Mining Paleocene Fort Union Formation Coals of the Red Desert-Great Divide Basin, South-Central Wyoming, Over the Next 100 Years*

Chris J. Carroll[1] **and Ranie Lynds**[1]

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[1]Wyoming Geological Survey, Laramie, Wyoming (Carroll_chris@msn.com)

Abstract

Coal companies have been mining thick coal beds in the Great Divide Basin over the past 120 years. This large synclinal feature has shallow, mineable coal near Point of Rocks on the west side and on the east side near Rawlins. Over 8.9 million short tons of coal were mined in Sweetwater County, Wyoming in 2013, nearly half of that by underground methods. The mines supply fuel to the local Bridger Power Plant. At a modest one (1) percent growth rate per year for the next 100 years, over 1.53 billion short tons of coal could be mined from the Fort Union, Lance, and Almond formations in this area. The axis is north-south in the southern part of the basin, and trends N60W in the northwest part of the basin. It is one of two eastern sub-basins of the Greater Green River Basin in Wyoming. It is geologically distinct from the Washakie Basin to the south by the Wamsutter Arch in the subsurface. The deepest part of the basin lies along the steep eastern flank of the Rawlins Uplift, but the depocenter for latest Cretaceous and Paleocene strata lie in the northern part of the basin just south of the Wind River Mountains.

Across the Great Divide Basin the Fort Union Formation thickens and increases in organic-rich bedding. The lower unit contains thick coals of mineable thickness near Point of Rocks, Wyoming, on the east side of the Rock Springs Uplift. This coal-bearing interval thins out 10 miles south of the Black Butte Coal Mine. Paleocene Fort Union Formation strata at T25N R95W reach a maximum thickness of 4,720 ft. Net coal is usually less than 50 ft. The deepest Fort Union coals in T23N R94W are 6,605 ft, near the basin depo-center. The thinnest Fort Union Formation at 1,480 ft thick occurs near Wamsutter Field at T20S R93W. These syn-depositional alluvial continental sediments were deposited from nearby tectonic uplifts during Laramide time that

formed the original Green River Basin. Only the lower part of the formation is organic rich containing subbituminous coal. WSGS coal geologists have correlated over 50 individual Fort Union coal beds from 1,992 petroleum wells and 3,562 coal exploration wells across the basin. These coals were mapped in the subsurface and correlated to known surface exposures. Shallow coal less than 3,500 ft was mapped for mining purposes, and coal calculations were determined in terms of thickness and depth. Significant minable coal resources were determined down dip from the active Bridger and Black Butte coal mines in Sweetwater County.

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Mining Coal in the Paleocene Fort Union Formation in the Great Divide Basin over the next 100 years

Chris Carroll and Ranie Lynds
Wyoming State Geological Survey
AAPG ACE, Denver, CO
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Presentation outline

- Introduction: Geology of the Great Divide Basin (GDB)
- WSGS Study Area
  - Maps, Cross sections
- Coal resources model: calculations
  - Petra – Tfu coal correlations
  - Format transfer NCRDS to ArcGIS
  - ArcGIS resource calculations
- CBM fields in the GGRB

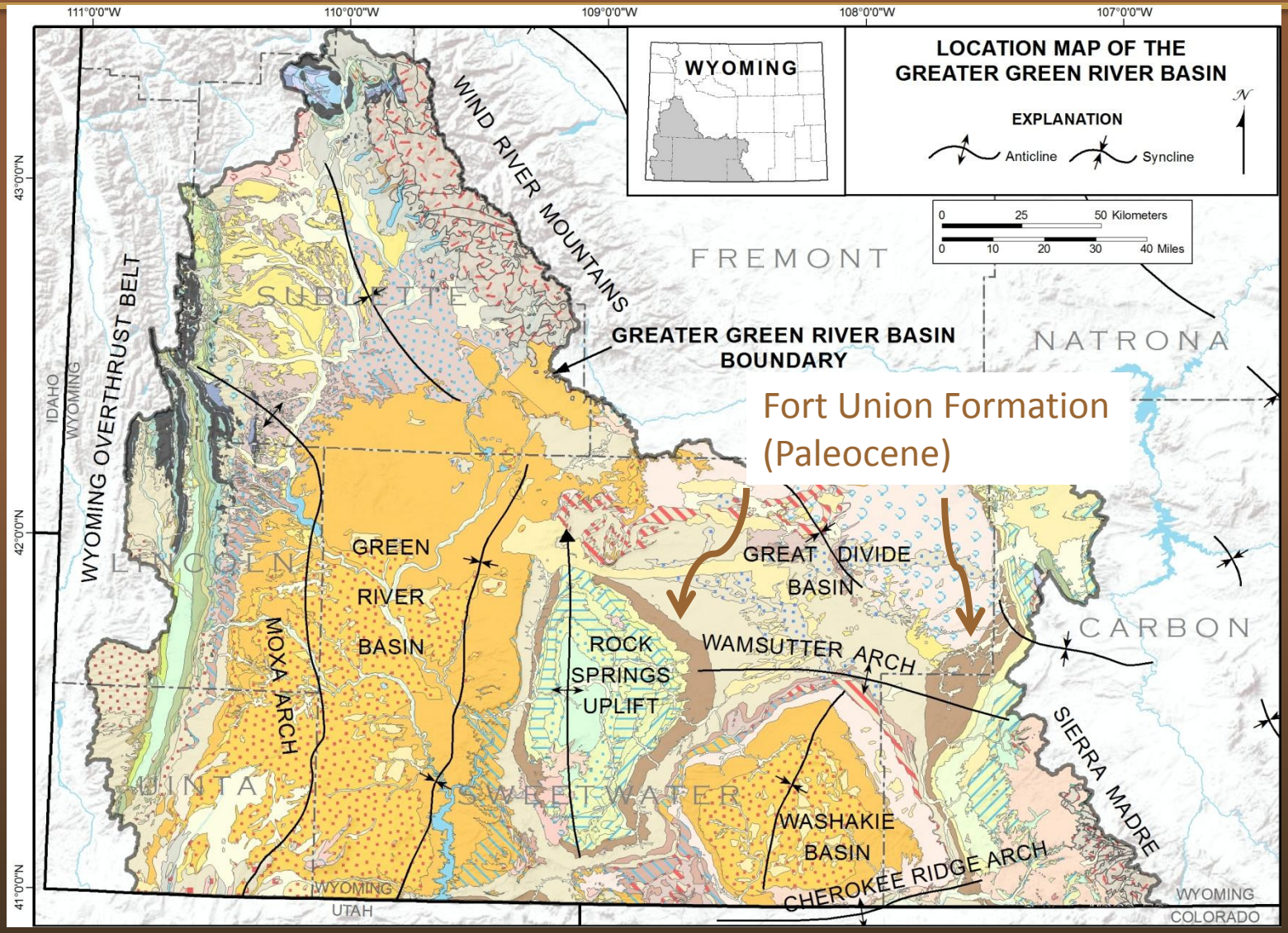
Introduction

- Coal in Mesaverde, Lance, Ft. Union, Wasatch
- Bituminous and Subbituminous Coal
  - Surface and underground mines
  - Coal to liquids
  - CBM
  - UCG

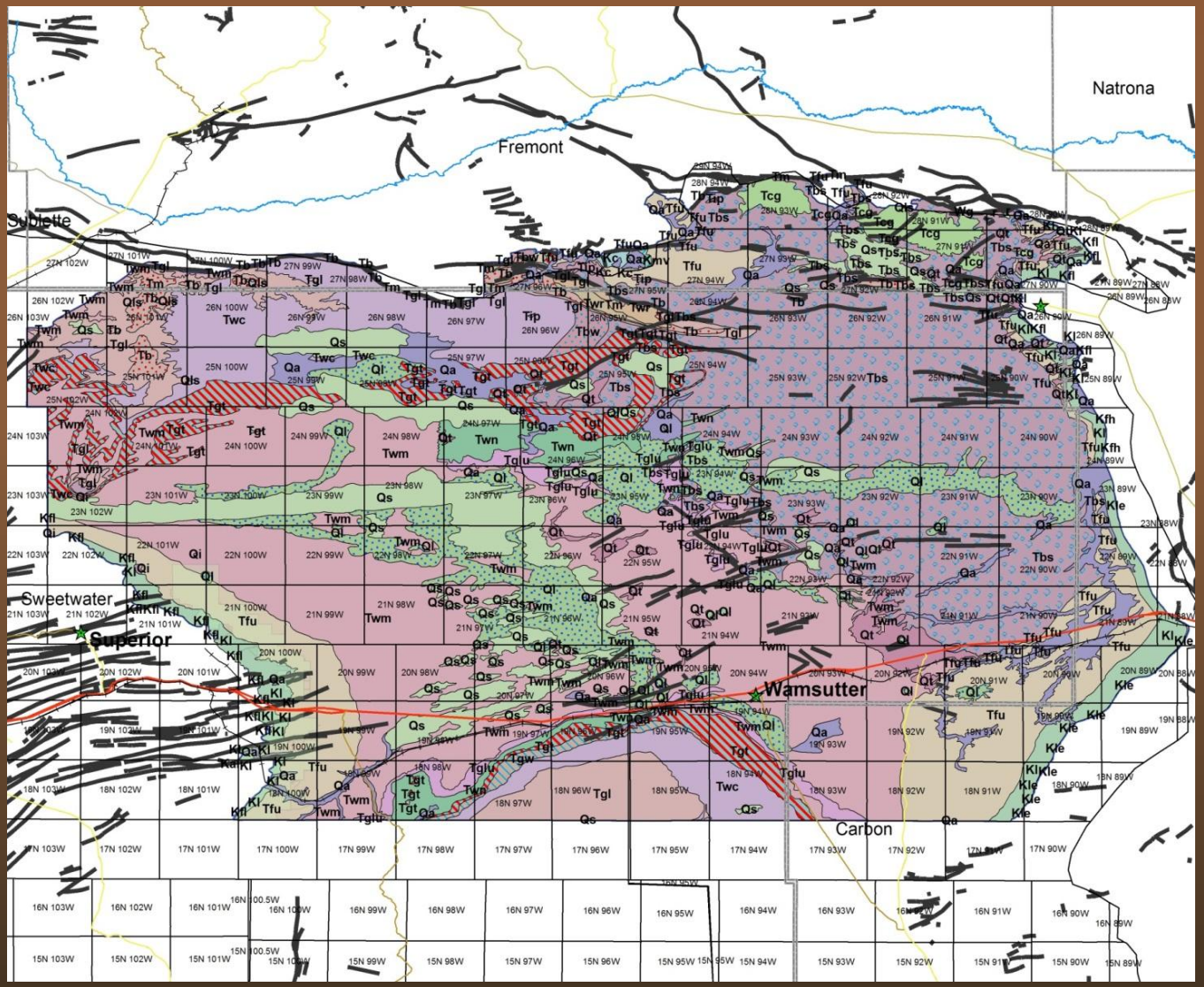
Estimated 82 BT coal in GGRB Cretaceous-Eocene system (*McCord, 1984*)

STATE OF WYOMING GEOLOGICAL SURVEY 1933

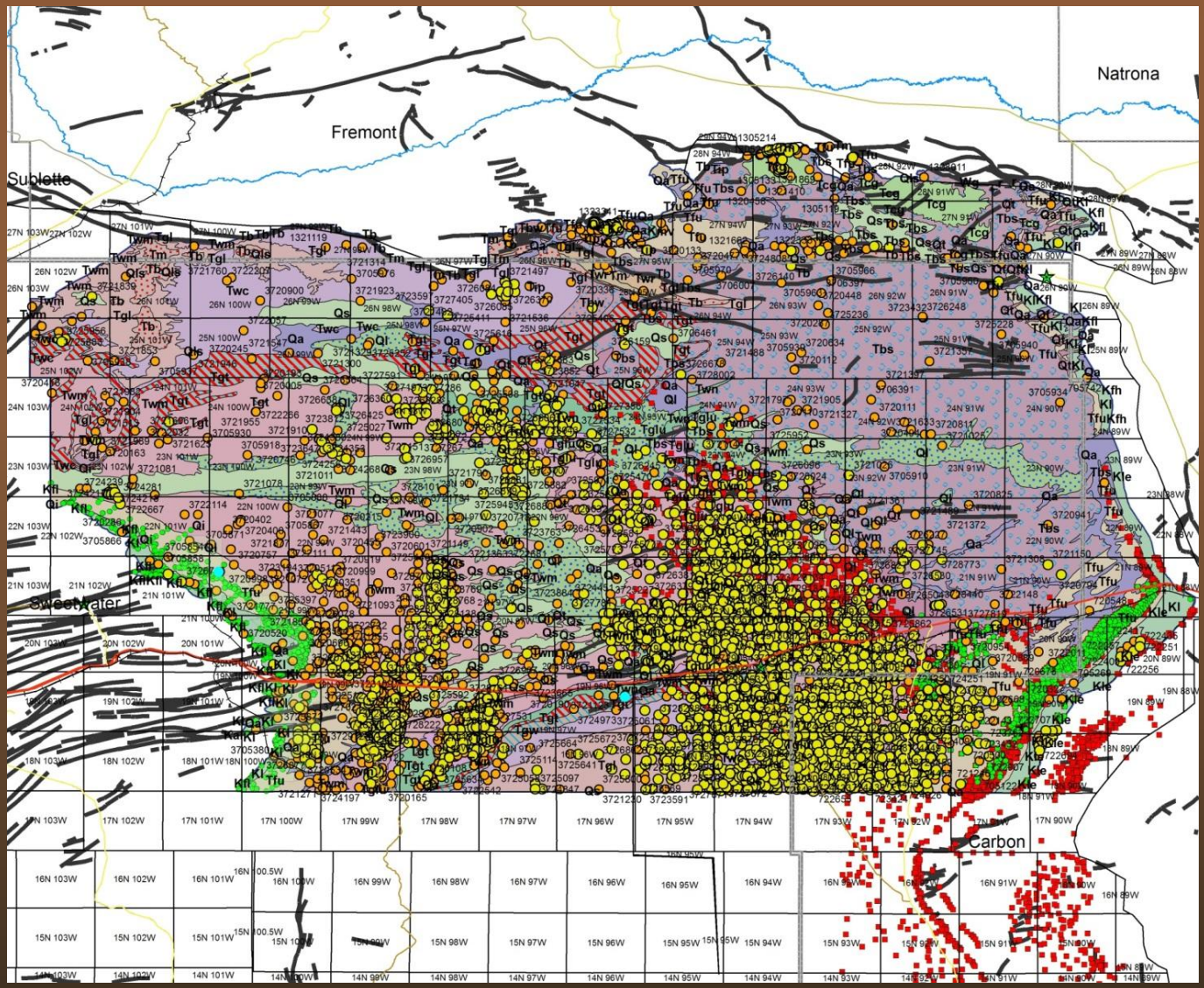
WSGS Wyoming GGRB Fort Union Project

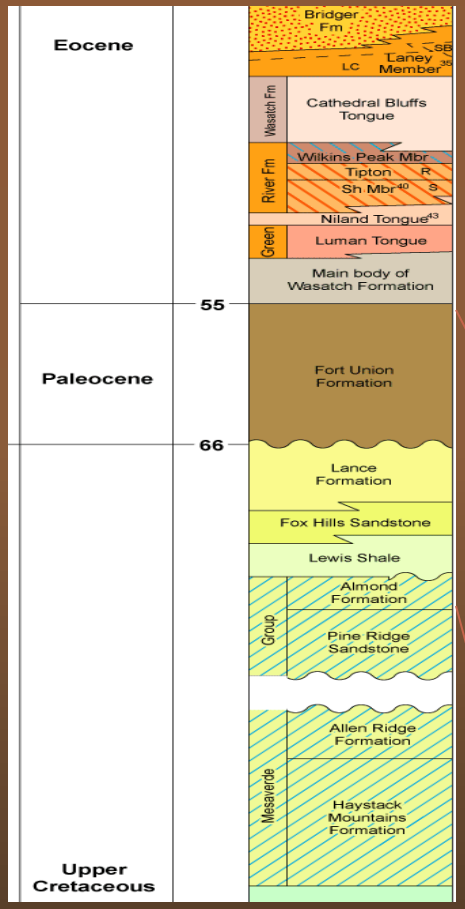


Great Divide Basin - Geology

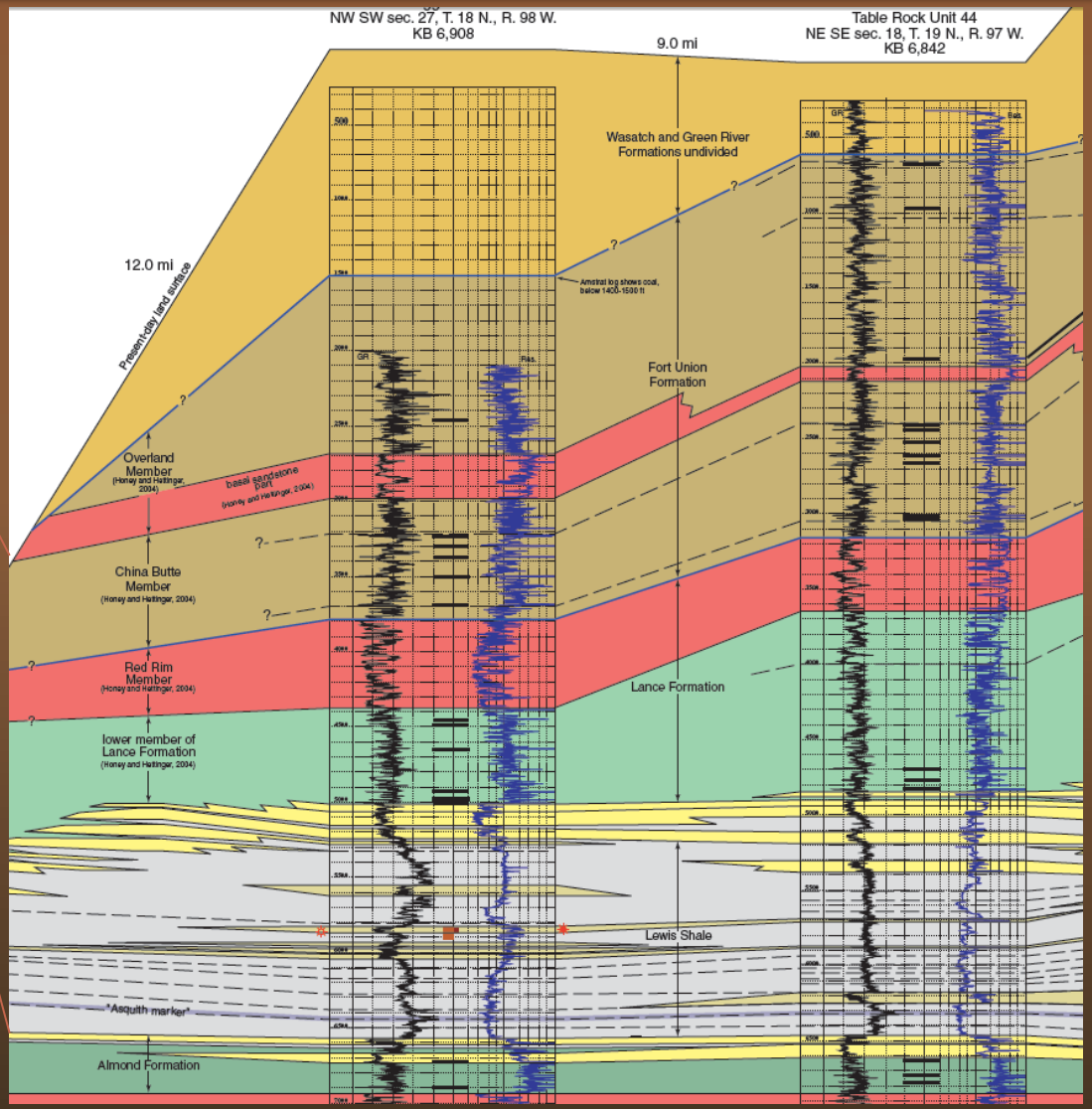


GDB – Geology and Wells

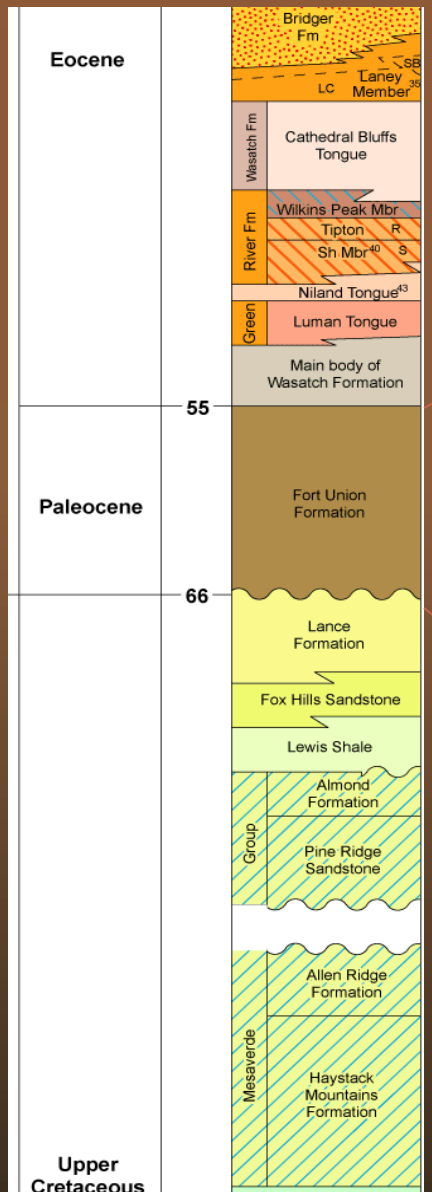


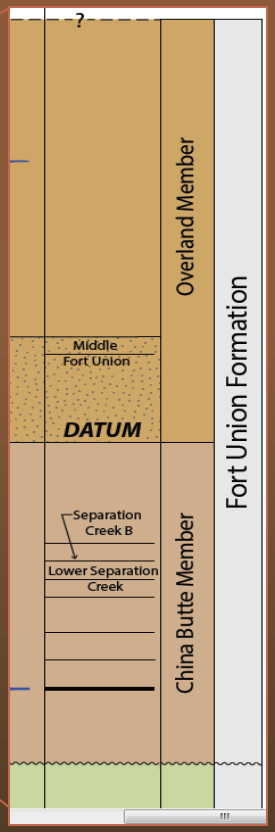


Modified from
Finn and Johnson, 2005

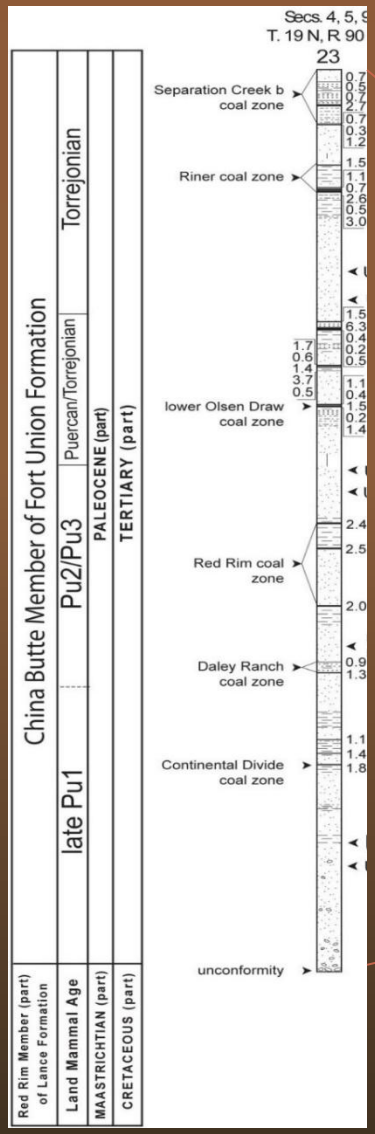


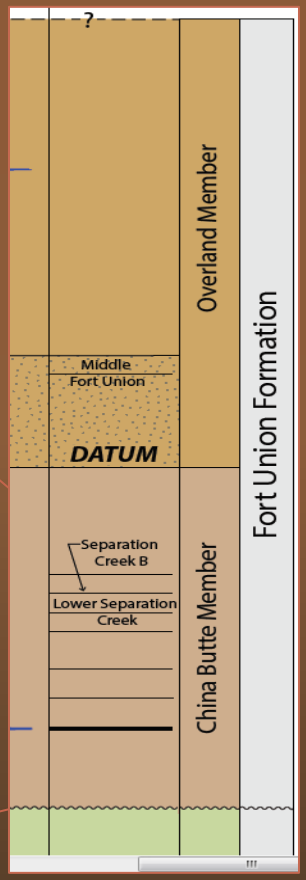
Eocene, Paleocene, uppermost Cretaceous



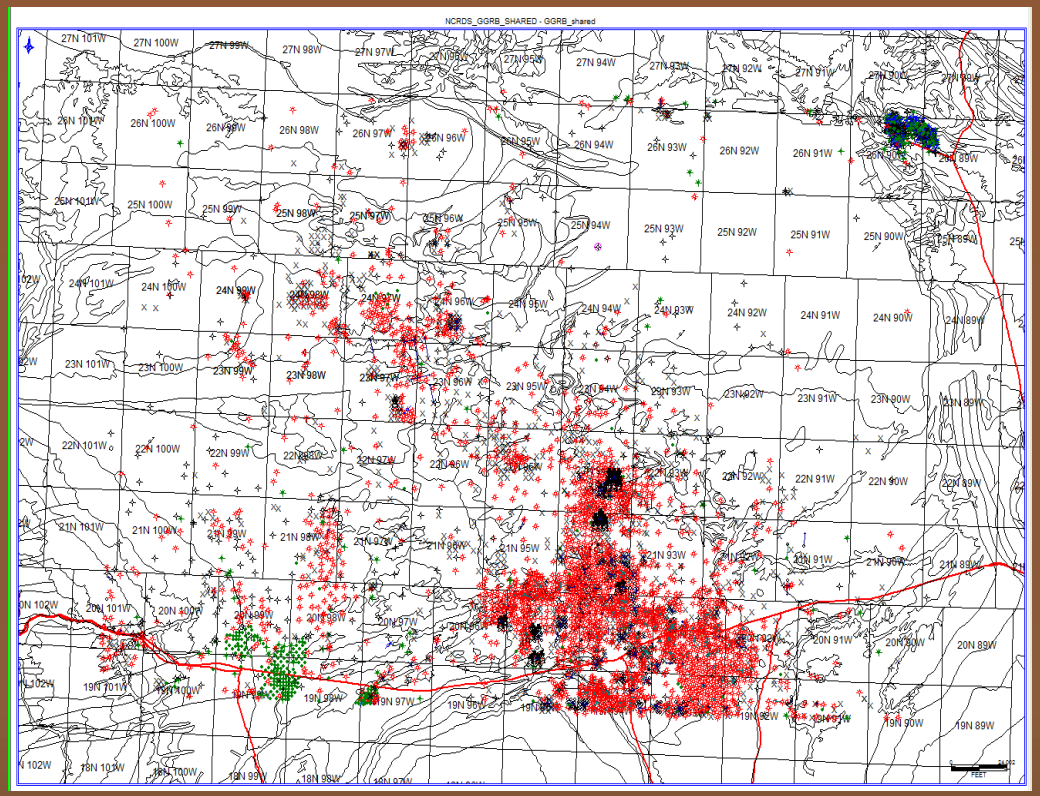


Fort Union Coal Strat Column eastern GDB





Modified from McComas, 2014; Hettinger and others, 2008

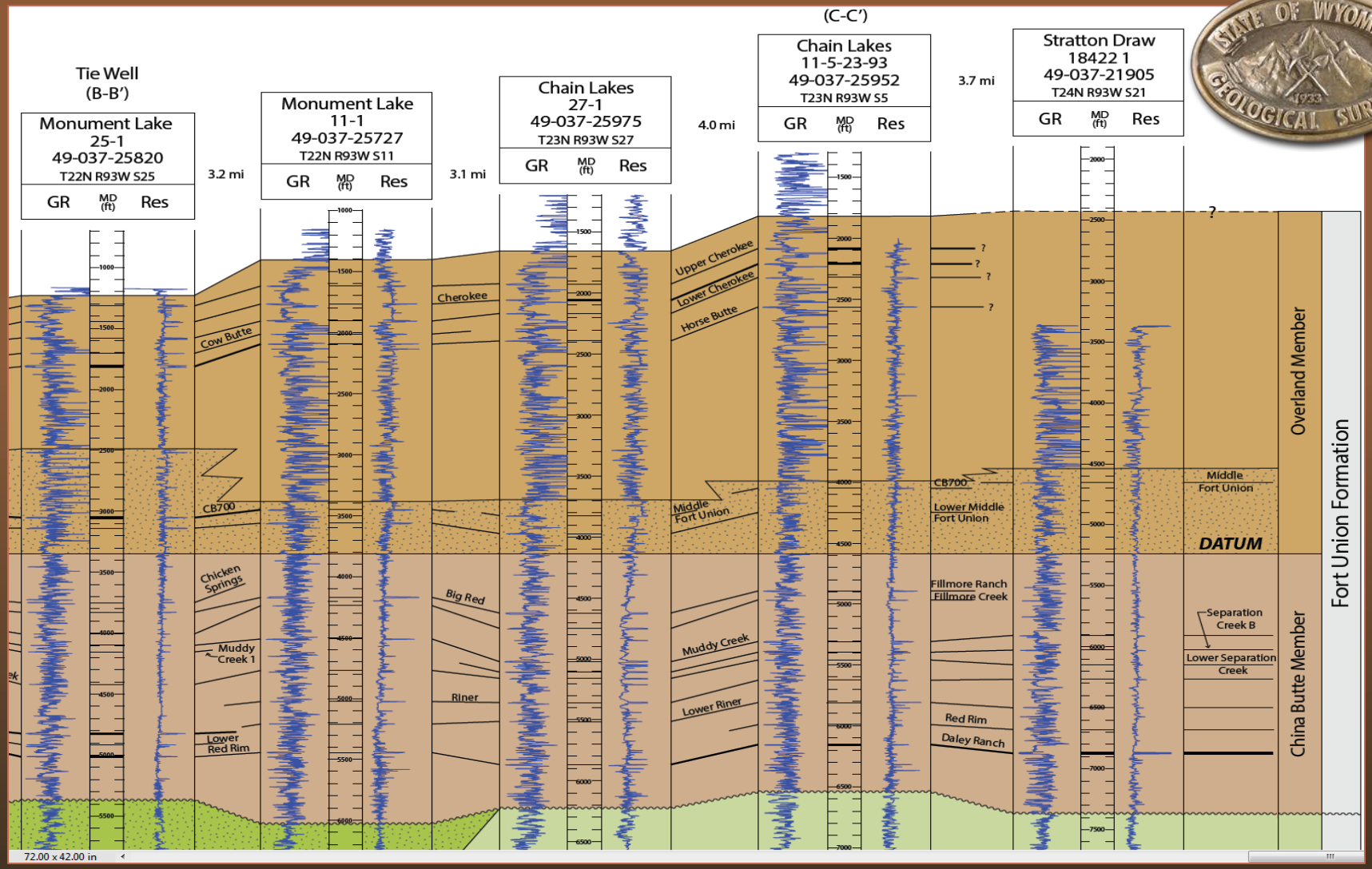


5000 Petroleum Wells GDB,
showing Wamsutter Field
Conventional and unconventional

WSGS Tasks:

- Regional correlations of the Fort Union coal
- Quantify coal beds by thickness and depth
- GDB cross sections, isopachs, structure contours
- Stratigraphic database of tops

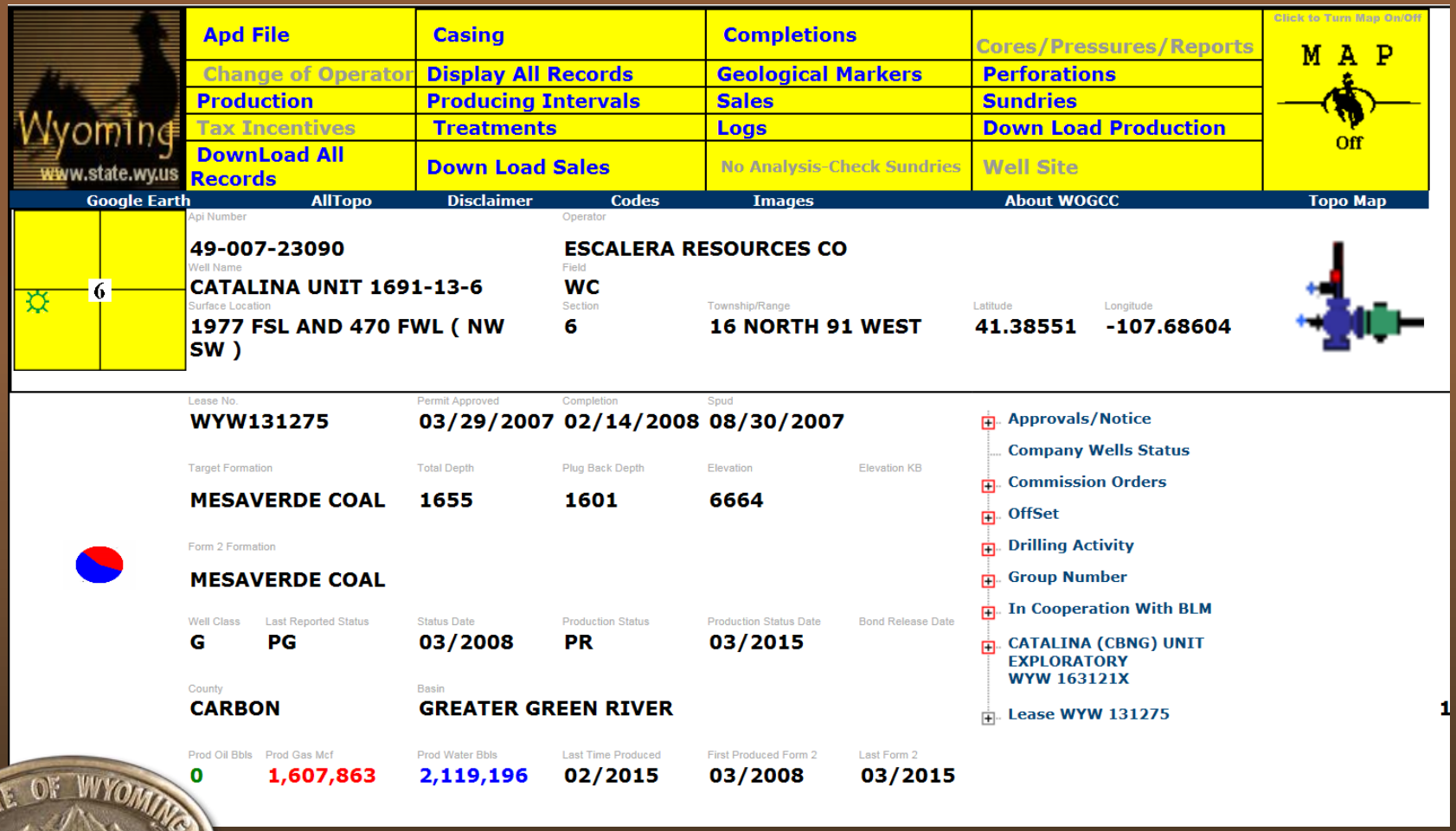
WSGS detailed cross sections with coal correlations



Carbon County Underground Coal Gasification

- DOE demonstration
- Vertical Tfu coal beds
- UCG H_2 and CH_4
- Now in reclamation

CBM production today



Prospective coal interests in the GGRB today

- Bridger Coal –Bridger Coal Mines
- Amber Energy/Anadarko – Black Butte Mine
- Carbon Energy –UCG northeast of Bridger Mine
- Linc Energy – UCG interest in thick, deep coal
- Wold Oil Prop.– Leased 250 units of Blm coal checkerboard leases
- Carbon County UCG – Exploration and Demonstration Project near Rawlins
- CBM interests – various companies, mostly BRC, Kmv
- Anadarko-RME data
- USGS-Coal assessment in GGRB

GGRB CBM estimates (TBEG 1995)

- Neogene erosion >3,000 ft (914 m) (VR data)
- Tfu coals avg 20 ft (6 m) thick; but deep
- Kmv coal 6,000-7500 ft (1828-2286 m) deep, 350 - 500 scf/ton, max 900 scf/ton Atlantic Rim (*Escalera Resources, 2015*)
- **GGRB total cbm resource 314 Tcf (2.38 Tm3)**
- CBM tests also from Scotty Lake area Cherokee coals on west and northwest side of GDB

Paleocene Coal Depositional Environment

- Coaly source rocks occur near limit of maximum westward marine transgression during Maastrichtian
- Poorly drained swamp in meandering river systems
- Point bar system (*Saracino, 1984*)
- Lacustrine deposits in upper Paleocene and Eocene
- Coal found at top of fining upward clastic sequences

Tfu Modern Fluvial Analog

S. Saskatchewan River, Canada

Sand-dominated braided channel with bar sands

Trough cross beds; Distally planar beds

Horizontally bedded gravels (*Saracino, 1984*)

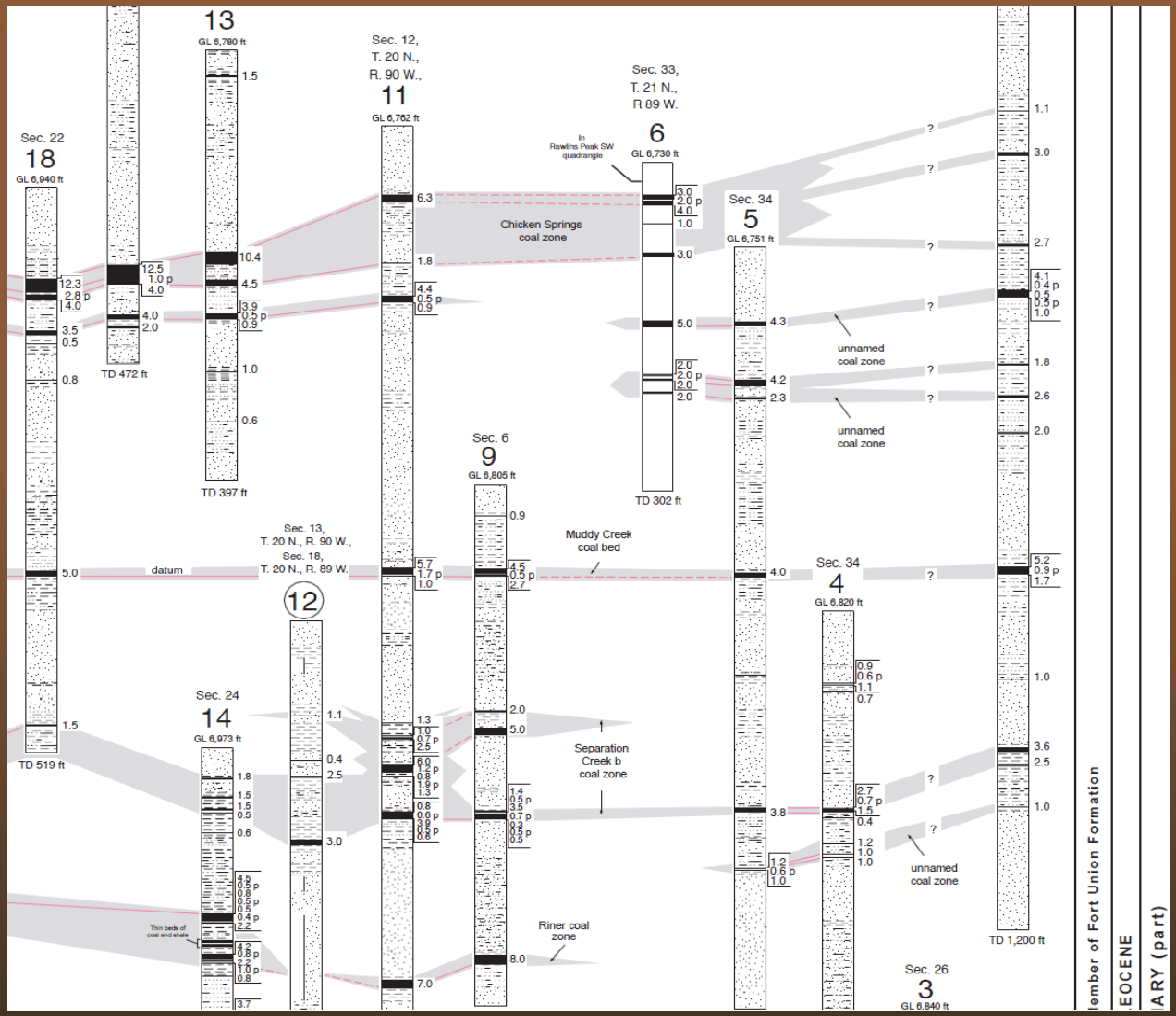
Requirements for thick Paleocene coals

- Slow rising groundwater table that stays ahead of subsidence/accommodation
- Fresh-water environment
- Minimal input from fluvial sediments
- Channel avulsion? (*Flores, 1981*)
- Thickening trends result from subsidence rate changes and differential erosion.

Cretaceous-Paleogene (K-Pg) Boundary

- Earliest Paleocene Puercan fauna 64-65 Ma
- GDB preserves entire Puercan time (*McComas, 2014*)
- During Puercan the GDB was contiguous with the Hanna Basin (*Lillegraven and others, 2004*).
- China Butte Mbr max thickness 1,850 ft (565 m)

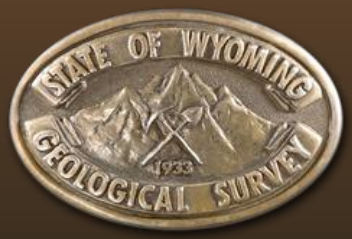
USGS Ft Union Coal Bed Correlation Names



Hettinger and others 2008

WSGS Tfu Coal Stratigraphy Table

Southwest	Northwest	Southcentral	Northcentral	Southeast	Northeast
	Upper Scotty Lake				
	Scotty Lake Main 1				
	Scotty Lake Main 2				
	Lower Scotty Lake				
		Upper Cherokee		Upper Cherokee	Upper Cherokee
		Cherokee		Cherokee	Cherokee
		Lower Cherokee		Lower Cherokee	Lower Cherokee
		Cow Butte		Cow Butte	
	Horse Butte	Horse Butte	Horse Butte	Horse Butte	Horse Butte
Nuttal	CB1200				
Fort Union 15	CB700	CB700	CB700		
				Middle Fort Union	Middle Fort Union
Fort Union 14					
	Lower Middle Fort Union	Lower Middle Fort Union			
Fort Union 13					
Fort Union 9					
Fort Union 8					
Fort Union 7					
	Chicken Springs	Chicken Springs	Chicken Springs	Chicken Springs	
	GU				
Upper Deadman	Upper Big Red	Upper Big Red			
	Big Red	Big Red	Fillmore Ranch	Fillmore Ranch	Fillmore Ranch
Lower Deadman	Lower Big Red	Lower Big Red	Fillmore Creek	Fillmore Creek	Fillmore Creek
	Muddy Creek	Muddy Creek	Muddy Creek	Muddy Creek	
Fort Union 4					
Upper Fort Union 3					
Fort Union 3					
Lower Fort Union 3					
				Separation Creek 1	
				Separation Creek 2	
	Seraration Creek B	Separation Creek B	Separation Creek B	Separation Creek B	
	Lower Separation Creek	Lower Separation Creek	Lower Separation Creek		Lower Separation Creek
Fort Union 2					
Fort Union 1					
Overland					
	Riner	Riner	Riner	Riner	Riner
	Lower Riner	Lower Riner	Lower Riner	Lower Riner	Lower Riner
				Olson Draw	
				Lower Olson Draw	
				Hadsell Draw	
	Red Rim	Red Rim	Red Rim	Red Rim	Red Rim
	Daley Ranch	Daley Ranch	Daley Ranch		Daley Ranch
					Continental Divide



Coal tops from our database

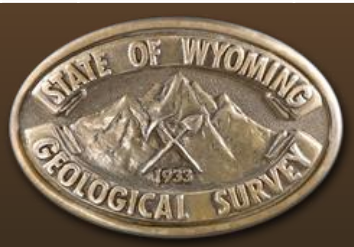
1666	49037258860000	4
1667	49037258870000	4
1668	49037258880000	4
1669	49037258900000	4
1670	49037258910000	4
1671	49037258970000	4
1672	49037258970001	4
1673	49037259000000	4
1674	49037259010000	4
1675	49037259020000	4
1677	49037259090000	4
1678	49037259100000	4
1681	49037259230000	4
1682	49037259230001	4
1683	49037259240000	4
1684	49037259270000	4
1685	49037259300000	4
1687	49037259370000	4
1690	49037259400000	4
1691	49037259410000	4
1692	49037259420000	4
1695	49037259450000	4
1696	49037259480000	4
1697	49037259490000	4
1698	49037259490001	4
1699	49037259510000	4
1700	49037259520000	4
1702	49037259580000	4
1703	49037259590000	4
1704	49037259590001	4
1705	49037259600000	4
1706	49037259610000	4
1707	49037259620000	4
1709	49037259670000	4
1710	49037259710000	4
1711	49037259720000	4
1712	49037259720001	4
1713	49037259730000	4
1714	49037259740000	4
1715	49037259750000	4
1716	49037259760000	4
1717	49037259760001	4
1718	49037259780000	4
1719	49037259790000	4
1720	49037259790001	4
1721	49037259800000	4
1722	49037259810000	4
1723	49037259820000	4
1724	49037259830000	4
1725	49037259860000	4
1726	49037259870000	4
1727	49037259880000	4
1728	49037259880001	4

Tops | Repeats

Fm Name	Src	MD	SS	TVD	QUAL	Time(ms)	Rpt	Sym	HoleAngle	ChgDate	Remark	Description
652WSTC	3	0.0	6,518.0	0.0				0		08/09/2013		WASATCH
FORT_UNION	RL	1,823	4,695	1,823				0		01/26/2015		FORT_UNION
UPPR_CHEROKEE	EC	2,079.5	4,438.5	2,079.5				0		03/05/2015		Upper Cherokee Coal
CHEROKEE_UPR	HAACKE	2,084	4,434	2,084				0		01/26/2015		CHEROKEE_UPR
CHEROKEE_UPR_BASE	HAACKE	2,090	4,428	2,090				0		03/03/2015	Horizon	COAL
UPPR_CHEROKEE_BASE	DR	2,091.5	4,426.5	2,091.5				0		03/05/2015		base of upper cherokee
CHEROKEE *	CJC	2,206.3	4,311.7	2,206.3				0		03/05/2015		Uppermost Tfu coal bed
CHEROKEE	HAACKE	2,208	4,310	2,208				0		01/26/2015		CHEROKEE
CHEROKEE_BASE	HAACKE	2,214	4,304	2,214				0		03/03/2015	Horizon	COAL
CHEROKEE_BASE	DR	2,218.4	4,299.6	2,218.4				0		03/05/2015		base of cherokee coal b
LOWER_CHEROKEE	EC	2,319.1	4,198.9	2,319.1				0		03/05/2015		Lower Cherokee Coal
CHEROKEE_LWR	HAACKE	2,324	4,194	2,324				0		01/26/2015		CHEROKEE_LWR
LOWER_CHEROKEE_BASE	DR	2,325.1	4,192.9	2,325.1				0		03/05/2015		base of lower cherokee
CHEROKEE_LWR_BASE	HAACKE	2,326	4,192	2,326				0		03/03/2015	Horizon	COAL
HORSE_BUTTE	EC	2,561.1	3,956.9	2,561.1				0		03/05/2015		Horse Butte Coal
HORSE_BUTTE	HAACKE	2,563	3,955	2,563				0		01/26/2015		HORSE_BUTTE
HORSE_BUTTE_BASE	HAACKE	2,567	3,951	2,567				0		03/03/2015	Horizon	COAL
HORSE_BUTTE_BASE	EC	2,567.0	3,951.0	2,567.0				0		03/05/2015		base of horse butte coal
OVERLAND_MBR_SS	RL	3,993	2,525	3,993				0		01/26/2015		OVERLAND_MBR_SS
CB700 *	EC	4,050.0	2,468.0	4,050.0				0		03/02/2015		coal 800 feet above Big
MIDDLE_F_UNION	HAACKE	4,052	2,466	4,052				0		01/26/2015		MIDDLE_F_UNION
MIDDLE_F_UNION_BASE	HAACKE	4,054	2,464	4,054				0		03/03/2015	Horizon	COAL
CB700_BASE	EC	4,054.0	2,464.0	4,054.0				0		03/02/2015		base of CB700
MIDDLE_FU_LOWER	CJC	4,246.2	2,271.8	4,246.2				0		03/05/2015		Thick coal occurring loc
MIDDLE_FU_LOWER_BASE	DR	4,252.2	2,265.8	4,252.2				0		03/05/2015		base of middle ft union lc
CHINA_BUTTE_MBR *	RL	4,589	1,929	4,589				0		01/26/2015		CHINA_BUTTE_MBR
FILLMORE_RANCH_COAL	CJC	4,889.8	1,628.2	4,889.8				0		02/27/2015		BRC equivalent
FILLMORE_RANCH	HAACKE	4,892	1,626	4,892				0		01/26/2015		FILLMORE_RANCH
FILLMORE_RANCH_BASE	HAACKE	4,897	1,621	4,897				0		03/03/2015	Horizon	COAL
FILLMORE_RANCH_BASE	DR	4,897.1	1,620.9	4,897.1				0		02/27/2015		base of fillmore ranch co
FILLMORE_CREEK	HAACKE	4,958	1,560	4,958				0		01/26/2015		FILLMORE_CREEK
FILLMORE_CREEK_BASE	HAACKE	4,960	1,558	4,960				0		03/03/2015	Horizon	COAL
FILLMORE_CREEK	CJC	4,964.3	1,553.7	4,964.3				0		03/02/2015		big coal beneath the Fillr
FILLMORE_CREEK_BASE	DR	4,968.3	1,549.7	4,968.3				0		03/02/2015		base of fillmore creek co
MUDDY_CREEK	EC	5,302.6	1,215.4	5,302.6				0		03/02/2015		Muddy Creek Coal
MUDDY_CREEK_BASE	EC	5,312.7	1,205.3	5,312.7				0		03/02/2015		base of Muddy Creek Cc
SEPARATION_CREEK_B	EC	5,392.0	1,126.0	5,392.0				0		03/05/2015		Separation Creek B coal
SEPARATION_CREEK_B_BASE	DR	5,400.1	1,117.9	5,400.1				0		03/05/2015		base of separation creek
LOWER_SEPARATION_CREEK	EC	5,456.4	1,061.6	5,456.4				0		03/05/2015		Lower Separation Creek
SEPARATION_LWR	HAACKE	5,460	1,058	5,460				0		01/26/2015		SEPARATION_LWR
SEPARATION_LWR_BASE	HAACKE	5,461	1,057	5,461				0		03/03/2015	Horizon	COAL
LOWER_SEPARATION_CREEK_BASE	DR	5,462.6	1,055.4	5,462.6				0		03/06/2015		base of separation creek
RINER_COAL	CJC	5,621.4	896.6	5,621.4				0		03/02/2015		Riner coal from hettinger
RINER_COAL_BASE	DR	5,630.1	887.9	5,630.1				0		03/02/2015		base of riner coal
LOWER_RINER	EC	5,805.7	712.3	5,805.7				0		04/07/2015		Lower Riner Coal
RINER	HAACKE	5,806	712	5,806				0		01/26/2015		RINER
RINER_BASE	HAACKE	5,809	709	5,809				0		03/03/2015	Horizon	COAL
LOWER_RINER_BASE	EC	5,810.2	707.8	5,810.2				0		04/07/2015		base of lower riner coal
RINER_LWR	HAACKE	5,888	630	5,888				0		01/26/2015		RINER_LWR
RINER_LWR_BASE	HAACKE	5,891	627	5,891				0		03/03/2015	Horizon	COAL
RED_RIM	CJC	5,985.3	532.7	5,985.3				0		03/02/2015		lower Tfu coal
RED_RIM_BASE	DR	5,990.9	527.1	5,990.9				0		03/06/2015		base of red rim coal
DALEY_RANCH	CJC	6,147.1	370.9	6,147.1				0		02/27/2015		coal 350 below Riner co
DALEY_RANCH	HAACKE	6,152	366	6,152				0		01/26/2015		DALEY_RANCH
DALEY_RANCH_BASE	HAACKE	6,156	362	6,156				0		03/03/2015	Horizon	COAL
DALEY_RANCH_BASE	DR	6,158.0	360.0	6,158.0				0		02/27/2015		base of daley ranch coal
LANCE_TOP *	RL	6,568	-50	6,568				0		03/04/2015		LANCE_TOP
604LNCE	3	8,360.0	-1,842.0	8,360.0				0		08/09/2013		LANCE
LOWER_LANCE	RL	8,771	-2,253	8,771				0		03/26/2015		LOWER_LANCE

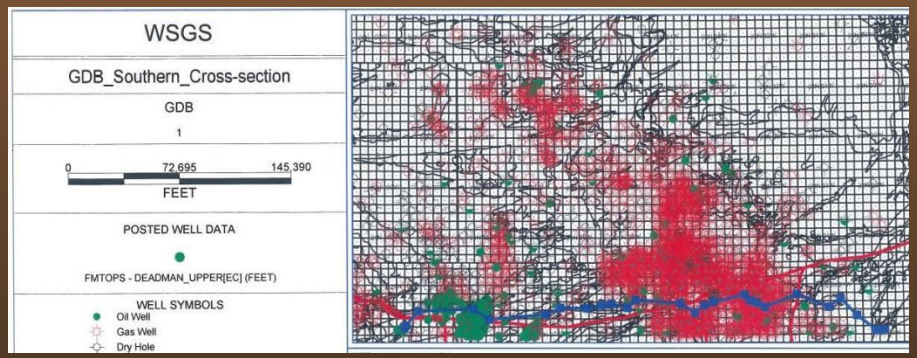
Outcrop Coal Samples 2014

		Moisture	EQM	Ash Content	Volatile Matter	Sulfur	BTU	Fixed Carbon	Carbon	Hydrogen	Nitrogen
		Total	As Received	As Received	As Received	As Received	As Received	As Received	As Received	As Received	As Received
Lab Id	Sample #	As Rec. %	%	%	%	%	%	%	%	%	%
N9972	B Ft. Un. Coal Lignite carb Sh	25.39	7.41	30.36	36.84	0.18	7596	46.16	2.20	0.50	18.16
N9973	C Carb Shale	41.85	25.92	18.86	13.37	0.30	2930	19.00	1.07	0.38	11.48
N9974	D Upper TFU coal	39.05	6.98	30.13	23.84	0.48	5004	32.95	1.46	0.68	18.40
N9975	E CCUCG coal	41.80	6.20	28.08	23.92	0.16	4862	31.76	1.36	0.40	18.33
N9976	F AML Site	32.75	3.72	30.61	32.92	0.07	6626	41.56	1.93	0.49	19.48
N9977	H eroded coal	28.91	13.96	11.80	45.32	0.27	7262	47.71	0.66	0.85	7.64



WSGS Fort Union Coal: Update

- 3,268 wells with formation tops
- 2,596 wells with WSGS coal picks + 1,578 NCRDS outcrop studies
- PETRA cross-sections, isopachs, structure contours
- Data verification now
- Next: transform to MS Excel for GIS resource calculations



Tfu Coal Stratigraphy

Tfu coals:24 coal zone model
Overland: Cherokee Coals
Middle Tfu Coal (CB700)
China Butte: Deadman/Big Red Coal/Fillmore Ranch Coals
Muddy Creek Coals
Tfu 15-1 Coals
Separation Creek Coals
Riner and Lower Riner Coals
Lower Olsen and Hadsell Draw Coals
Red Rim Coal
Daley Ranch Coal

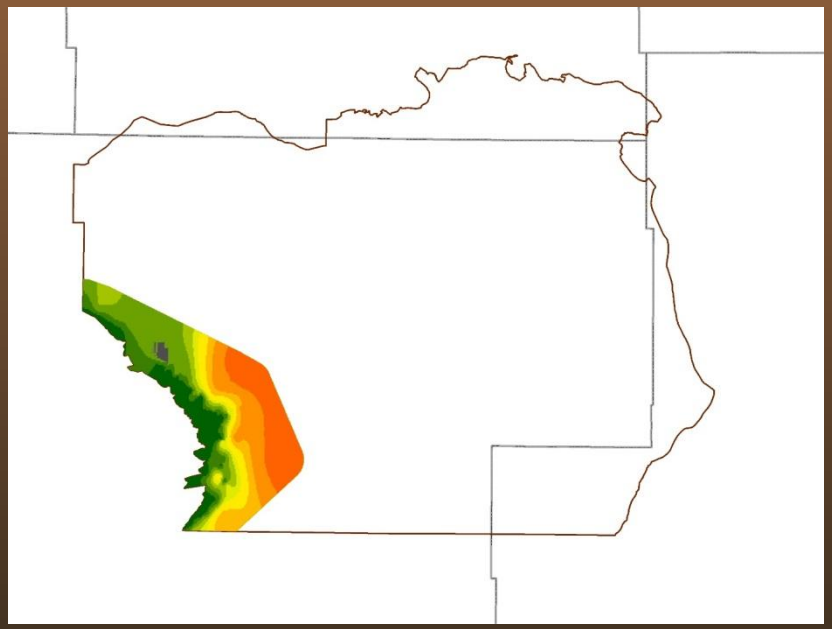
Deadman coals mined today

Bridger and Black Butte Coal Mines produce 10 MT/y

In 100 years, that is 1 Billion tons of coal

Economic coal reserve is 2.6 BT for Deadman

Bridger
Underground Mine



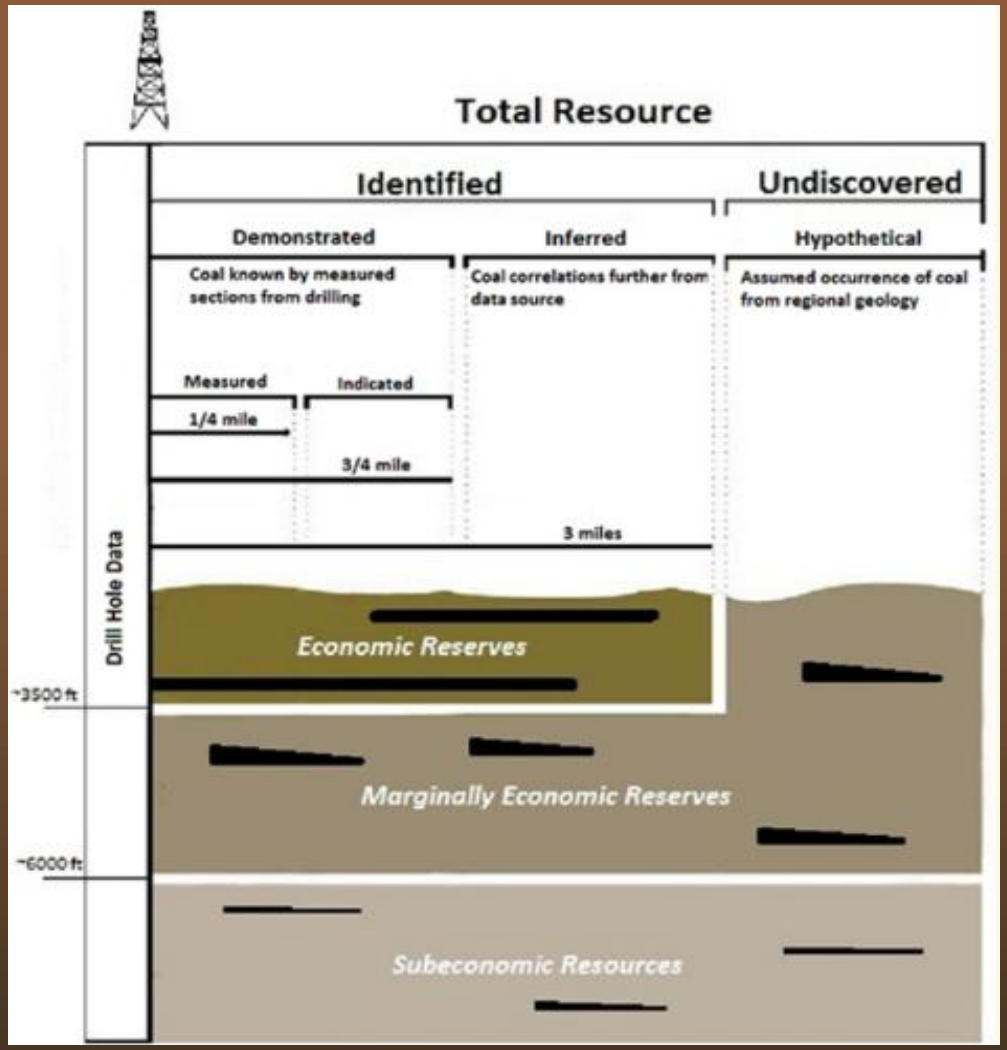
Active Ft Union Coal Mines

Bridger and Black Butte
Coal Mines

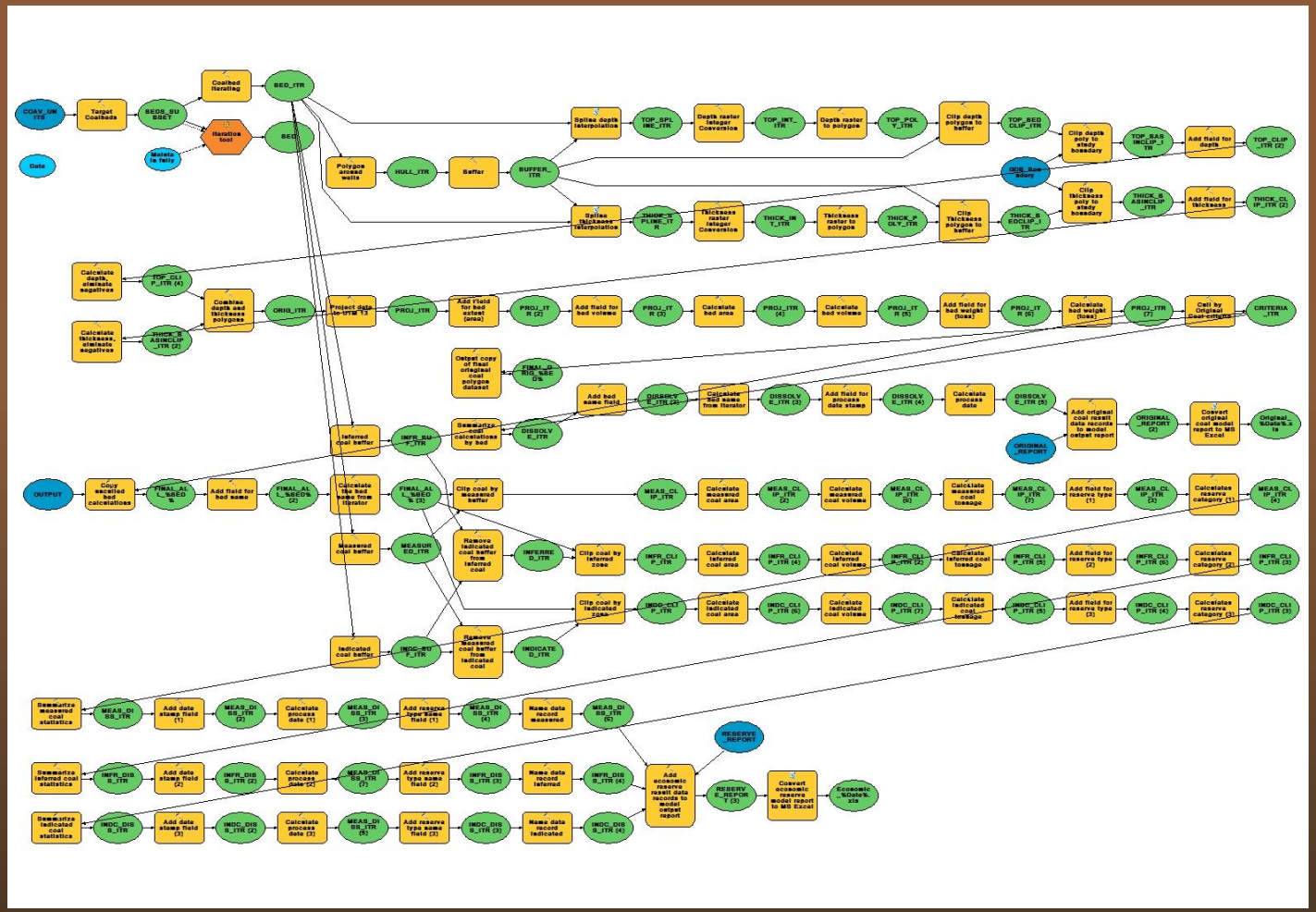
STATE OF WYOMING
GEOLOGICAL SURVEY
1933

Resource Categories

3.5 BT coal reserve (Measured And Indicated), *McCord, 1984*



Resource Model for Original and Economic Coal



Tfu Coal Resource Results

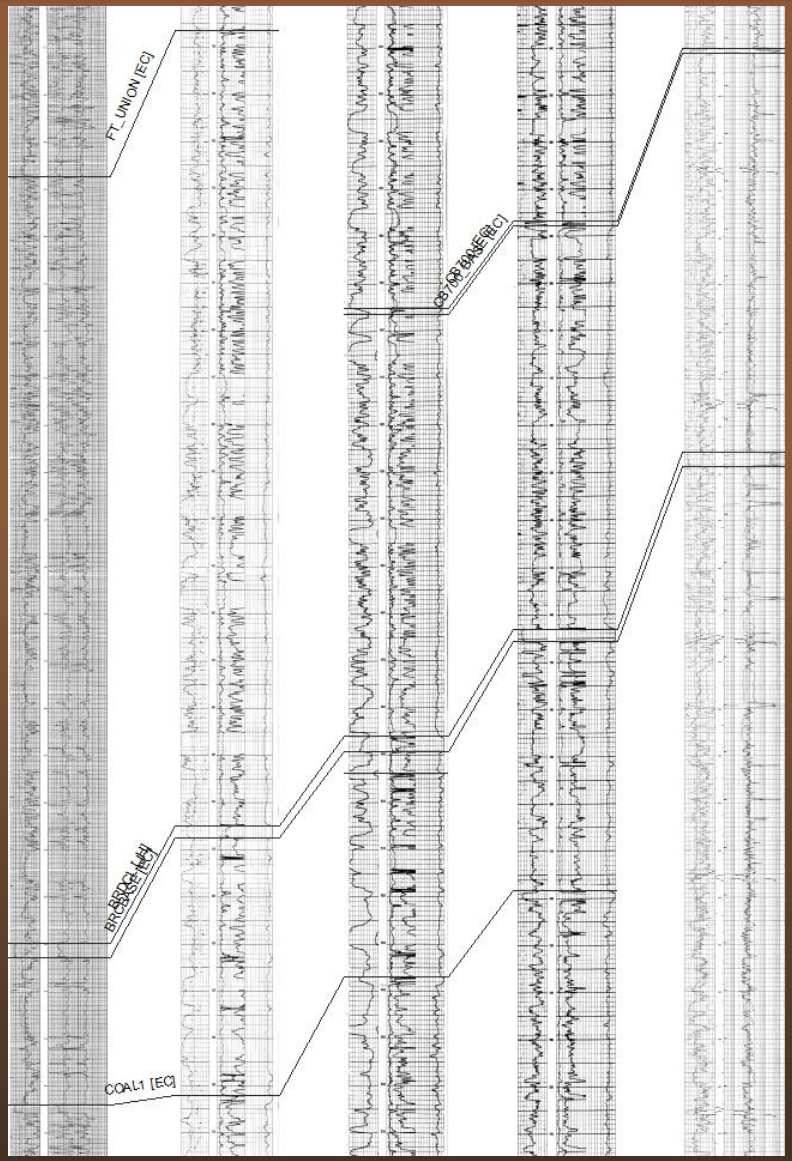
Shallowest coals (avg depths):

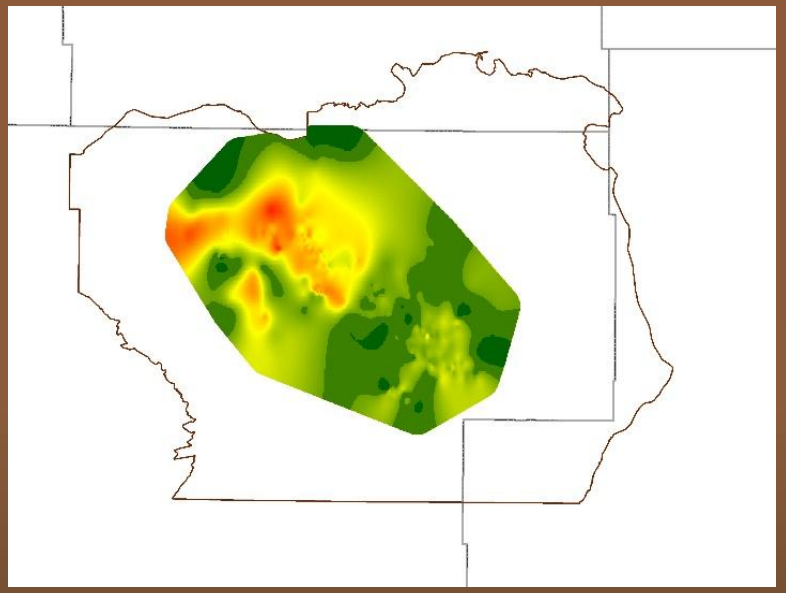
1. Fort Union #9 1,133 ft
2. Upper Cherokee 1,171 ft
3. Cherokee 1,312 ft
4. Lower Cherokee 1,348 ft
5. Deadman Upper 1,377 ft

Thickest coals (avg)

1. Big Red Coal 18.8 ft
2. Lower Riner 11 ft
3. Fillmore Ranch 11 ft
4. Horse Butte 10.7 ft
5. BR Coal Upper 9.4 ft

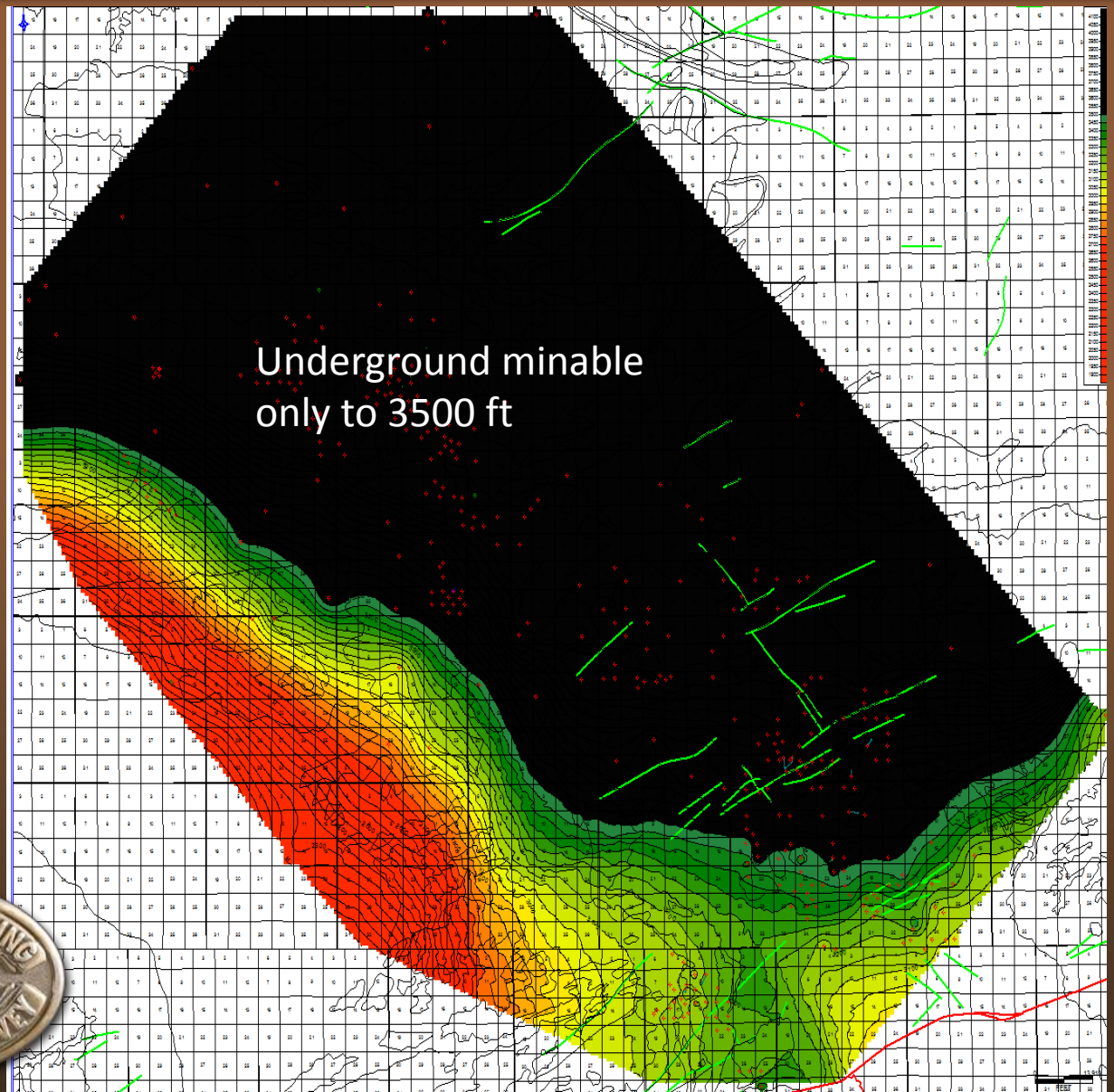
Coal resources of the Big Red coal





Ft. Union Fm.
CB700 ~700 ft above BRDC
Big Red Coal
Coal 1 ~400 ft below BRDC
Muddy Cr coals

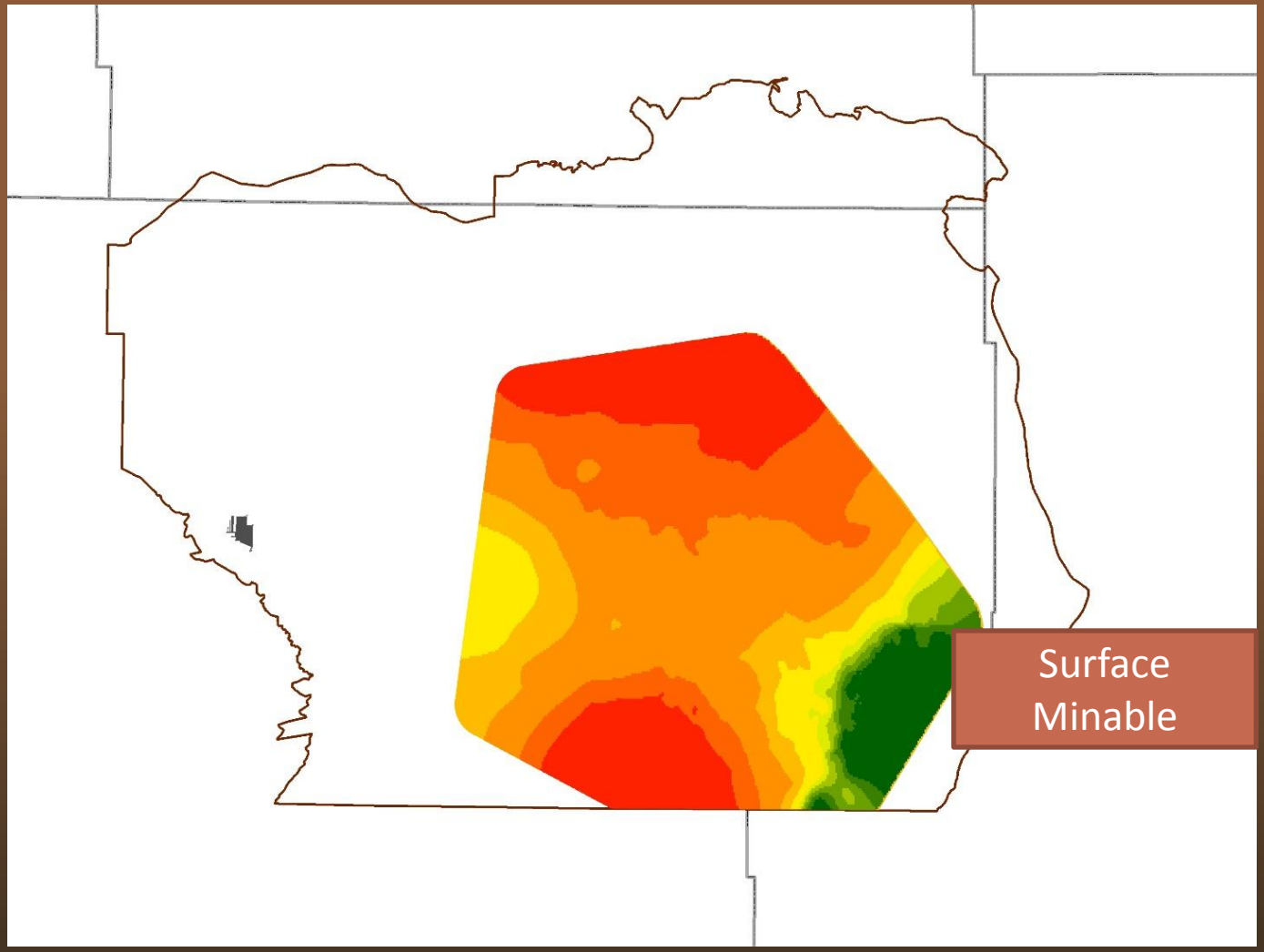
Overburden map of the Big Red Coal



Cherokee coals

Tfu Overland Mbr

Subbituminous C



WSGS Preliminary Coal Resources

Bed Name	Total Tons	mined out	COAV_EST_2015	COAV_EST_2065	COAV_EST_2115	
DEADMAN	2,196,541,506	270,000,000	1,926,541,506	1,426,541,506	926 MT	
CHEROKEE	1,360,047,121					
UPPR_CHEROKEE	972,579,944					
LWR_DEADMAN	888,865,439	20,000,000	868,865,439	829 MT	769 MT	
UPPR_DEADMAN	845,758,330	30,000,000	815,758,330	755 MT	695 MT	
FILLMORE_RANCH	792,990,025					
HORSE_BUTTE	650,480,892					
CHICKEN_SPGS	567,974,010					**Surface Minable coal only. Total for coal beds >2.5 ft thick and 0-500 ft deep**
MUDDY_CR	509,649,415					

3.561 BT strippable reserve, all coals GGRB

Remaining surface minable coal for Black Buttes, Bridger, Creston areas: 1.909 BT (McCord, 1984)

Future Studies: Statemap 2014

2014 pollen sampling

- 5 Ft Union, 1 Almond, 1 Lance coal samples
- Very good recovery, %Ro 0.6

Table 5: Age summary:

Sample ID	*Age*
GGRB 14-1	Earliest Eocene
GGRB 14-2	Earliest Eocene
GGRB 14-3	Early Eocene - Late Paleocene
GGRB 14-4	Early Eocene - Middle Paleocene
GGRB 14-5	Earliest Eocene
GGRB 14-6	Early Eocene - Late Cretaceous
GGRB 14-7	Early Eocene

West side of Great Divide Basin

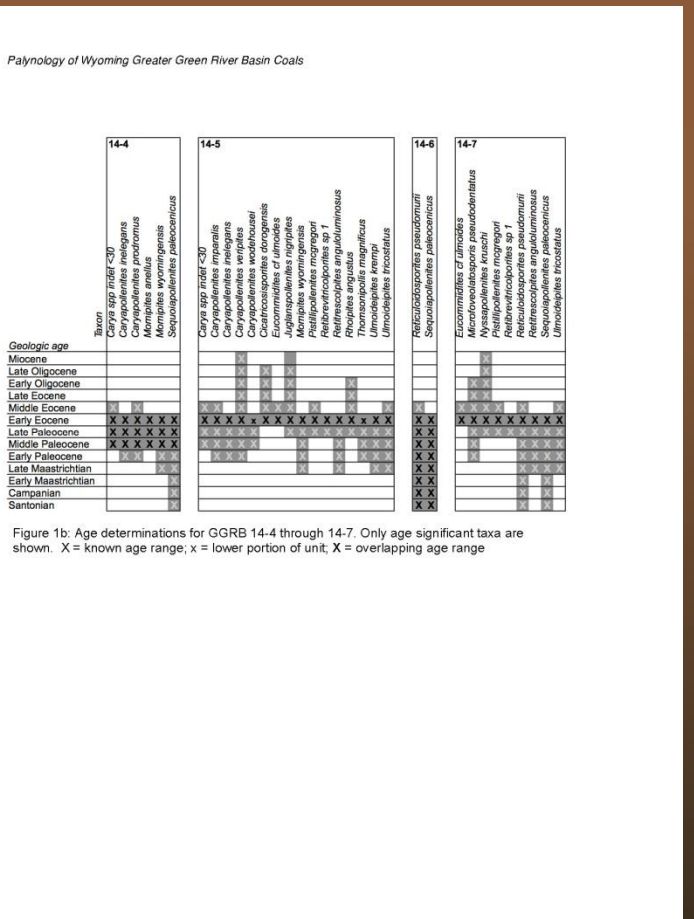


Figure 1b: Age determinations for GGRB 14-4 through 14-7. Only age significant taxa are shown. X = known age range; x = lower portion of unit; **X** = overlapping age range

Summary

>5% of the available coal in the GDB has been mined to date

Paleocene Ft Union Coals are thick and prevalent in the GDB

There are over 20 billion tons of coal to mine in the Tfu in GDB

Paleocene coals are very contiguous in GDB, over 30 miles

Environmental Regulations in the next 100 years?

Acknowledgements

This project benefits from the hard work of my WSGS colleagues Dr. Ranie Lynds, Deirdre Ratigan, Elizabeth Cola, Jim Stafford, and Jim Rodgers. Thanks.

And please attend Ranie's presentation on the petroleum resources of the Paleocene/ Upper Cretaceous of the GDB at 4:45 pm Weds, rm 605.