93-1	S-1-75	10	Dip	Stack	1 km
Shell 93-1	E11-77	MA-112B	Strike	Migrated	1 km
Shell 93-1	E11-77	MA-191	Dip	Migrated or Depth	1 km
Tenneco 495-	E22-75	5044	Oblique	Stack	< 1 km
Tenneco 495-	E11-77	MA-153	Dip	Migrated or Depth	1 km
Tenneco 495-	S-1-77	TD15A	Strike	Stack	< 1 km

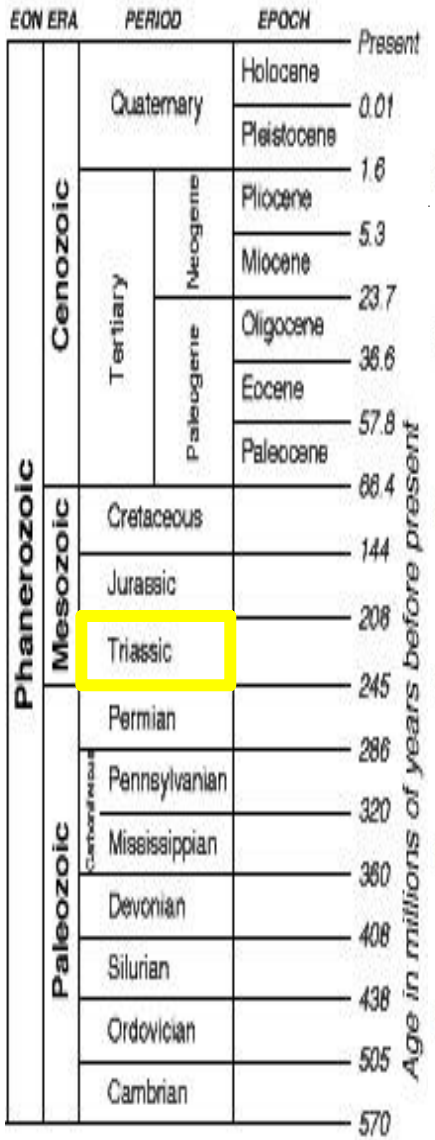
Preliminary Results: Seismic Interpretation

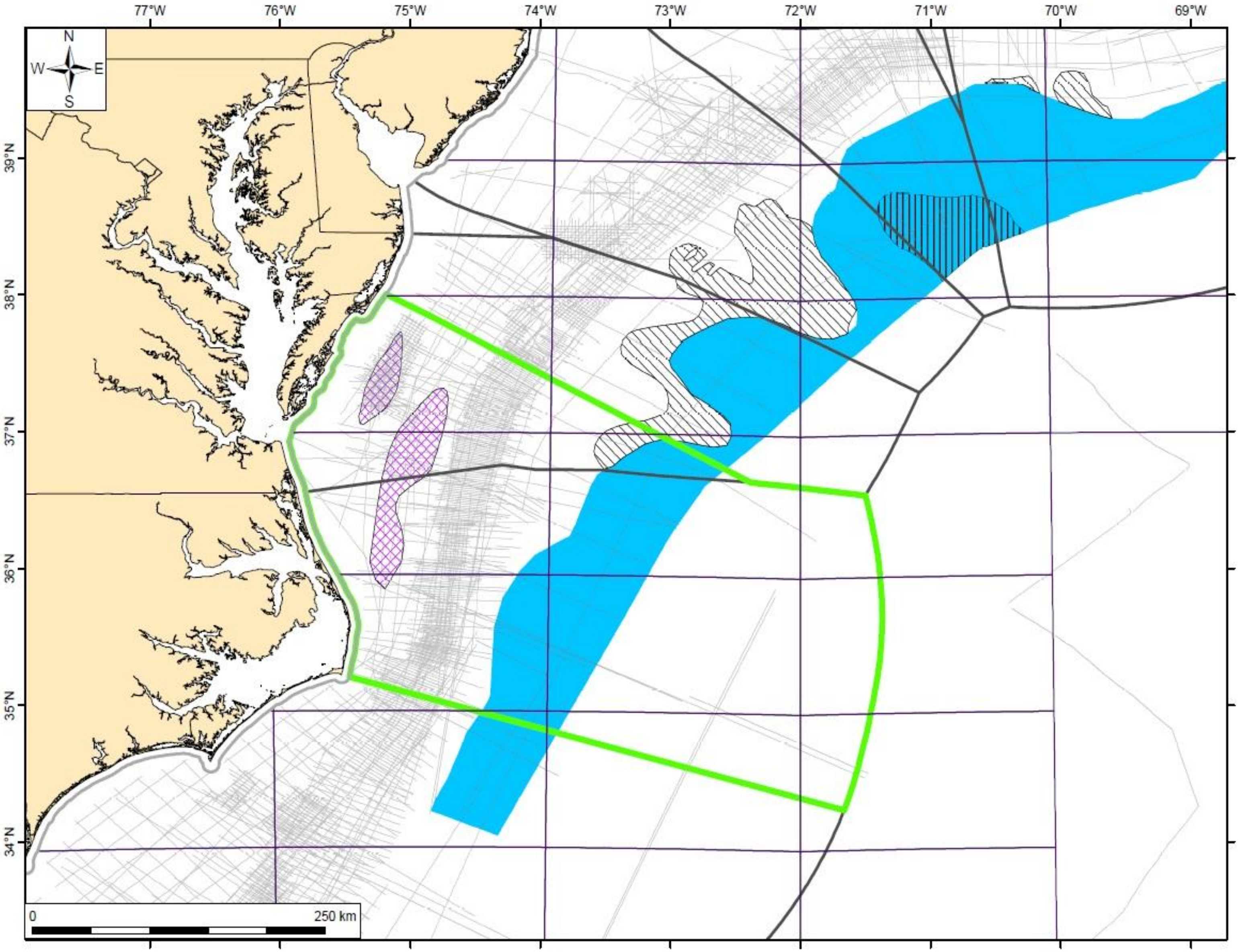
- Klitgord, K.D., Poag, C.W., Schneider, C.M., and North, L., 1994, Geophysical database of the East Coast of the United States: northern Atlantic margin - cross sections and gridded database (Georges Bank Basin, Long Island Platform, and Baltimore Canyon Trough), U.S. Geological Survey Open-File Report 94-637, 190 p.

- Klitgord, K.D., and Schneider, C., 1994, Geophysical database of the East Coast of the United States: northern Atlantic margin - velocity analyses, U.S. Geological Survey Open-File Report 94-192, 74 p.

- Bayer, K.C., and Milici, R.C., 1987, Geology and petroleum potential of Mesozoic and Cenozoic rocks, offshore Virginia: Virginia Division of Mineral Resources Publication 73, pt. D, 111 p. and two plates.

Few surveys were public when these papers were published and therefore only the USGS regional lines have been used for the interpretation.





LEGEND

- Extent of Potential Triassic Synrift CO_2 Reservoirs[1]
- Extent of Potential Middle Jurassic CO_2 Reservoirs[2]

Extent of Potential Jurassic CO_2 Reservoirs

- Confining Unit: 120[3]
- Confining Unit: 140[4]
- Study Area
- Seismic Tracklines Described in Report
- Outer Continental Shelf (OCS) Protractions
- Federal-State Boundary (3 Nautical Mile Limit)
- State Boundary OCS Extension and 200 Nautical Mile Line International Boundary

Notes:

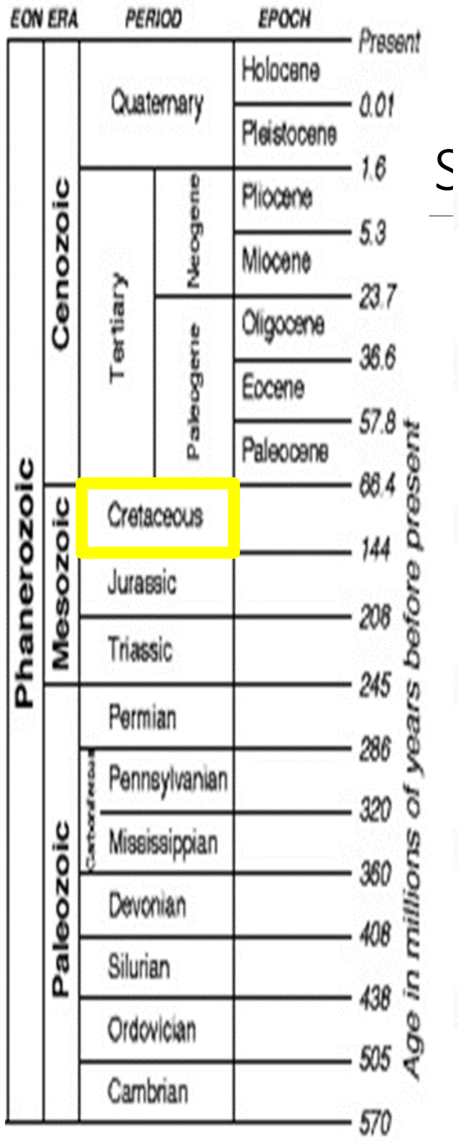
[1]Potential Triassic Synrift CO_2 Reservoirs:
Source of reservoir extent: Bayer and Milici (1987)
Confining Unit: Unknown
Reservoir: Many of the exposed Triassic basins along the US East Coast are sandstone-rich making these offshore buried synrift basins potential CO_2 reservoirs.

[2]Potential Middle Jurassic CO_2 Reservoirs:
Source of reservoir extent: Klitgord et al. (1994)
Confining Unit: Late Jurassic shale (Seismic Reflector 150)
Reservoirs: Middle Jurassic limestones, sandstones and siltstones

[3]Potential Jurassic CO_2 Reservoirs:
Source of reservoir extent: Klitgord et al. (1994)
Confining Unit: Late Jurassic shale (Seismic Reflector 140)
Reservoirs: Late and Middle Jurassic limestones, sandstones

[4]Potential Late Jurassic CO_2 Reservoirs:
Source of reservoir extent: Klitgord et al. (1994)
Confining Unit: Early Cretaceous shale (Seismic Reflector 120)
Reservoirs: Late Jurassic (Kimmeridgian and Tithonian) sandstones and siltstones

POTENTIAL CO_2 RESERVOIRS: TRIASSIC AND JURASSIC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Cretaceous
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Jurassic
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Triassic
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Mesozoic
Permian
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Pennsylvanian
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Devonian
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Silurian
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Ordovician
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Cambrian
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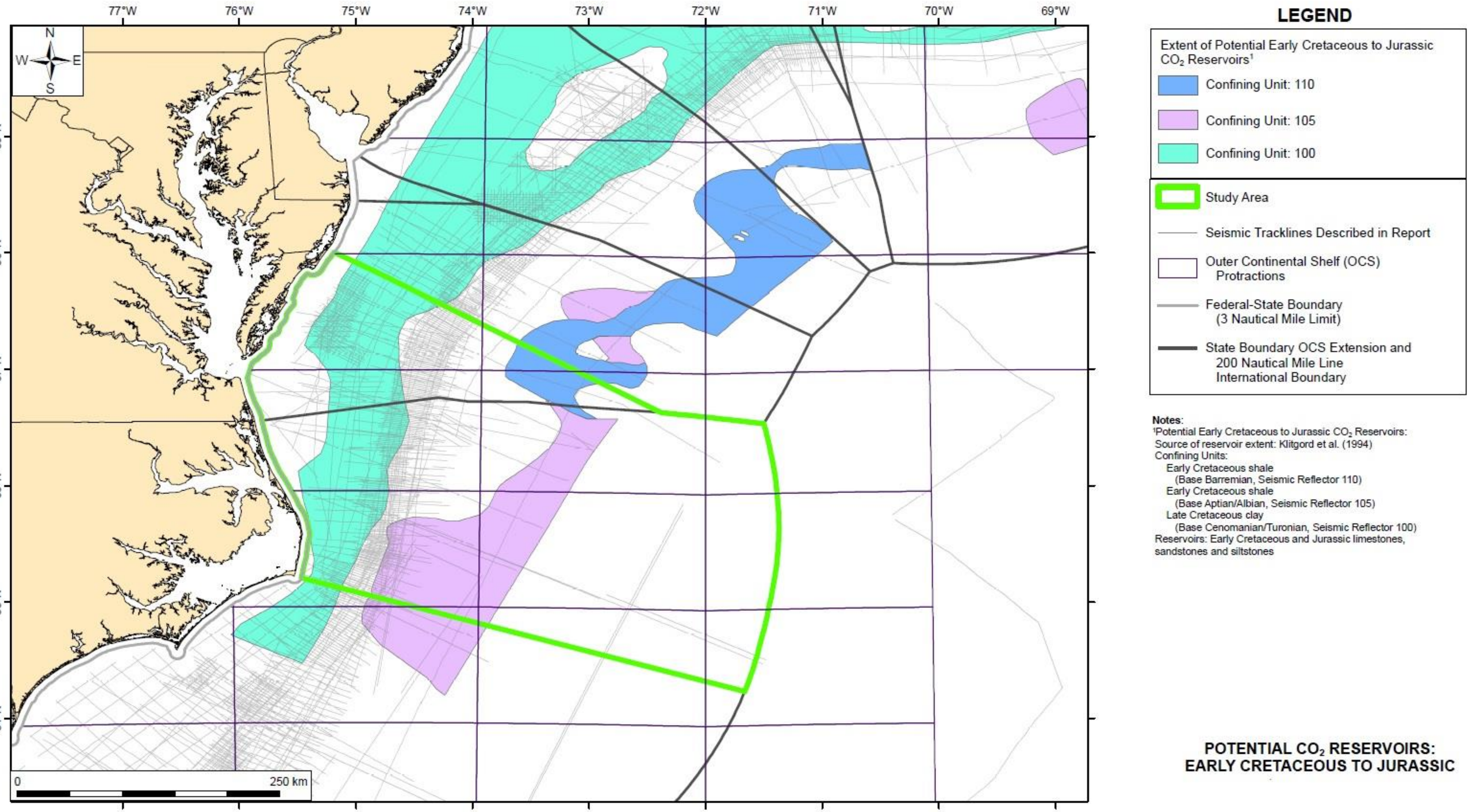
Paleozoic
Phanerozoic
Age in millions of years before present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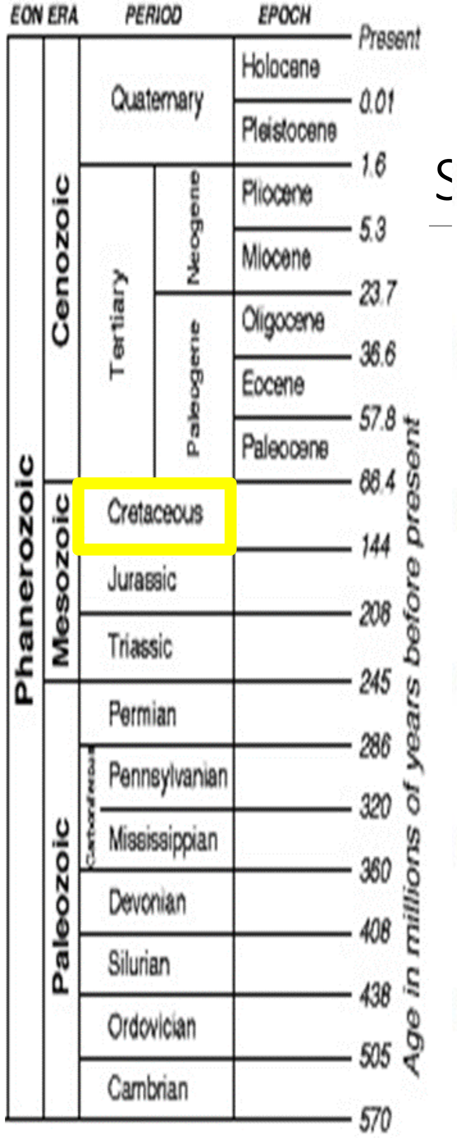
LEGEND
Extent of Potential Early Cretaceous to Jurassic CO_2 Reservoirs[1]
Confining Unit: 110
Confining Unit: 105
Confining Unit: 100
Study Area
Seismic Tracklines Described in Report
Outer Continental Shelf (OCS) Protractions
Federal-State Boundary (3 Nautical Mile Limit)
State Boundary OCS Extension and 200 Nautical Mile Line International Boundary
Notes:
[1]Potential Early Cretaceous to Jurassic CO_2 Reservoirs:
Source of reservoir extent: Klitgord et al. (1994)
Confining Units:
Early Cretaceous shale
(Base Barremian, Seismic Reflector 110)
Early Cretaceous shale
(Base Aptian/Albian, Seismic Reflector 105)
Late Cretaceous clay
(Base Cenomanian/Turonian, Seismic Reflector 100)
Reservoirs: Early Cretaceous and Jurassic limestones, sandstones and siltstones
POTENTIAL CO_2 RESERVOIRS: EARLY CRETACEOUS TO JURASSIC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Silurian
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Ordovician
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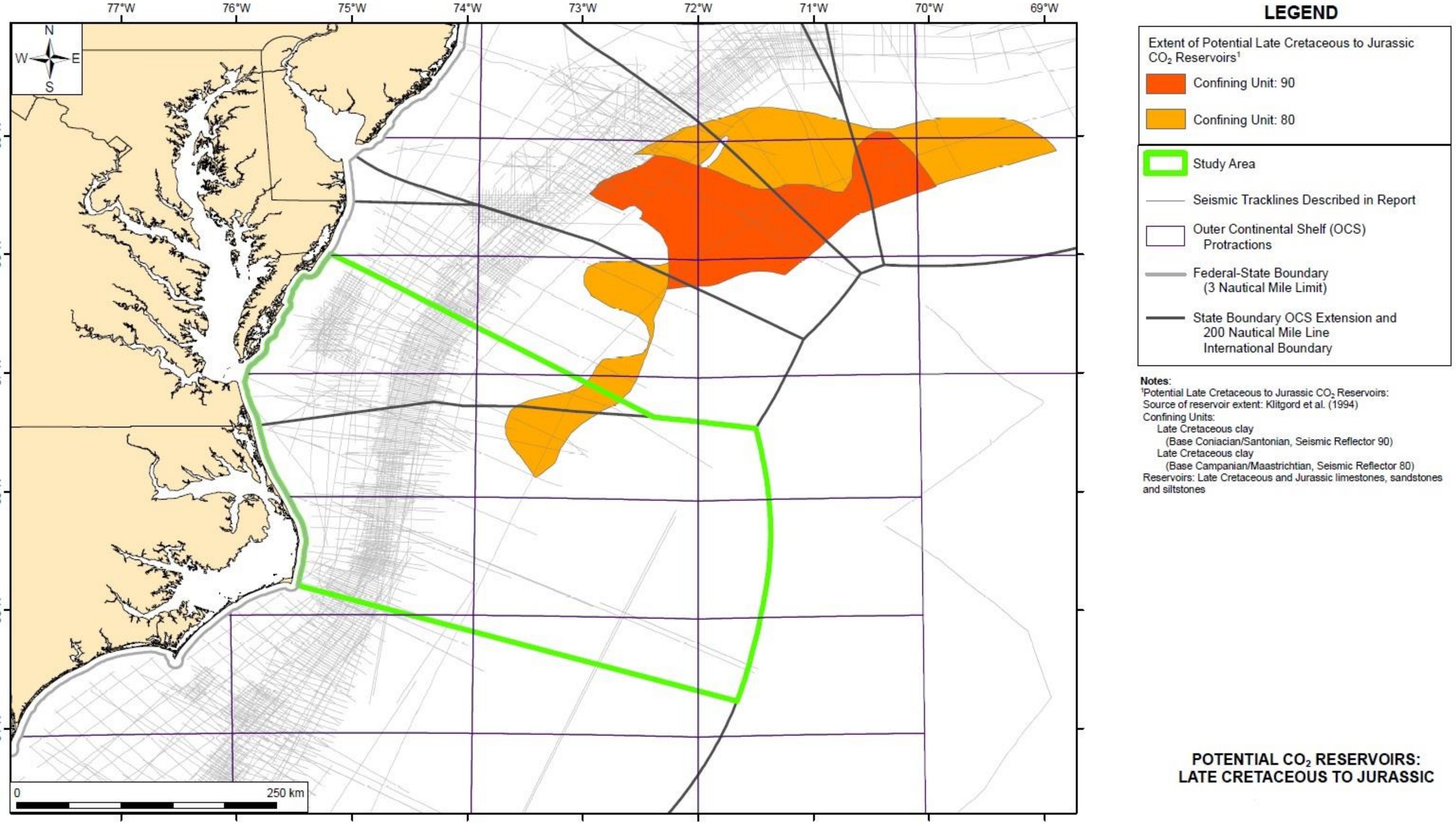
Age in millions of years before present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LEGEND
Extent of Potential Late Cretaceous to Jurassic CO_2 Reservoirs[1]
Confining Unit: 90
Confining Unit: 80
Study Area
Seismic Tracklines Described in Report
Outer Continental Shelf (OCS) Protractions
Federal-State Boundary (3 Nautical Mile Limit)
State Boundary OCS Extension and 200 Nautical Mile Line International Boundary
Notes:
[1]Potential Late Cretaceous to Jurassic CO_2 Reservoirs:
Source of reservoir extent: Klitgord et al. (1994)
Confining Units:
Late Cretaceous clay
(Base Coniacian/Santonian, Seismic Reflector 90)
Late Cretaceous clay
(Base Campanian/Maastrichtian, Seismic Reflector 80)
Reservoirs: Late Cretaceous and Jurassic limestones, sandstones and siltstones
POTENTIAL CO_2 RESERVOIRS:
LATE CRETACEOUS TO JURASSIC

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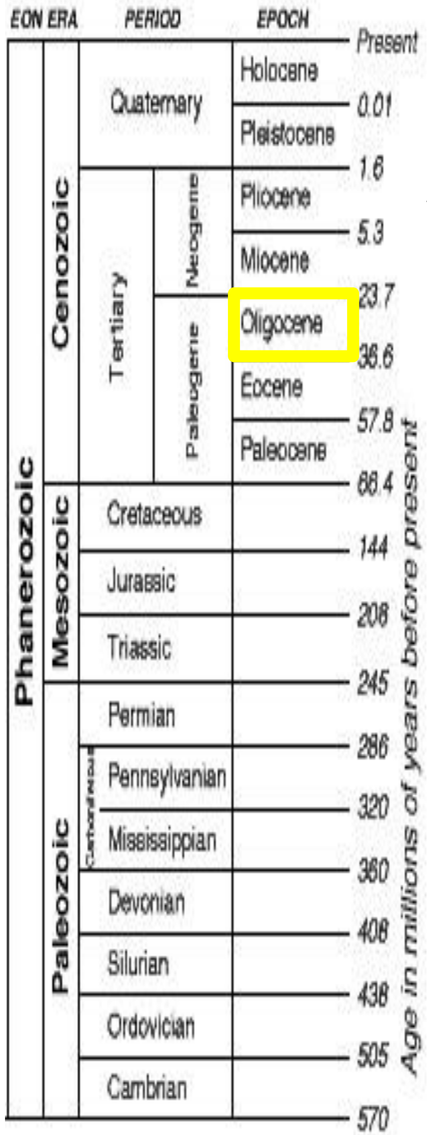
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PERIOD
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Holocene
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Paleozoic
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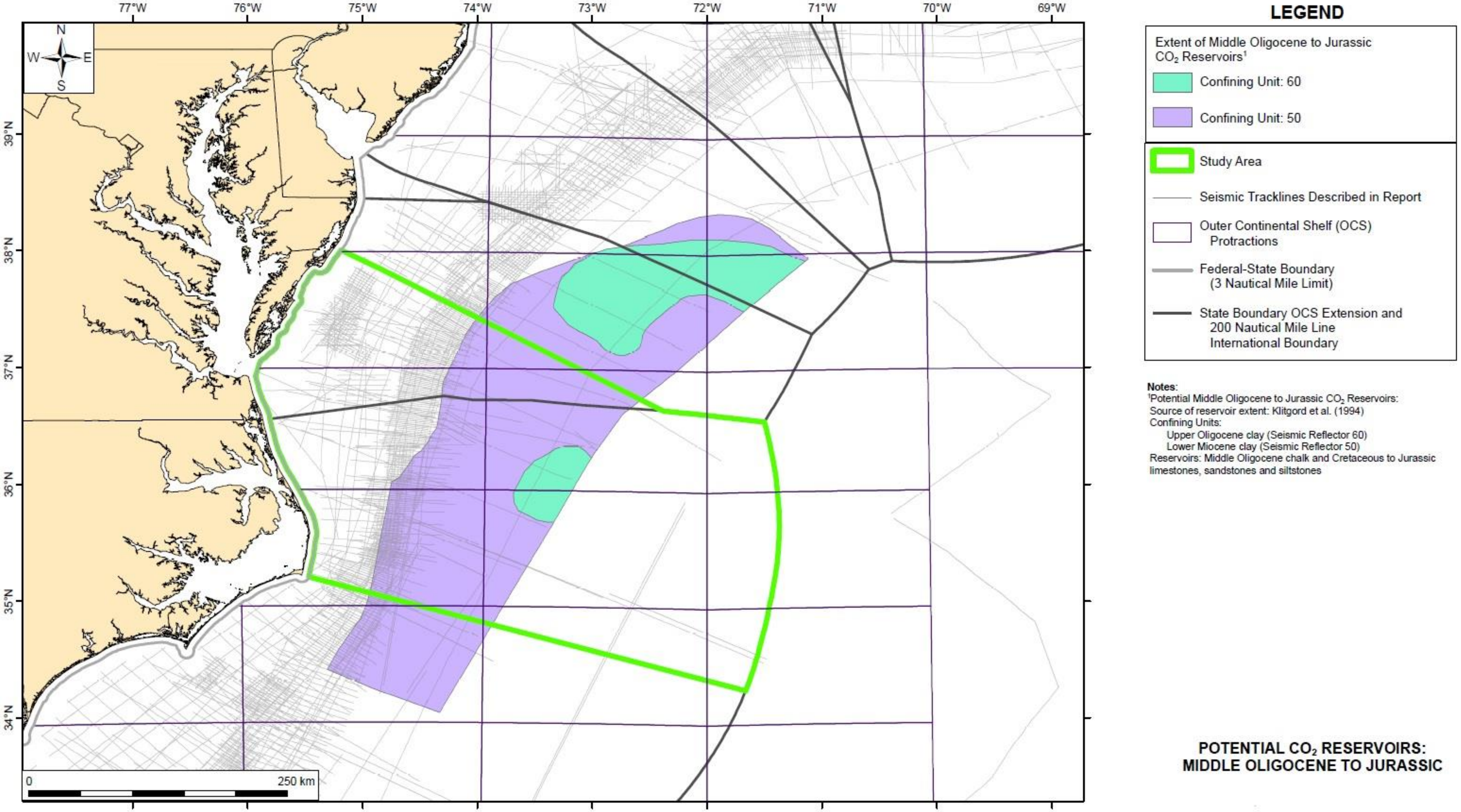
Age in millions of years before present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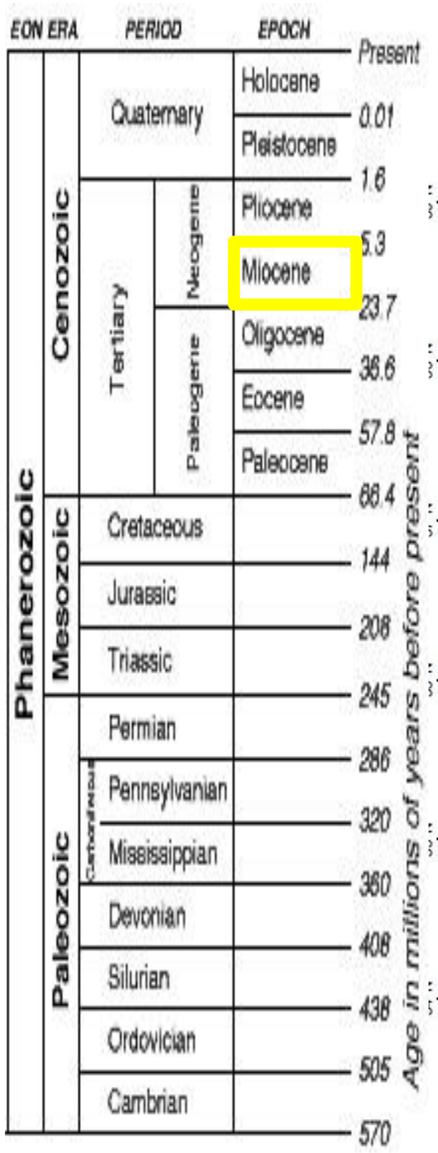
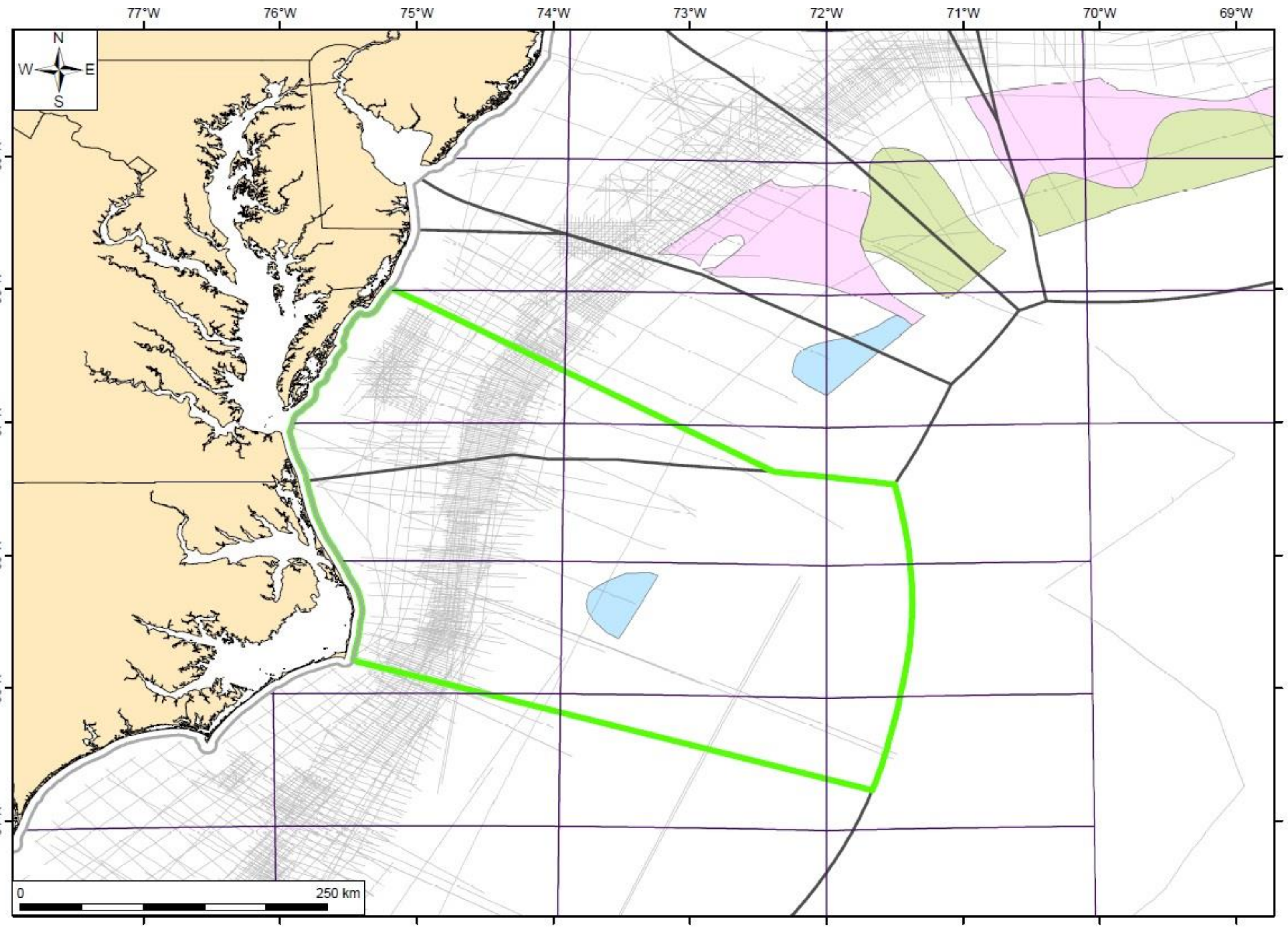
LEGEND
Extent of Middle Oligocene to Jurassic CO_2 Reservoirs[1]
Confining Unit: 60
Confining Unit: 50
Study Area
Seismic Tracklines Described in Report
Outer Continental Shelf (OCS) Protractions
Federal-State Boundary (3 Nautical Mile Limit)
State Boundary OCS Extension and 200 Nautical Mile Line International Boundary
Notes:
[1]Potential Middle Oligocene to Jurassic CO_2 Reservoirs:
Source of reservoir extent: Klitgord et al. (1994)
Confining Units:
Upper Oligocene clay (Seismic Reflector 60)
Lower Miocene clay (Seismic Reflector 50)
Reservoirs: Middle Oligocene chalk and Cretaceous to Jurassic limestones, sandstones and siltstones
POTENTIAL CO_2 RESERVOIRS:
MIDDLE OLIGOCENE TO JURASSIC





LEGEND

Extent of Miocene to Jurassic CO_2 Reservoirs

- Confining Unit: 45[1]
- Confining Unit: 40[2]
- Confining Unit: 30[3]
- Study Area
- Seismic Tracklines Described in Report
- Outer Continental Shelf (OCS) Protractions
- Federal-State Boundary (3 Nautical Mile Limit)
- State Boundary OCS Extension and 200 Nautical Mile Line International Boundary

Notes:
Potential Miocene to Jurassic CO_2 Reservoirs:
Source of reservoir extent: Klitgord et al. (1994)

[1]Confining Unit: Middle Miocene clay (Seismic Reflector 45)
Reservoirs: Middle Oligocene chalk and Cretaceous to Jurassic limestones, sandstones and siltstones

[2]Confining Unit: Upper Miocene clay (Seismic Reflector 40)
Reservoirs: Middle Miocene sand and silt, Middle Oligocene chalk and Cretaceous to Jurassic limestones, sandstones and siltstones

[3]Confining Unit: Pliocene clay (Seismic Reflector 30)
Reservoirs: Upper and Middle Miocene sand and silt

POTENTIAL CO_2 RESERVOIRS: MIOCENE TO JURASSIC

Summary on Data Analysis

- Good Coverage of Seismic Lines in the Mid-Atlantic
- Poor Coverage of Wells in the Mid-Atlantic

- Quality variable of the Seismic Lines: Older lines tend to have a lower quality than younger ones
- Quality variable of the Well-Logs: Scanned paper copies provide poor quality data

Summary of Initial Interpretation

- Starting Point: Interpretation of the lines closest to the wells selected
- Interpretation of the regional lines to establish basic framework of the Baltimore Canyon Trough and Carolina Trough
- Interpretation of the best quality data to identify formation target for CO_2 sequestration
- Use onshore wells to provide a potential correlation between onshore and offshore basins (Potomac Aquifer)

Questions