

Tenth Annual Conference on Carbon Capture & Sequestration

Sequestration of CO₂ in Geologic Formations (2)

U.S. Geological Survey Geologic Carbon Dioxide Storage Resource Assessment of the United States – Project Update

Peter D. Warwick, Madalyn S. Blondes, Sean T. Brennan, Marc L. Buursink, Margo D. Corum, Jacob A. Covault, William H. Craddock, Christina A. De Vera, Ronald M. Drake II, Philip A. Freeman, Mayur A. Gosai, Celeste D. Lohr, John C. Mars, Matthew D. Merrill, Tina Roberts-Ashby, and Ernie R. Slucher

May 2-5, 2011 • David L. Lawrence Convention Center • Pittsburgh, Pennsylvania

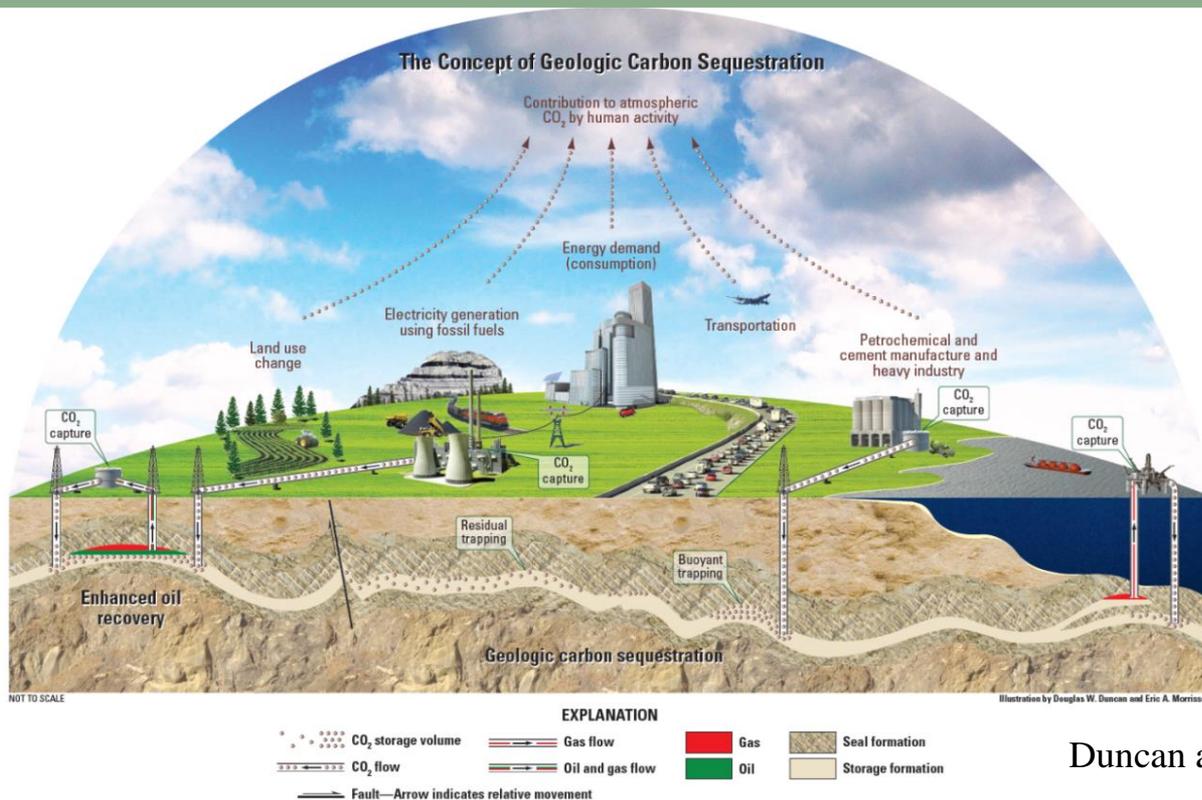
Outline for Presentation

- Energy Independence and Security Act 2007
- Assessment Methodology Overview
- Current Assessment Activities
- Plans for Final CO₂ Assessment Report
- Conclusions

Energy Independence and Security Act 2007

Title VII: Carbon Capture and Sequestration

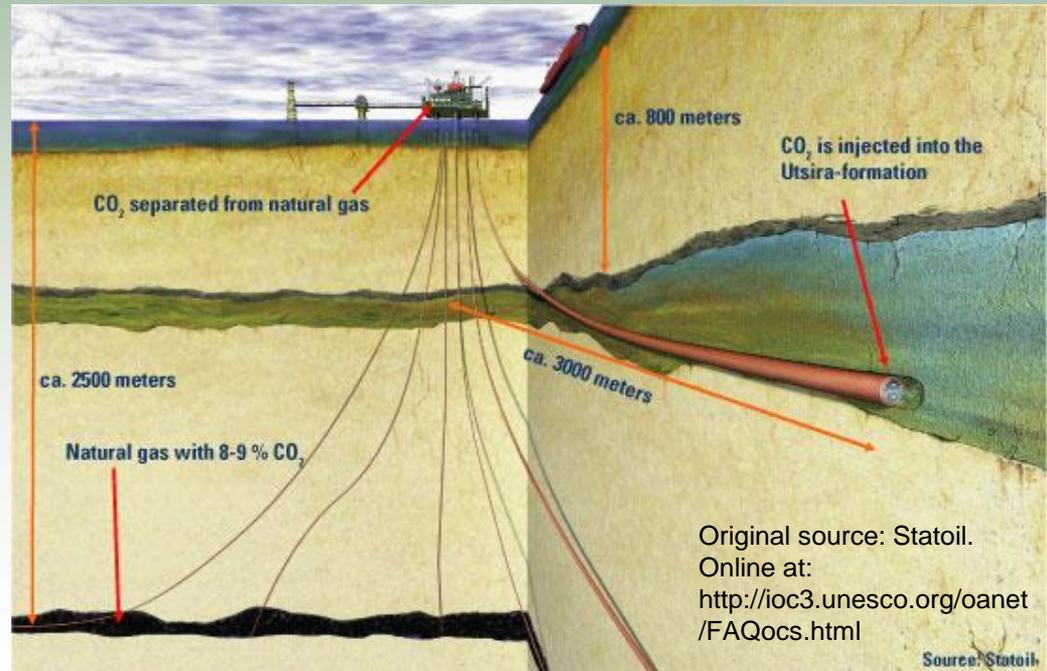
- Subtitle B: Carbon Capture and Sequestration Assessment and Framework
 - Sec. 711: Carbon Dioxide Sequestration Capacity Assessment
 - » Methodology
 - » Coordination



Duncan and Morrissey (2011)

Energy Independence and Security Act 2007

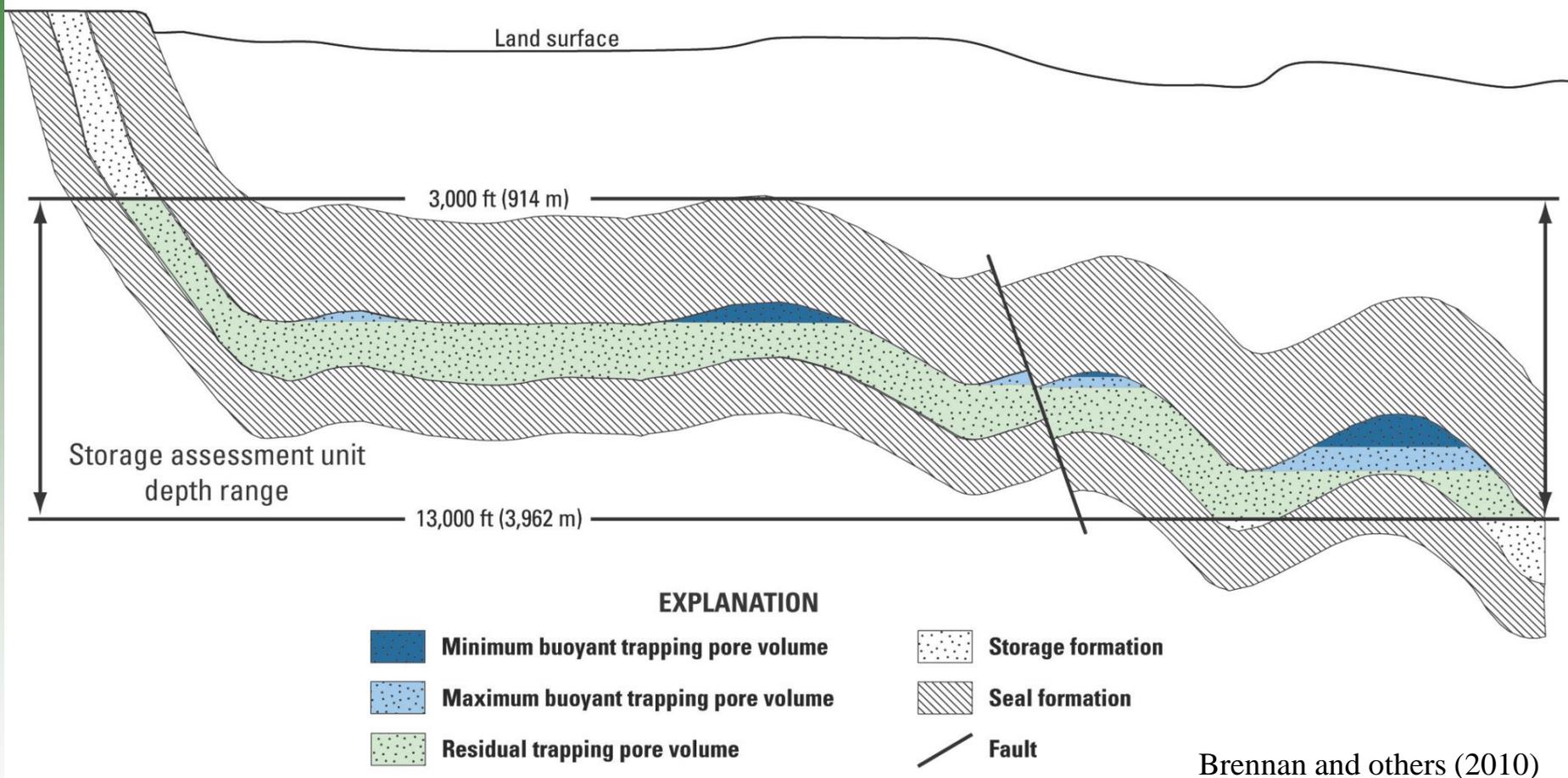
- **METHODOLOGY** ...shall develop a methodology for conducting an assessment... taking into consideration:
 - Geographical extent of all potential sequestration [non-coal] formations in all States
 - Capacity of the potential sequestration formations
 - Injectivity of the potential sequestration formations
 - Estimate of potential volumes of oil and gas recoverable by injection and sequestration of industrial carbon dioxide in potential sequestration formations (Stanford/USGS EOR Workshop May 10-11, 2011)
- **COORDINATION**
 - Federal Coordination
 - State Coordination



USGS CO₂ Assessment Methodology

Schematic Storage Formation Model

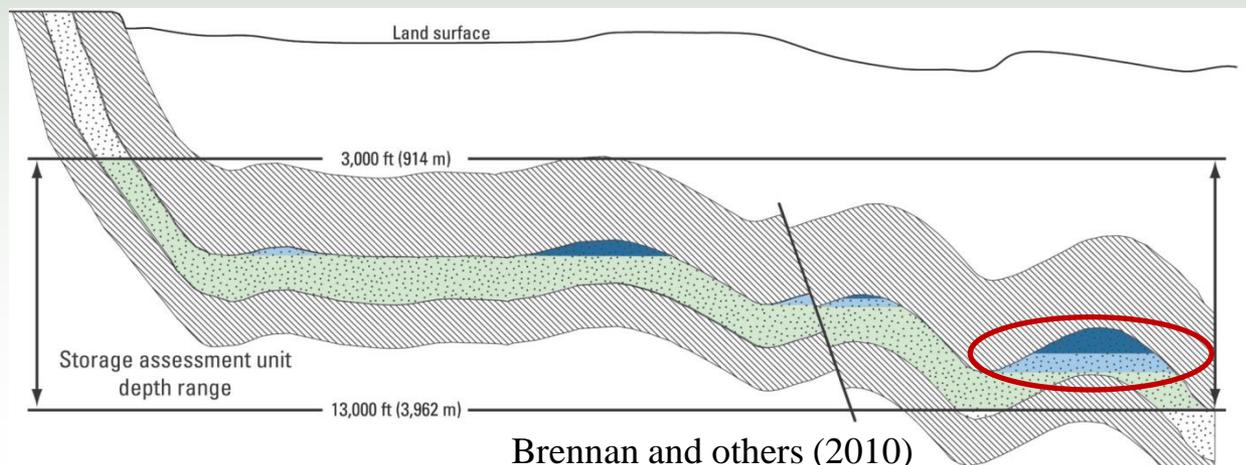
Storage Assessment Unit, Cross Section



Salinity of water in storage formation must be > 10,000 ppm TDS per USEPA (2008) regulations

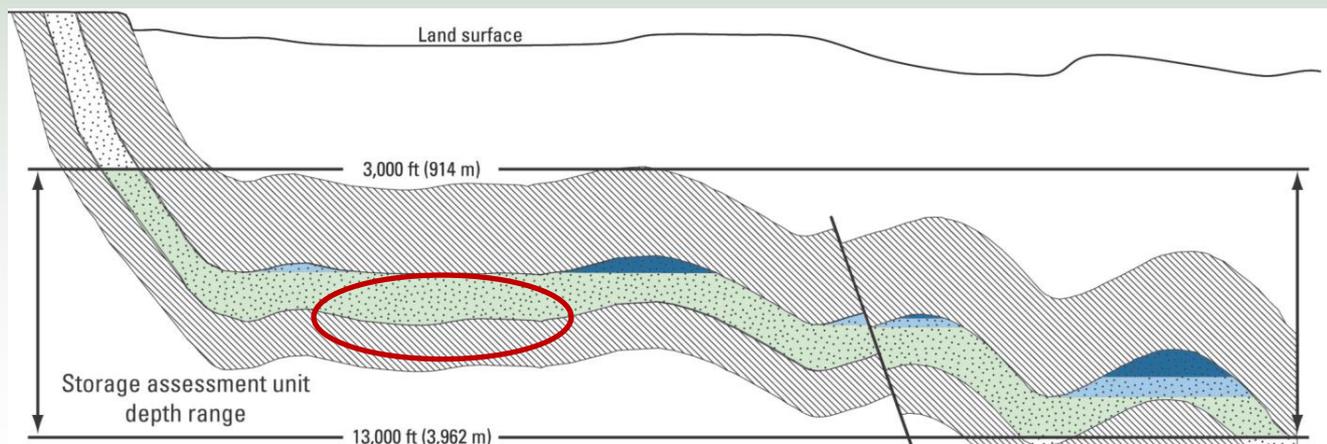
Buoyant Storage

- Resource based on petroleum reservoir-sized enclosures that will trap CO₂
- To estimate buoyant storage resource, we can use:
 - Petroleum production data to identify known enclosures
 - USGS National Oil and Gas Assessment (NOGA) results to identify undiscovered enclosures
 - Data gathered during our assessment research to estimate non-petroleum filled enclosures
- Storage efficiency estimates: 10% min, 30% mode, 60% max

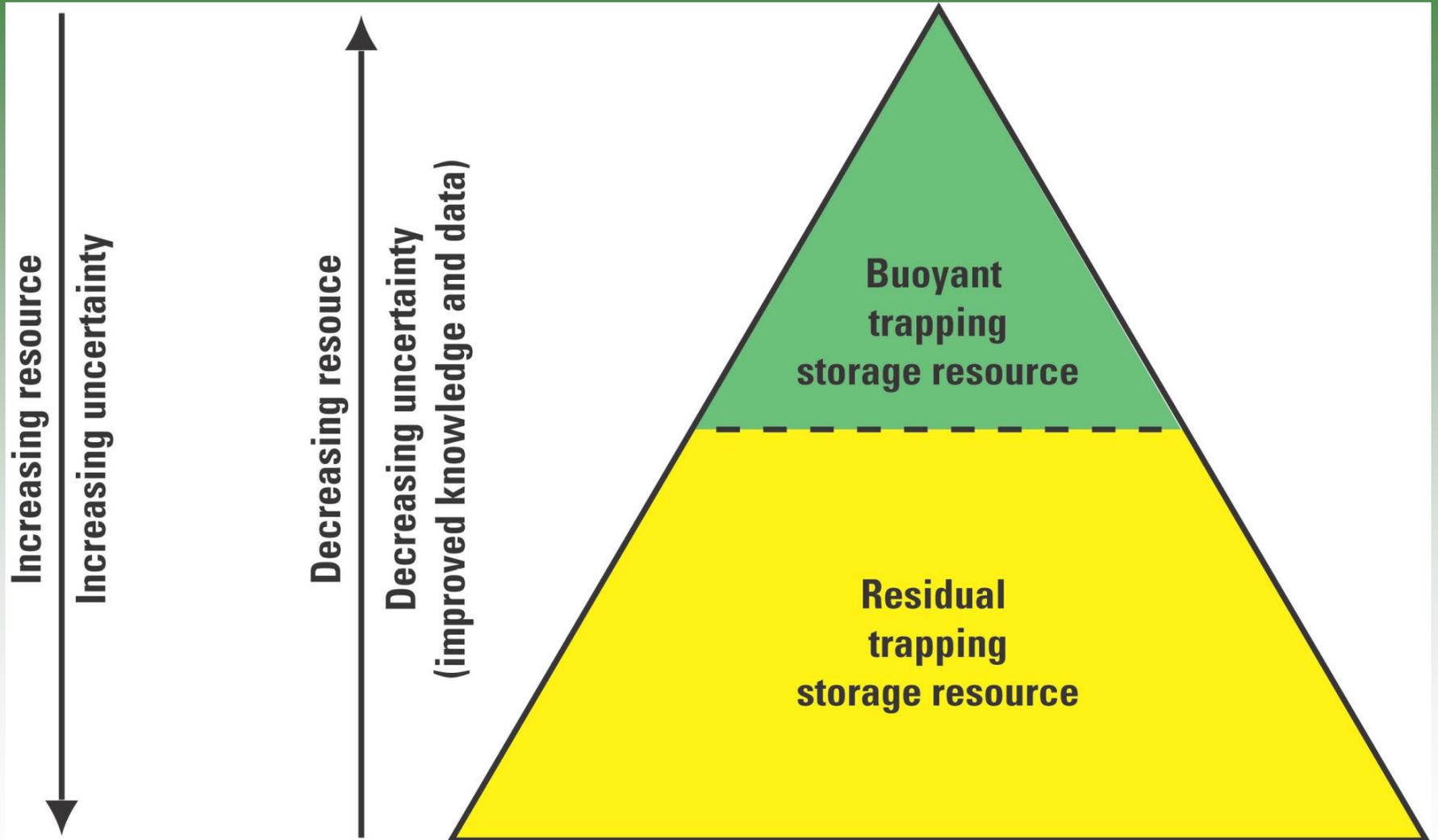


Residual Storage

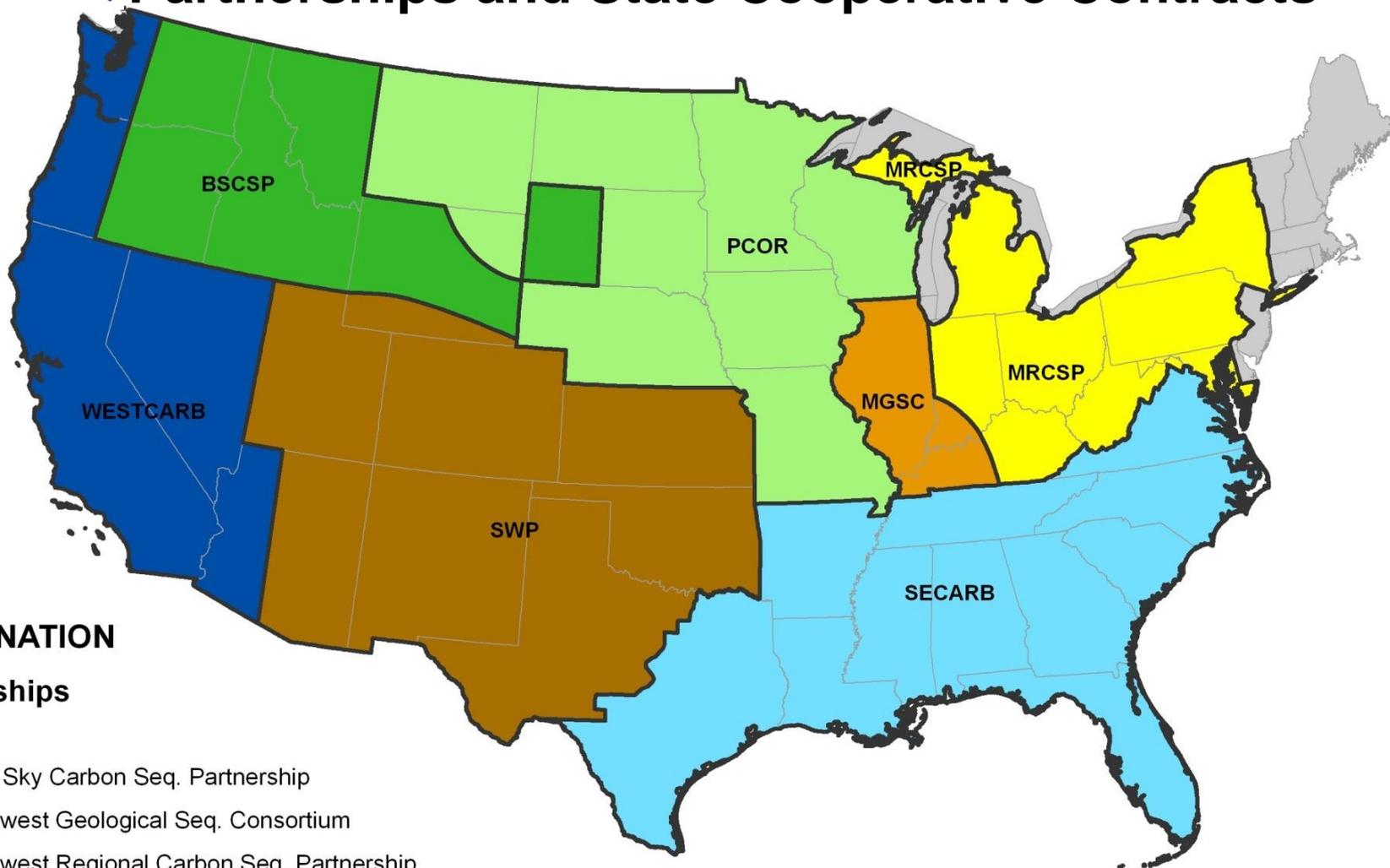
- Remainder of pore space within the Storage Formation that is *not available for buoyant storage*
- Includes residual trapped CO₂ and all buoyant trapping in enclosures that are less than petroleum reservoir-sized
- Resource divided into three classes based on variations in permeability of the storage formation
 - Low, Medium, or High permeability



Technically Accessible CO₂ Storage Resources



Data provided by Regional Carbon Sequestration Partnerships and State Cooperative Contracts



EXPLANATION

Partnerships

Name

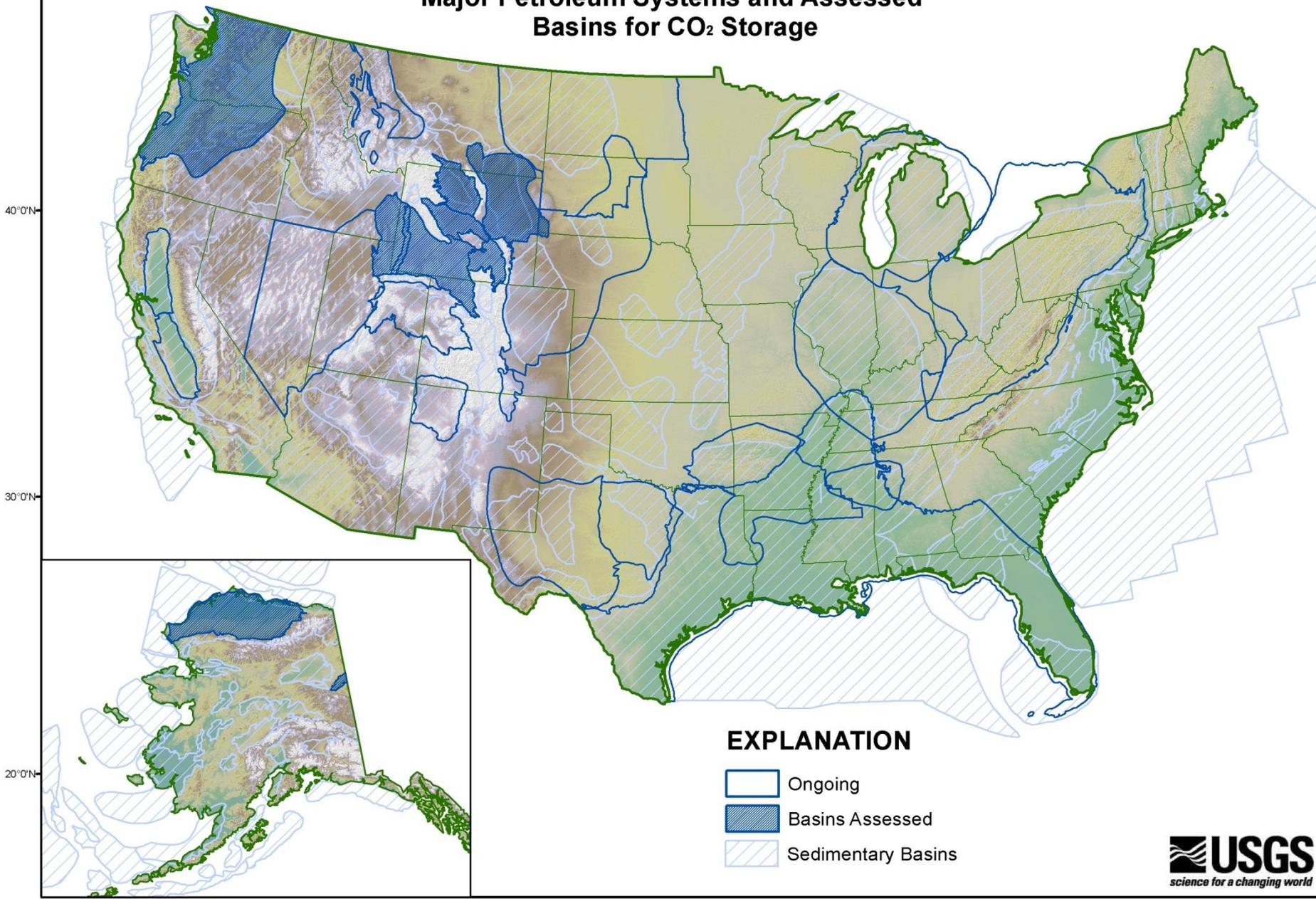
-  Big Sky Carbon Seq. Partnership
-  Midwest Geological Seq. Consortium
-  Midwest Regional Carbon Seq. Partnership
-  Southeast Regional Carbon Seq. Partnership
-  Southwest Regional Partnership on Carbon Seq.
-  The Plains CO2 Reduction Partnership
-  West Coast Regional Carbon Seq. Partnership



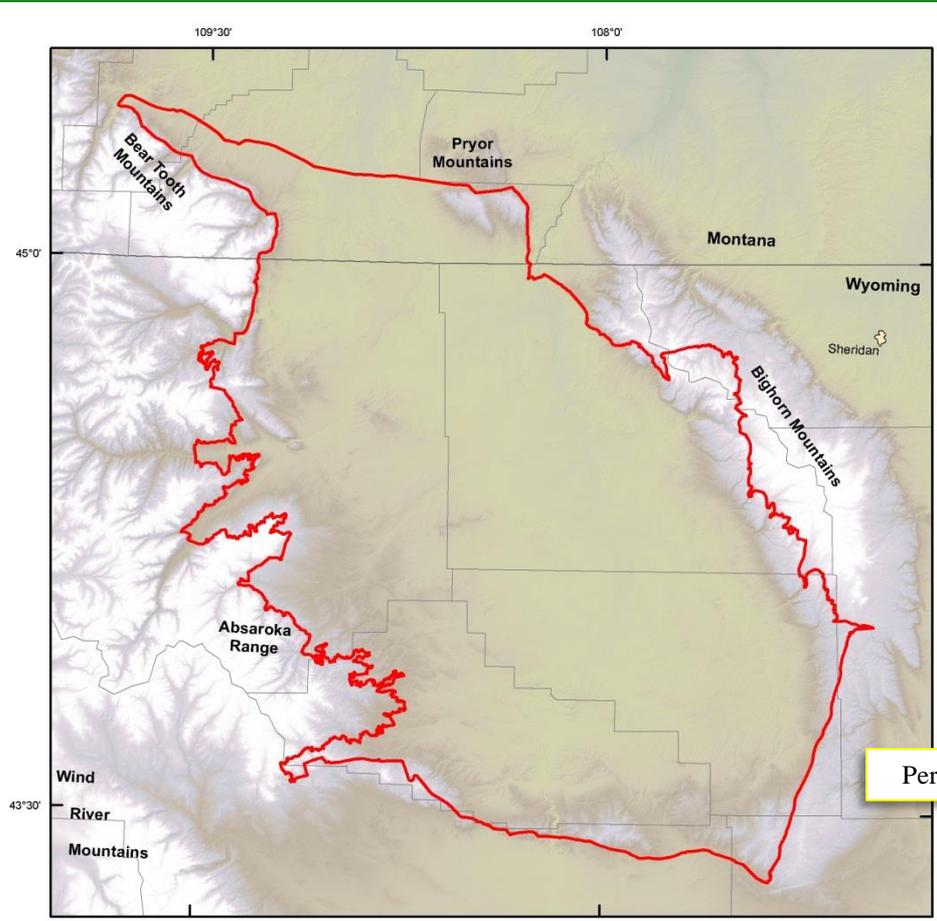
Modified from DOE NETL (2010)

130°0'W 120°0'W 110°0'W 100°0'W 90°0'W 80°0'W 70°0'W

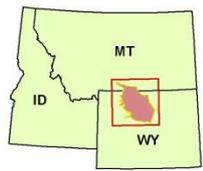
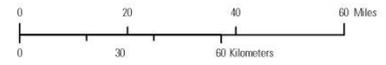
Major Petroleum Systems and Assessed Basins for CO₂ Storage



Bighorn Basin, Wyoming and Montana



Elevation from U.S. Geological Survey National Elevation Dataset digital elevation model, 2009, 30-meter resolution Albers Equal Area Projection



EXPLANATION
 Bighorn Basin outline modified from USGS National Oil and Gas Assessment Bighorn Basin Total Petroleum Systems boundary U.S. Geological Survey Bighorn Basin Assessment Team, 2010

Roberts and others (2008); Finn (2010)

Upper Cretaceous Frontier Formation

Lower Cretaceous Muddy Sandstone

Lower Cretaceous Cloverly Formation

Triassic Crow Mountain Sandstone

Permian Ervay Member of the Phosphoria Formation

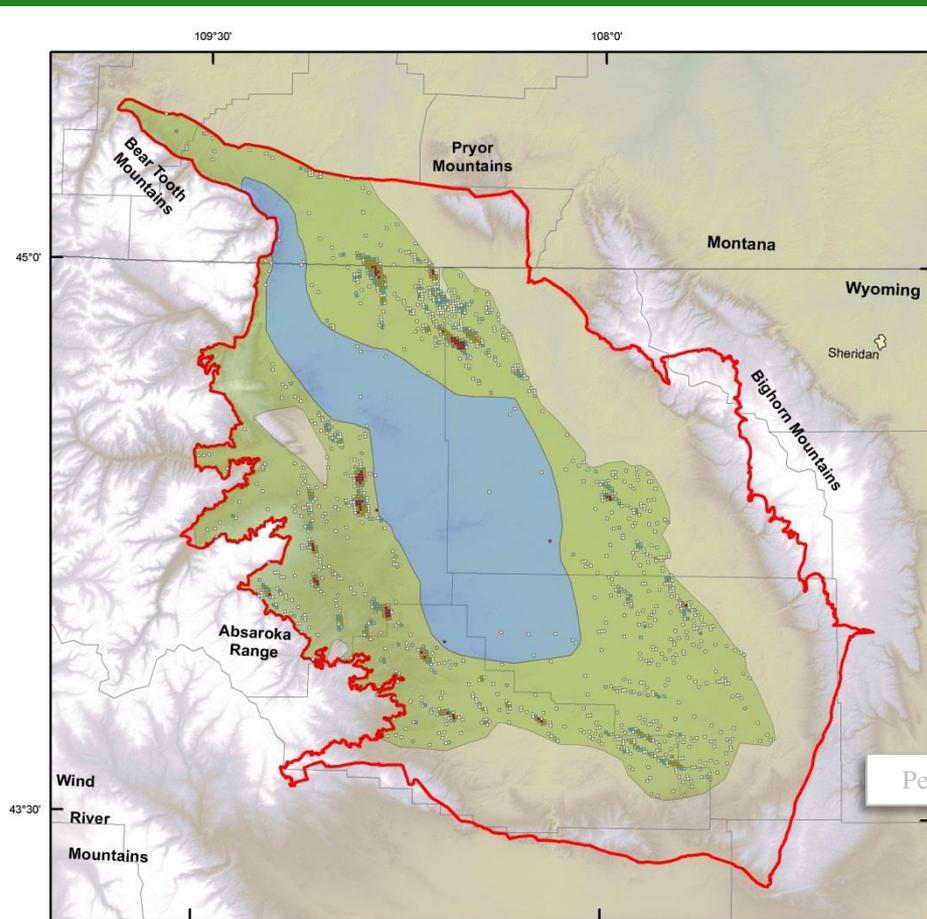
Pennsylvanian Tensleep Sandstone

ERA	SYSTEM/SERIES	ROCK UNIT			
CENOZOIC	TERTIARY	Pliocene			
		Miocene			
		Oligocene			
		Eocene	Willwood Fm.		
		Paleocene	Fort Union Fm.		
			Lance Fm.		
		MESOZOIC	CRETACEOUS	Upper	Meeteetse Fm. / Lewis Sh.
				Mesaverde Formation	
				Cody Shale	
				Torchlight Sandstone	
Frontier Formation					
Peay Sandstone					
Lower	Mowry Shale				
Shell Creek Shale					
Muddy Sandstone					
Thermopolis Shale					
Rusty beds					
Cloverly Formation					
Morrison Formation					
JURASSIC	Upper	Sundance Formation			
	Middle	Gypsum Spring Fm.			
	Lower				
TRIASSIC		Chugwater Group			
		Dinwoody Formation			
PERMIAN		Phosphoria Formation			
		Goose Egg Fm.			
PENNSYLVANIAN		Tensleep Sandstone			
		Amsden Formation			
MISSISSIPPIAN		Madison Limestone			
		Darby Fm.			
DEVONIAN					
		Beartooth Butte Fm.			
SILURIAN					
		Bighorn Dolomite			
ORDOVICIAN					
		Lander Sandstone			
CAMBRIAN	Upper	Gallatin Group			
	Middle	Gros Ventre Formation			
	Lower	Flathead S.S.			
PRECAMBRIAN					

Fox and Dolton (1996)



Pennsylvanian Tensleep Sandstone – eolian deposits



Elevation from U.S. Geological Survey National Elevation Dataset digital elevation model, 2009, 30-meter resolution
Albers Equal Area Projection



EXPLANATION

- C50340101 Tensleep (3,000 to 13,000 ft below surface)
- C50340102 Tensleep Deep (> 13,000 ft below surface)
- Bighorn Basin outline modified from USGS National Oil and Gas Assessment Bighorn Basin Total Petroleum Systems boundary U.S. Geological Survey Bighorn Basin Assessment Team, 2010

- Well Penetration Density per 1/4 Square Mile
- 1
 - 2
 - 3 - 4
 - 5 - 16
 - 17 +



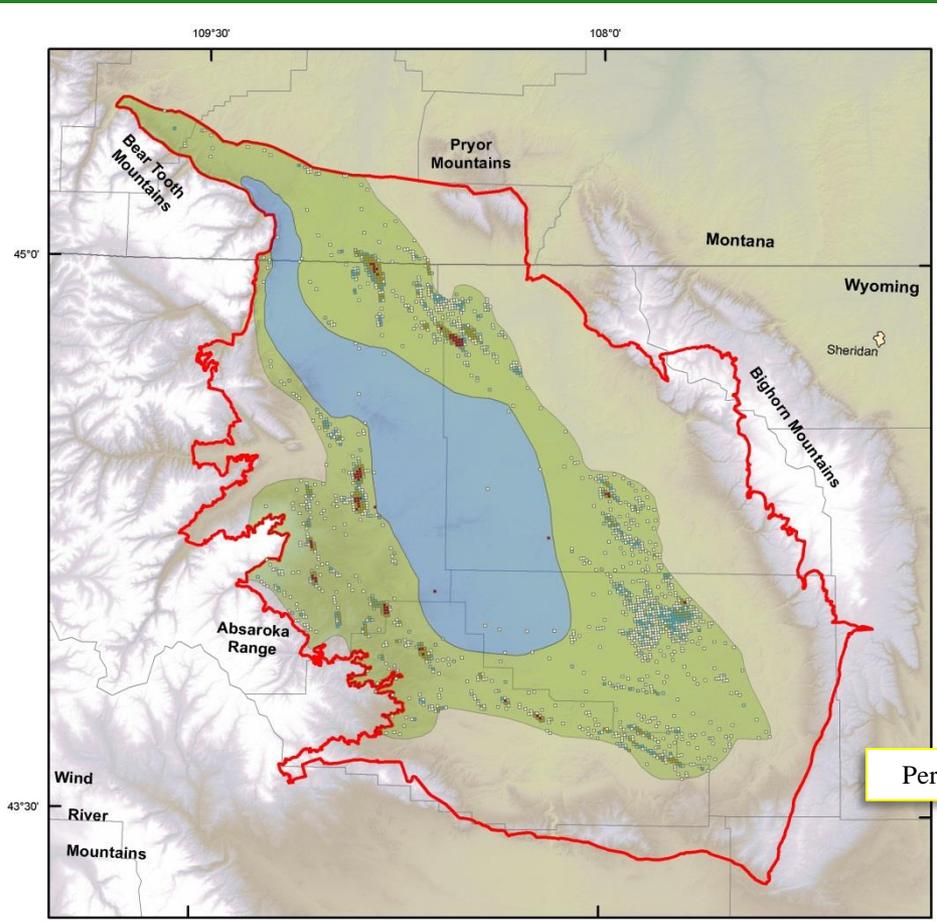
- Upper Cretaceous Frontier Formation
- Lower Cretaceous Muddy Sandstone
- Lower Cretaceous Cloverly Formation
- Triassic Crow Mountain Sandstone
- Permian Ervay Member of the Phosphoria Formation
- Pennsylvanian Tensleep Sandstone**

ERA	SYSTEM/SERIES	ROCK UNIT				
CENOZOIC	TERTIARY	Pliocene				
		Miocene				
		Oligocene				
	Paleocene	Eocene	Willwood Fm.			
		Paleocene	Fort Union Fm. Lance Fm.			
	MESOZOIC	CRETACEOUS	Upper	Meeteetse Fm. / Lewis Sh. Mesaverde Formation Cody Shale Torchlight Sandstone Frontier Formation Peay Sandstone		
			Lower	Mowry Shale Shell Creek Shale Muddy Sandstone Thermopolis Shale Rusty beds Cloverly Formation Morrison Formation		
				JURASSIC	Upper	Sundance Formation
					Middle	Gypsum Spring Fm.
					Lower	
TRIASSIC		Chugwater Group Dinwoody Formation				
PERMIAN		Phosphoria Formation Goose Egg Fm.				
PENNSYLVANIAN		Tensleep Sandstone Amsden Formation				
MISSISSIPPIAN		Madison Limestone Darby Fm.				
PALEOZOIC		DEVONIAN	Beartooth Butte Fm.			
	SILURIAN	Bighorn Dolomite				
	ORDOVICIAN	Lander Sandstone				
	CAMBRIAN	Upper	Gallatin Group			
		Middle	Gros Ventre Formation Flathead Ss.			
Lower						
PRECAMBRIAN						



Permian Ervay Member of the Phosphoria Formation –

carbonates and tidal deposits



Elevation from U.S. Geological Survey National Elevation Dataset digital elevation model, 2009, 30-meter resolution
Albers Equal Area Projection



EXPLANATION

- C50340103 Ervay (3,000 to 13,000 ft below surface)
 - C50340104 Ervay Deep (> 13,000 ft below surface)
 - Bighorn Basin outline modified from USGS National Oil and Gas Assessment Bighorn Basin Total Petroleum Systems boundary U.S. Geological Survey Bighorn Basin Assessment Team, 2010
- Well Penetration Density per 1/4 Square Mile: 1
 - 2
 - 3 - 4
 - 5 - 16
 - 17 +



Upper Cretaceous Frontier Formation

Lower Cretaceous Muddy Sandstone

Lower Cretaceous Cloverly Formation

Triassic Crow Mountain Sandstone

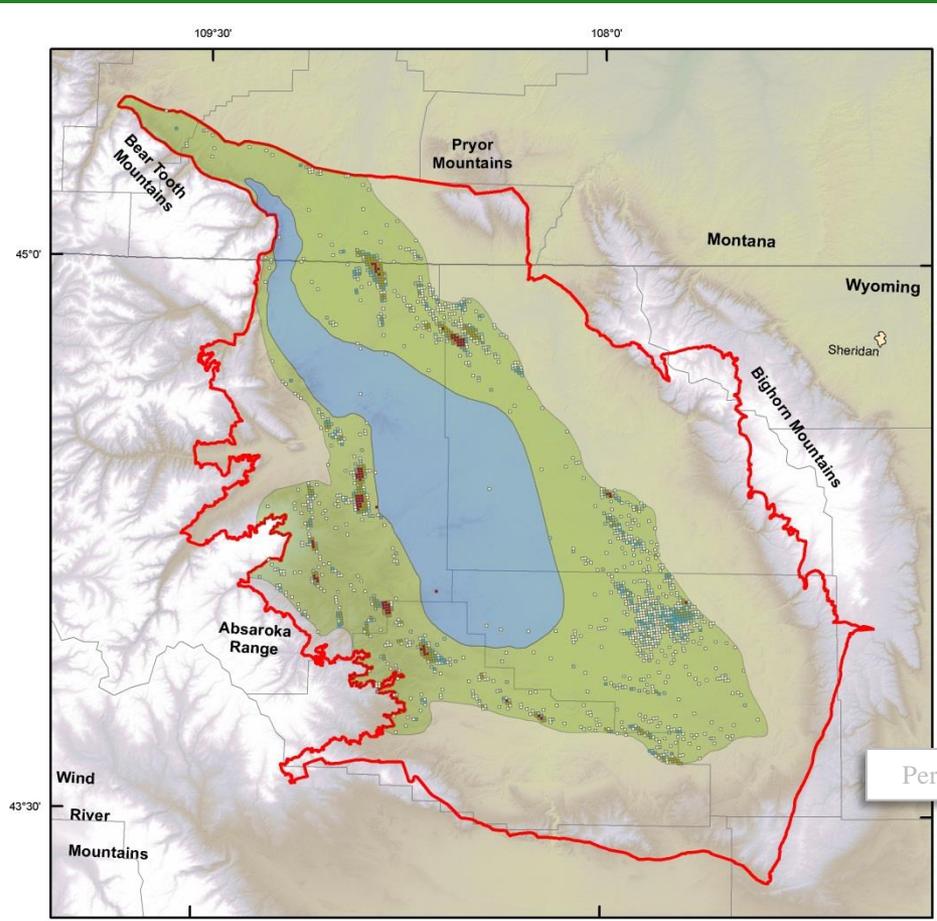
Permian Ervay Member of the Phosphoria Formation

Pennsylvanian Tensleep Sandstone

ERA	SYSTEM/SERIES	ROCK UNIT	
CENOZOIC	TERTIARY	Pliocene	
		Miocene	
		Oligocene	
	Paleocene	Eocene	Willwood Fm.
			Fort Union Fm.
	MESOZOIC	CRETACEOUS	
			Meeteetse Fm. / Lewis Sh.
Upper			Mesaverde Formation
			Cody Shale
			Torchlight Sandstone
		Frontier Formation	
		Peay Sandstone	
		Mowry Shale	
Lower			Shell Creek Shale
			Muddy Sandstone
		Thermopolis Shale	
JURASSIC	Upper		Rusty beds
			Cloverly Formation
		Morrison Formation	
	Lower	Sundance Formation	
TRIASSIC	Middle	Gypsum Spring Fm.	
	Lower		
		Chugwater Group	
PERMIAN		Dinwoody Formation	
		Phosphoria Formation	
PENNSYLVANIAN		Goose Egg Fm.	
		Tensleep Sandstone	
		Amsden Formation	
MISSISSIPPIAN		Madison Limestone	
		Darby Fm.	
DEVONIAN		Beartooth Butte Fm.	
SILURIAN		Bighorn Dolomite	
ORDOVICIAN		Lander Sandstone	
		Gallatin Group	
CAMBRIAN	Upper		
	Middle	Gros Ventre Formation	
	Lower	Flathead Ss.	
PRECAMBRIAN			



Triassic Crow Mountain Sandstone – non-marine deposits



Elevation from U.S. Geological Survey National Elevation Dataset digital elevation model, 2009, 30 meter resolution
Albers Equal Area Projection

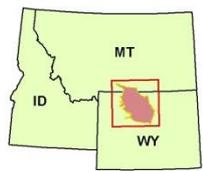


EXPLANATION

- C50340105 Crow Mountain (3,000 to 13,000 ft below surface)
- C50340106 Crow Mountain Deep (> 13,000 ft below surface)
- Bighorn Basin outline modified from USGS National Oil and Gas Assessment Bighorn Basin Total Petroleum Systems boundary U.S. Geological Survey Bighorn Basin Assessment Team, 2010

Well Penetration Density per 1/4 Square Mile

- 1
- 2
- 3 - 4
- 5 - 16
- 17 +



Upper Cretaceous Frontier Formation

Lower Cretaceous Muddy Sandstone

Lower Cretaceous Cloverly Formation

Triassic Crow Mountain Sandstone

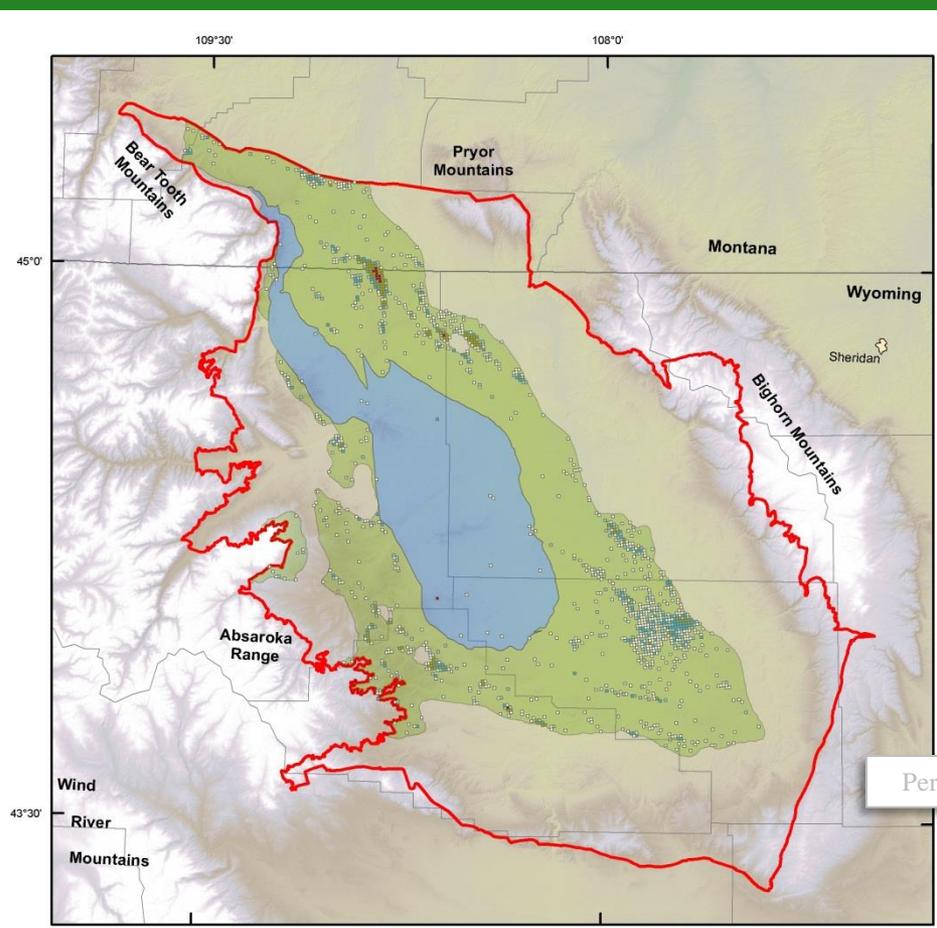
Permian Ervay Member of the Phosphoria Formation

Pennsylvanian Tensleep Sandstone

ERA	SYSTEM/SERIES	ROCK UNIT			
CENOZOIC	TERTIARY	Pliocene			
		Miocene			
		Oligocene			
	Paleocene	Eocene	Willwood Fm.		
		Paleocene	Fort Union Fm. Lance Fm.		
	MESOZOIC	CRETACEOUS	Upper	Meeteetse Fm. / Lewis Sh. Mesaverde Formation Cody Shale Torchlight Sandstone Frontier Formation Peay Sandstone	
			Lower	Mowry Shale Shell Creek Shale Muddy Sandstone	
				Thermopolis Shale Rusty beds Cloverly Formation Morrison Formation	
			JURASSIC	Upper	Sundance Formation
				Middle	Gypsum Spring Fm.
Lower					
TRIASSIC			Chugwater Group		
PALEOZOIC		PERMIAN	Dinwoody Formation Phosphoria Formation Goose Egg Fm.		
			PENNSYLVANIAN	Tensleep Sandstone Amsden Formation	
		MISSISSIPPIAN	Madison Limestone Darby Fm.		
DEVONIAN		Beartooth Butte Fm.			
SILURIAN		Bighorn Dolomite			
ORDOVICIAN		Lander Sandstone			
CAMBRIAN	Upper	Gallatin Group			
	Middle	Gros Ventre Formation			
	Lower	Flathead S.S.			
PRECAMBRIAN					



Lower Cretaceous Cloverly Formation – fluvial deposits

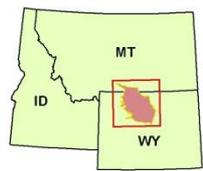


Elevation from U.S. Geological Survey National Elevation Dataset digital elevation model, 2009, 30-meter resolution
Albers Equal Area Projection



EXPLANATION

- C50340107 Cloverly (3,000 to 13,000 ft below surface)
 - C50340108 Cloverly Deep (> 13,000 ft below surface)
 - Bighorn Basin outline modified from USGS National Oil and Gas Assessment Bighorn Basin Total Petroleum Systems boundary U.S. Geological Survey Bighorn Basin Assessment Team, 2010
-
- Well Penetration Density per 1/4 Square Mile: 1
 - 2
 - 3-4
 - 5-16
 - 17+



Upper Cretaceous Frontier Formation

Lower Cretaceous Muddy Sandstone

Lower Cretaceous Cloverly Formation

Triassic Crow Mountain Sandstone

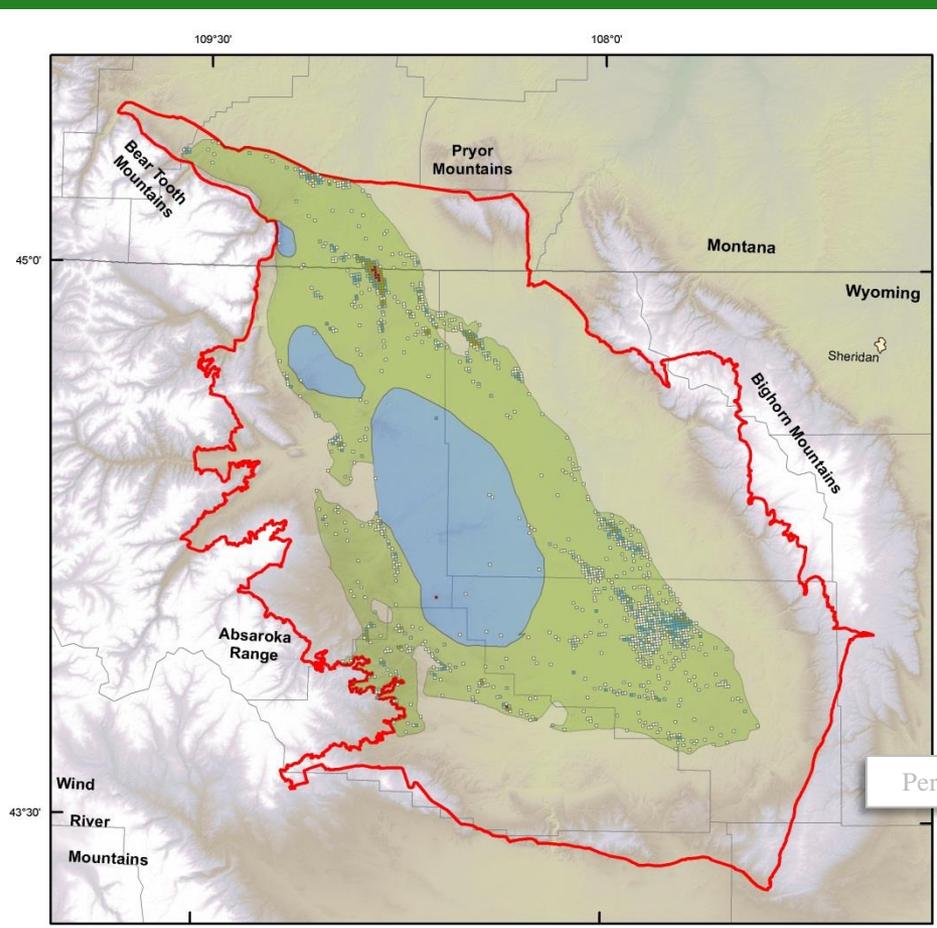
Permian Ervay Member of the Phosphoria Formation

Pennsylvanian Tensleep Sandstone

ERA	SYSTEM/SERIES	ROCK UNIT		
CENOZOIC	TERTIARY	Pliocene		
		Miocene		
		Oligocene		
	Paleocene	Eocene	Willwood Fm.	
		Paleocene	Fort Union Fm. Lance Fm.	
	MESOZOIC	CRETACEOUS	Upper	Meeteetse Fm. / Lewis Sh. Mesaverde Formation Cody Shale Torchlight Sandstone Frontier Formation Peay Sandstone
			Lower	Mowry Shale Shell Creek Shale Muddy Sandstone Thermopolis Shale Rusty beds Cloverly Formation Morrison Formation
				JURASSIC
			TRIASSIC	Chugwater Group Dinwoody Formation
			PERMIAN	Phosphoria Formation Goose Egg Fm.
PENNSYLVANIAN		Tensleep Sandstone Amsden Formation		
PALEOZOIC		MISSISSIPPIAN	Madison Limestone Darby Fm.	
		SILURIAN	Beartooth Butte Fm.	
		ORDOVICIAN	Bighorn Dolomite Lander Sandstone	
		CAMBRIAN	Upper	Gallatin Group
	Middle		Gros Ventre Formation Flathead Ss.	
Lower				
PRECAMBRIAN				



Lower Cretaceous Muddy Sandstone – fluvial and estuarine deposits



Elevation from U.S. Geological Survey National Elevation Dataset digital elevation model, 2009, 30-meter resolution Albers Equal Area Projection



EXPLANATION

- C50340109 Muddy (3,000 to 13,000 ft below surface)
 - C50340110 Muddy Deep (> 13,000 ft below surface)
 - Bighorn Basin outline modified from USGS National Oil and Gas Assessment Bighorn Basin Total Petroleum Systems boundary U.S. Geological Survey Bighorn Basin Assessment Team, 2010
-
- Well Penetration Density per 1/4 Square Mile**
 - 1
 - 2
 - 3 - 4
 - 5 - 16
 - 17 +



Upper Cretaceous Frontier Formation

Lower Cretaceous Muddy Sandstone

Lower Cretaceous Cloverly Formation

Triassic Crow Mountain Sandstone

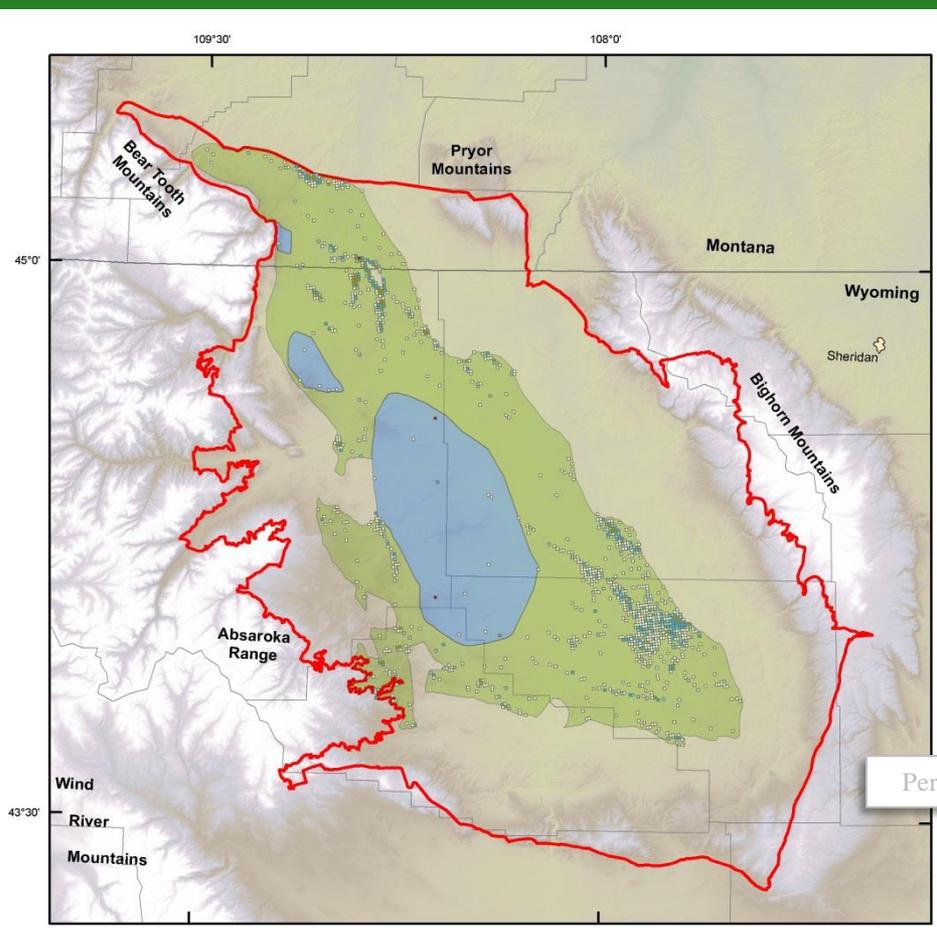
Permian Ervay Member of the Phosphoria Formation

Pennsylvanian Tensleep Sandstone

ERA	SYSTEM/SERIES	ROCK UNIT			
CENOZOIC	TERTIARY	Pliocene			
		Miocene			
		Oligocene			
	Paleocene	Eocene	Willwood Fm.		
		Paleocene	Fort Union Fm. Lance Fm.		
	MESOZOIC	CRETACEOUS	Upper	Meeteetse Fm. / Lewis Sh. Mesaverde Formation Cody Shale Torchlight Sandstone Frontier Formation Peay Sandstone	
			Lower	Mowry Shale Shell Creek Shale Muddy Sandstone Thermopolis Shale Rusty beds	
				JURASSIC	Cloverly Formation Morrison Formation Sundance Formation
			TRIASSIC	Upper	Gypsum Spring Fm.
				Lower	Chugwater Group
PERMIAN		Dinwoody Formation			
		Phosphoria Formation Goose Egg Fm.			
PENNSYLVANIAN		Tensleep Sandstone			
		Amsden Formation			
PALEOZOIC		MISSISSIPPIAN	Madison Limestone Darby Fm.		
	DEVONIAN	Beartooth Butte Fm.			
CAMBRIAN	SILURIAN	Bighorn Dolomite			
	ORDOVICIAN	Lander Sandstone			
PRECAMBRIAN	Upper	Gallatin Group			
		Gros Ventre Formation			
	Lower	Flathead Ss.			



Upper Cretaceous Frontier Formation – shallow-marine deposits

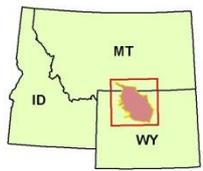


Elevation from U.S. Geological Survey National Elevation Dataset digital elevation model, 2009, 30-meter resolution
Albers Equal Area Projection



EXPLANATION

- C50340111 Frontier (3,000 to 13,000 ft below surface)
 - C50340112 Frontier Deep (> 13,000 ft below surface)
 - Bighorn Basin outline modified from USGS National Oil and Gas Assessment Bighorn Basin Total Petroleum Systems boundary U.S. Geological Survey Bighorn Basin Assessment Team, 2010
-
- Well Penetration Density per 1/4 Square Mile: 1
 - 2
 - 3 - 4
 - 5 - 16
 - 17 +



- Upper Cretaceous Frontier Formation
- Lower Cretaceous Muddy Sandstone
- Lower Cretaceous Cloverly Formation
- Triassic Crow Mountain Sandstone
- Permian Ervay Member of the Phosphoria Formation
- Pennsylvanian Tensleep Sandstone

ERA	SYSTEM/SERIES	ROCK UNIT	
CENOZOIC	TERTIARY	Pliocene	
		Miocene	
		Oligocene	
	Paleocene	Eocene	Willwood Fm.
		Paleocene	Fort Union Fm. Lance Fm.
	CRETACEOUS	Upper	Meeteetse Fm. / Lewis Sh.
			Mesaverde Formation
			Cody Shale
			Torchlight Sandstone
			Frontier Formation
Lower		Peay Sandstone	
		Mowry Shale	
		Shell Creek Shale	
		Muddy Sandstone	
		Thermopolis Shale	
JURASSIC	Upper	Rusty beds	
		Cloverly Formation	
	Lower	Morrison Formation	
		Sundance Formation	
		Gypsum Spring Fm.	
TRIASSIC	Upper	Chugwater Group	
		Dinwoody Formation	
	Lower	Phosphoria Formation	
PERMIAN	Upper	Goose Egg Fm.	
		Tensleep Sandstone	
	Lower	Amsden Formation	
PENNSYLVANIAN	Upper	Madison Limestone	
		Darby Fm.	
	Lower	Beartooth Butte Fm.	
SILURIAN	Upper	Bighorn Dolomite	
		Lander Sandstone	
	Lower	Gallatin Group	
ORDOVICIAN	Upper	Gros Ventre Formation	
		Flathead Ss.	
	Lower		
CAMBRIAN	Upper		
PRECAMBRIAN			



Project Deliverables

- USGS Circular
 - Modeled on 1995 USGS National Oil and Gas Assessment report summary (National Oil and Gas Resource Assessment Team, 1995)
 - Includes data tables and resource estimates
 - Resource estimates will be made available for each suitable formation
 - Buoyant storage resource
 - Three classes of the residual storage resource
 - Total aggregate storage resource of the Storage Formation
- Online Supporting Data
 - GIS maps with Storage Assessment Unit boundaries and metadata
 - Summary Open-File Reports for each assessed basin and Storage Assessment Units
- Note: Assessment methodology will be used to assess the storage resource of the onshore and State water areas of the United States, but is applicable throughout the world (currently working with International Energy Agency to develop an international CO₂ assessment methodology)

Conclusions

- The methodology uses geologic data, processes, geologic models, and rock properties to populate probabilistic analysis models to produce a robust estimate of CO₂ storage resource within a Storage Assessment Unit (SAU)
- This assessment methodology will be used to assess the storage resource of the U.S., but it is applicable throughout the world
- To date, we have assessed the onshore basins in Wyoming, Utah, Idaho, Montana, Oregon, Washington, and Alaska and have begun to assess the onshore and State water areas the Gulf Coast of the United States
- Assessment will be completed within three years, resource estimates will be made available at that time; other supporting data will be published on line as individual basin assessments are completed

References

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<http://energy.usgs.gov>

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