High-Priority Geologic Formations and Sites with CO_2 Storage Potential in Wyoming

WYOMING CARBON UNDERGROUND SEQUESTRATION PROJECT

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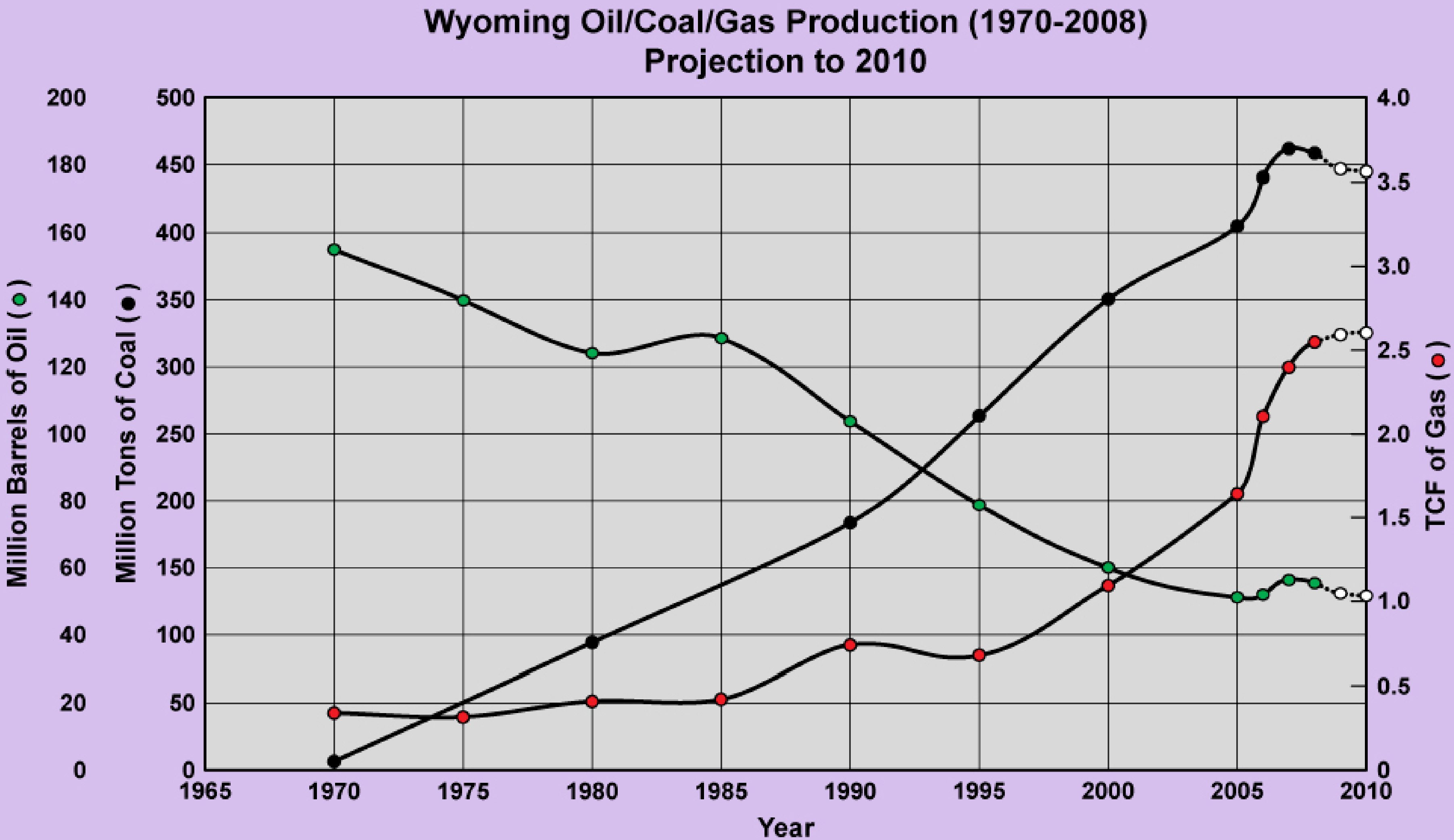
SER

UNIVERSITY OF WYOMING

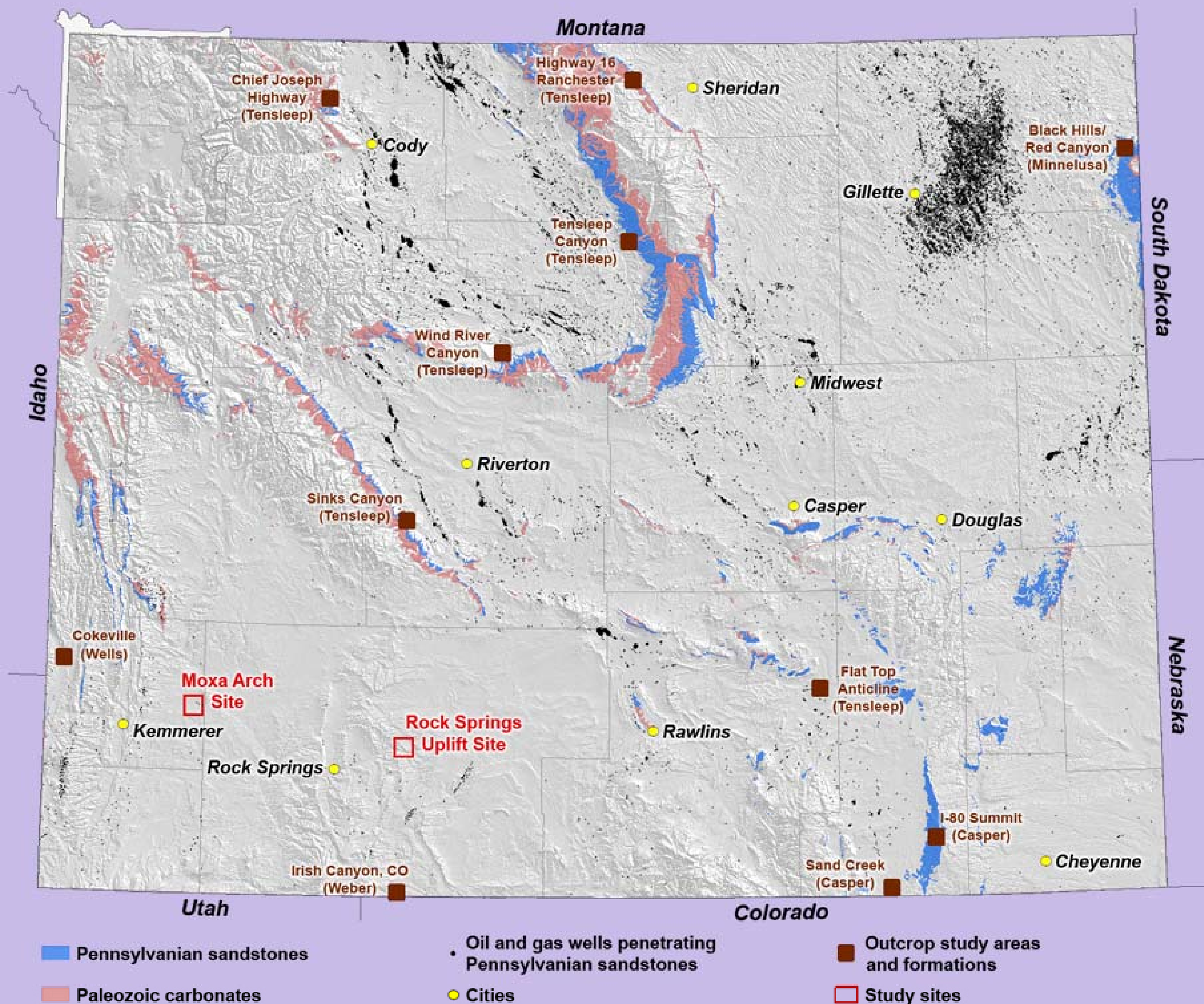
STATE OF WYOMING GEOLOGICAL SURVEY 1933

Wyoming's coal industry contributes 1.2 billion dollars annually to State revenues.

Photo by Meg Ewald, WSGS.



Modified from Surdam, R.C., 2008, Wyoming energy development in the context of the global economy: Wyoming State Geological Survey Challenges in Geologic Resource Development No. 6, 38 p.



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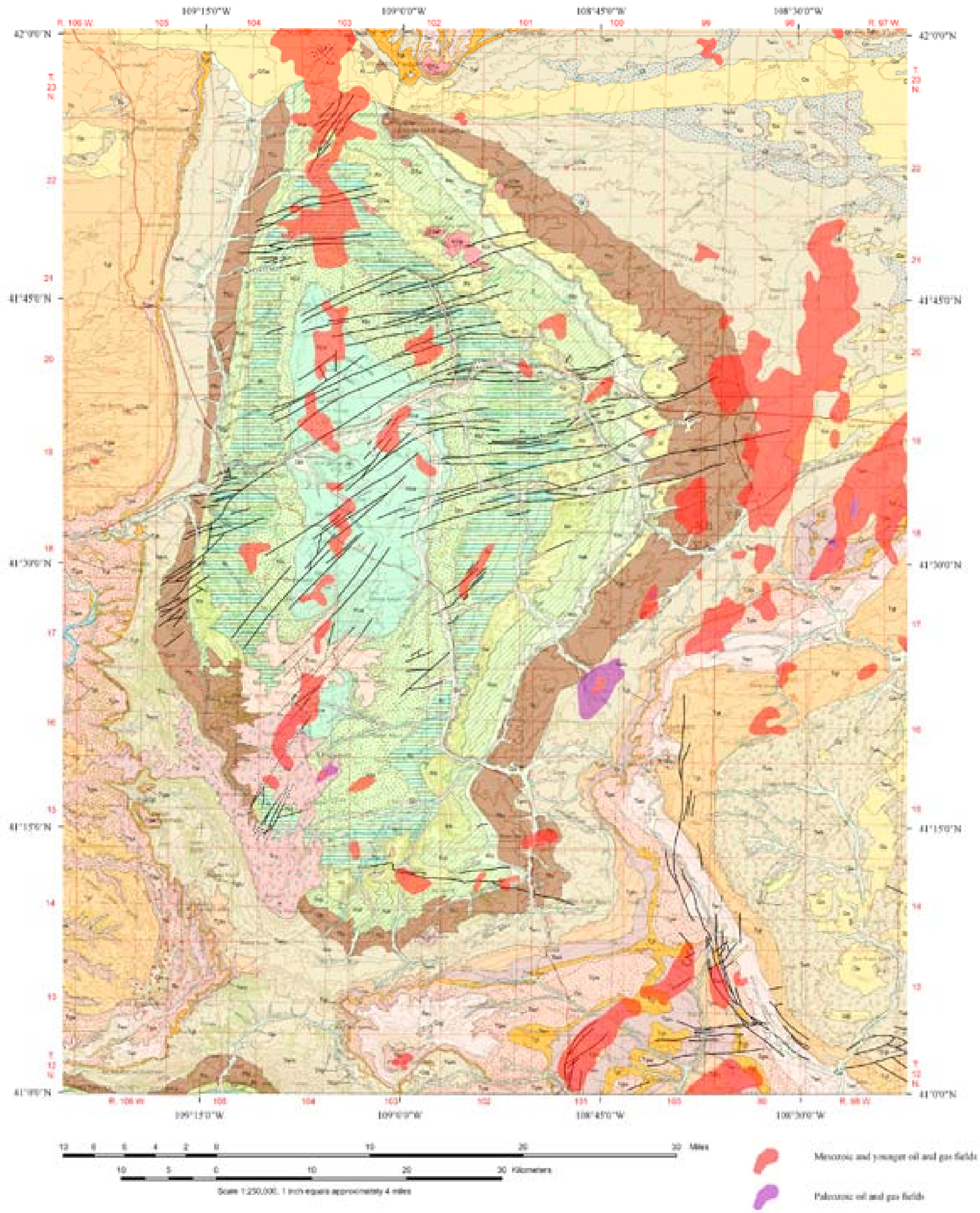
GEOLOGIC MAP AND OIL AND GAS FIELDS OF THE ROCK SPRINGS UPLIFT AREA, SWEETWATER COUNTY, SOUTHWESTERN WYOMING



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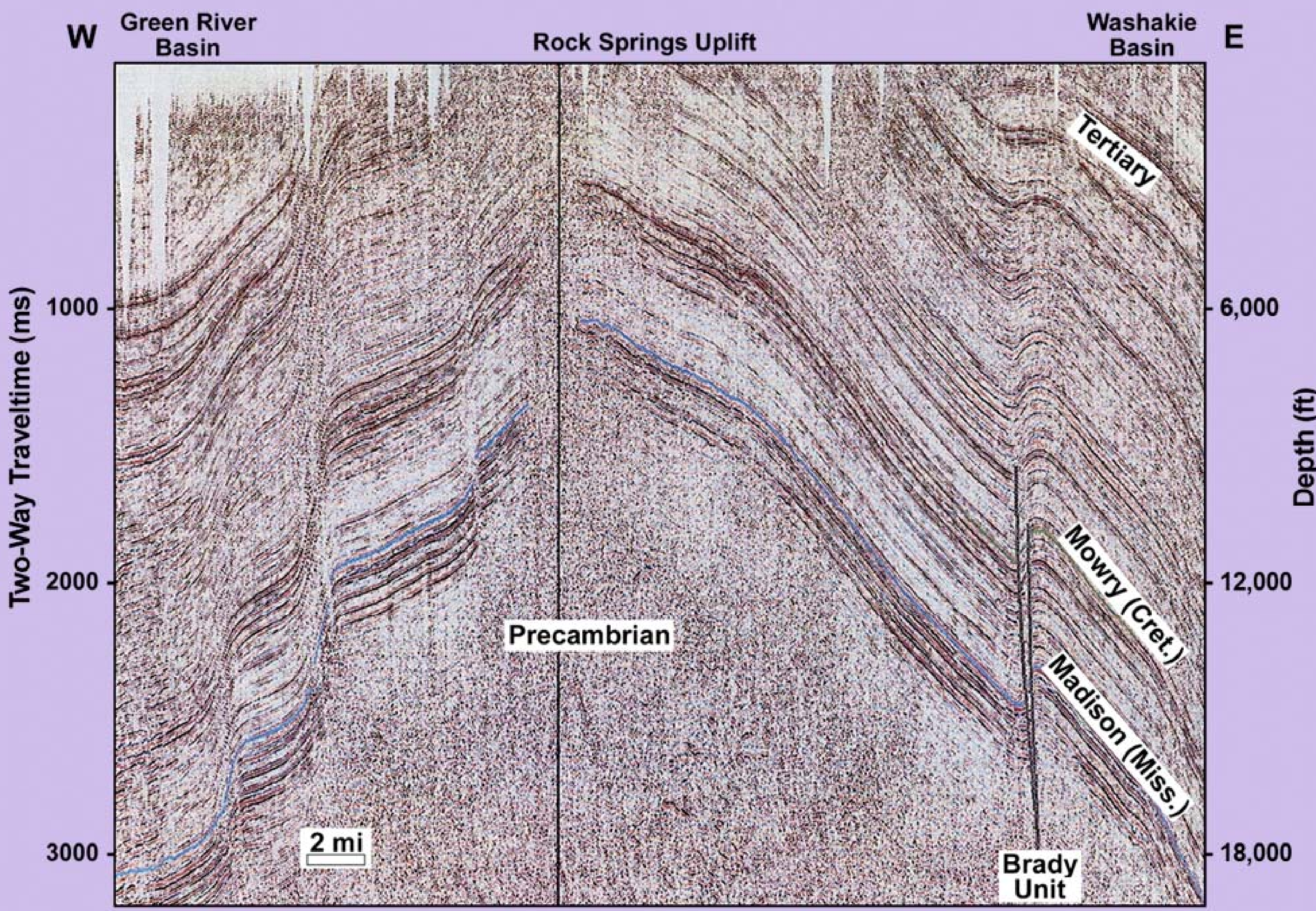

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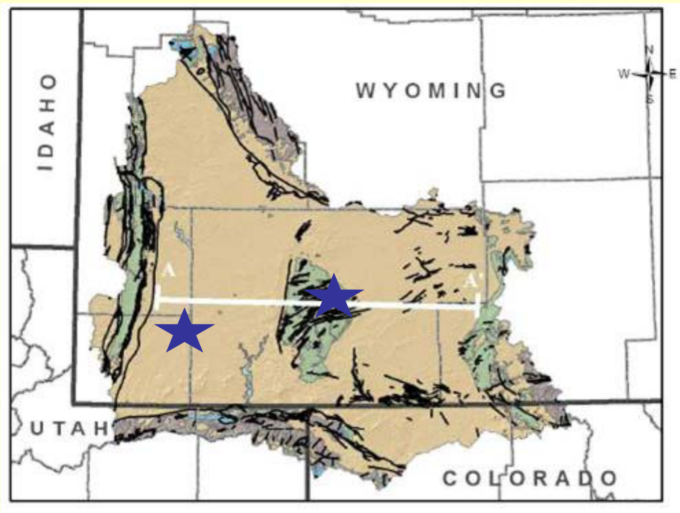
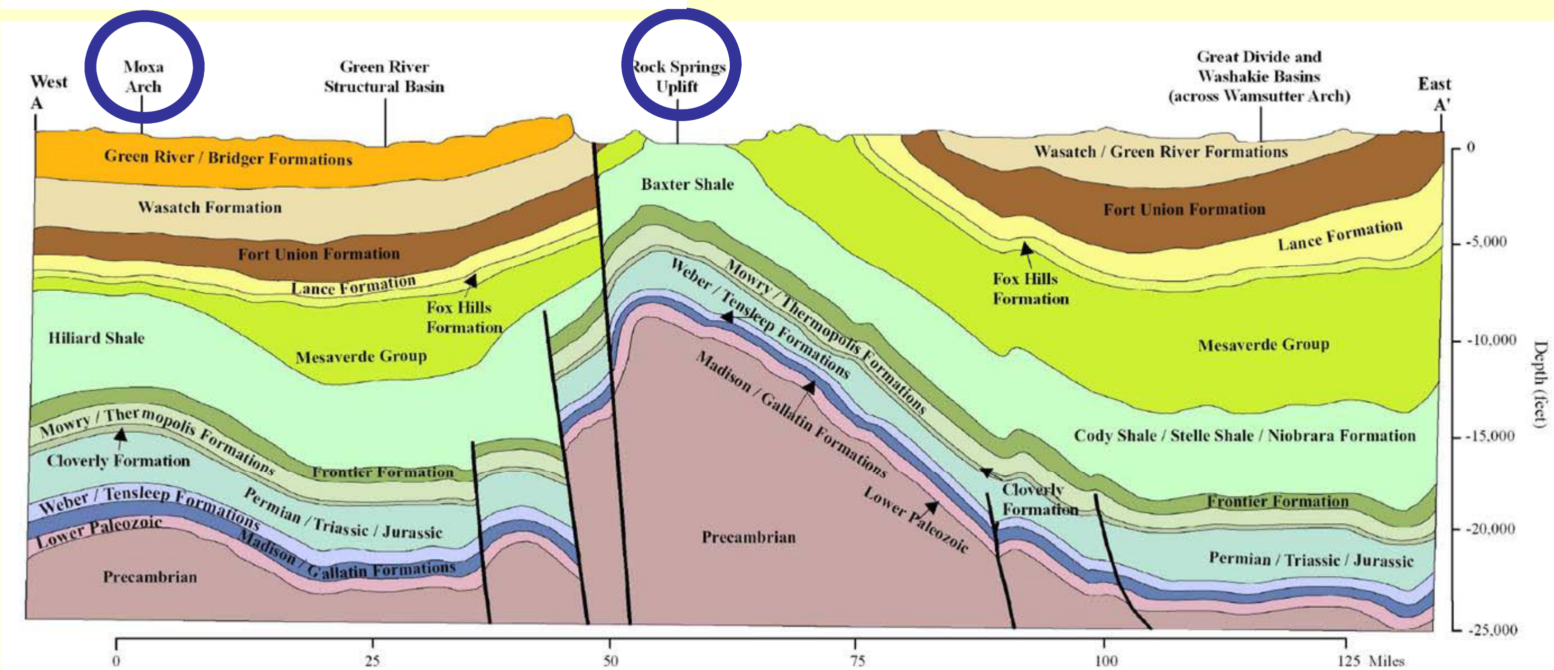
Background – Past Research



WSGS, UW, State, and DOE-funded research identified two high-capacity sites in southwest Wyoming:
Rock Springs Uplift & Moxa Arch



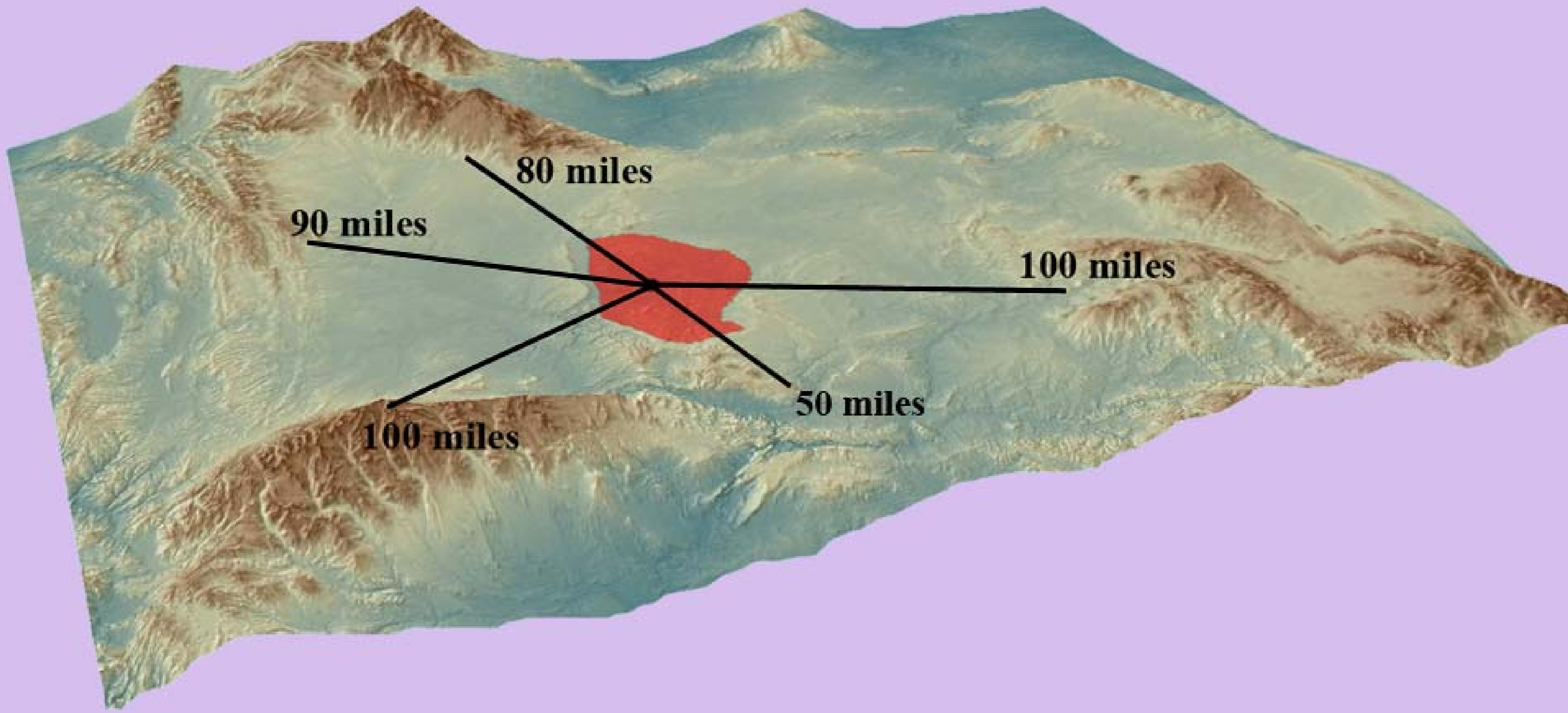


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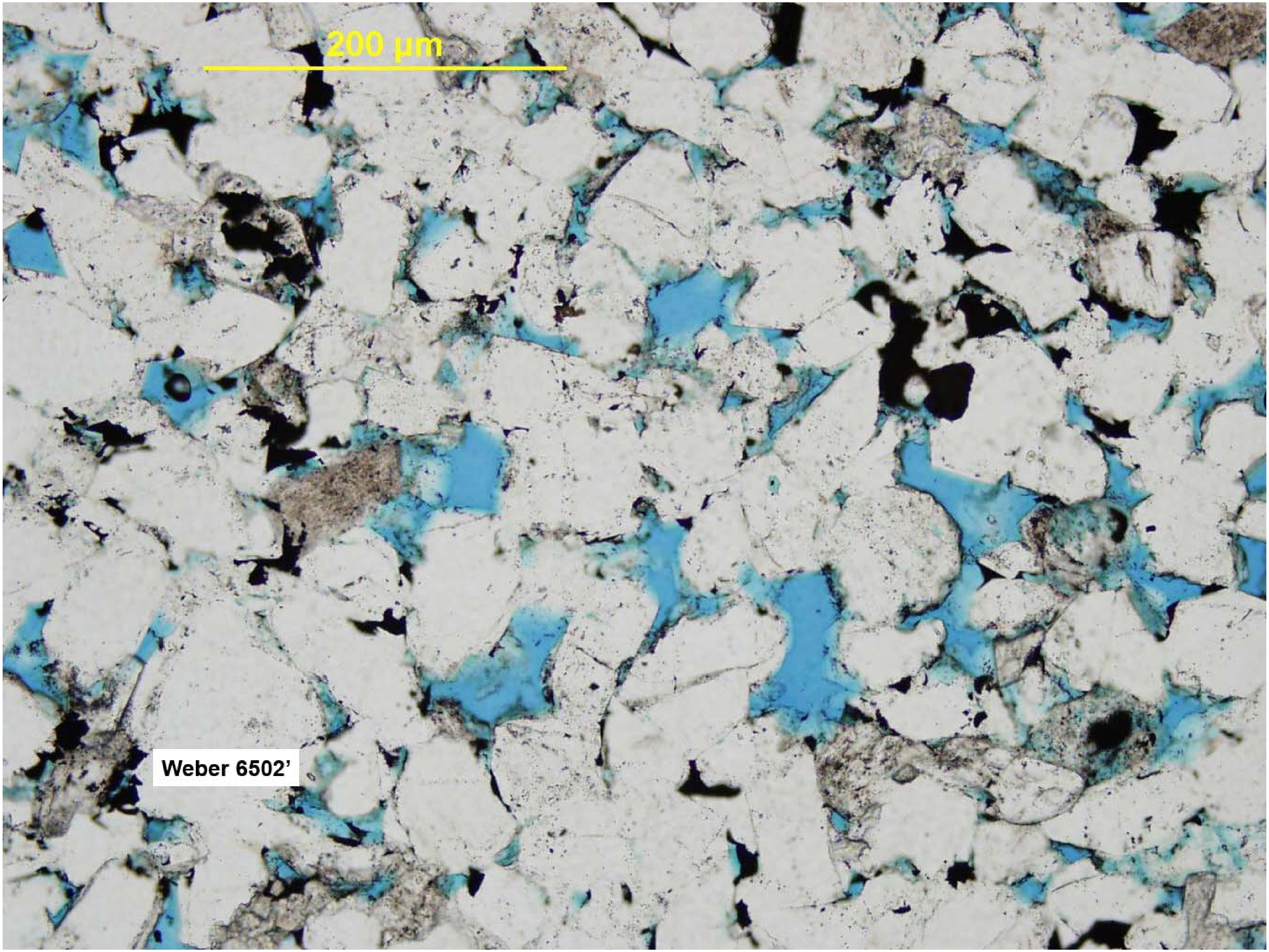
Photo by Z. Jiao, WSGS.

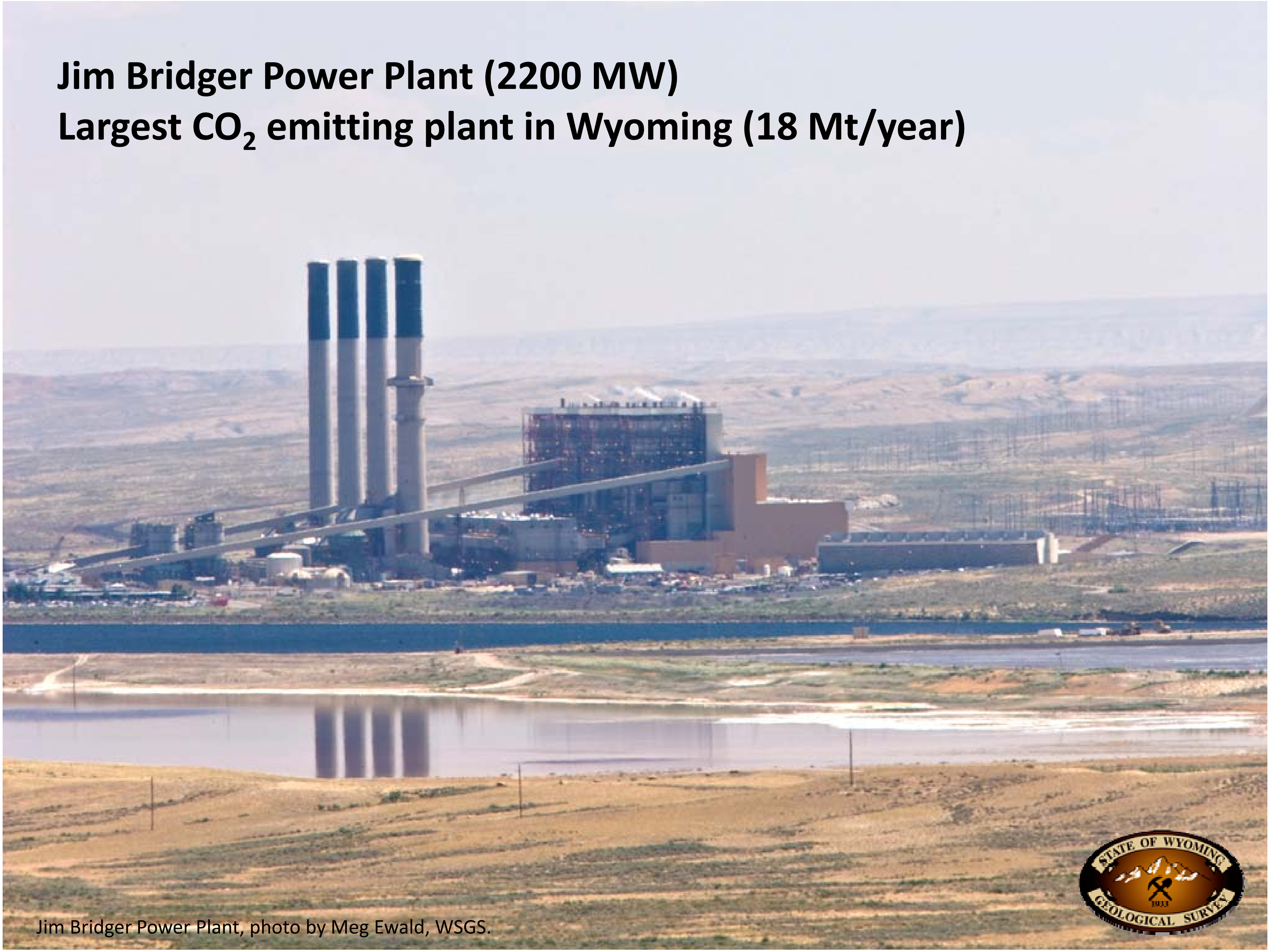
Photo by Meg Ewald, WSGS.


200 µm
Weber 6502’

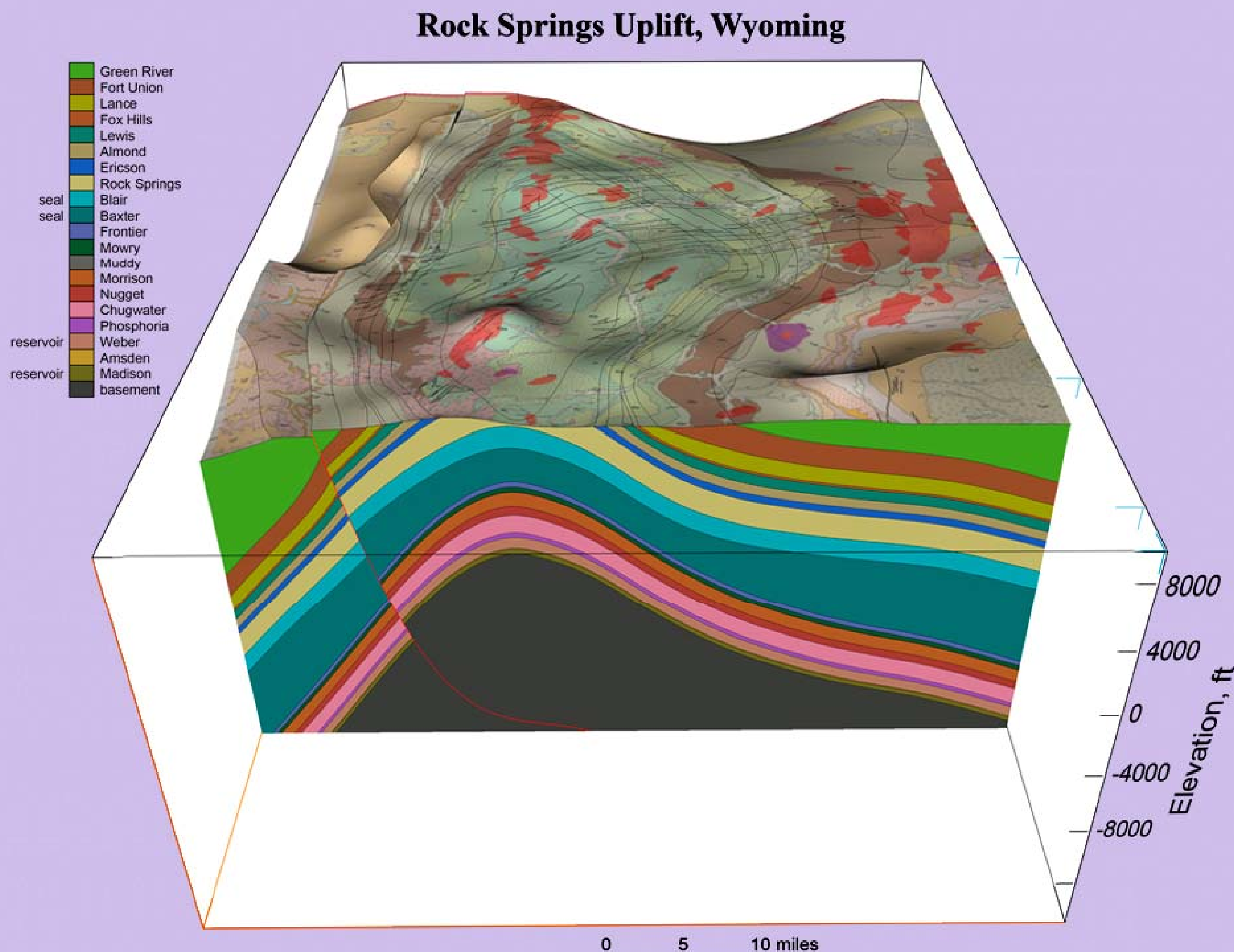
Rock Springs Uplift: an outstanding geological CO_2 sequestration site in southwestern Wyoming

- Thick saline aquifer sequence overlain by thick sealing lithologies.
- Doubly-plunging anticline characterized by more than 10,000 ft of closed structural relief.
- Huge area (50 x 35 mile).
- Required reservoir conditions; including, but not limited to fluid chemistry, porosity (pore space), fluid-flow characteristics, temperature and pressure (i.e., regional burial history).

Jim Bridger Power Plant (2200 MW)
Largest CO_2 emitting plant in Wyoming (18 Mt/year)



Jim Bridger Power Plant, photo by Meg Ewald, WSGS.



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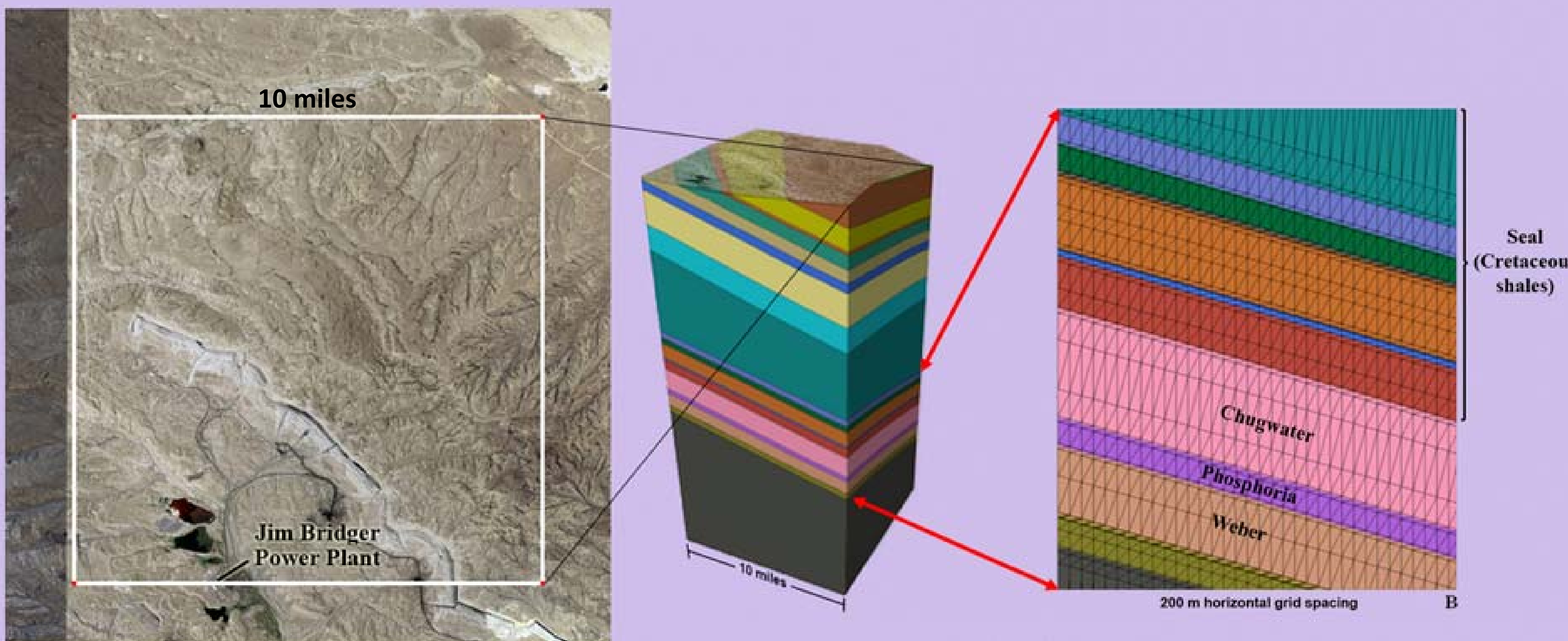

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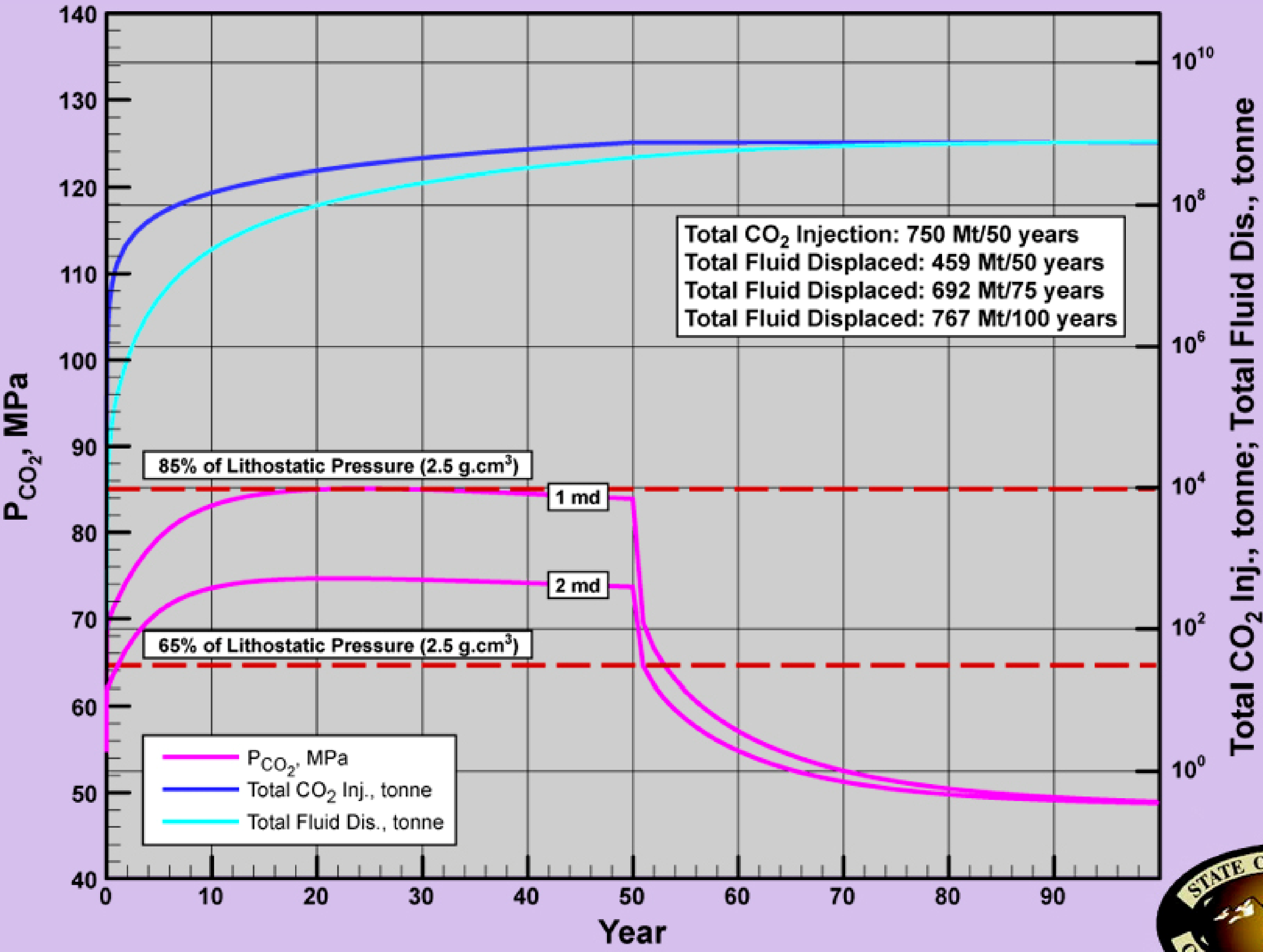
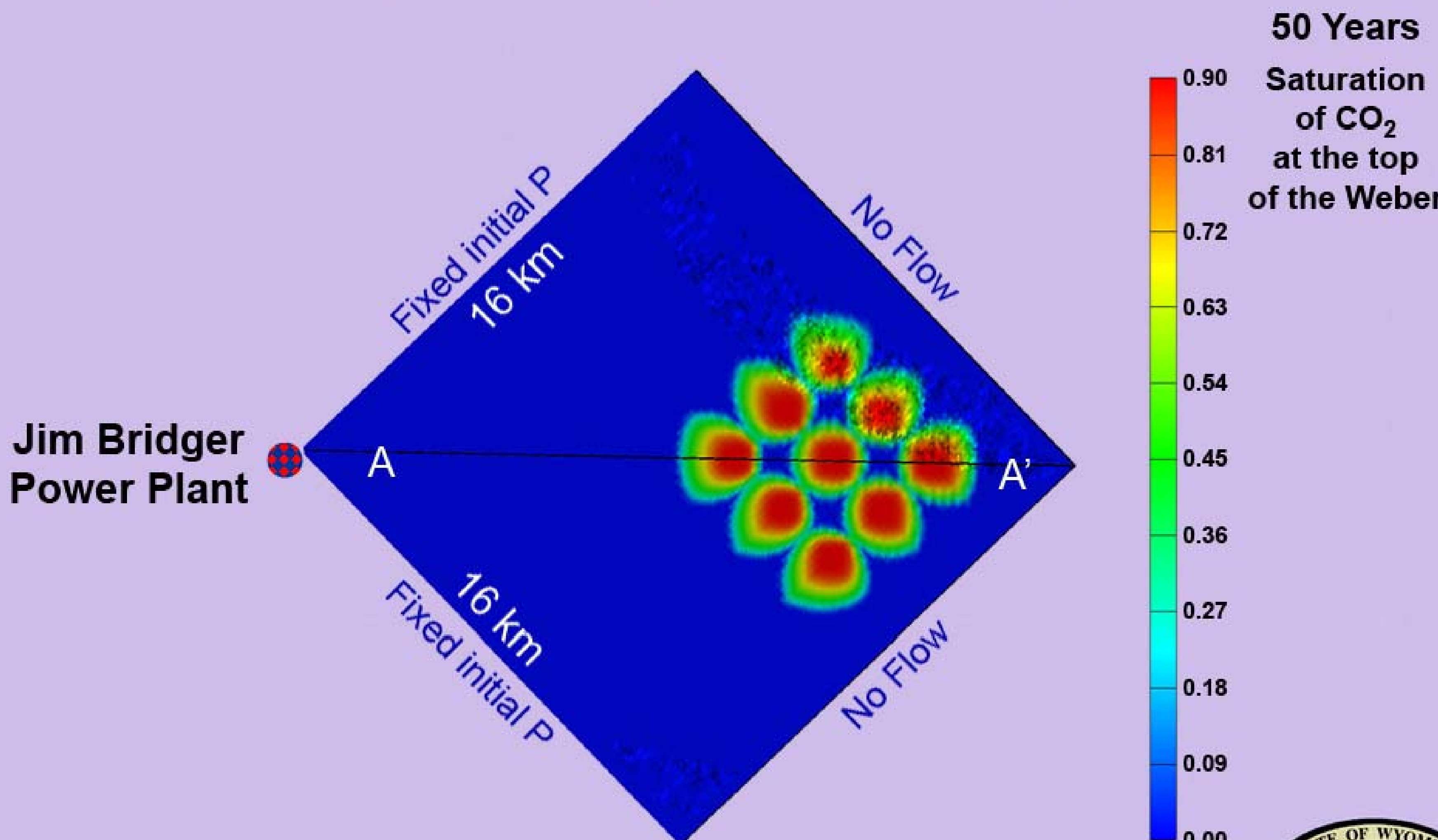
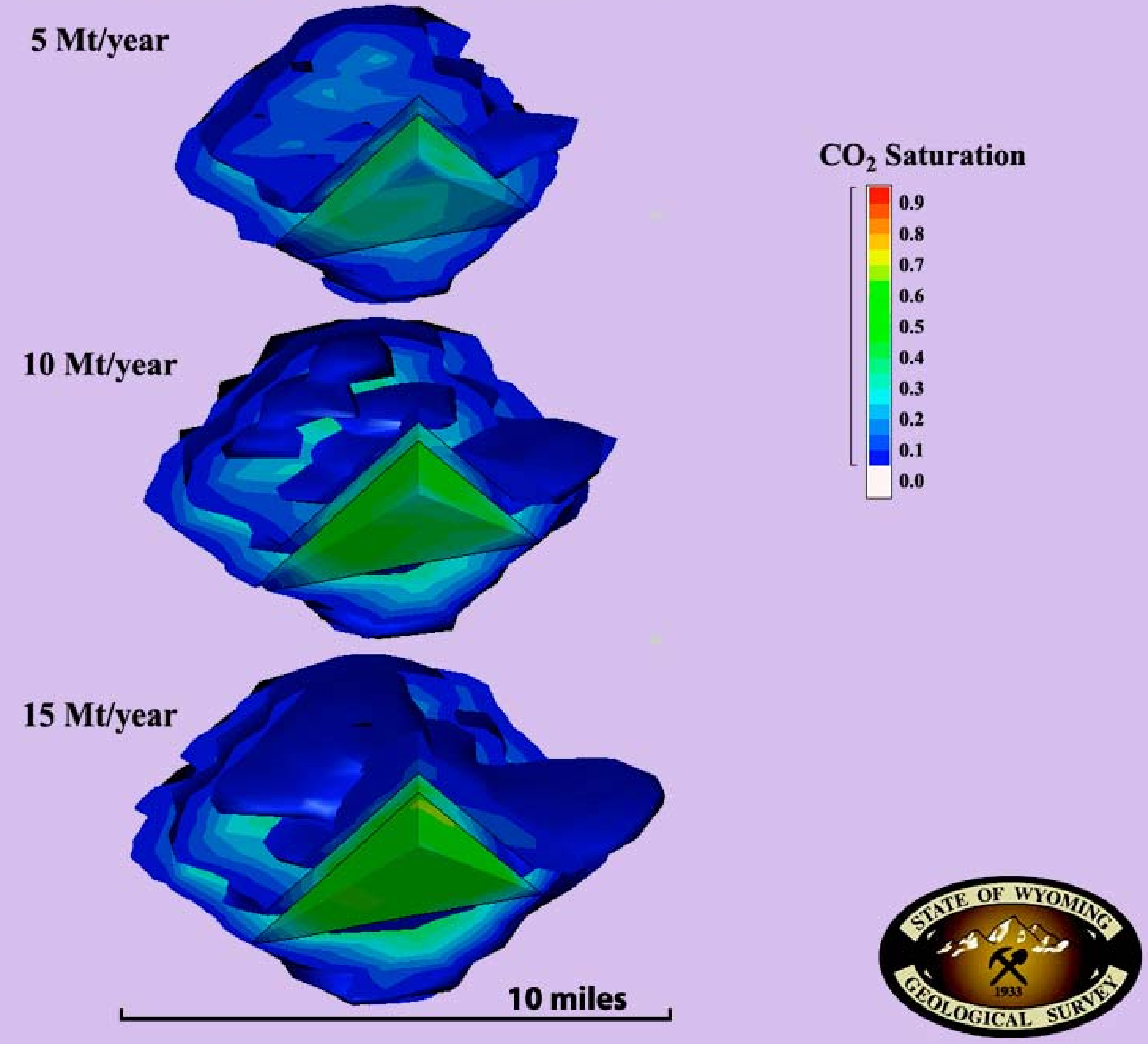
CO_2 Injection Simulation Results from FEHM for the Weber Sandstone, Rock Springs Uplift
Injection Interval 700 ft, Porosity 10%, Relative Permeability 1 - 2 md,
Injection Rate 17.61x27 kg/s, 15 Mt/year, 9 Injection Wells



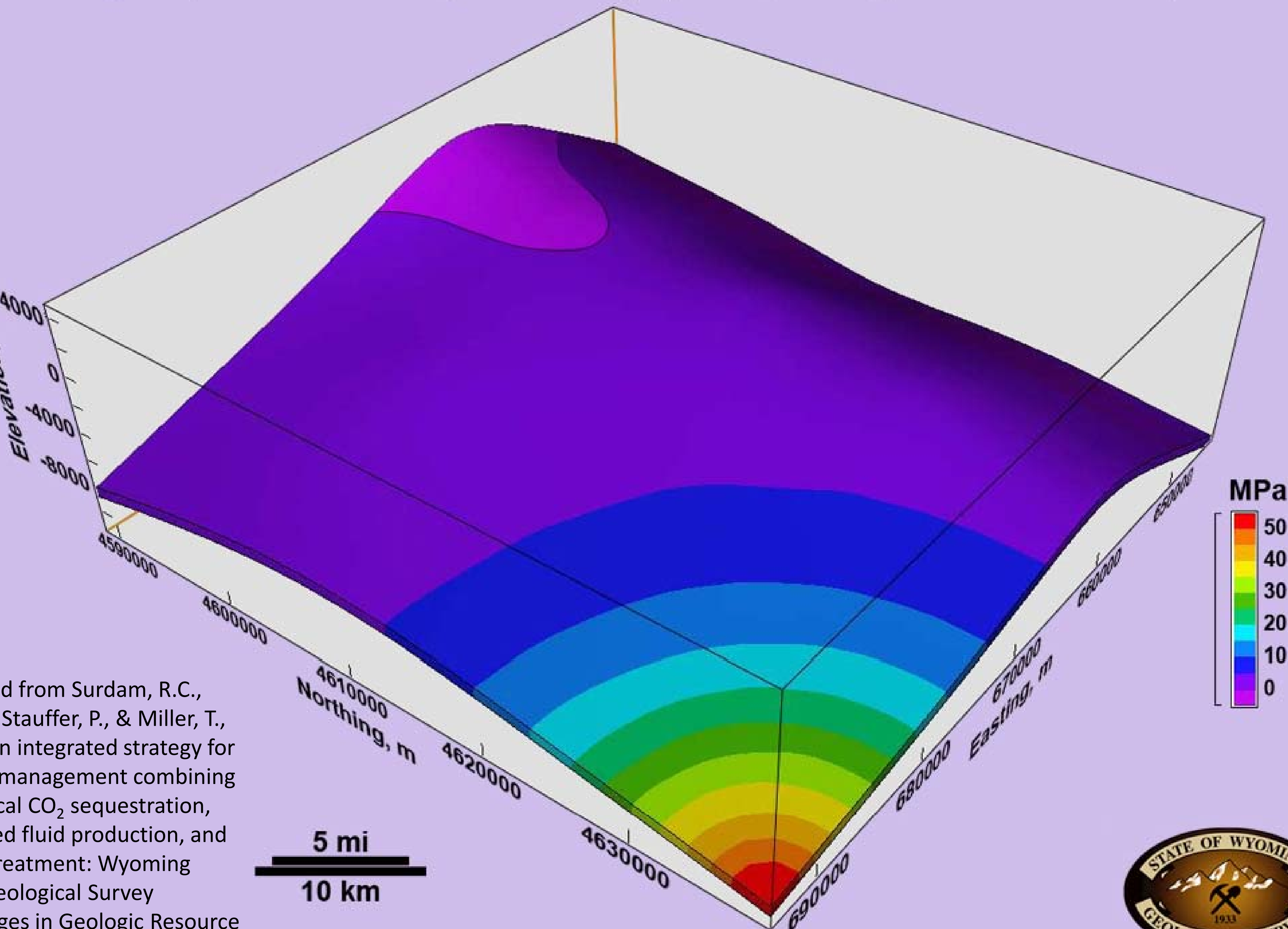
Nine point injector example



Geological CO_2 Sequestration, after 50 Years Injection, Weber Sandstone
Rock Springs Uplift, 9 Injection Wells



Change in pressure after 50 years of CO_2 injection, 15 mt/y, Weber Sandstone, RSU



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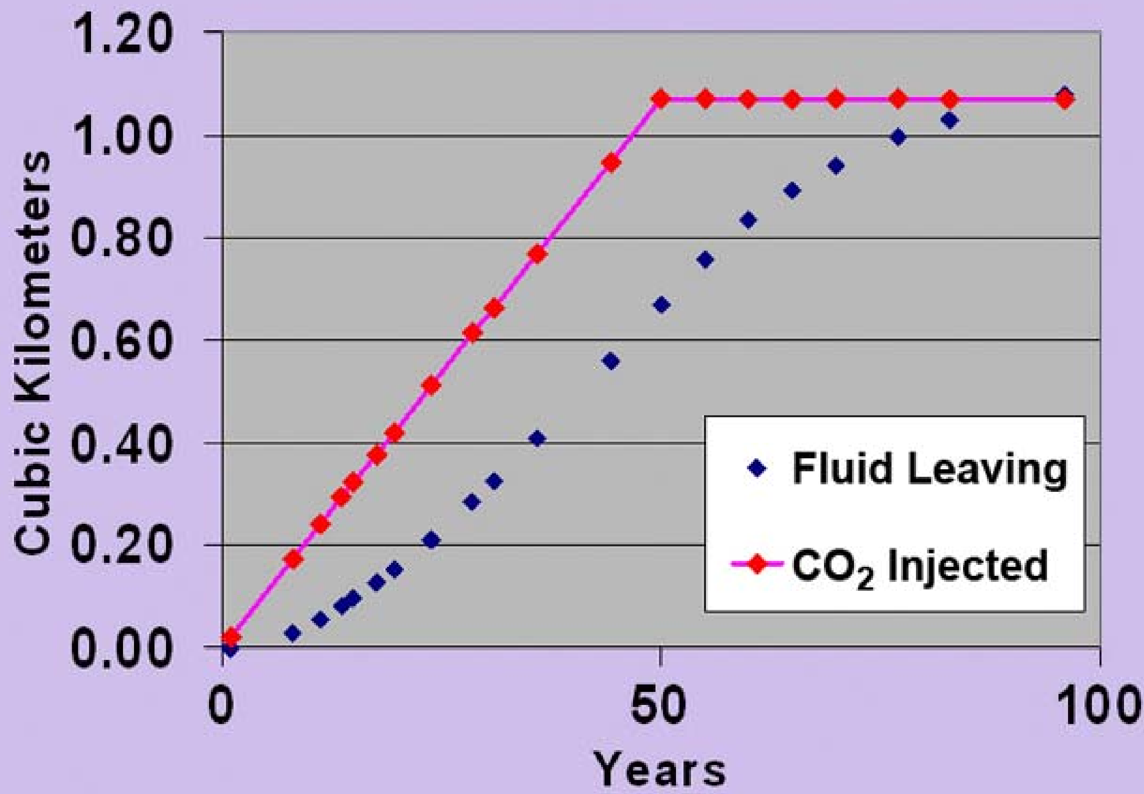
Injected CO_2 versus fluid leaving the domain



Scale:

750 Mt of CO2 displaces ~1 cubic kilometer.

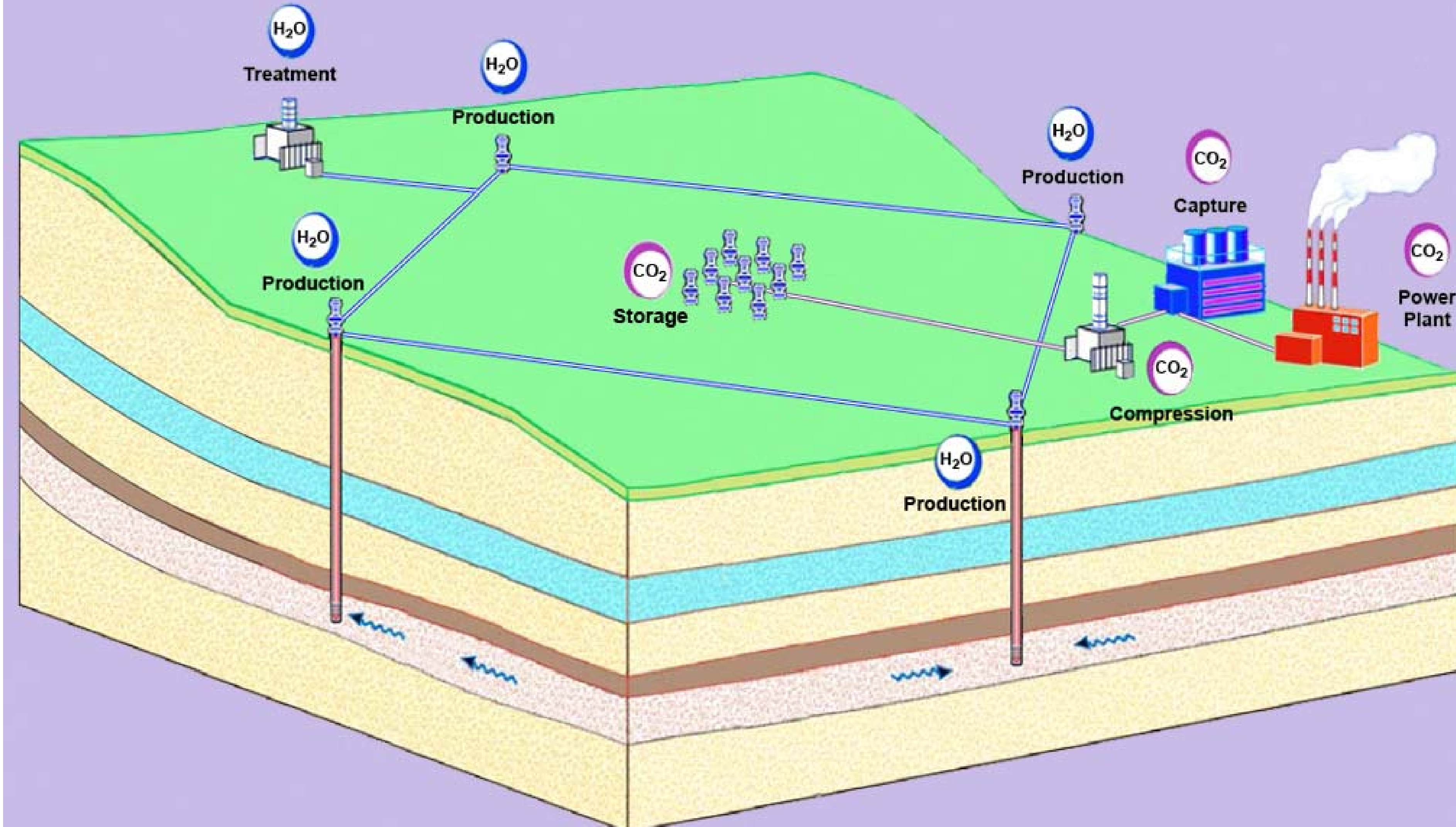
1 cubic kilometer of displaced fluids is ~6,000,000,000 barrels

Salt Creek Oil production (the largest oil field in Wyoming) is ~680,000,000 barrels (120 yrs)

1 cubic kilometer of water is ~710,000 acre-feet.

Boysen Reservoir is 792,000 acre-feet.

Modified from Surdam, R.C., Jiao, Z., Stauffer, P., & Miller, T., 2009, An integrated strategy for carbon management combining geological CO_2 sequestration, displaced fluid production, and water treatment: Wyoming State Geological Survey Challenges in Geologic Resource Development No. 8, 25 p.



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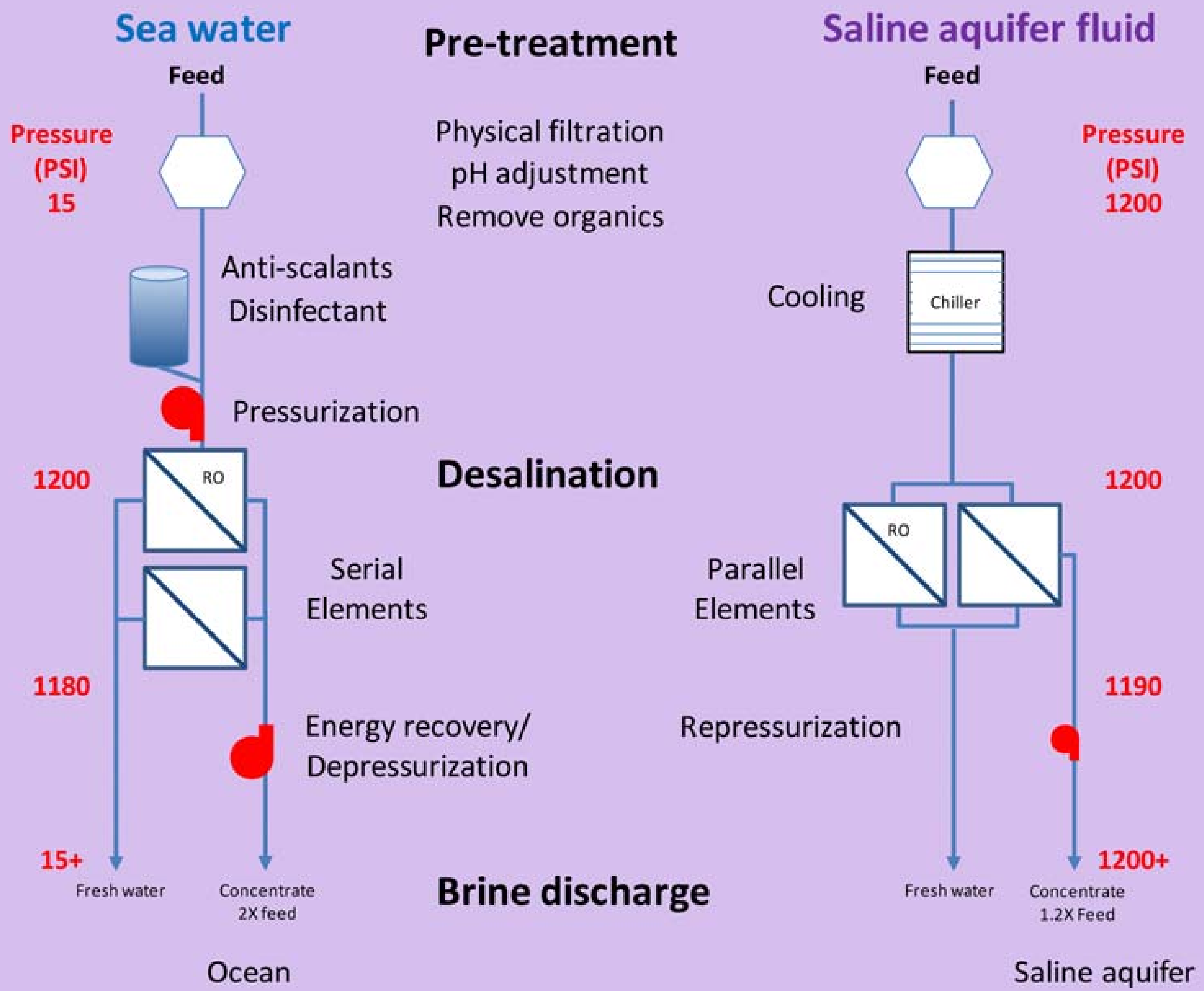

Wolery, T.J., Aines, R.D., Hao, Y., Bourcier, W., Wolfe, T., and Haussman, C., 2009, Fresh Water Generation from Aquifer-Pressured Carbon Storage: Annual Report FY09. Lawrence Livermore National Laboratory Report LLNL-TR-420857, 44 p.

One Year Average Water Production

Amount of CO_2 Sequestrated	*Amount of Water Produced*		*Treatment Cost*		*80% Recovery*		*Value*	
Million ton	Million ton	Acre-foot	$450/Acre-ft	$600/Acre-ft	Million ton	Acre-foot	Agricultural, $240/Acre-ft	Residential, $1270/Acre-ft
15	9.2	7,474	$3,363,120	$4,484,160	7.4	5,979	$1,434,931	$7,593,178
10	6.0	4,871	$2,191,860	$2,922,480	4.8	3,897	$935,194	$4,948,733
5	2.8	2,268	$1,020,600	$1,360,800	2.2	1,814	$435,456	$2,304,288

75 Year Water Production

Amount of CO_2 Sequestrated	*Amount of Water Produced*		*Treatment Cost*		*80% Recovery*		*Value*	
Million ton	Million ton	Acre-foot	$450/Acre-ft	$600/Acre-ft	Million ton	Acre-foot	Agricultural $240/Acre-ft	Residential, $1270/Acre-ft
750 Mt (15 Mt/year)	692	560,520	$252,234,000	$336,312,000	554	448,416	$107,619,840	$569,488,320
500 Mt (10 Mt/year)	451	365,310	$164,389,500	$219,186,000	361	292,248	$70,139,520	$371,154,960
250 Mt (5 Mt/year)	210	170,100	$76,545,000	$102,060,000	168	136,080	$32,659,200	$172,821,600

Conclusions

- The most critical problem with commercial scale geological CO_2 sequestration is management of displaced fluids. To solve this problem, the Wyoming State Geological Survey proposes a strategy that includes integration of fluid production/water treatment with injection of CO_2.
- The greatest uncertainty in numerically simulating CO_2 sequestration processes is characterizing geological heterogeneity in 3 dimensions.

The WY-CUSP Partnership

SER – WSGS – UW is conducting one of the DOE sequestration characterization studies on the Rock Springs Uplift, Wyoming.

The Primary Objectives of this study are
1) to design the water treatment facility required to solve the displacement fluid problem, and
2) to significantly reduce the numerical simulation uncertainty by documenting the geological heterogeneity in 3-D.

Project Structure

DOE/NETL
$4.975 M

UW
$6.8 M

School of Energy Resources (UW)
Wyoming State Geological Survey

Task 1: Project Management
Project Director: R. Surdam

Industrial & LANL Partners (Data Sharing)

Task 2:	**Task 3:**	**Task 4:**	**Task 5:**	**Task 6:**	**Task 7:**
Well Design & Construction	Geophysical Characterization	Well Catalog	Structural & Stratigraphic Characterization	Mineral & Brine Containment	Commercial Sequestration Design & Assessment
P. Williams Baker Hughes	*S. Mallick, UW (Y. Ganshin, WSGS)*	*J. Myers, UW*	*Campbell-Stone, UW (F. McLaughlin, WSGS)*	*J. Kaszuba, UW*	*R. Surdam, WSGS Z. Jiao, WSGS*

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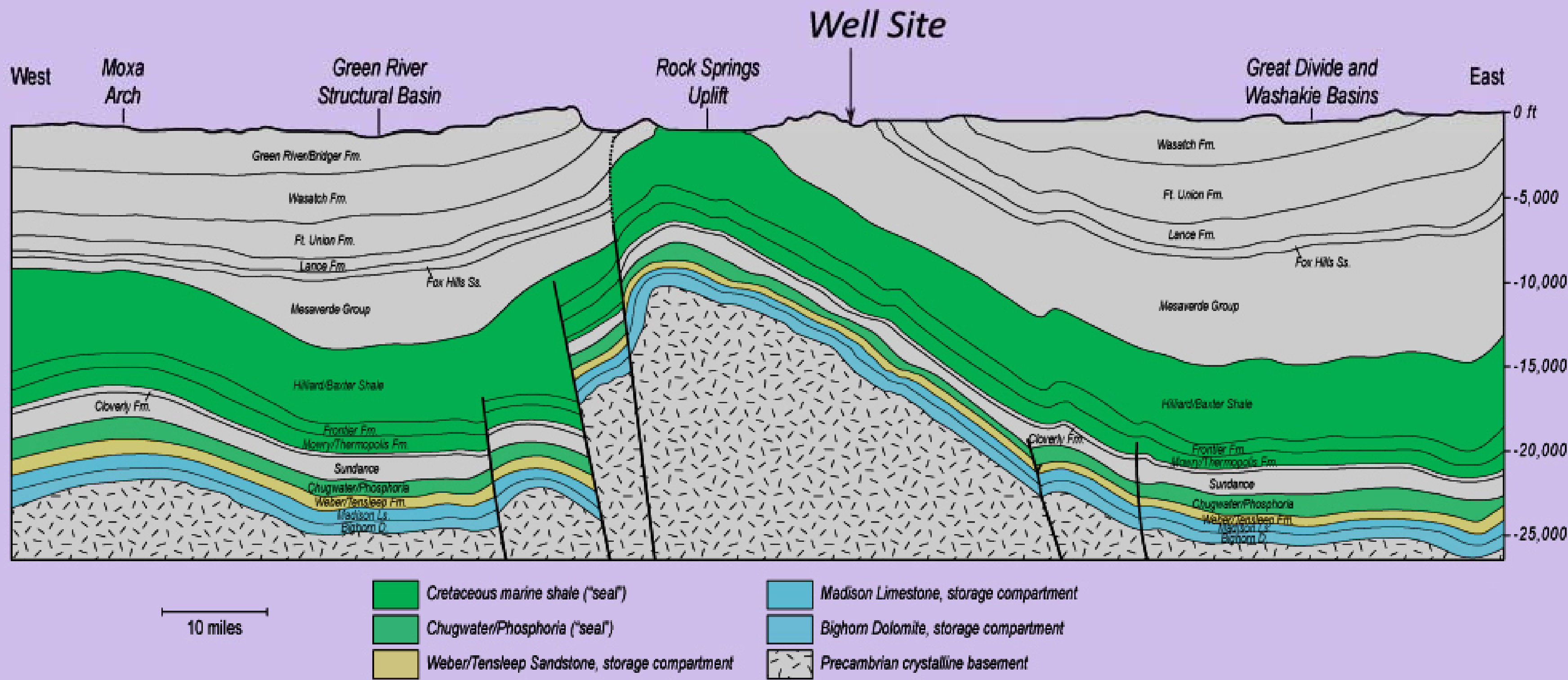
Basic elements of the Rock Springs Uplift characterization project are the acquisition of a 3D seismic survey and a stratigraphic test at the selected geological CO_2 sequestration site.



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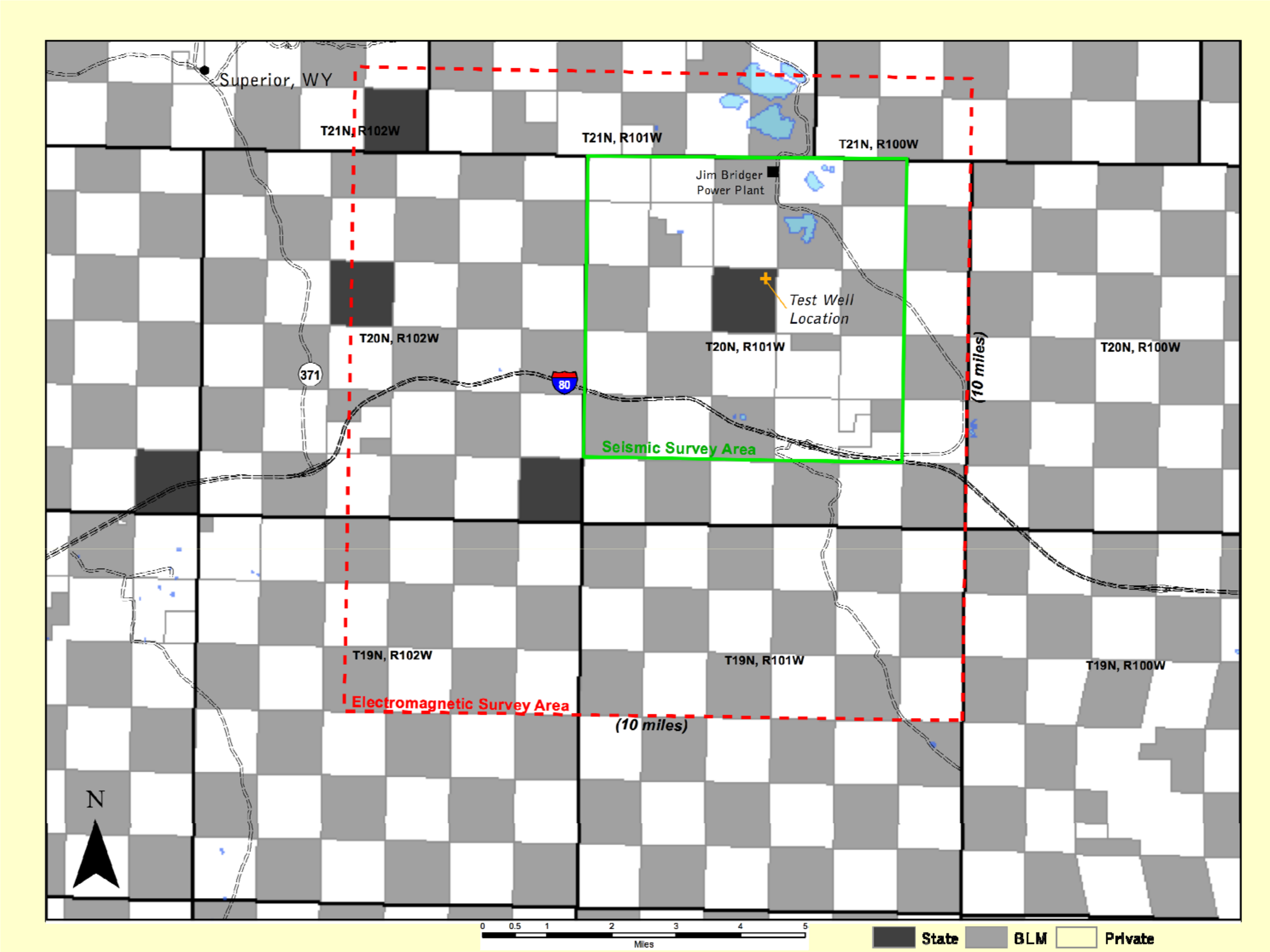
Superior, WY
T21N, R102W
T21N, R101W
T21N, R100W
Jim Bridger
Power Plant
Test Well
Location
T20N, R102W
T20N, R101W
T20N, R100W
371
80
(10 miles)
Seismic Survey Area
T19N, R102W
T19N, R101W
T19N, R100W
Electromagnetic Survey Area
(10 miles)
N
0 0.5 1 2 3 4 5
Miles
State
BLM
Private

Future Directions

Wyoming Governor Freudenthal's letter to the 60th (2010) Legislature:

> "Other . . . recommendations in the University of Wyoming budget include $45 million for continuation and acceleration of carbon sequestration research . . ."

With this and other funds, UW hopes to develop a commercial-scale CO_2 sequestration site by 2016 that will be able to inject >>1 million tons of CO_2/year

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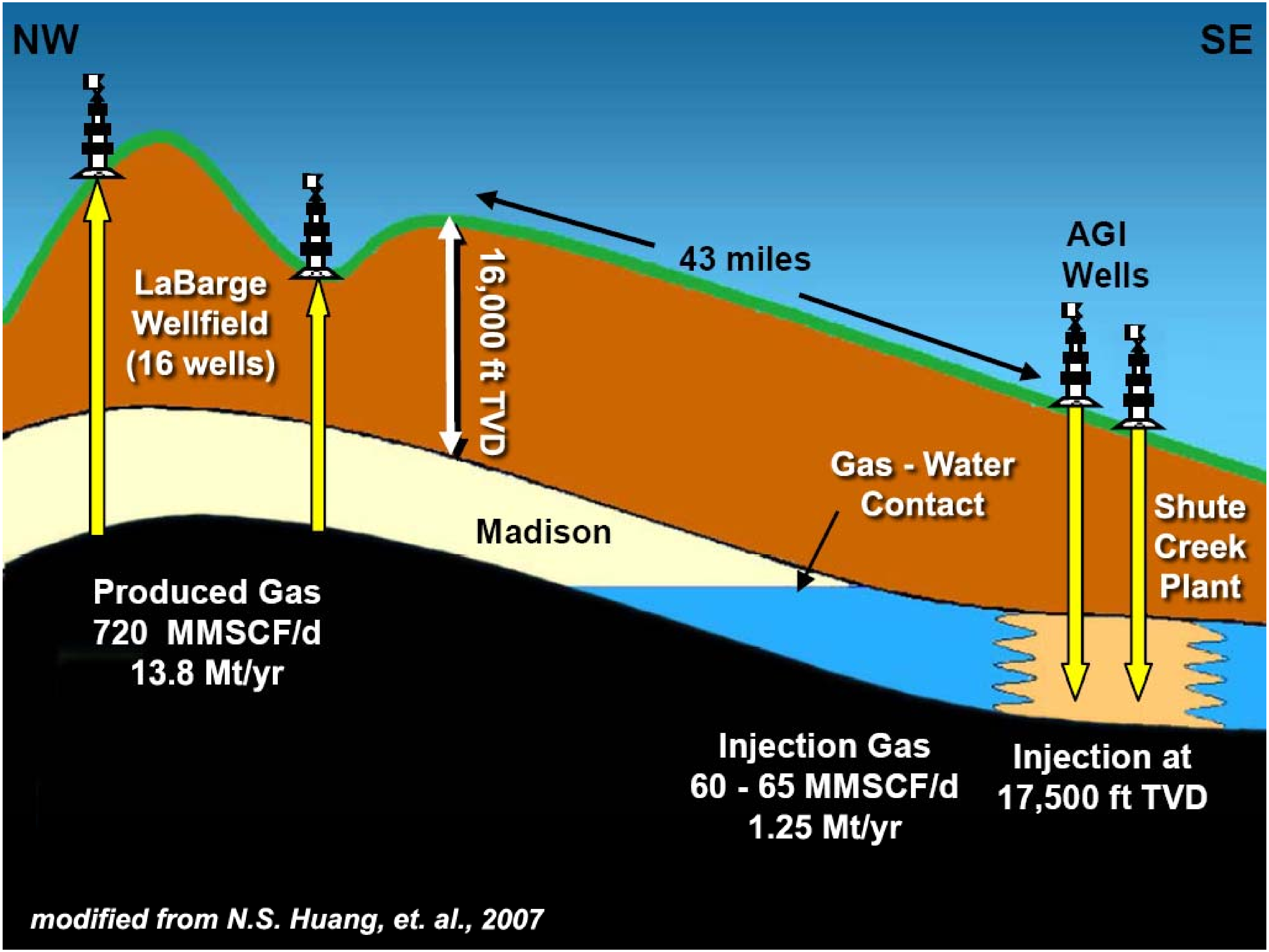
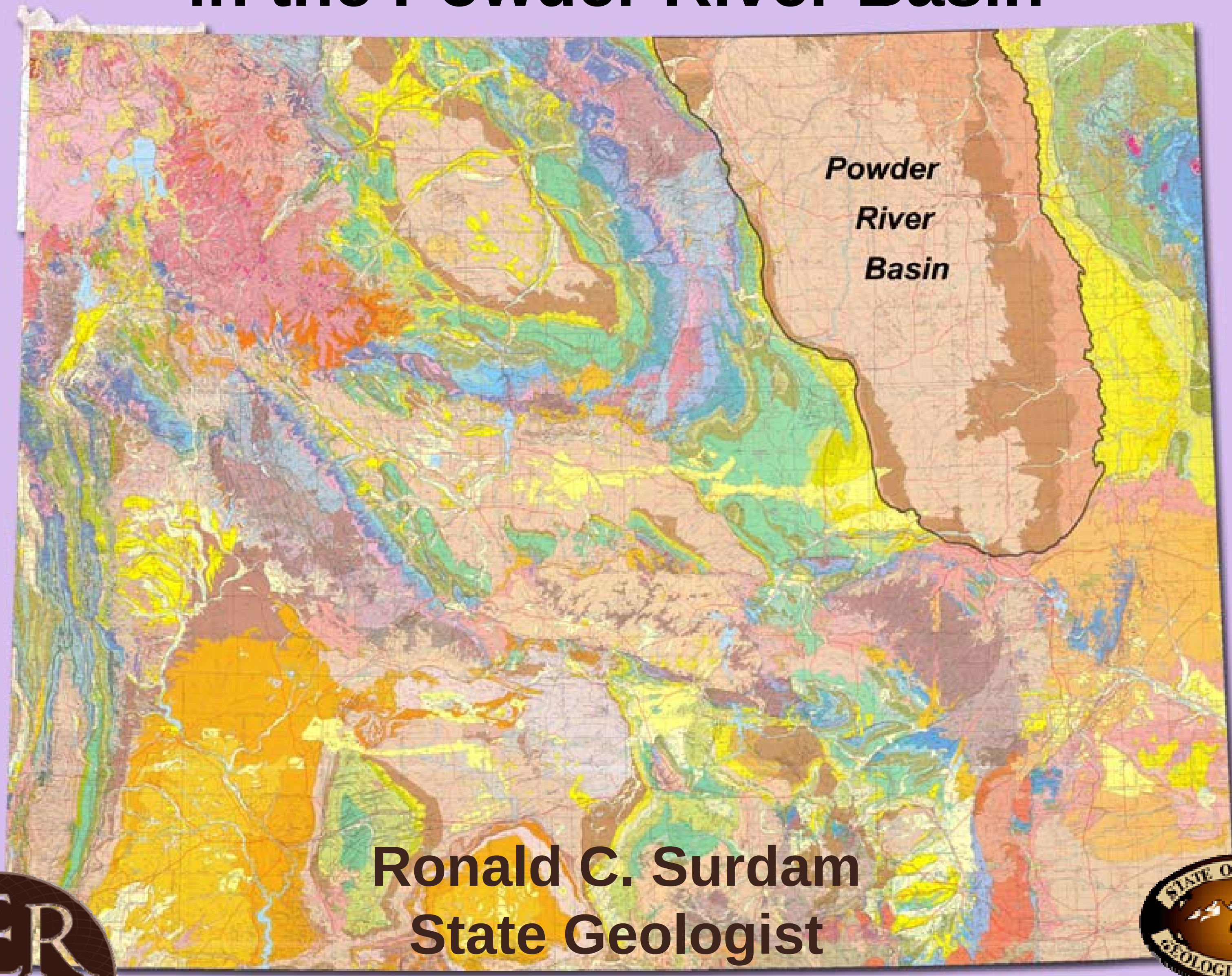
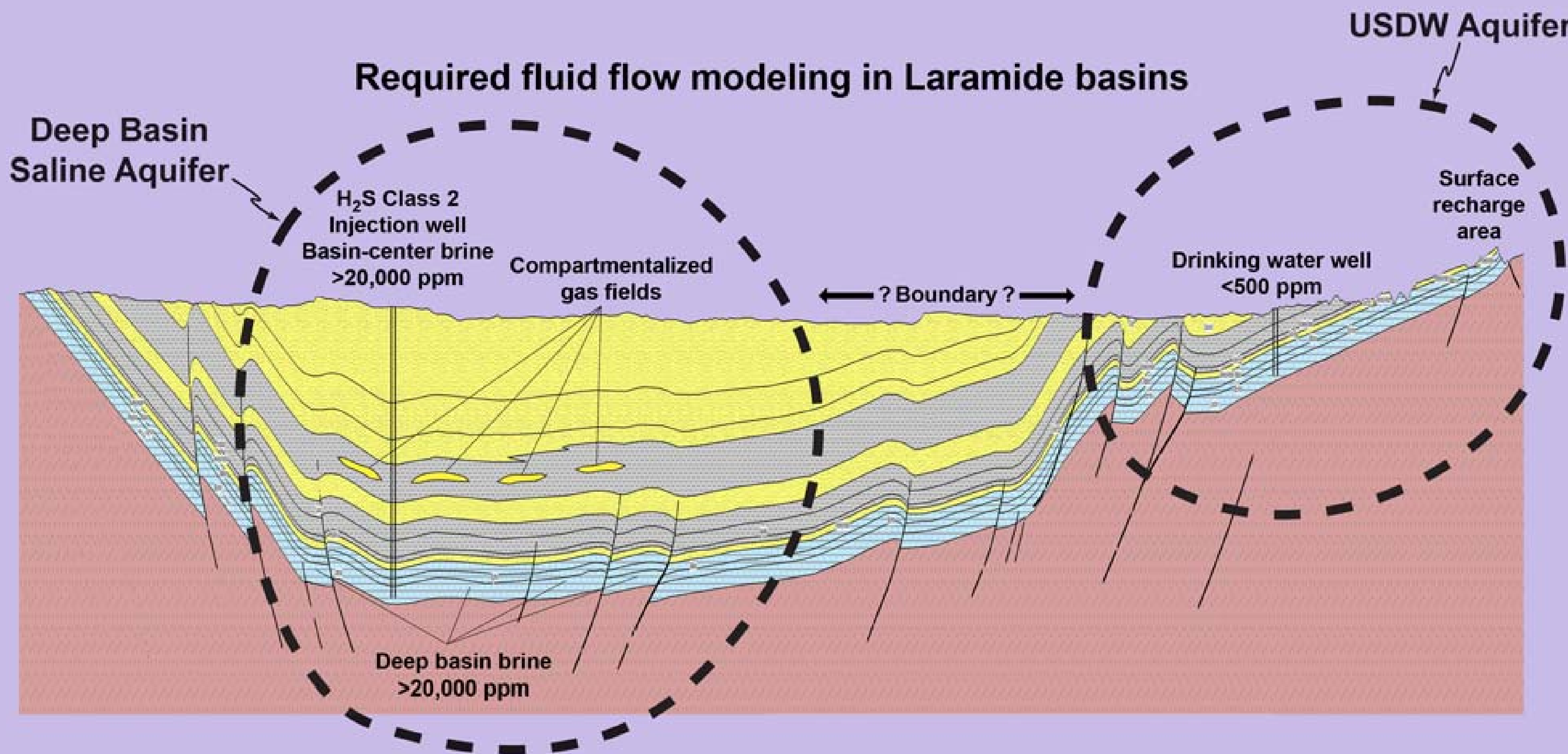

NW
SE
LaBarge
Wellfield
(16 wells)
16,000 ft TVD
43 miles
AGI
Wells
Gas - Water
Contact
Madison
Shute
Creek
Plant
Produced Gas
720 MMSCF/d
13.8 Mt/yr
Injection Gas
60 - 65 MMSCF/d
1.25 Mt/yr
Injection at
17,500 ft TVD
modified from N.S. Huang, et. al., 2007

Geologic Carbon Sequestration in the Powder River Basin



Ronald C. Surdam
State Geologist

Typical Wyoming Laramide Basin



Brines resulting from original depositional environment and subsequent digenesis during burial.

Flushed by Meteoric Water

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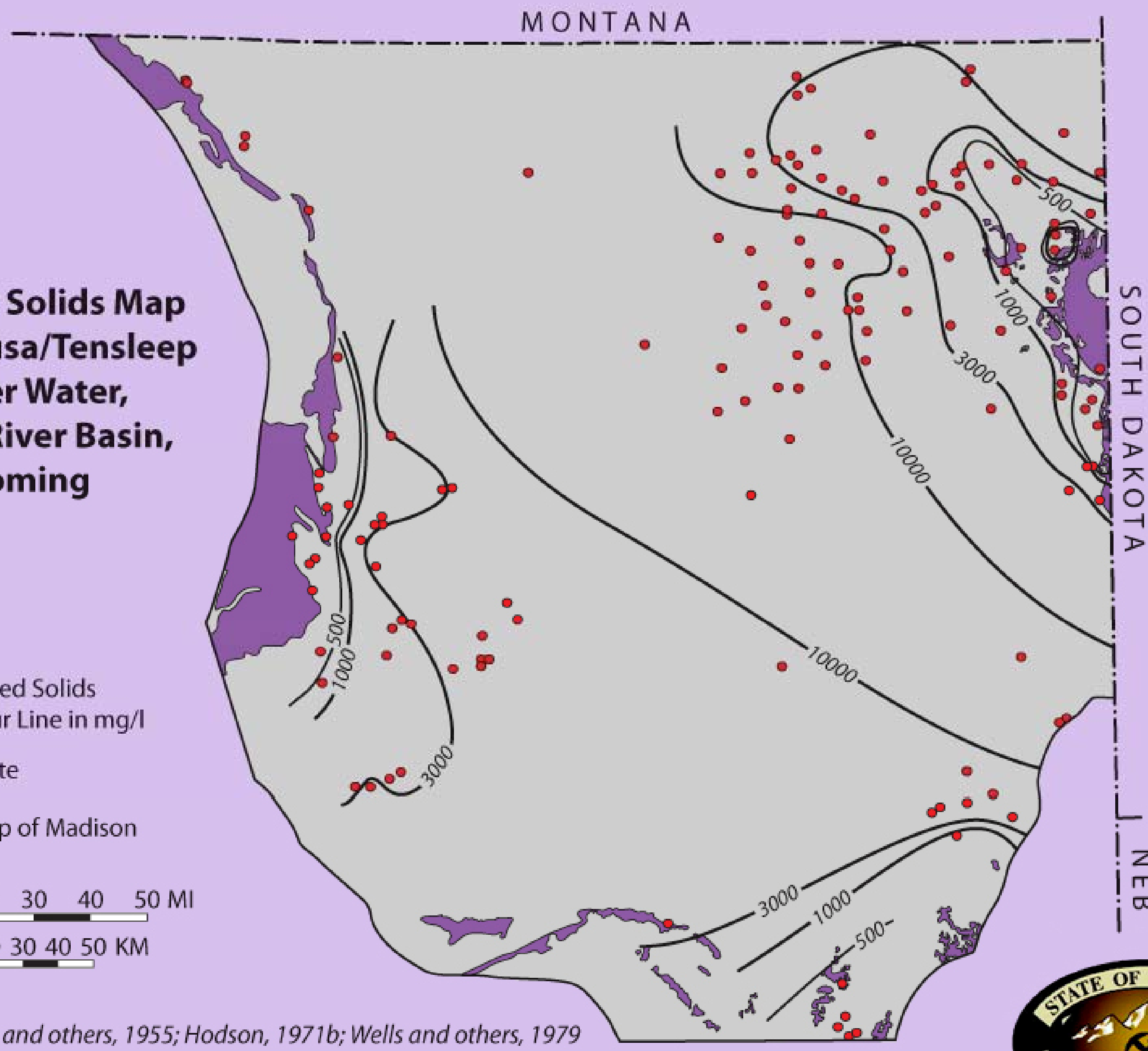
Dissolved Solids Map of Minnelusa/Tensleep Aquifer Water, Powder River Basin, Wyoming



Dissolved Solids Contour Line in mg/l

Data Site

Outcrop of Madison

0 10 20 30 40 50 MI

0 10 20 30 40 50 KM

Sources: Love and others, 1955; Hodson, 1971b; Wells and others, 1979

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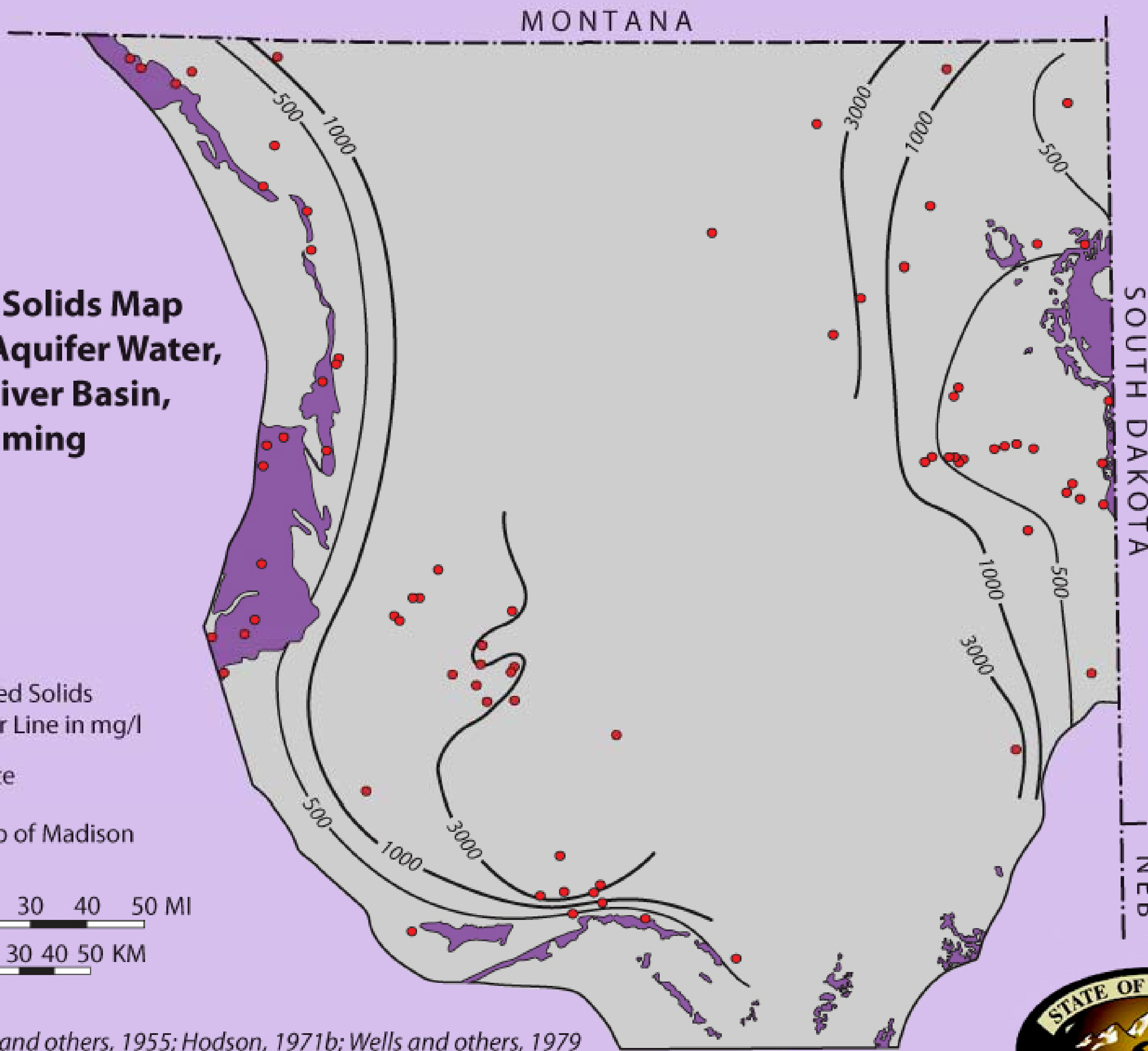
Dissolved Solids Map of Madison Aquifer Water, Powder River Basin, Wyoming



Dissolved Solids Contour Line in mg/l

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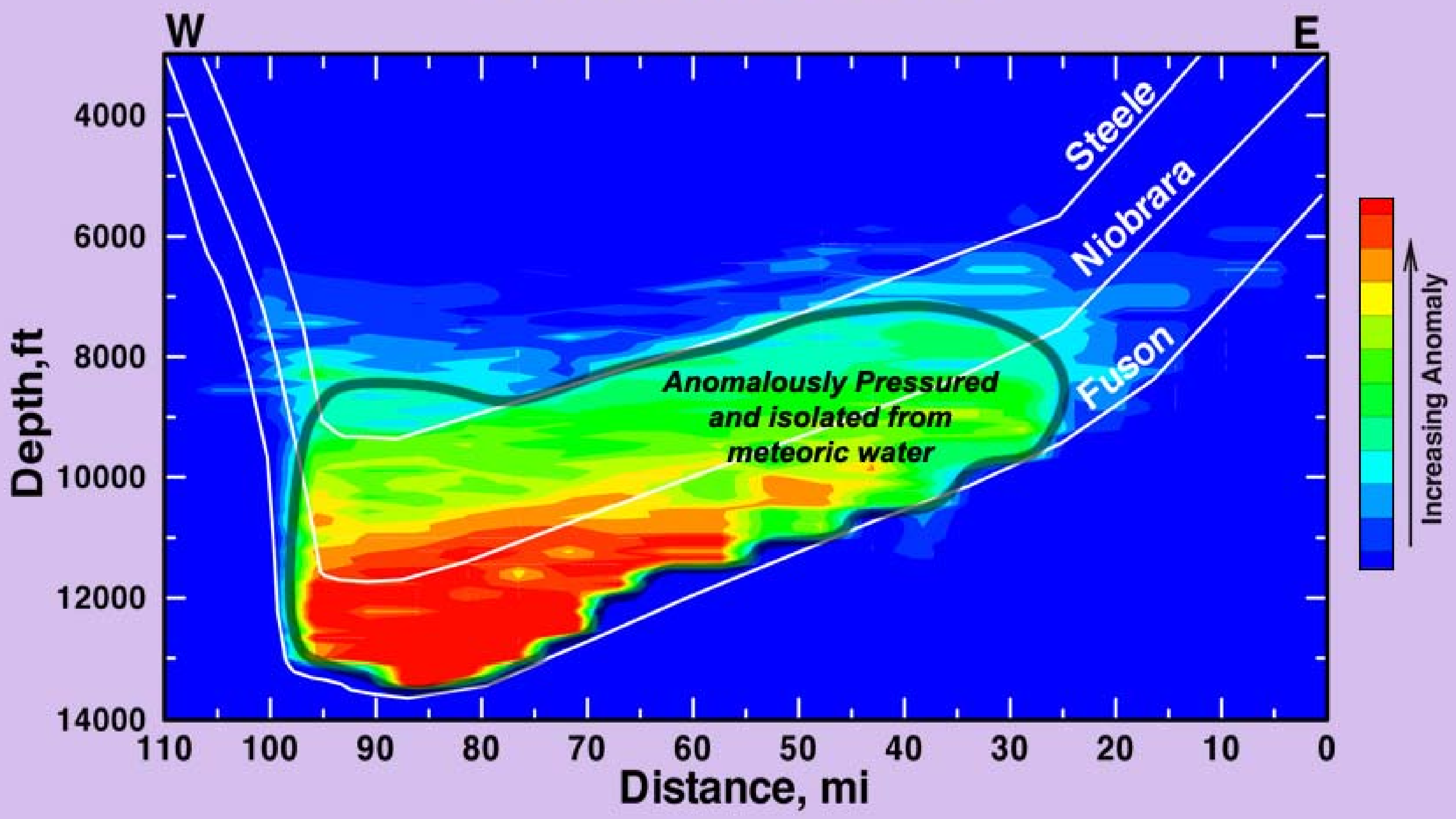
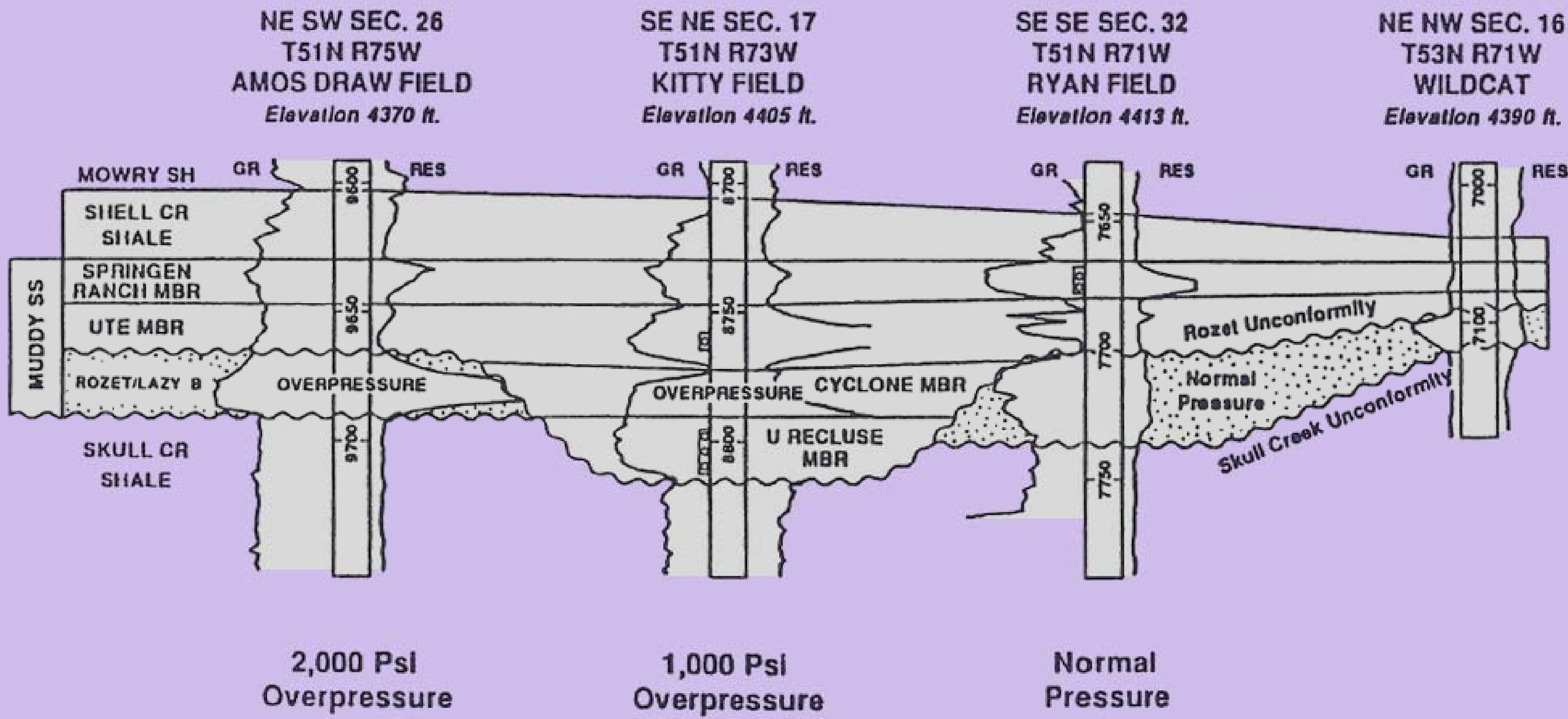
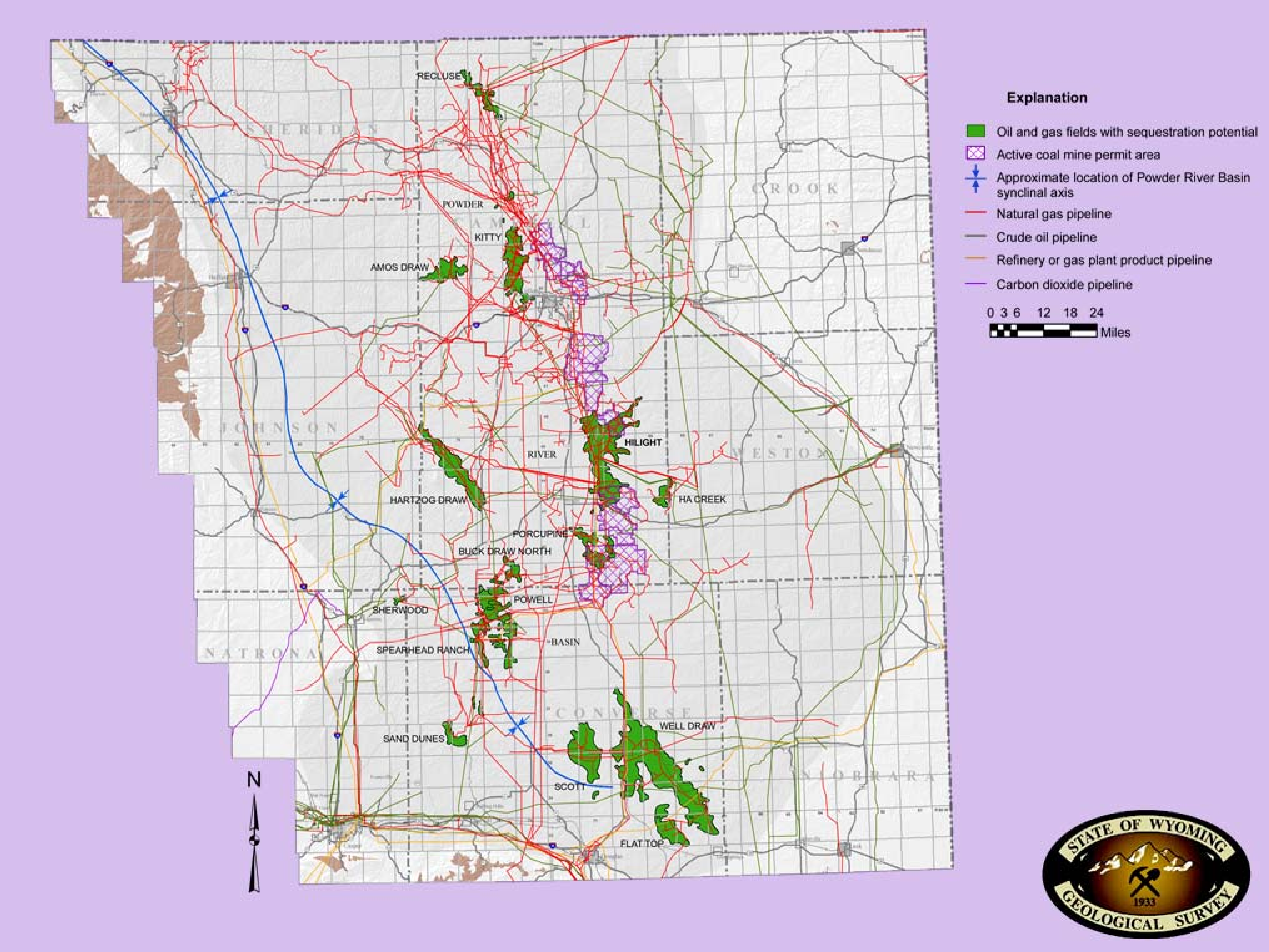
Powder River Basin





NE SW SEC. 26
T51N R75W
AMOS DRAW FIELD
Elevation 4370 ft.
SE NE SEC. 17
T51N R73W
KITTY FIELD
Elevation 4405 ft.
SE SE SEC. 32
T51N R71W
RYAN FIELD
Elevation 4413 ft.
NE NW SEC. 16
T53N R71W
WILDCAT
Elevation 4390 ft.
GR
RES
MOWRY SH
SHELL CR SHALE
SPRINGEN RANCH MBR
UTE MBR
ROZET/LAZY B
MUDDY SS
SKULL CR SHALE
OVERPRESSURE
CYCLONE MBR
U RECLUSE MBR
Rozet Unconformity
Normal Pressure
Skull Creek Unconformity
9600
9650
9700
8700
8750
8800
7650
7700
7750
7000
7100
2,000 Psi Overpressure
1,000 Psi Overpressure
Normal Pressure

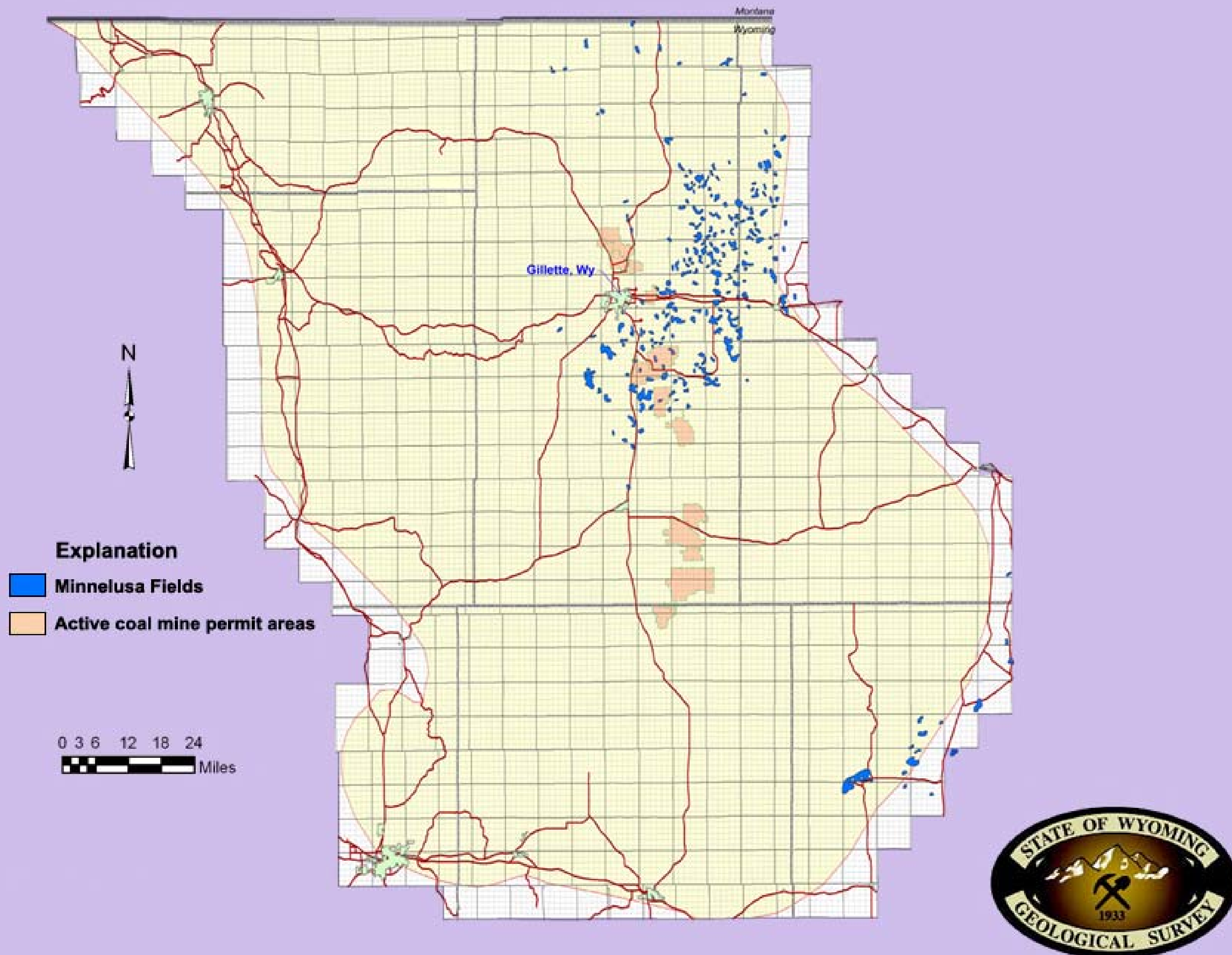

Explanation
Oil and gas fields with sequestration potential
Active coal mine permit area
Approximate location of Powder River Basin synclinal axis
Natural gas pipeline
Crude oil pipeline
Refinery or gas plant product pipeline
Carbon dioxide pipeline
0 3 6 12 18 24
Miles
SHERIDAN
CAMPBELL
CROOK
JOHNSON
WESTON
NATRONA
CONVERSE
NIOBRARA
RECLUSE
POWDER
KITTY
AMOS DRAW
HILIGHT
RIVER
HA CREEK
HARTZOG DRAW
PORCUPINE
BUCK DRAW NORTH
POWELL
SHERWOOD
BASIN
SPEARHEAD RANCH
WELL DRAW
SAND DUNES
SCOTT
FLAT TOP
N
STATE OF WYOMING
GEOLOGICAL SURVEY
1933

CO_2 Sequestration Potential in Depleted Gas Fields, Powder River Basin, Wyoming

Field	Formation	CO_2 Capacity (million tons)
Amos Draw Complex	**Muddy**	**13.8**
Kitty	**Muddy**	**18.8**
Hartzog Draw	**Shannon**	**18.5**
Buck Draw North	**Dakota**	**15.6**
Powell	**Frontier**	**38.0**
Spearhead Ranch	**Frontier**	**6.9**
Sand Dunes	**Muddy**	**12.4**
House Creek	**Sussex**	**8.2**
Scott	**Parkman**	**5.4**
		Total = **137.6** million tons

Preliminary results based on volumetric calculations using USGS protocol.

Minnelusa Fields with Enhanced Oil Recovery Potential
Powder River Basin, Wyoming

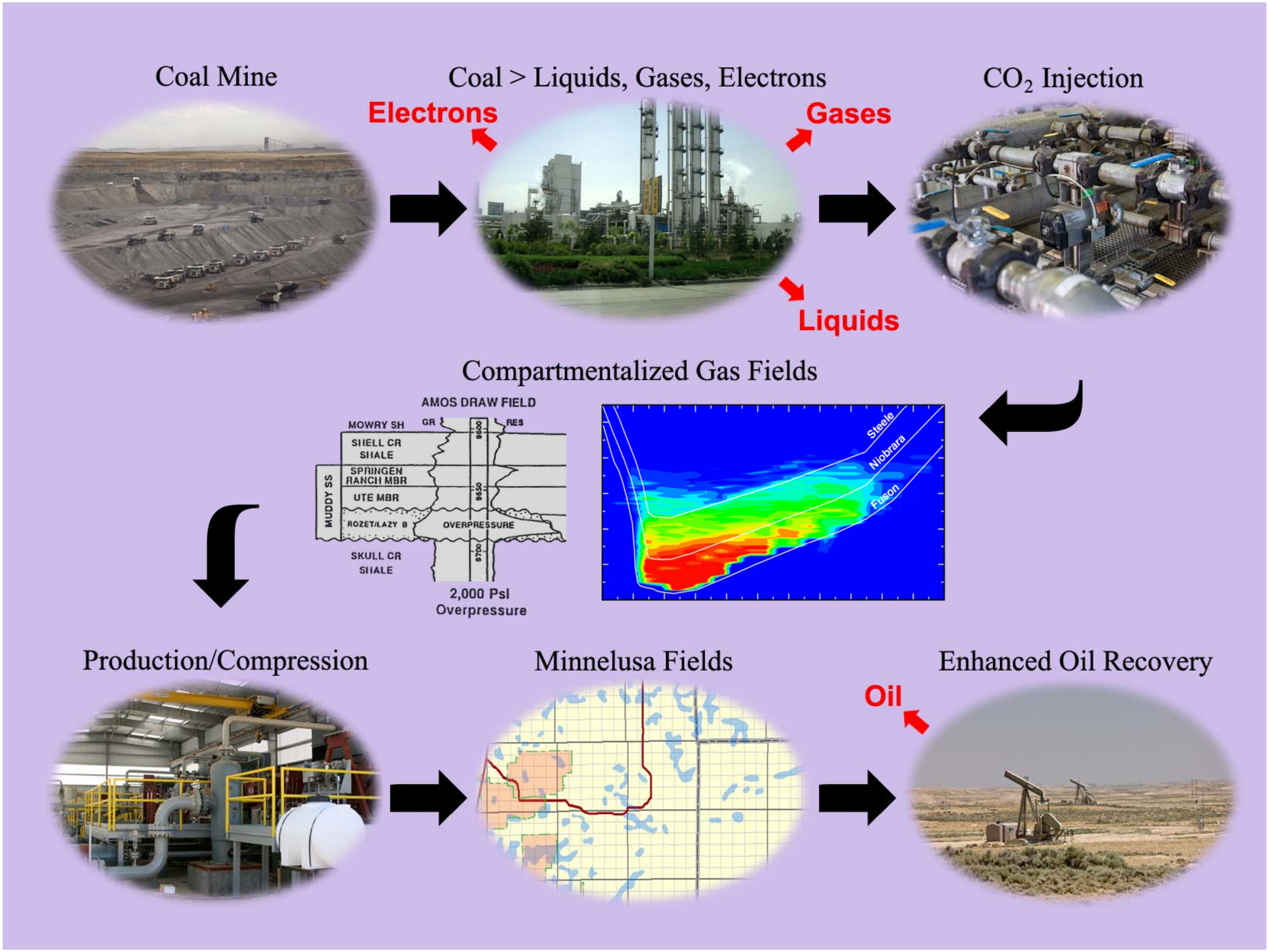


Enhanced Oil Recovery Opportunities in Powder River Basin - Minnelusa

- Approximately 150 candidate Minnelusa oil fields. Many have gone through the secondary recovery waterflood stage and appear ideal for CO_2 miscible flooding
- 1.2 Billion barrels of Original Oil in Place (OOIP), CO_2 flooding adding 10% additional production, 120 million barrels @ $65/barrel = $7.8 Billion
- Final sequestration available in field after flooding complete

CO_2 Flood Enhanced Oil Recovery Returns and CO_2 Requirements

Recovery 10% OOIP (barrels)	120 million barrels
Value @ $65/barrel	$7.8 billion
CO_2 required @ 10 mcf/barrel	1.2 billion mcf (1.2 TCF)
Tonnes of CO_2 needed (19.3 mcf/tonne)	62 million tonnes
CO_2 Cost @ $2/mcf	$2.4 billion



Coal Mine
Coal > Liquids, Gases, Electrons
Electrons
Gases
Liquids
CO_2 Injection
Compartmentalized Gas Fields
AMOS DRAW FIELD
MOWRY SH
GR
RES
SHELL CR SHALE
SPRINGEN RANCH MBR
MUDDY SS
UTE MBR
ROZET/LAZY B
OVERPRESSURE
SKULL CR SHALE
9600
9650
9700
2,000 Psi Overpressure
Steele
Niobrara
Fuson
Production/Compression
Minnelusa Fields
Enhanced Oil Recovery
Oil

U.S. Energy Imports
2006

Rank	Country or State of Origin	Crude Oil Production Million Bbl/year	Crude Oil Quadrillion Btu	Natural Gas Production Trillion Cubic ft/year	Natural Gas Quadrillion Btu	Coal Production million tons/year	Coal Quadrillion Btu	Total Quadrillion Btu
1	Wyoming	52.93	0.28	1.75	1.77	446.74	7.96	10.01
2	Canada	648.97	3.41	3.59	3.63	1.49	0.04	7.08
3	West Virginia	1.83	0.01	0.22	0.22	152.37	3.91	4.14
4	Mexico	575.61	3.02	0.01	0.01	0.00	0.00	3.04
5	Saudi Arabia	519.40	2.73	0.00	0.00	0.00	0.00	2.73
6	Venezuela	416.83	2.19	0.00	0.00	3.07	0.08	2.27
7	Nigeria	378.51	1.99	0.06	0.06	0.00	0.00	2.05
8	Alaska	270.47	1.42	0.42	0.43	0.00	0.00	1.85
9	Iraq	201.85	1.06	0.00	0.00	0.00	0.00	1.06
10	Angola	187.25	0.98	0.00	0.00	0.00	0.00	0.98
	Total	3,253.61	17.08	6.05	6.12	603.67	11.99	35.19

Note: Total may not equal sum of components because of independent rounding.
Coal imports include coal to Puerto Rico and the Virgin Islands.

Source: Bureau of the Census, U.S. Department of Commerce, *Monthly Report IM 145.*
EIA, U.S. Natural Gas Imports by Country
EIA, U.S. Crude oil Net Imports by Country
EIA, Gross Heat Content of Coal Production, Most Recent Annual Estimates, 1980-2006

Why is geological CO_2 sequestration so important? Implications of Federal Legislation and EPA rule making! Consider the following:

- April 2007 – In Massachusetts v. EPA, Supreme Court finds that EPA does have authority to regulate GHGs under the Clean Air Act.
- GHGs fall within the Act's definition of "air pollutant."
- Supreme Court ruled EPA would have to determine if these pollutants pose a danger to public health and welfare before EPA could regulate them.
- December 8, 2009 – EPA declares there is compelling scientific evidence that global warming from green-house gases emitted from cars, power plants and factories endangers American's health.
- EPA's view is once an air pollutant is subject to an emission limitation or control requirement under any part of the Act, that pollutant automatically becomes subject to NSR.
- New and modified plants must have "best available control technology" (BACT) for GHG emissions.

EPA likely will begin by suggesting efficiency improvements, but environmental groups and some state/federal permitting authorities will argue that BACT should be more stringent:

- Fuel switching?
- CCS?
- IGCC?

EPA is pursuing the development of new source performance standards (NSPS) and existing-source guidelines for CO_2 and other GHG emissions from power plants.

- Work on these rules will accelerate in 2010.
- W-M/K-B would establish performance standards for new coal-fired power plants.
- 50% reduction for new plants started after 2008, subject to CCS availability, but no later than 2020.
- 65% reduction for new plants started after 2020.
- Geological CO_2 sequestration must work if these reduction standards are to be met by 2020.
- W-M/K-B and EPA have common goals; survival of up-stream and down-stream coal to electrons/chemical industries depend on geological CO_2 sequestration.

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