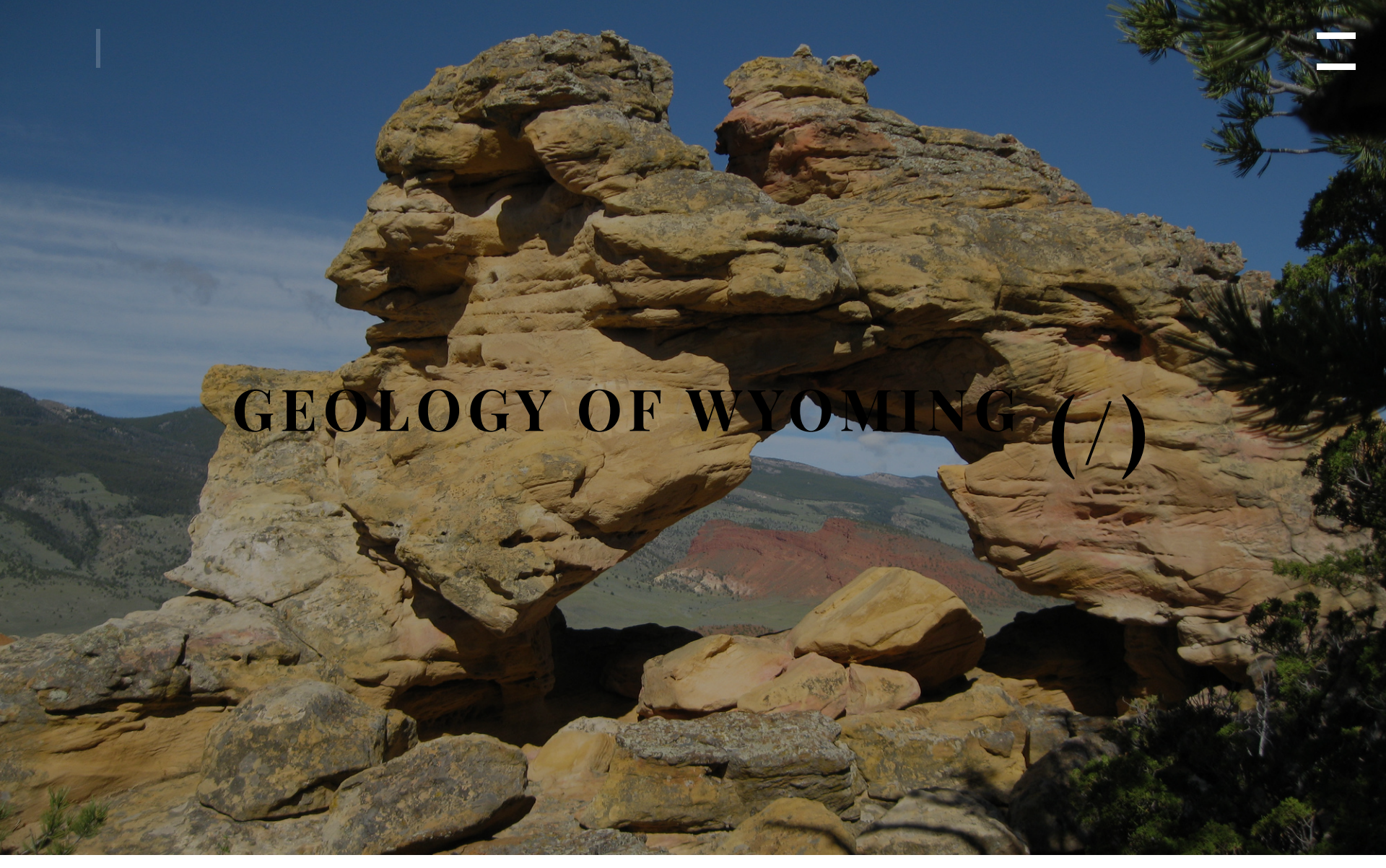


WIND RIVER CANYON PART ONE

Wow Factor *(4 out of 5 stars):*

★★★★

Geologist Factor *(4 out of 5 stars):*

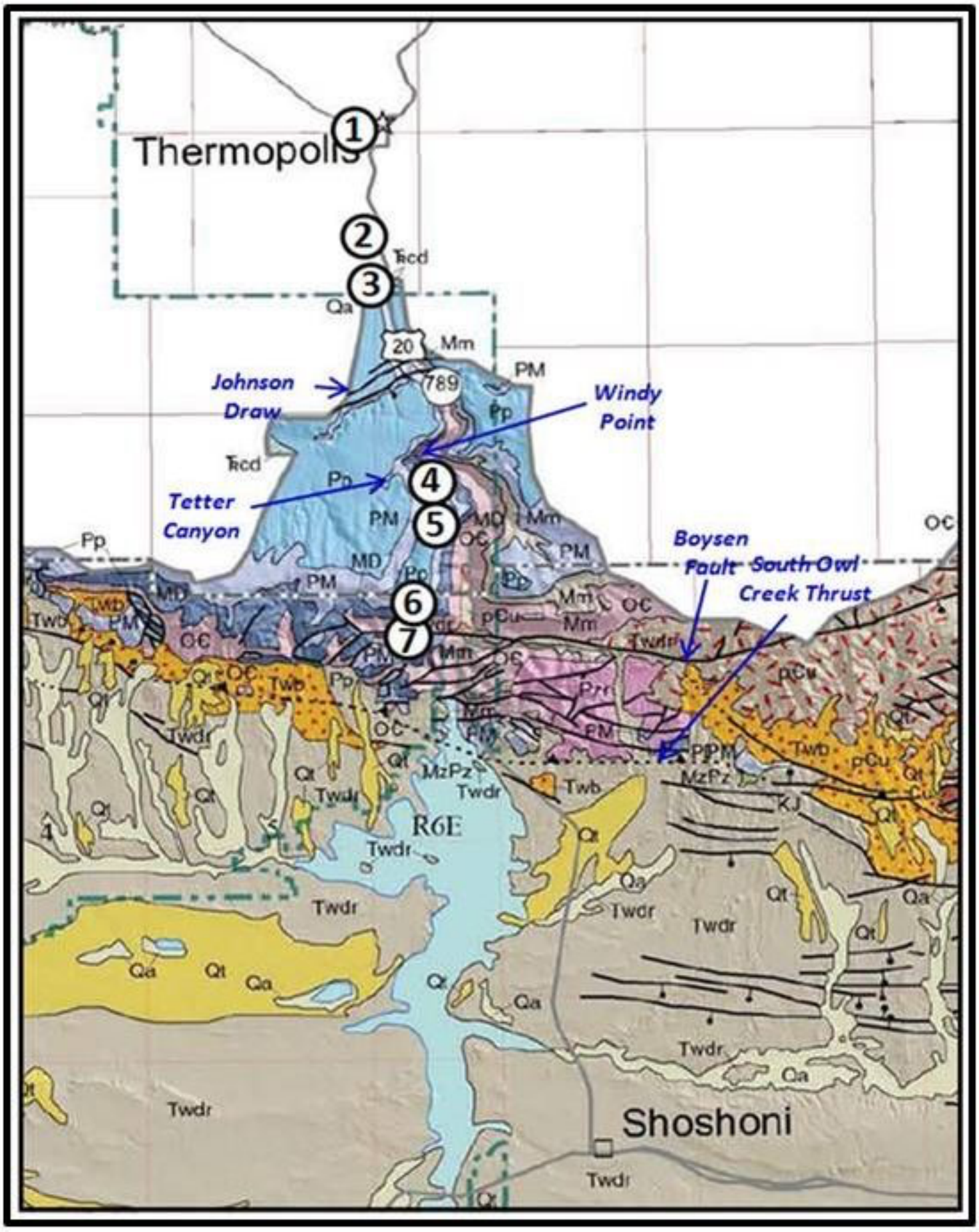
★★★★

Attraction

It is the best place to see Paleozoic and Precambrian rocks in Wyoming because of great exposures and easy highway access. The Wind River Canyon is also one of the prettiest places in Wyoming with the high cliffs and clear flowing water. This is a special place and geology is the main event.

Geology of Wind River Canyon

The Wind River Canyon is a crack in time, 17 miles long, 200 to 3,000 feet wide and 2,500 feet deep. The road through the canyon has over 300 feet elevation climb southward and crosses rocks recording about 3 billion years in time.



(/uploads/8/4/7/8/84786270/edited/wrc-1-geologic-map-picture_1.jpg)

Geologic map of Wind River Canyon with geologic stops numbered.
Image: After Lynds, R.M., 2013, WSGS Technical Memorandum 3, Plate 7,
http://www.wsgs.uwyo.edu/Research/Energy/docs/CO2-Plates/Plate7.pdf
(http://www.wsgs.uwyo.edu/Research/Energy/docs/CO2-Plates/Plate7.pdf)

Wind River Canyon Road Log

Mileage				Description
N/S		S/N		L = left; R = right
Increment	Cumulative	Increment	Cumulative	Blue = North to South route; Brown = South to North route
U.S. 20				
0.0	0.0	1.1	17.8	Gas station parking lot at south end of Thermopolis.

* Now an Exxon station (2014)

Geologic Notation Key

Phase	Formation
2	Kcv = Cloverly Fm.
	Jm = Morrison Fm.
1	Js = Sundance Fm.
	Jgs = Gypsum Spring Fm.
	Trp = Popo Agie Mbr, Chugwater Fm.
	Trcm = Crow Mtn, Mbr, Chugwater Fm.
	Trr = Red Peak Mbr, Chugwater Fm.

Google earth Street View Images

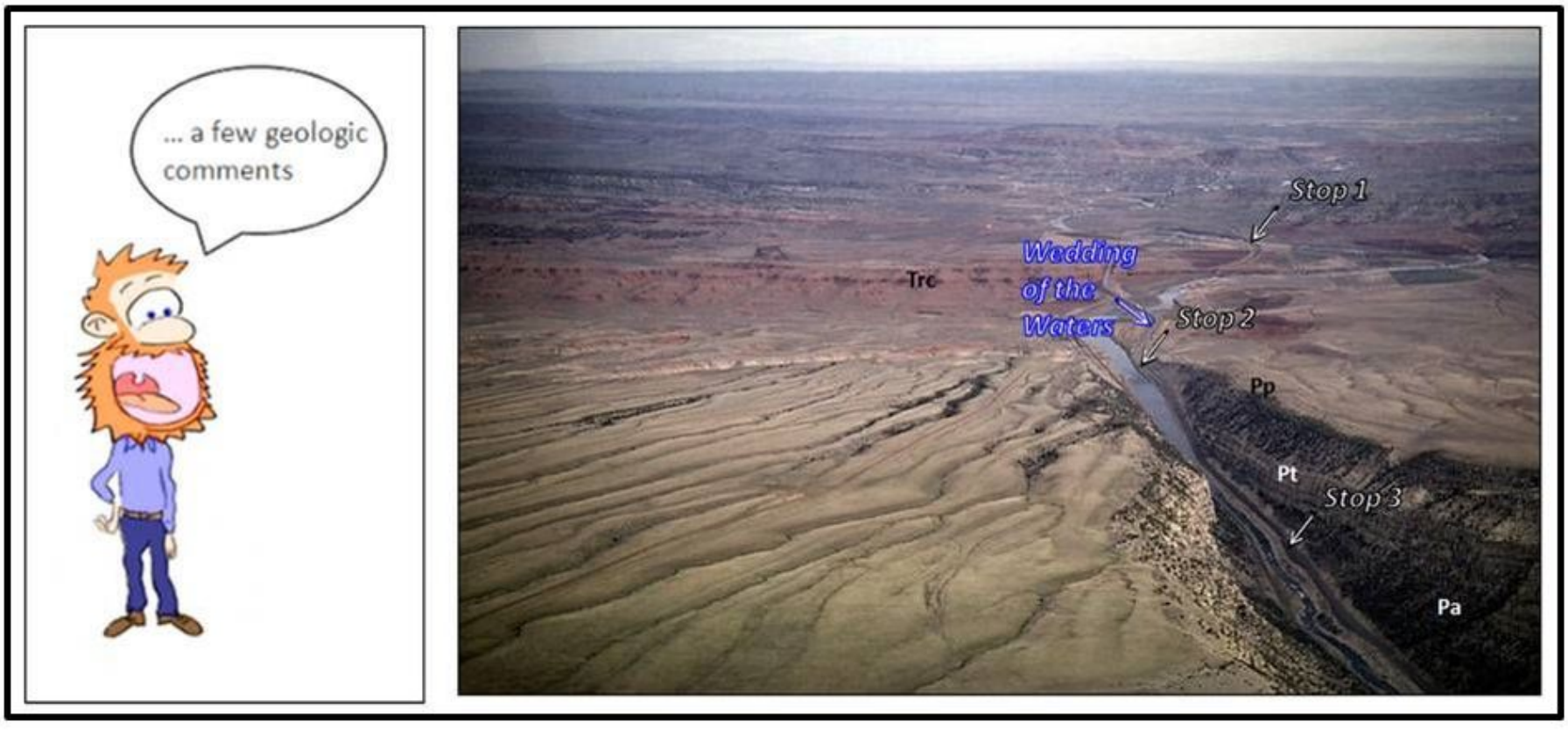
Top: Road log start at Exxon gas station, south end of Thermopolis. Bottom: East aerial view of the geology at first meander loop of the Bighorn River. Geologic notation shown in key to the right of image. Last chance for a cup of coffee and snacks inside store.

Images: After Google Earth Street View

This material is taken from a field trip led by the authors. It is a compilation from multiple sources that include data from the Wyoming Geological Association, Wyoming State Geological Survey, Wyoming Oil and Gas Conservation Commission, Geological Society of America, academic and professional papers. Geology is a science that stands on the shoulders of many researchers. The trip begins here as a convenience for those who might need gas, beverages, snacks or a restroom.

Please Be Safe.

1.1	1.1	0.8	16.7	Intersection with Buffalo Creek Road. **Turn south on Buffalo Creek Road (L/R).** View to east (L/R) across river shows lower Cretaceous Lakota Sandstone (pine covered rim on skyline). Underlying the Lakota is the Upper Jurassic Morrison Formation (poorly exposed varicolored shale in which gastroliths are common locally). Underlying the Morrison is the Upper Jurassic Sundance Formation which is mostly green glauconitic sandstones with some thin highly fossiliferous limestones (belemnoids, oysters, pelecypods, and crinoids are common in most outcrops). Immediately below the Sundance are the pink and white banded beds of the Middle Jurassic Gypsum Spring Formation. The top of the Triassic Chugwater Formation (the redbeds which are approximately 1,000 feet thick and extend to the entrance of Wind River Canyon) is marked by the dark red to purplish shales below the Gypsum Spring Formation.
0.8	1.9	0.6	15.9	Bridge over railroad tracks.



North aerial view of the Chugwater overlying the Owl Creek dip slope at the north portal of Wind River Canyon.

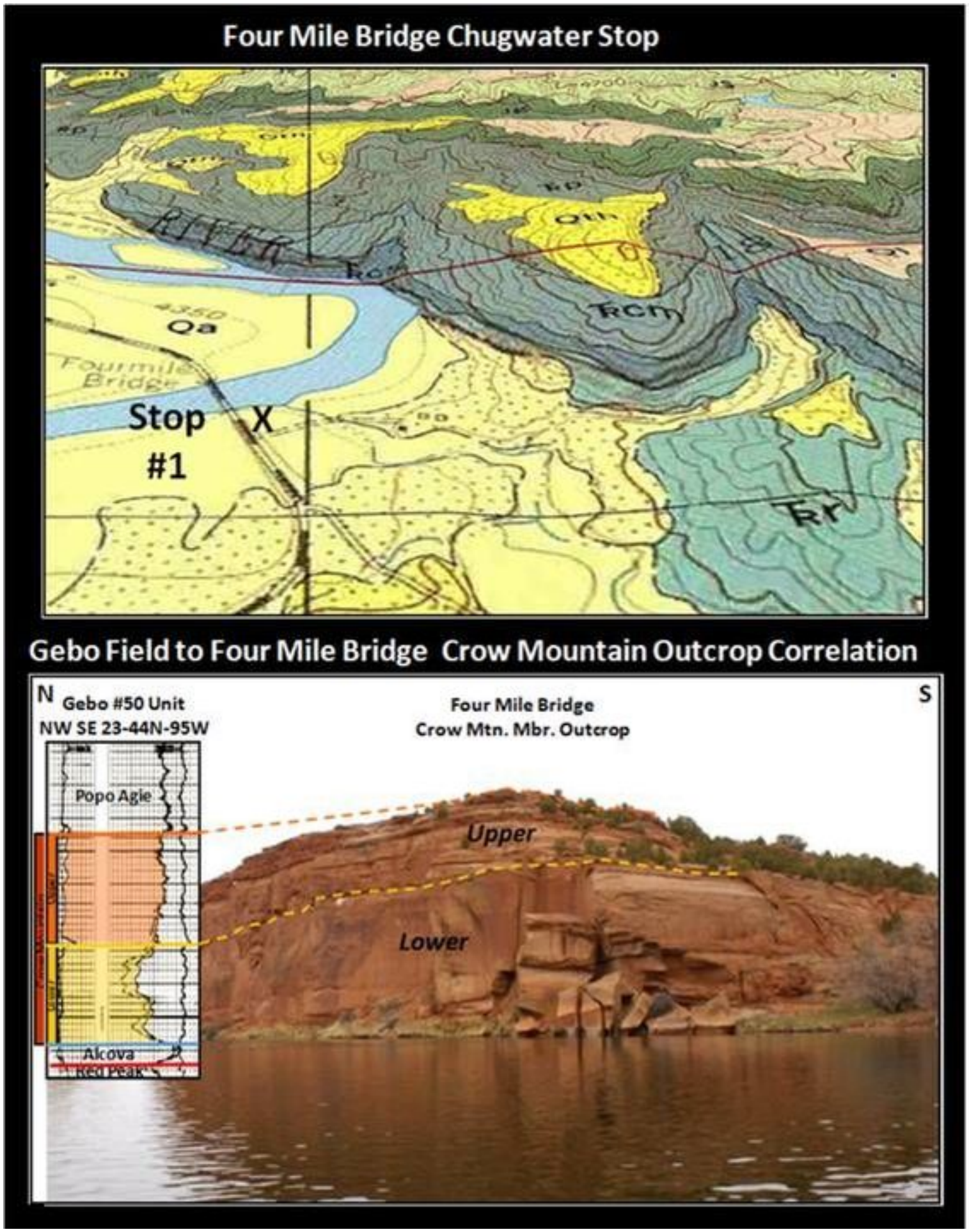
Image: Maher, L.J., Jr., 2002, Image 130-20

ftp://ftp.geology.wisc.edu/maher/air/130-20k2.jpg (ftp://ftp.geology.wisc.edu/maher/air/130-20k2.jpg)

Stop 1. After bridge over the Bighorn River: Directly south is the Wind River Canyon through the Owl Creek Mountains. The road approaching the canyon from the north crosses the gently dipping south rim of the structural basin. The topographic slope of the mountain uplift is formed by the resistant uppermost members of the Phosphoria Formation. Locally the entire range is made up of stripped dip slopes, and there is no evidence of Tertiary high level erosion surface in the sharply eroded Precambrian formations exposed in the core of the range. The present course of the river was inherited from a previous erosion cycle. The master streams in the region meandered across an aggraded Tertiary fill which blanketed the mountain ranges developed during the Laramide Orogeny. Their courses may have been controlled by greater amounts of wash from the exposed mountain cores such as the south end of the Big Horn Mountains on the

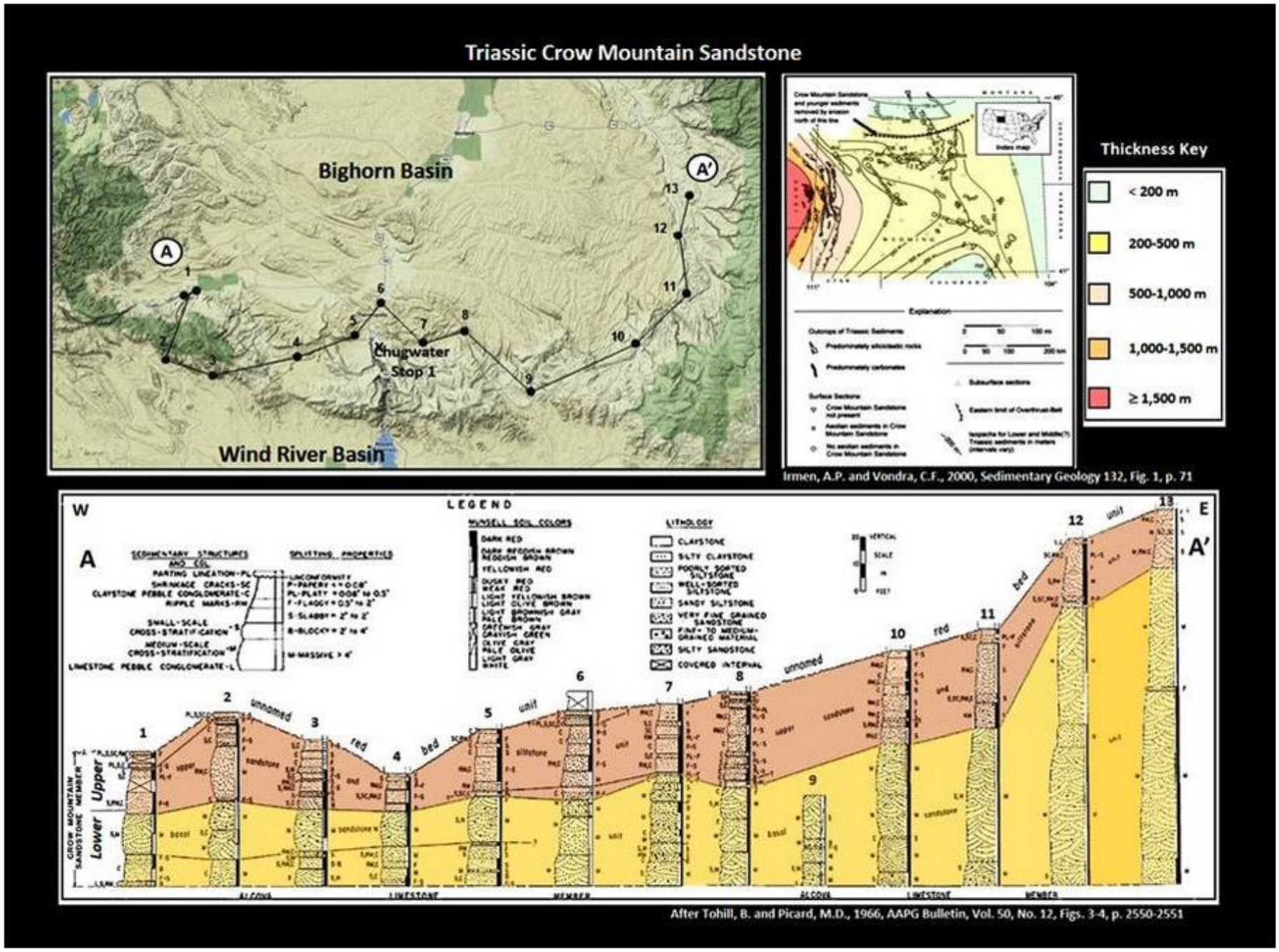
0.6	2.5	0.2	15.3

east, and the higher structural elevations of the Owl Creek Mountains to the east and west. Regional uplift accelerated erosion and the streams incised themselves through the Tertiary cover and into the buried, deformed Mesozoic and Paleozoic formations. Bridge across Big Horn River. Directly in front (south) is a stripped Phosphoria slope, dipping about 8° north. This dip persists about two miles from the mouth of the canyon and then diminishes fairly abruptly to dips varying between 4° and 1° north. West of the canyon mouth is the Red Canyon anticline, a large flexure with a steep southwest limb. This feature dies out as a fold in the canyon, but the line of deformation is indicated by a small high-angle fault, upthrown on the north side. This fault will be seen at mileage point 11.4. The mountain range itself is asymmetrical, in that it has a gentle dip on the north side and is overthrust along the south flank. The horizontal displacement is calculated to be about six miles, and the vertical offset about three miles.



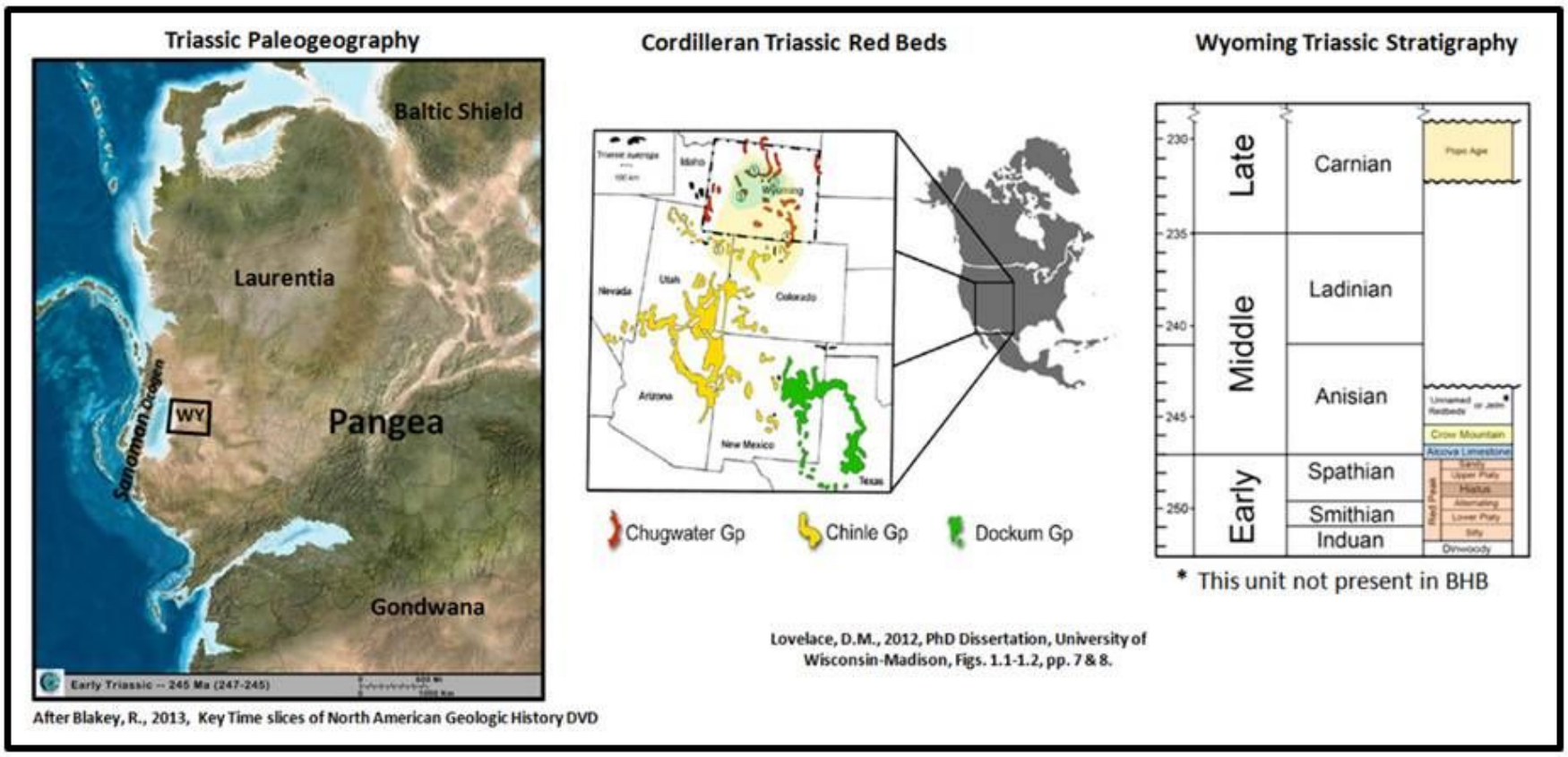
Stop 1: Four Mile Bridge. Top: Geologic map; Bottom: Crow Mountain Sandstone outcrop along Bighorn River. Correlation with Gebo Field subsurface log on left.

Images: Top: Base: Google earth, Overlay: Maughan, E.K., 1972, Geologic map of the Wedding of the Waters quadrangle, Hot Springs County, Wyoming: U.S. Geological Survey, Geologic Quadrangle Map GQ-1042, scale 1:24,000. Bottom: Google Earth, Panoramio, Photo, 2010 at http://www.panoramio.com/photo/34832365 (http://www.panoramio.com/photo/34832365); *Log from Wyoming Oil and Gas Conservation at http://wogcc.state.wy.us/legacywogcce.cfm* (http://wogcc.state.wy.us/legacywogcce.cfm)



Crow Mountain Sandstone Member of the Triassic Chugwater Formation southern Bighorn Basin outcrop cross section and regional Wyoming thickness map.
Images: Cross section: After Tohill, B. and Picard, M.D., 1966, AAPG Bulletin, Vol. 50, No. 12, Figs. 3-4, p. 2550-2551; Isopach Map: After Irmen, A.P. and Vondra, C.F., 2000, Sedimentary Geology 132, Fig. 1, p. 71

The Chugwater Formation consists of four members in the Bighorn and Northern Wind River Basin area: Popo Agie, Crow Mountain, Alcova, and Red Peak. These units were deposited across an area that was located on the western edge of the continent of Pangea. The Chugwater beds are part of the larger Cordilleran Triassic red bed sequence deposited in the Rocky Mountain area.



Triassic Paleogeography, Cordilleran Red Bed sequence and Wyoming Stratigraphy of the Chugwater Formation.

Images: Left: After Blakey, R., 2013, Key Time slices of North American Geologic History DVD, Center & Right: Lovelace, D.M., 2012, PhD Dissertation, University of Wisconsin-Madison, Figs. 1.1-1.2, pp. 7 & 8.

The Red Peak is the oldest and thickest unit. This red bed sequence was deposited on the wide shelf developed in Wyoming at a paleolatitude of 30o north. Salt casts, gypsum veins, mud cracks and scarce fossils suggest the climate was warm and semiarid to arid.

Left: Red Peak outcrop on west (R/L) side of US 20. Right: Gypsum veins in shale layers.

Images: Left: http://kgbudge.com/essays/Excellent/Photos/2014/07/07/DSCI0629.JPG (http://kgbudge.com/essays/Excellent/Photos/2014/07/07/DSCI0629.JPG); *Right: https://en.wikipedia.org/wiki/File:Chugwater_gypsum_veins.jpg* (https://en.wikipedia.org/wiki/File:Chugwater_gypsum_veins.jpg)

The Alcova member is a marine carbonate tongue of the Thaynes Limestone deposited along the Wyoming shelf in the southwestern corner of the state. Limited presence of stromatolitic algae and mollusk fauna indicate a restricted marine environment of deposition.

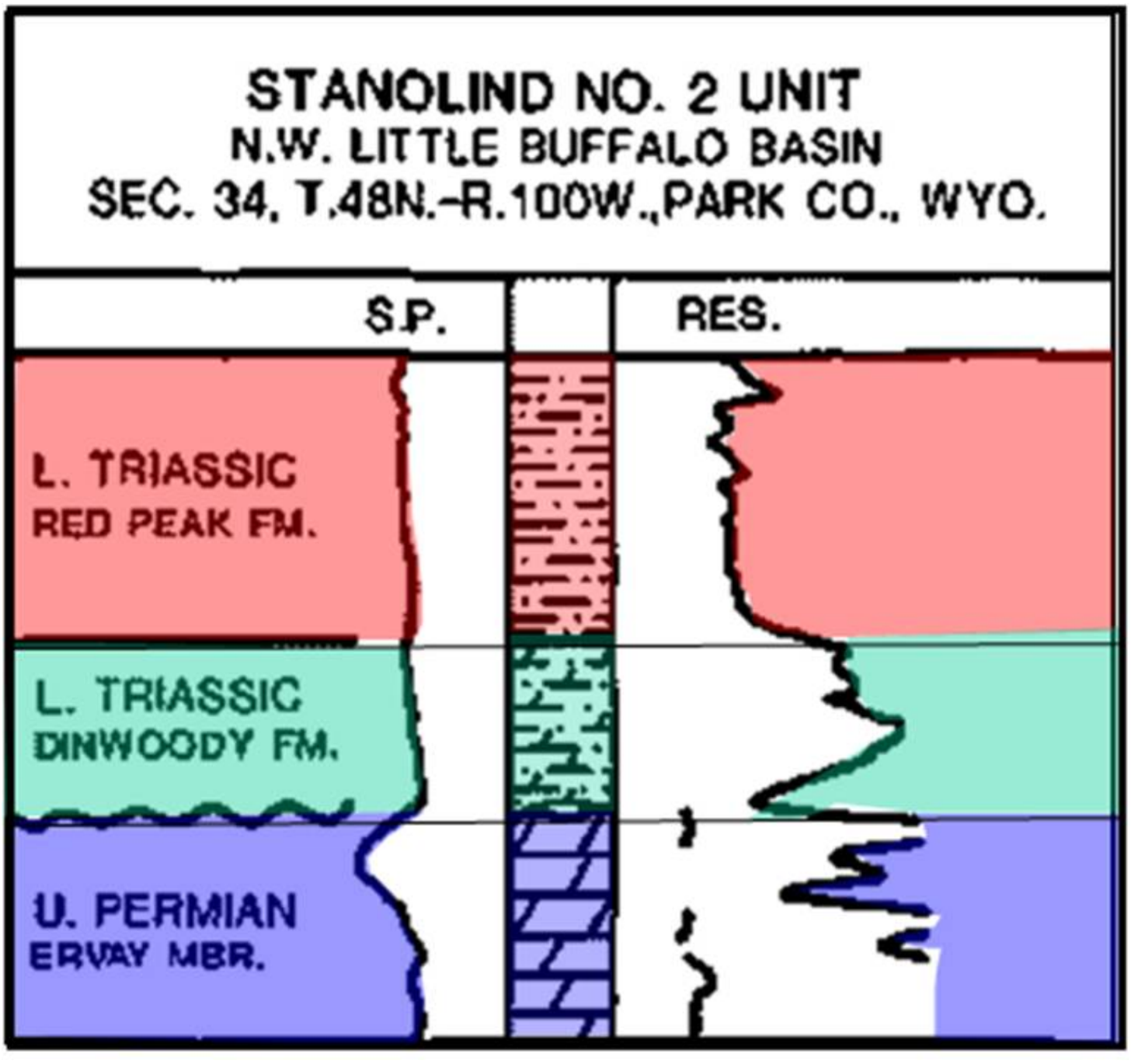
The Crow Mountain member consists of a basal sandstone and an upper sandstone/siltstone sequence. It is economically important as a hydrocarbon reservoir. Oil was discovered at Hamilton Dome Field (formerly Cottonwood Anticline) in 1918. Drillers called this pay sand "Curtis" after the manager of Empire Oil who made the discovery. The Crow Mountain Member was not formally recognized until 1939 (J.D. Love PhD Dissertation).

The Popo Agie member overlies the rest of the Chugwater with an over 10 million year unconformity. It is composed of clastics deposited in a river/lake environment. It represents one of the largest known ancient lakes which extended into large portions of four States (ID, WY, CO & UT).

MEMBER	LITHOLOGY	DEPOSITIONAL ENVIRONMENT	RESERVOIR	Thickness (ft)	PHI (%)	K (md)	Hydrologic Character
Popo Agie/Jelm (Trc_{pa})	mudstone & carbonates/siltstone & sandstone	lacustrine/fluvial to deltaic	Not reported	0-300	Not reported	Not reported	Confining Unit
Crow Mountain (Trc_{cm})	fine to medium grained crossbedded silty sandstone & sandy slitstone	shoreface, tidal flat, marine shelf	BHB: *Adam, Grass Creek, Hamilton Dome, Murphy Dome, Enos Creek, Gebo, Manderson, Prospect Creek, Baird Peak* WRB: *Beaver Creek, Clark Ranch, Pilot Butte, Poison Spider, Rolff Lake, Sage Creek Anticline, Sheldon NW & Steamboat*	0-130	13-20	7-120	Marginal to Subaquifer (< 20 gpm near outcrops)
Alcova (Trc_{a})	limestone & dolomite w/ abundant algal structures & minor mollusks	resricted marine	WRB: *Big Sand Draw* (fracture porosity)	0-30	0	Not reported	Confining Unit
Red Peak (Trc_{rp})	silty claystone to sandstone w/ casts of salt, mud cracks & raindrop impressions; 75-85% silt-sized sediment (High & Picard, 1963, p. 15-20; Picard & High, 1963, p. 89)	tidal flat to nearshore marine	BHB: *Oregon Basin, Garland*	900-950	13-18	5	Marginal to Subaquifer (< 10 gpm near outcrops)

Summary table of Chugwater stratigraphy.
Image: Steele, K.K., 2012, Chugwater Stratigraphy after Taucher et al., 2012, Wind/Bighorn River Basin Water Plan Update Groundwater

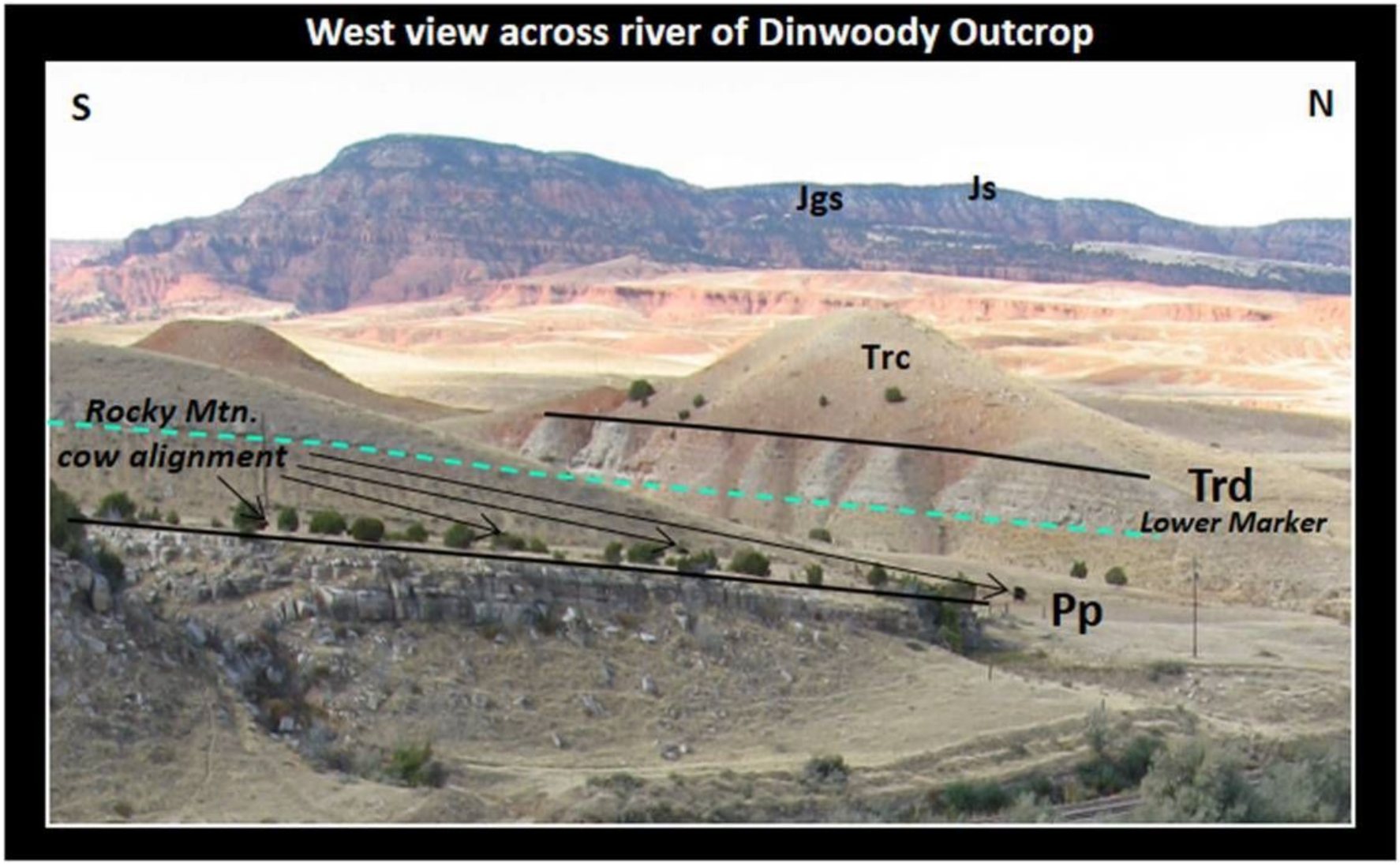
0.2	2.7	1.6	15.1	Road curves to the right and becomes Hot Springs County 31 (South Yellowstone Road)
1.6	4.3	0.1	13.5	Top of Triassic Dinwoody Formation. The gypsum bed on the east and the two knobs on west side of river are erosional remnants of the Dinwoody Formation which is only about 60 feet thick. The Dinwoody Formation is mostly gray-green pyritic shales and dolomitic shales. In well-cuttings, the top of the Dinwoody is differentiated from the overlying Chugwater Formation by the gypsum beds at the top. On open hole logs the Dinwoody has higher resistivity than the overlying Chugwater, but lower than the underlying Phosphoria Formation.



Subsurface electric log displaying typical resistivity response for the Red Peak, Dinwoody and Upper Phosphoria units. The log signature indicates that the Dinwoody Formation in the well is a dolomitic siltstone. Four points to note on Dinwoody log character: 1. the base line

SP, 2. the higher resistivity than overlying Red Peak, 3. the lower resistivity than underlying carbonate of the Phosphoria, 4. the erratic distribution of anhydrite marker beds throughout the formation.
Well cuttings often show a color change from red to greenish from the Red Peak to the Dinwoody and an increase in disseminated pyrite.
Image: After Paull, R.A. and Paull, R. K., 1986, MGS, Fig. 9, p.18.

The early Triassic Dinwoody Formation represents the most northeastern extent of the Griesbachian (251 million years ago) seaway advance onto the Wyoming shelf. The north-south trending depositional limit of the formation is on the east side of the Bighorn Basin where the Dinwoody and Phosphoria interfinger with the Goose Egg Formation. Maximum thickness of the unit is found along the south flank of the Owl Creek Mountains and is under 100 feet. The formation is generally 60 to 65 feet thick within the Bighorn Basin and serves as a part of the Dinwoody-Chugwater-Gypsum Spring regional seal for the large Paleozoic oil accumulations in the Bighorn Basin. Four gradational lithologies make up the formation: dolomitic siltstone, gypsum, silty dolomite and sandstone. These rocks were deposited in a normal marine in the west to a shallow, low energy, hypersaline shelf at the seaway margin (eastern Bighorn Basin).



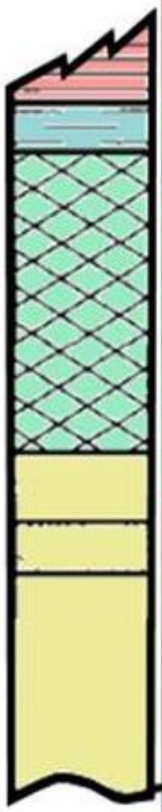
View of Dinwoody outcrop on the west side of the Wind River at north mouth of Wind River Canyon, NOTE: Rocky Mountain Bovimatry – cows show northward alignment with the earth's

magnetic field. Bovimatry is a lesser used geophysical technique that is today somewhat out of favor.

Image: Steele, K.K., 2009, Dinwoody at the mouth of Wind River Canyon.

Wedding of the Waters, Hot Springs Co., WY

ne ne 26-T42N-R95W



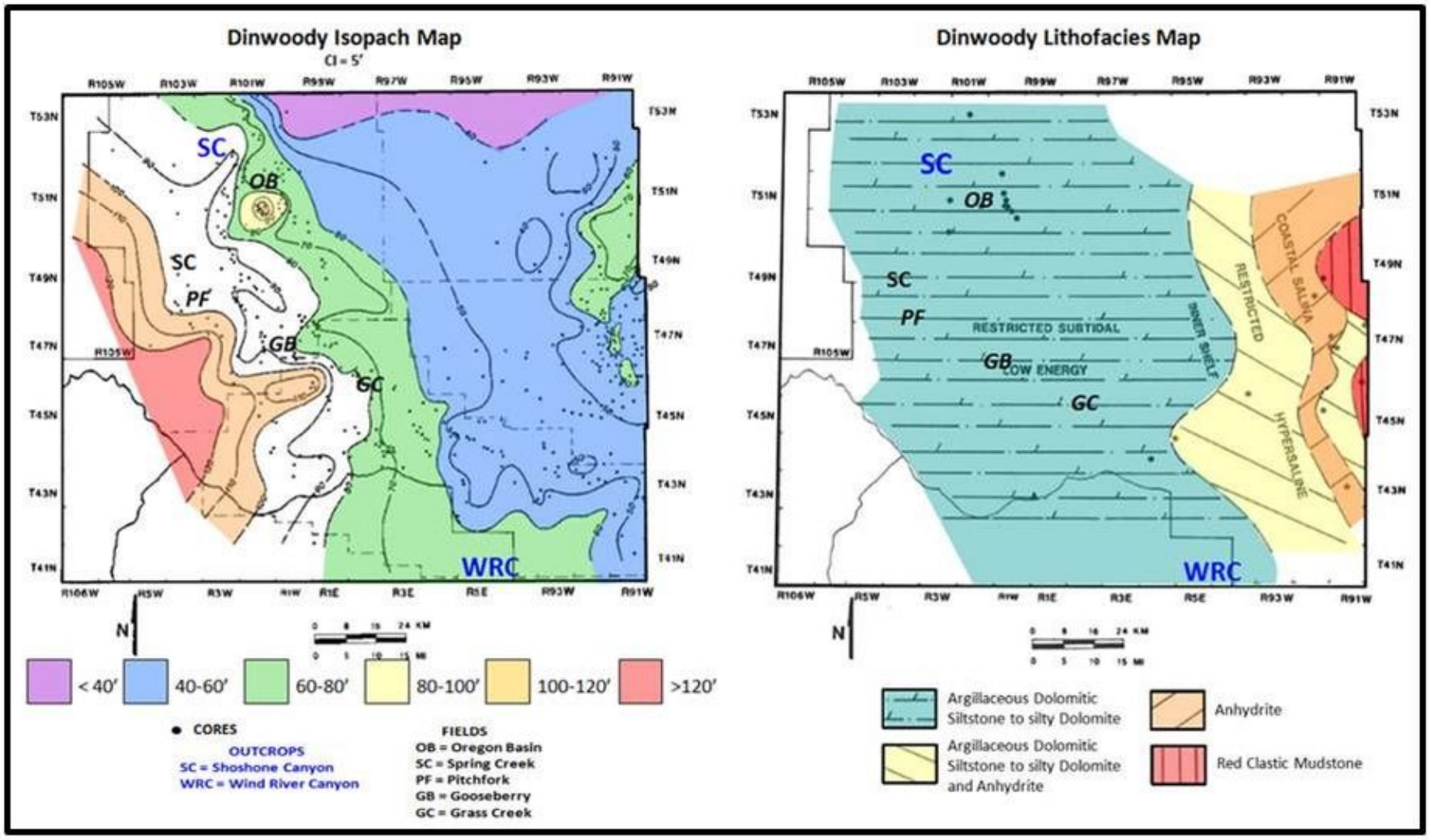
Unit	Ft	M	Lithology
Trc_{gp}	Contact abrupt		
Trd 7	4.9	1.5	sltstn., as Units 2, 3 & 5 below, soft soil
Trd 6	28.7	8.75	gyp., lt. gray, v. thick bed., resistant
Trd 5	7.4	2.25	sltstn., calc., med. tan, thin crinkly bed., thin gyp. veinlets
Trd 4	4.1	1.25	ss., sl. calc., vfg., lt. to med. Yellow tan, resistant, thin irreg. bed
Trd 3	8.2	2.5	sltstn., sl. calc., lt. yellow tan, forms thin chips & plates
Trd 2	7.4	2.25	sltstn., sl. calc., lt. to med.yellow tan, soft
Trd 1	4.9	1.5	covered, probably as Unit 2 above
Pp	Contact abrupt, basal Triassic not exposed		

Dinwoody Formation outcrop description.

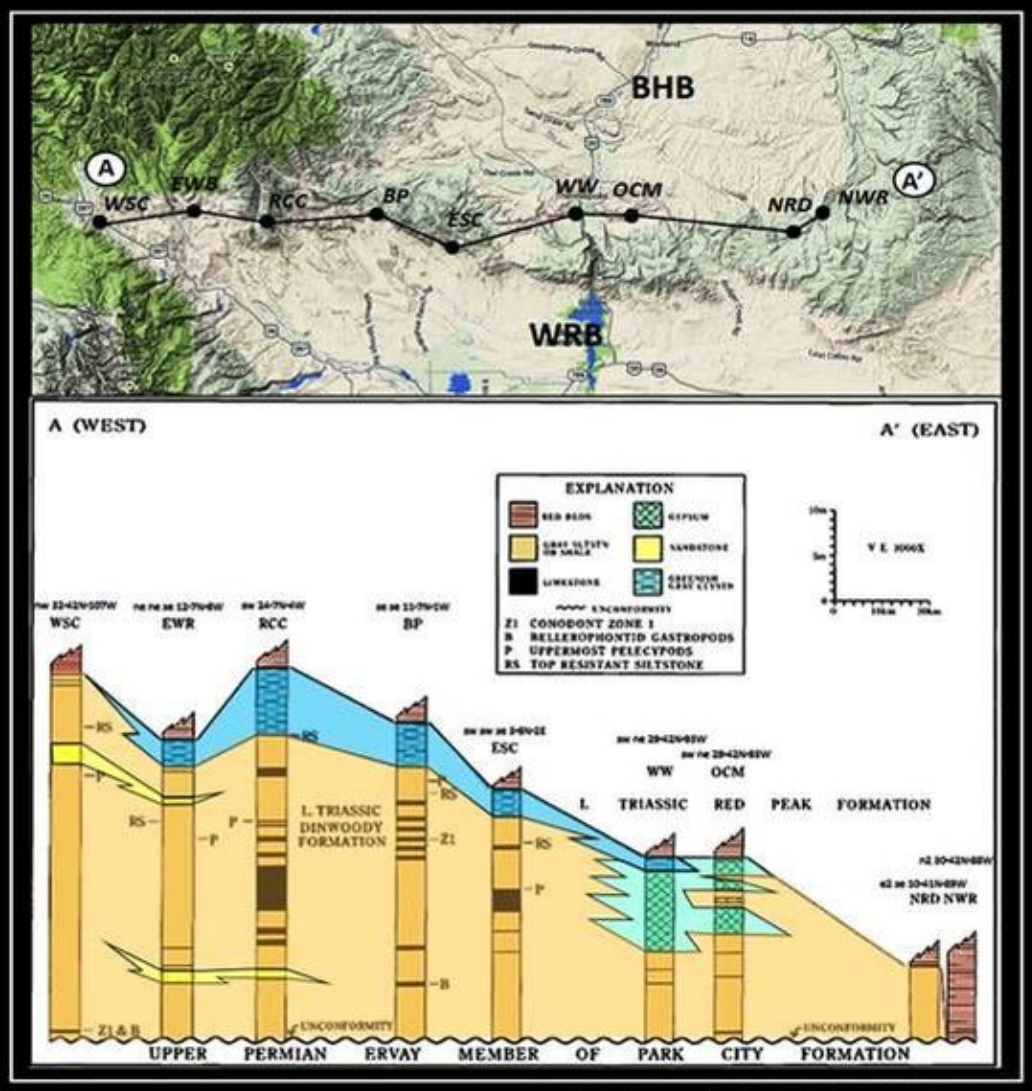
After Paull, R.A. and Paull, R.K., 1993, WGA, Stratigraphy of the Lower Triassic Dinwoody Formation in the Wind River Basin Area, Wyoming: Oil and Gas and Other Resources of the Wind River Basin, Wyoming; Special Symposium, Fig. 4, p. 35 & Table, p. 47.

Interpretive signs about Wedding of the Waters are located about 0.4 miles north of the junction of WY Hwy 137 and US 20. When Lewis and Clark reached this stream in Montana they named it the Bighorn River after the abundant number of native sheep in the area. Native Americans named the same river to the south for the strong prevailing northwest winds blowing downstream between the Absaroka and Wind River mountains. The Wedding of the Waters, a half-mile to the south at the mouth of the canyon (top of Phosphoria), is the geographical point chosen for the name change. Wind River is applied to the stream's upper

reaches in the Wind River Basin, and Bighorn River from Wedding of the Waters northward.



Dinwoody Formation Isopach and Lithology Maps for a portion of the Bighorn Basin.
Images: After Clark, W.J., 1994, An Integrated Sequence Stratigraphic Approach to Reservoir Characterization of the Lower Mississippian Madison Limestone, Emphasizing Elk Basin Field, Bighorn Basin, Wyoming: Ph.D. Dissertation, Colorado School of Mines, Fig. 61, p. 161 & Fig. 63, p. 165.



Regional Dinwoody Outcrop Cross Section

Locations

WSC = Warm Springs Creek (nw 32-42N-107W)

EWR = East Fork of Wind River (nw nw se 12-7N-6W

RCC = Red Canyon (sw 24-7N-4W)

BP = Blondie Pass (se se 11-7N-1W)

ESC = East Fork of Sheep Creek (sw sw se 3-6N-2E)

WW = Wedding of the Waters (ne ne 26-42N-95W)

OCM = Owl Creek Mountains (sw ne 29-42N-93W)

NRD = Nowood Road (e/2 se 10-47N-89W

NWR = Nowood River (n/2 30-42N-88W)

After Paull, R.A. and Paull, R.K., 1993, WGA, Fig. 4, p. 35

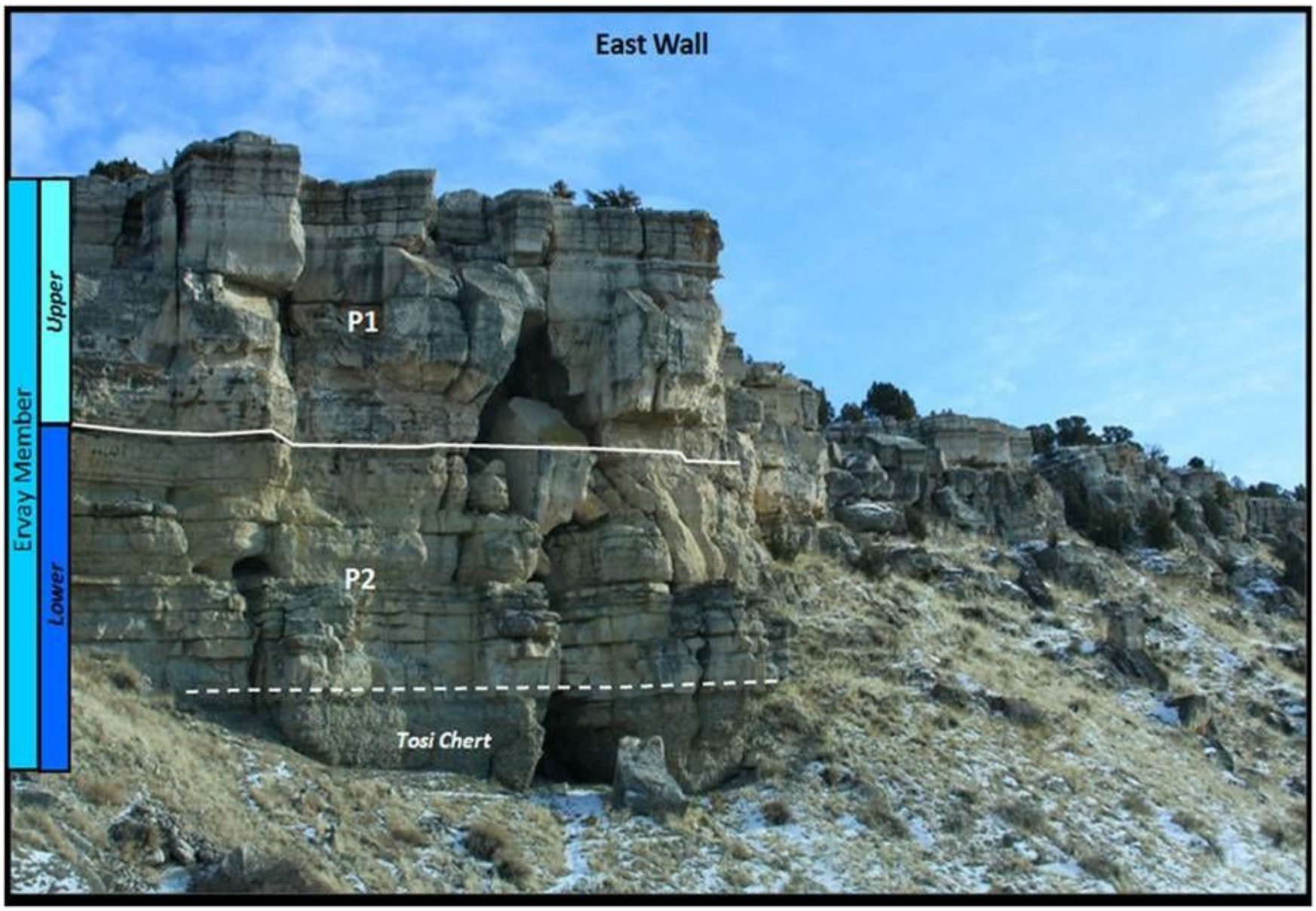
Regional Dinwoody Formation outcrop cross section along southern margin of Bighorn Basin.
Image: After Paull, R.A. and Paull, R.K., 1993, WGA, Fig. 4, p. 35

Hypersaline Dinwoody Formation at seaway margin at the north nose of Sheep Mountain Anticline.

Images: Steele, K.K., 2009, Sheep Mountain Anticline

0.1 4.4 0.2 13.4

Phosphoria turnout. Stop 2. The Phosphoria (Park City, USGS) Formation is mostly dolomite and limestone and is approximately 220 feet thick in this area. Phosphate nodules are common in this formation. Brachiopods and bryozoa are common fossils in the outcrops. Mud cracks may be observed on the surface of the exposed Phosphoria dip slope. Some caves are present on east side of highway. The Phosphoria is a good oil producer in many fields throughout the Bighorn and Wind River basins. The primary reservoir interval is within the Ervay (P1 & P2) subzone which is exposed here. Dip is 9° north.

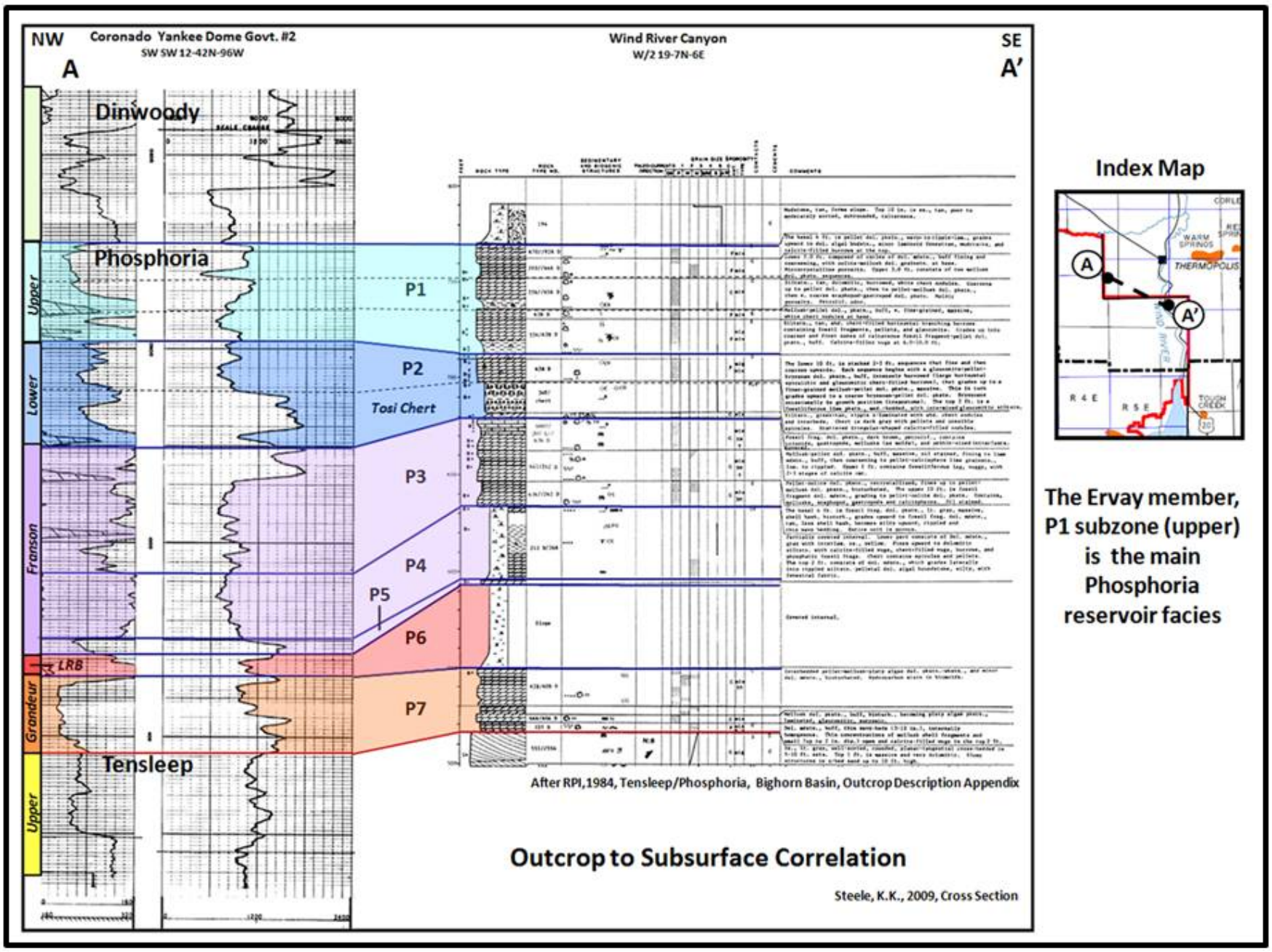


Ervay Member of the Phosphoria Formation, Wind River Canyon.

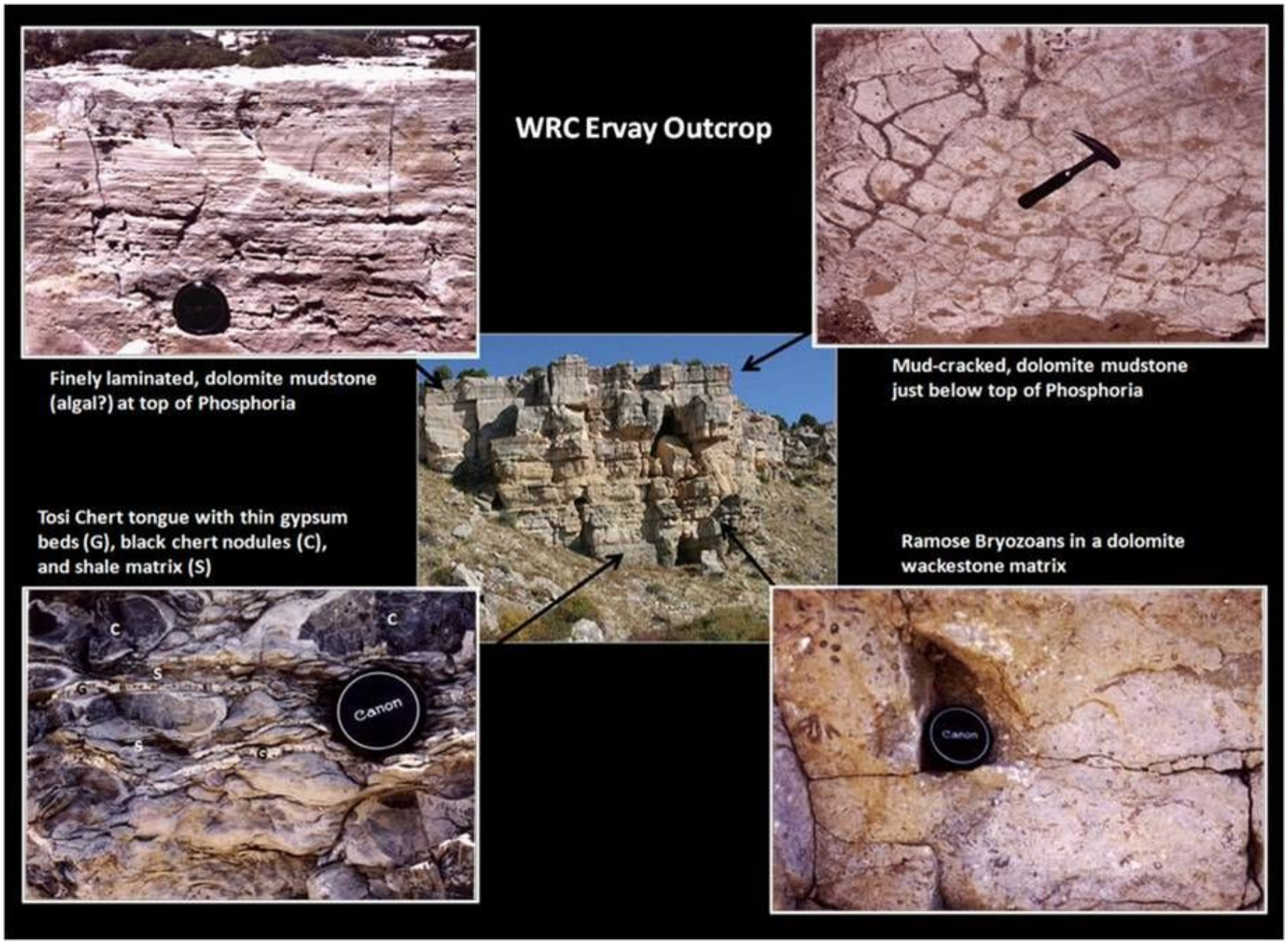
Image: After https://www.flickr.com/photos/wy_jackrabbit/4249397308/ (https://www.flickr.com/photos/wy_jackrabbit/4249397308/)

The boundary with the overlying Dinwoody Formation is a one to six million year unconformity that represents the greatest extinction event on the Earth. Up to 90% of marine organisms and 70% of land-based lifeforms perished. Reefs, chert, and coal or peat beds disappear from the geologic record. The Dinwoody is a time of global warming, acid rain, ocean acidification and anoxia.

The Phosphoria in Wind River Canyon is located at about the center of the Ervay Member of the Park City facies of the Permian rock complex. Three formations comprise this interfingering and laterally equivalent rock complex. The Phosphoria is the marine facies deposited in westernmost Wyoming and eastern Idaho and Utah. The Park City Formation is the middle facies deposited on the Wyoming shelf. The Goose Egg Formation is a sequence of continental redbeds and evaporites. Westward of the Wind River Canyon exposure the Ervay Member consists of marine carbonate, alternating with phosphatic siltstone and chert beds. Eastward the Ervay grades into restricted carbonates and terrestrial red beds.



Subsurface geophysical log correlation to Wind River Canyon Permian outcrop section.
Images: Log: Wyoming oil and Gas Conservation website
http://wogcc.state.wy.us/legacywogcce.cfm (http://wogcc.state.wy.us/legacywogcce.cfm)
Outcrop description: After RPI, 1984, Tensleep/Phosphoria, Bighorn Basin, Outcrop Description Appendix.



Ervay outcrop sedimentary features, Wind River Canyon.

Images: Rath, B.A., 1981, Stratigraphy and diagenesis of the Ervay member of the Park City and Goose Egg formations (Permian), eastern Wind River Basin, Wyoming: M.S. Thesis, Colorado School of Mines, Figs. 5, 19, 56 & 57, pp., 16, 34 & 12

https://dspace.library.colostate.edu/handle/11124/78294?show=full

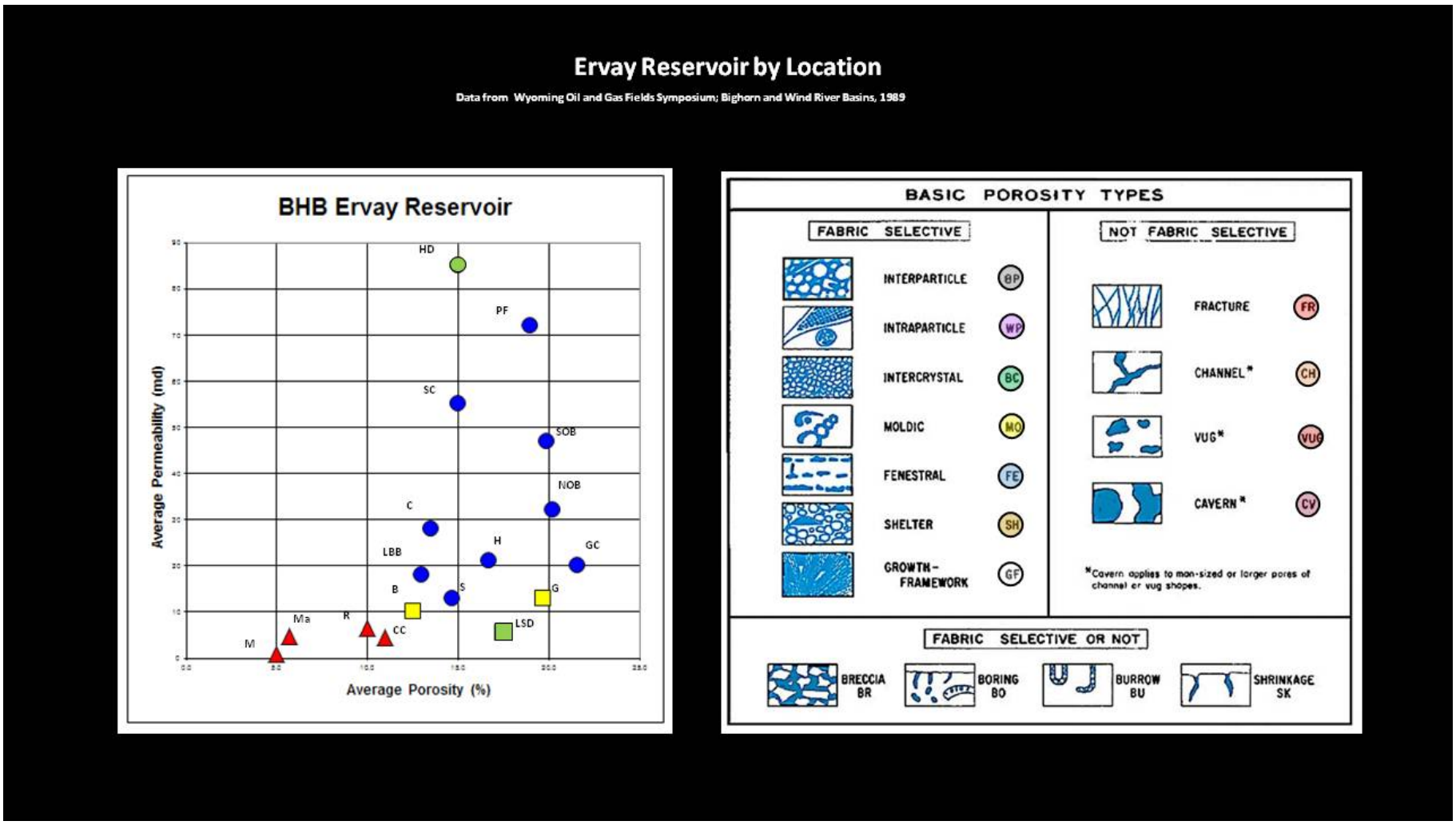
(https://dspace.library.colostate.edu/handle/11124/78294?show=full)

Ervay Reservoir by Location

Basin Location	Field	Discovery Date	Average Pay Thickness	Reservoir Continuity	Average Porosity (Range)	Average Permeability (Range)	Reservoir Lithology	Main Depositional Facies	Oil Gravity	Strartigraphic Zone of Reservoir
NW	Cody (C)	1977	24'	Continuous	13.5% (Core: 10-27%)	28 md (Core: 1-100md)	Dolomite	Open-Restricted Marine Transition	24	P1OM-RM
	Shoshone (S)	1952	17'	Continuous, Faulted	14.7%	13 md	Dolomite	Open-Restricted Marine Transition	19	P1OM-RM
	North Oregon Basin (NOB)	1927	38'	Continuous, Fractured	21.5% (Core: 7-31%)	77 md (Core: 0.1-550 md)	Dolomite	Open-Restricted Marine Transition	23	P1OM-RM
	South Oregon Basin (SOB)	1928	30'	Continuous, Fractured	19.9% (Core: 2.5-31%)	47 md (Core: 0.1-276 md)	Dolomite	Open-Restricted Marine Transition	20.8	P1OM-RM
	Halfmoon (H)	1944	40'	Continuous	16.7% (Core: 8-26%)	21 md (Core: 0.1-115 md)	Dolomite	Open-Restricted Marine Transition	14.7	P1& P2 OM-RM
W	Spring Creek (SC)	1946	15'	Semi-continuous	15% (Core: 10-20%)	55 md (Core: 1-103 md)	Dolomite	Open-Restricted Marine Transition	15	P1OM-RM
	Pitchfork (PF)	1930	32'	Continuous	19% (Core: 7-30%)	72 md (Core: 0.5-378 md)	Dolomite	Open-Restricted Marine Transition	18	P1OM-RM
	Little Buffalo Basin (LBB)	1945	39'	Heterogeneous	13% (Core: 10-19%)	18 md (Core: 1-121 md)	Anhydritic Dolomite	Open-Restricted Marine Transition	16-20	P1OM-RM
	Grass Creek (GC)	1922	35'	Heterogeneous	22% (Core: %)	20 md (Core: md)	Limestone & Dolomite	Open-Restricted Marine Transition	24.5	P1OM-RM & minor P3
S Cnt	Hamilton Dome (HD)	1918	31'	Continuous, Fractured	15% (Core: %)	85 md (Core: md)	Dolomite & Dolomitic Limestone	Open-Restricted Marine Transition	18-26	P1
	Little Sand Draw (LSD)	1949	60'	Continuous, Fractured	17.5% (Core: 4-20%)	5.4 md (Core: 0.1-34 md)	Dolomite	Inner Shelf Restricted Marine	36	P1/P2
NE	Elk Basin (EB)	1942		Continuous			Dolomite	Inner Shelf Restricted Marine		P1
	Alkali Anticline (AA)	1957	24'	Discontinuous, Faulting	11%	0.13-8.23 md	Dolomite	Inner Shelf Restricted Marine	24	P1
	Byron (B)	1930	20'	Continuous, Fractured	12.50%	10 md	Dolomite	Inner Shelf Restricted Marine	23	P1
	Garland (G)	1927	23.5	Continuous	20.10%	14 md	Dolomite	Inner Shelf Restricted Marine	20-24.3	P1
E	Rattlesnake (R)		30'	Continuous, Fractured		6.5 md	Dolomite	Peritidal/Lagoonal	27	P1/P2
	Cottonwood Creek (CC)	1953	21'	Discontinuous	11% (2-18%)	4.5 md (0.1-27 md)	Dolomite	Peritidal/Lagoonal	26-28	P1/P2
	Manderson (M)	1951	25'	Discontinuous, Fractured	5% (1.5-18.2%)	1 md	Dolomite	Peritidal/Lagoonal	33	P1/P2
	Marshall (Ma)		38'	Continuous	5.7% (2-17.2%)	4.7 md (0.01-88 md)	Dolomite	Peritidal/Lagoonal	27	P1/P2

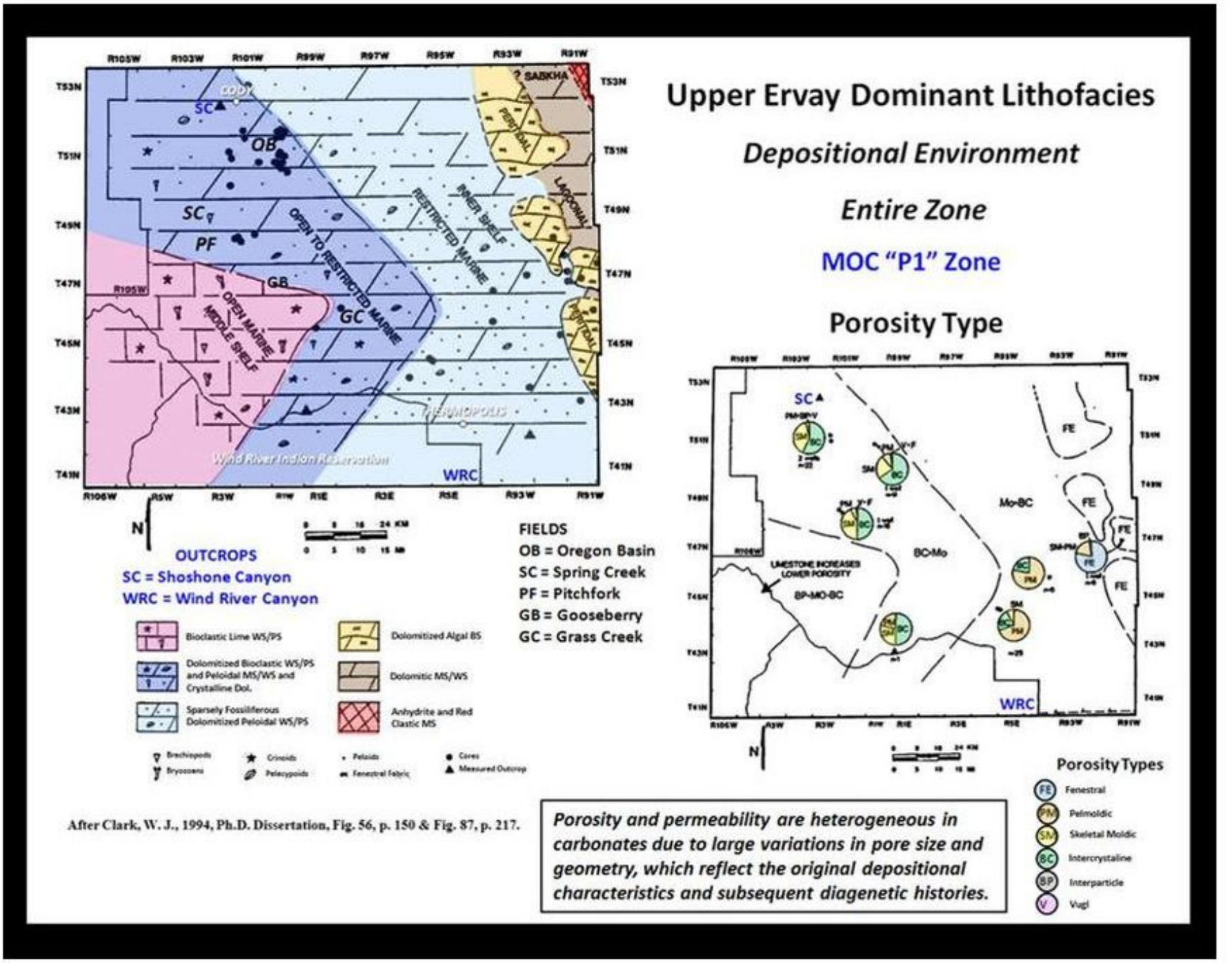
Ervay Reservoir by Location

Stratigraphic Domain	Main Rock Type	Main Porosity Type
P1 Open Marine-Restricted Marine Transition: Upper Ervay	Dolomitized Bioclastic Wackestone/Packstone to sparsely fossiliferous Peloiodal Mudstone/Wackestone (Crinoid -Mollusk-Brachiopod-Pelecypoid)	Intercrystaline - Skeletal Moldic
P2 Open Marine-Restricted Marine Transition: Lower Ervay (includes Shedhorn SS)	Bioturbated Sandstone, Silicious Siltstones - Phosphatic Shales	Intercrystaline - Skeletal Moldic
P3 Open Marine-Restricted Marine Transition: Upper Franson	Algal Boundstones to Dolomitized Peloidal Wackestone/Packstone	Pelmoldic - Intercrystaline to Fenestral?
P1 Inner Shelf Restricted Marine: Upper Ervay	Sparsely fossiliferous Peloiodal Mudstone/Wackestone (Peloid -Mollusk)	Pelmoldic - Intercrystaline
P2 Inner Shelf Restricted Marine: Lower Ervay	Sparsely fossiliferous Peloiodal Mudstone/Wackestone (Peloid -Mollusk)	Pelmoldic - Intercrystaline
P1 Peritidal Restricted Marine: Upper Ervay	Dolomitized Algal Boundstones & Dolomitized Mudstone/Wackestone to Red Clastic Mudstone	Fenestral
P2 Peritidal Restricted Marine: Lower Ervay	Dolomitized Algal Boundstones & Dolomitized Mudstone/Wackestone to Red Clastic Mudstone	Fenestral



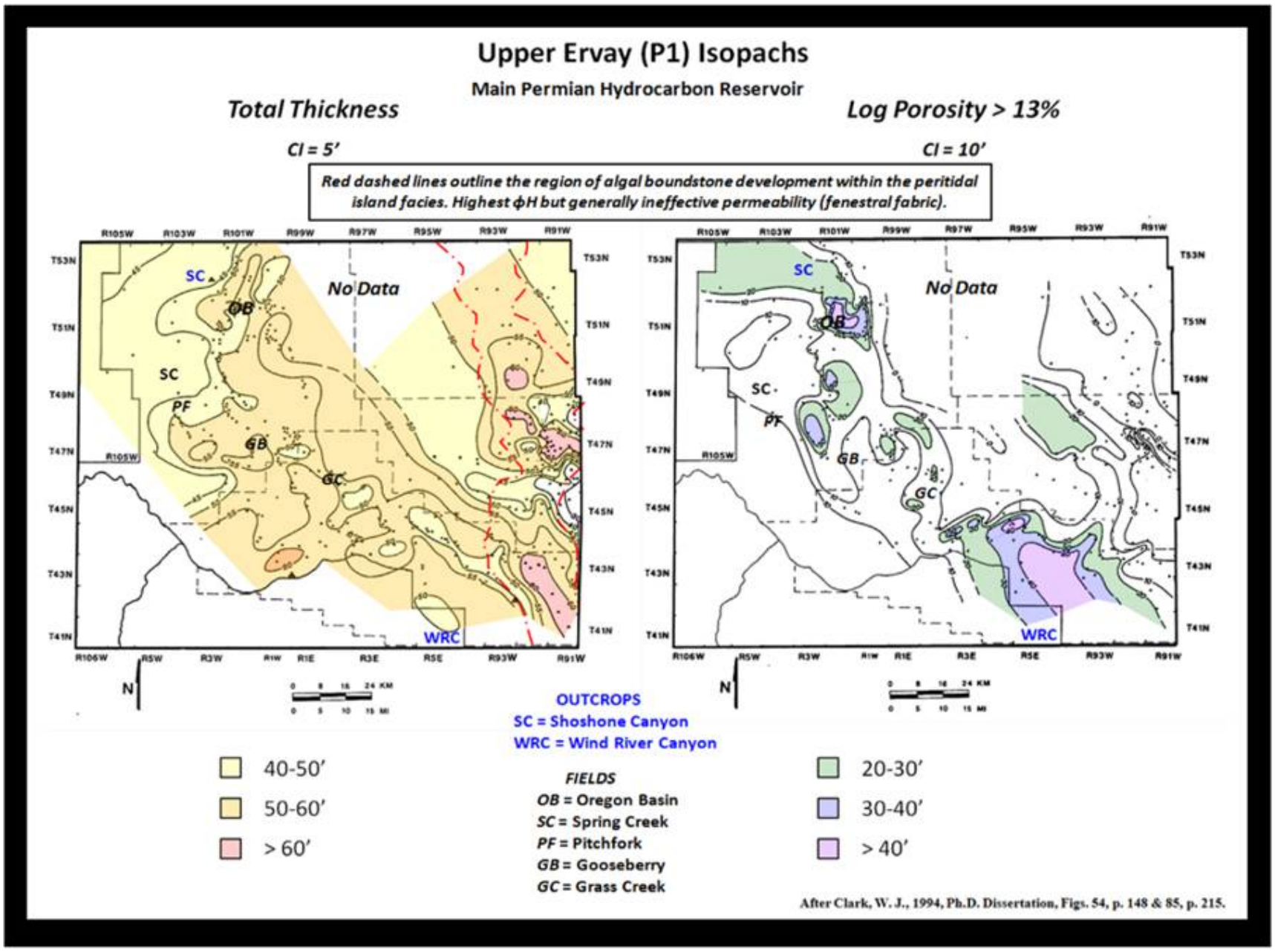
Phosphoria reservoir porosity and permeability development is a function of depositional facies.

Images: Left Tables: After Clark, W.J., 1994, An Integrated Sequence Stratigraphic Approach to Reservoir Characterization of the Lower Mississippian Madison Limestone, Emphasizing Elk Basin Field, Bighorn Basin, Wyoming: Ph.D. Dissertation, Colorado School of Mines. Bottom: Left:: Steele, K.K. (data from WGA, 1989) Bottom: Right: http://www.sepmstrata.org/page.aspx?&pageid=480&6 (http://www.sepmstrata.org/page.aspx?&pageid=480&6)



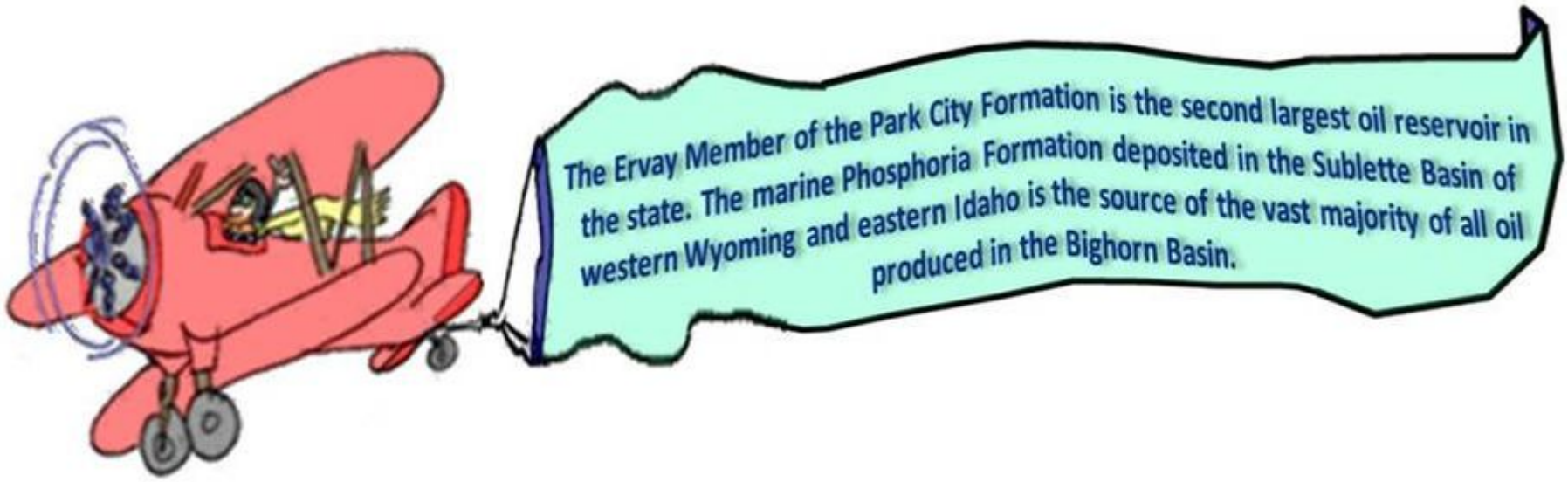
Upper Ervay (Phosphoria/Park City) dominant rock and porosity type maps.

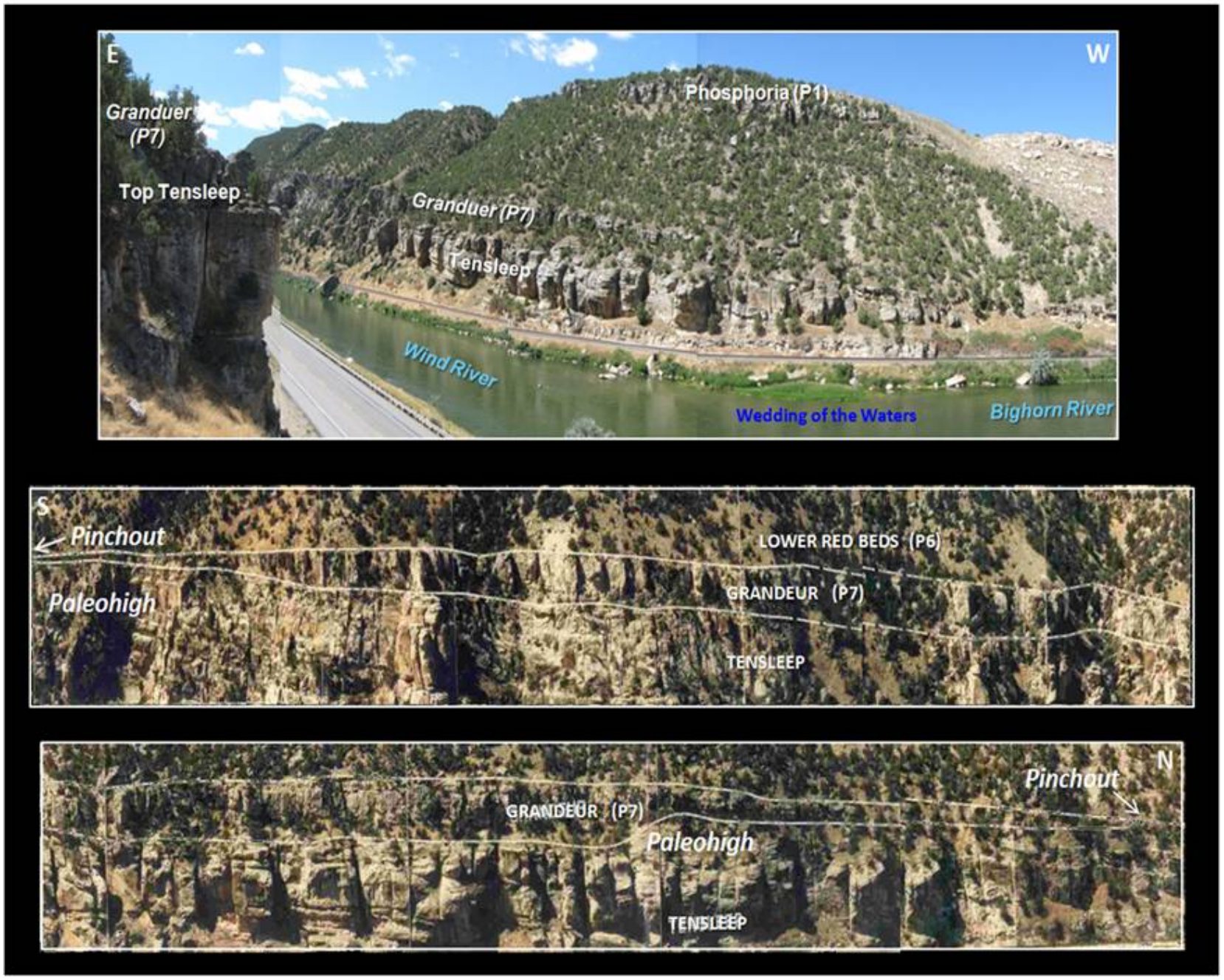
Images: After Clark, W.J., 1994, An Integrated Sequence Stratigraphic Approach to Reservoir Characterization of the Lower Mississippian Madison Limestone, Emphasizing Elk Basin Field, Bighorn Basin, Wyoming: Ph.D. Dissertation, Colorado School of Mines, Fig. 56, p. 150 and Fig. 87, p. 217.



Upper Ervay (Phosphoria/Park City) thickness and porosity > 13% thickness maps.
Images: After Clark, W.J., 1994, An Integrated Sequence Stratigraphic Approach to Reservoir Characterization of the Lower Mississippian Madison Limestone, Emphasizing Elk Basin Field, Bighorn Basin, Wyoming: Ph.D. Dissertation, Colorado School of Mines, Fig. 56, p. 150 and Fig. 87, p. 217.

0.2 **4.6** **1.0** **13.2** Base Phosphoria/Top Tensleep contact Dip 7° north.

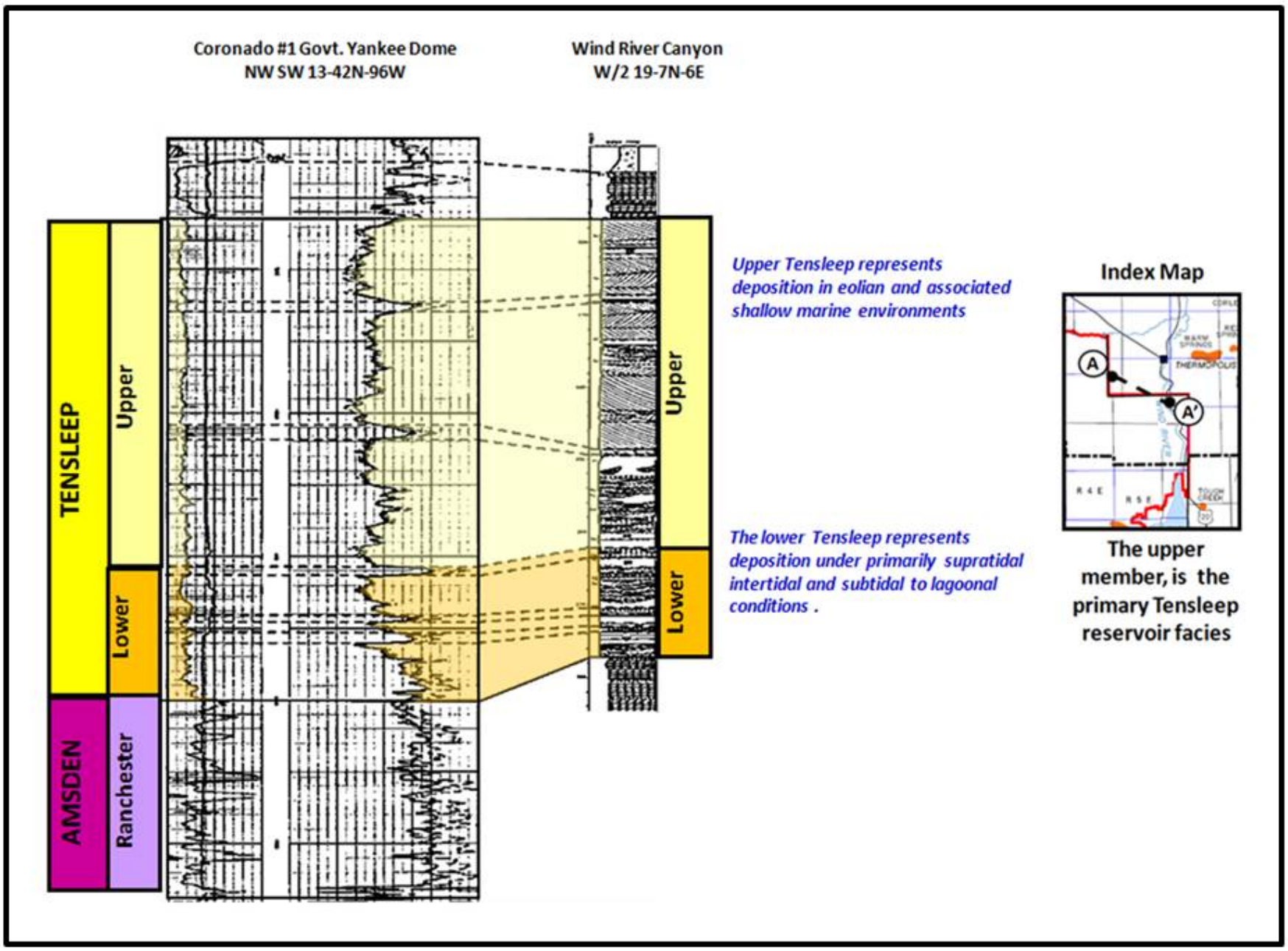




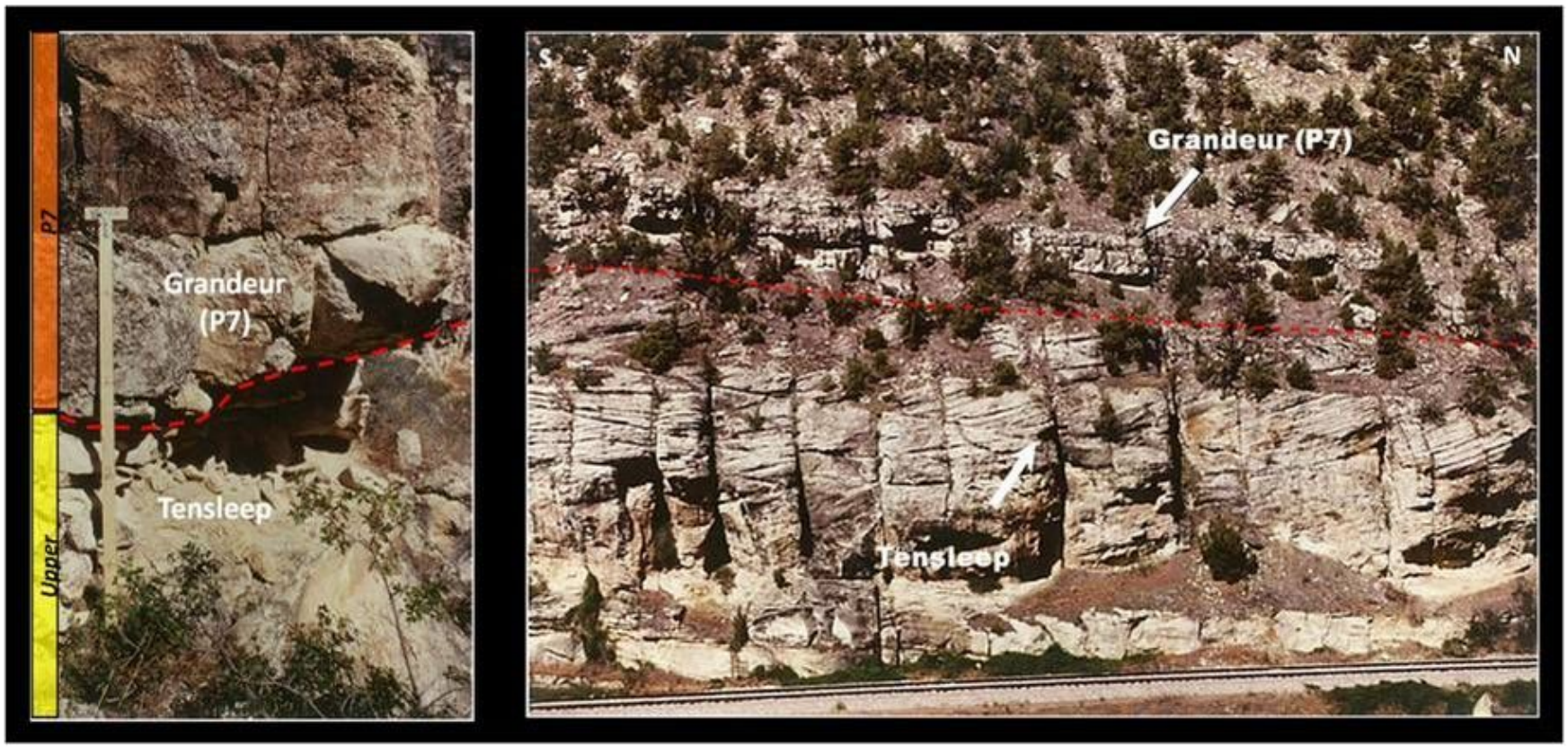
The Phosphoria/Tensleep contact on the west (R/L) side of the river. Lower two images are a south-to-north close-up of lateral pinchouts of the basal member of the Park City Formation (Grandeur Member of the Phosphoria Formation (P7)).

Images: Top: Steele, K.K., 2009, Pp/Pt Unconformity and Wedding of the Waters. Center and Bottom: After RPI, 1984, Tensleep/Phosphoria, Bighorn Basin.

The Tensleep is part of a large Pennsylvanian-Permian dune complex that developed on the western edge of the Late Paleozoic continent of Pangea. The Tensleep Sandstone exposure in the canyon presents a depositional dip profile of most the entire formation. The rocks are informally divided into an upper, thick-bedded member, and a lower, thinner bedded member. The upper unit is about 230 feet of dominantly wind-blown, carbonate-cemented quartz sandstone with interbeds of dolomite or dolomitic sandstone. The 75 foot lower member consists of interbedded marine sandstones and carbonates with an occasional, reworked eolian deposit

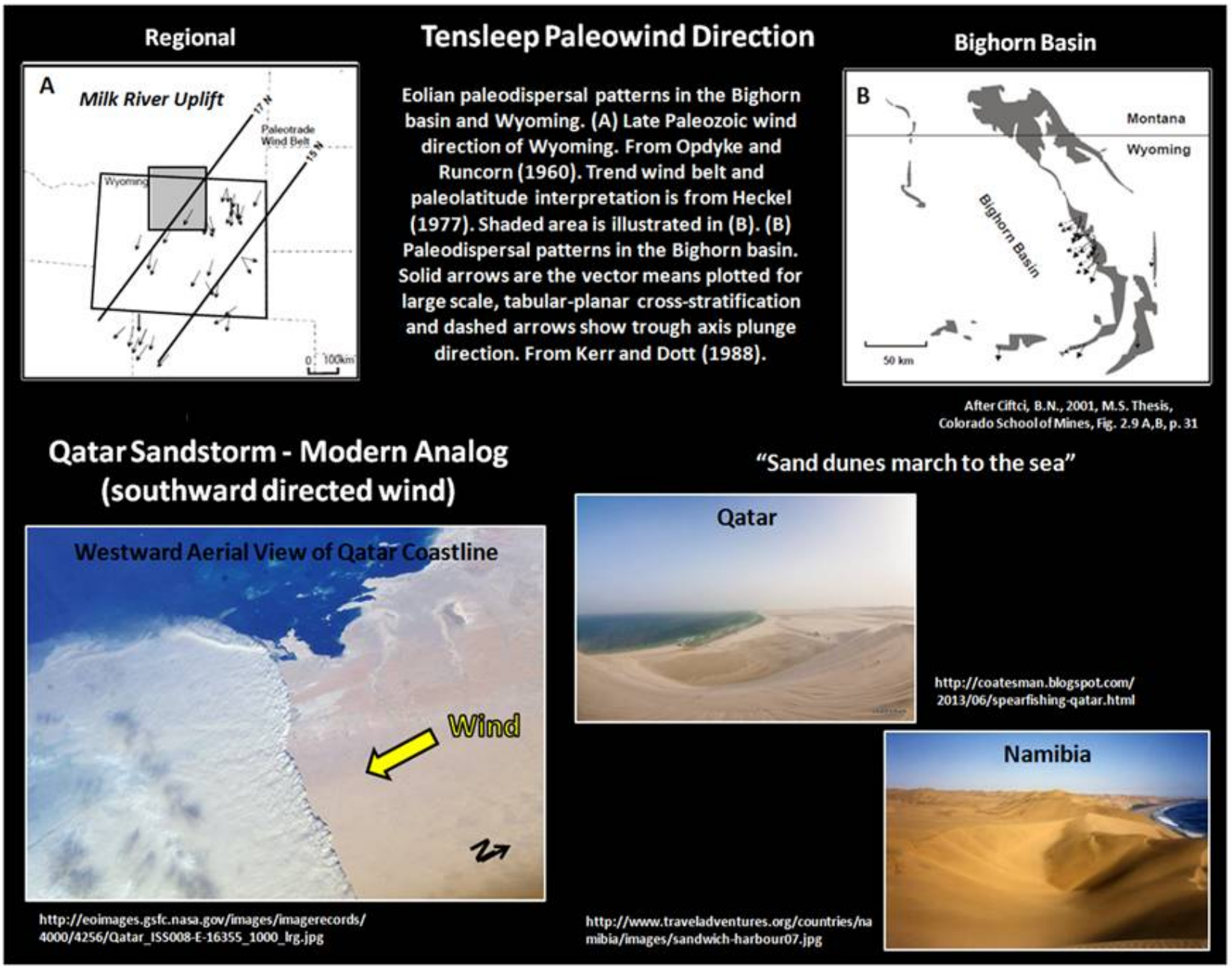


Subsurface geophysical log correlation to Wind River Canyon Tensleep outcrop section.
Image: After Inden et al., 1996, WGA Field Trip, Wind River Canyon, pp. 76-77.



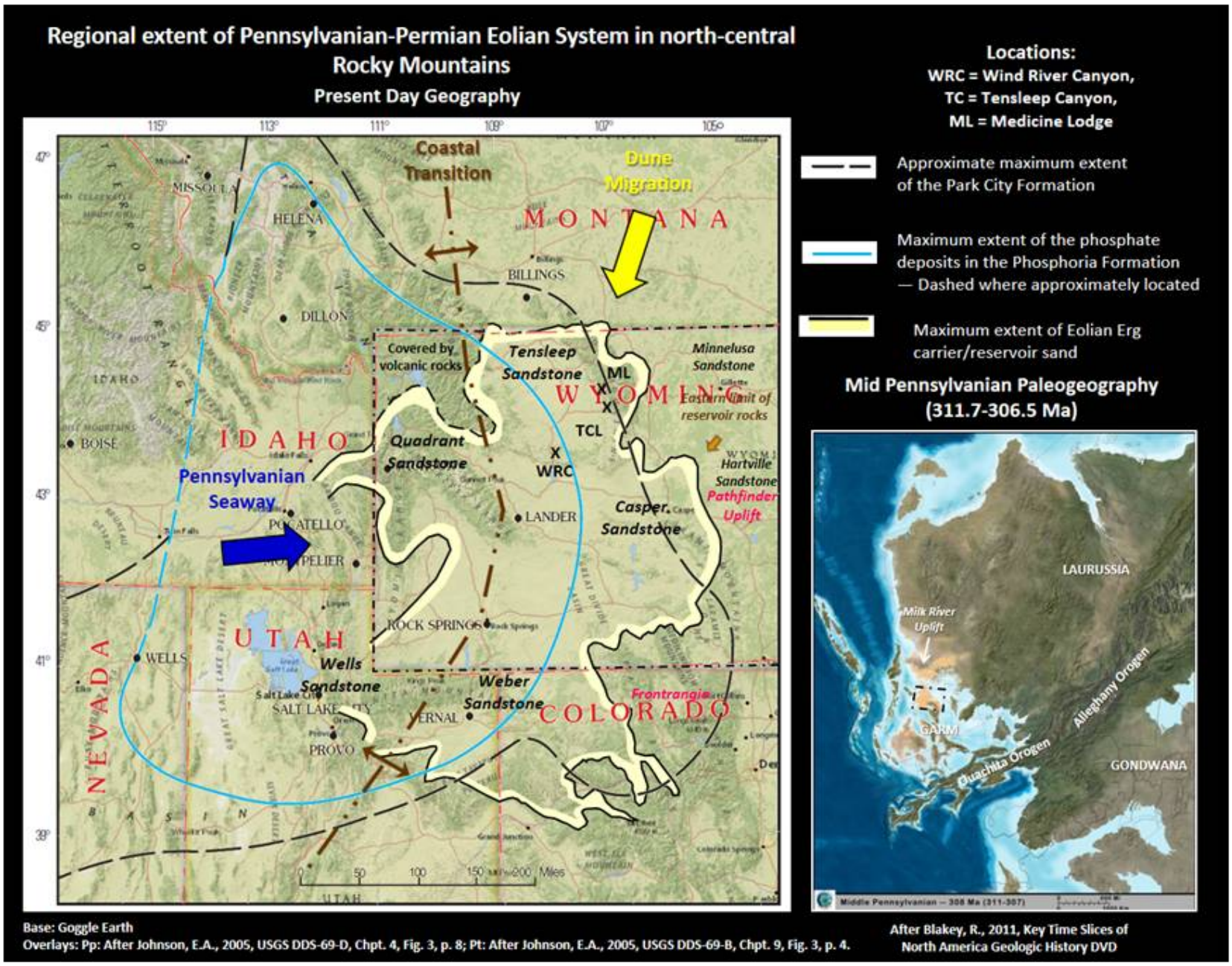
Phosphoria/Tensleep unconformity contact shown by dashed red line. Image to right shows Tensleep dunes climbing in the direction of wind transport. Here dune migration is from north to south (left to right).

Images: Left: After Wheeler, D., 1986, Stratigraphy and sedimentology of the Tensleep sandstone, southeast Bighorn Basin, Wyoming: M.S. Thesis, Colorado School of Mines, Fig. 19, p. 49, https://dspace.library.colostate.edu/handle/11124/170478 (https://dspace.library.colostate.edu/handle/11124/170478), *Right: After Wheeler, D., 1986, Ibid., Fig. 37, p. 80.*



Tensleep sand dune depositional system paleowind and modern analogs.

Images: Top: After Ciftci, B.N., 2001, Outcrop-based 3-D modeling of the Tensleep sandstone at Alkali Creek, Bighorn Basin, Wyoming: M.S. Thesis, Colorado School of Mines, Fig. 2.9A, B, p. 31, *https://dspace.library.colostate.edu/handle/11124/170531* (https://dspace.library.colostate.edu/handle/11124/170531) ,
Bottom: Left: *http://eoimages.gsfc.nasa.gov/images/imagerecords/4000/4256/Qatar* (http://eoimages.gsfc.nasa.gov/images/imagerecords/4000/4256/Qatar),
Center: *http://coatesman.blogspot.com/2013/06/spearfishing-qatar.html* (http://coatesman.blogspot.com/2013/06/spearfishing-qatar.html) ,
Right: *http://www.traveladventures.org/countries/namibia/images/sandwich-harbour07.jpg* (http://www.traveladventures.org/countries/namibia/images/sandwich-harbour07.jpg).

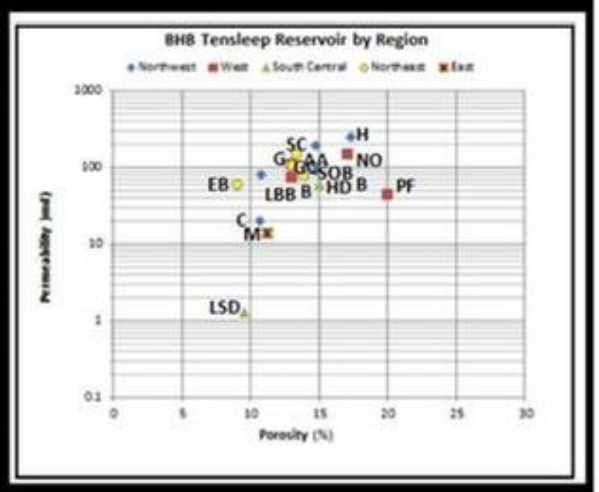


The Late Paleozoic sand dune complex on western Pangea.
Images: Left: Base: Google Earth, Data: Pp: After Johnson, E.A., 2005, USGS DDS-69-D, Chapter 4, Fig. 3, p. 8; Pt: After Johnson, E.A., 2005, USGS DDS-69-B, Chapter 9, Fig. 3, p. 4; *https://pubs.usgs.gov/dds/dds-069/dds-069-d/reports.html* (https://pubs.usgs.gov/dds/dds-069/dds-069-d/reports.html), *Right: After Blakey, R., 2011, NAM_key-308Ma_MPenn, Key Time Slices of North America Geologic History DVD*

The Tensleep is the largest oil reservoir in the state. The sandstone reservoir has excellent porosity and permeability distributed throughout the Bighorn Basin. Natural fractures present in the rock in the subsurface enhance the productivity of the reservoir. Much like the hot water system in a house, where the reservoir tank holds the water (Tensleep reservoir) and the plumbing delivers the water (Tensleep natural fracture system), fractures enhance oil movement in the subsurface.

Tensleep Reservoir by Location

Basin Location	Field	Discovery Date	Average Pay Thickness	Reservoir Continuity	Average Porosity (Range)	Average Permeability (Range)	Main Lithology	Main Depositional Facies	Oil Gravity	Stratigraphic Zone of Reservoir
NW	Cody (C)	1976	19'	Continuous	10.7% (Core: 0.7-19.8%)	20 md (Core: md)	Sandstone	Open Marine	24	Upper
	Shoshone (S)	1942	38'	Continuous, Faulted	10.8% (Core: 0.7-19.8%)	80 md (Core: .01-790 md)	Sandstone	Open Marine	17.7	Upper
	North Oregon Basin (NOB)	1927	83'	Continuous, Fractured	14.7% (Core: 5-24%)	193 md (Core: 1-1000 md)	Sandstone	Open Marine	23	Upper
	South Oregon Basin (SOB)	1928	60'	Gradational	14.7% (Core: 5-24%)	90 md (Core: 0.1-276 md)	Sandstone	Open Marine	20.8	Upper
	Halfmoon (H)	1945	120'	Continuous, Fractured	17.3% (Core: 10-23%)	251 md (Core: 19-612+ md)	Sandstone	Open Marine	15.3	Upper & Lower
W	Spring Creek (SC)	1930	125'	Continuous	17% (Core: 10-23%)	150 md (Core: 1-930 md)	Sandstone	Open Marine	15.3	Upper & Lower
	Pitchfork (PF)	1930	30'	Continuous	20% (Core: %)	45 md (Core: md)	Sandstone	Open Marine	18.2	Upper
	Little Buffalo Basin (LBB)	1944	158'	Continuous	13% (Core: %)	75 md (Core: md)	Sandstone	Open Marine	16-20	Upper & Lower
	Grass Creek (GC)	1922	124'	Heterogeneous	13% (Core: %)	112 md (Core: md)	Sandstone	Open Marine	24.5	Upper & Lower
S Cnt	Hamilton Dome (HD)	1929	184'	Continuous	15% (Core: %)	60 md (Core: md)	Sandstone	Open Marine	20.5	Upper & Lower
	Little Sand Draw (LSD)	1949	45'	Continuous	9.5% (Core: 4-20%)	1.2 md (Core: 0.84-1.72md)	Sandstone	Open Marine	35	Upper
NE	Elk Basin (EB)	1942	168'	Continuous	9%	60 md (Core: md)	Sandstone	Restricted Marine	29.5	Upper & Lower
	Alkali Anticline (AA)	1957	28'	Discontinuous, Faulting	13%	0.87-211 md	Sandstone	Restricted Marine	24	Upper
	Byron (B)	1930	97'	Continuous	0.1	78 md	Sandstone	Restricted Marine	23	Upper & Lower
	Garland (G)	1927	62'	Continuous	0.1	150 md	Sandstone	Restricted Marine	23	Upper & Lower
E	Rattlesnake (R)									
	Cottonwood Creek (CC)	1972	30	Continuous	18% (%)	NR md (md)	Sandstone	Peritidal	22	Upper
	Manderson (M)	1954	25'	Discontinuous	11.2% (0.9-18%)	13.9 md	Sandstone	Peritidal	36.1	Upper
	Marshall (Ma)									



Tensleep intergranular porosity/permeability distributed throughout Bighorn Basin

Data from Wyoming Oil and Gas Fields Symposium; Bighorn and Wind River Basins, 1989

Tensleep reservoir characteristics by location in the Bighorn Basin.

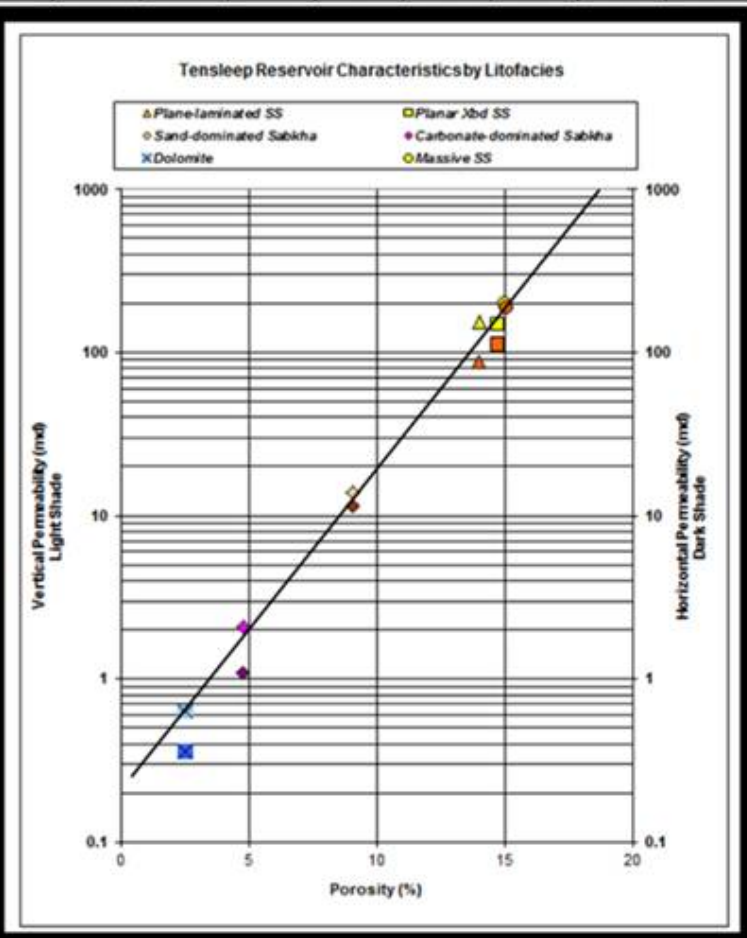
Image: Steele, K.K. (data from WGA, 1989)

Tensleep Reservoir by Lithofacies

	Massive SS (sheet or apron)			Plane-laminated SS			Planar Xbd SS			Sand-dominated Sabkha			Carbonate-dominated Sabkha			Dolomite		
	Phi (%)	k_h (md)	k_v (md)	Phi (%)	k_h (md)	k_v (md)	Phi (%)	k_h (md)	k_v (md)	Phi (%)	k_h (md)	k_v (md)	Phi (%)	k_h (md)	k_v (md)	Phi (%)	k_h (md)	k_v (md)
Maximum	25.6	1187	1196	24.5	1070	463	22.9	759	514	15.2	81	69	12.1	54	28	8.2	9.56	4.76
Minimum	3.9	4.5	4.6	6.8	3.5	0.3	4.2	5.4	7.5	1.3	0.3	0.3	1	0.01	0.01	0.4	0.01	0.01
Mean	15.04	198.63	190.1	14	155.55	87.96	14.73	149.43	112.17	9.07	13.85	11.46	4.78	2.1	1.09	2.52	0.63	0.36
Median	14.4	122	112	13.75	98	53.5	14.2	59	66	8.9	4.6	4.5	4.7	0.1	0.1	2.2	0.1	0.1
St. Dev.	4.46	246.89	228.63	3.13	173.94	106.18	4.36	170.04	120	2.77	18.42	15.6	2.2	6.86	3.57	1.78	1.91	1.05
n	96	96	96	89	89	89	50	50	50	71	71	71	80	80	80	28	28	28

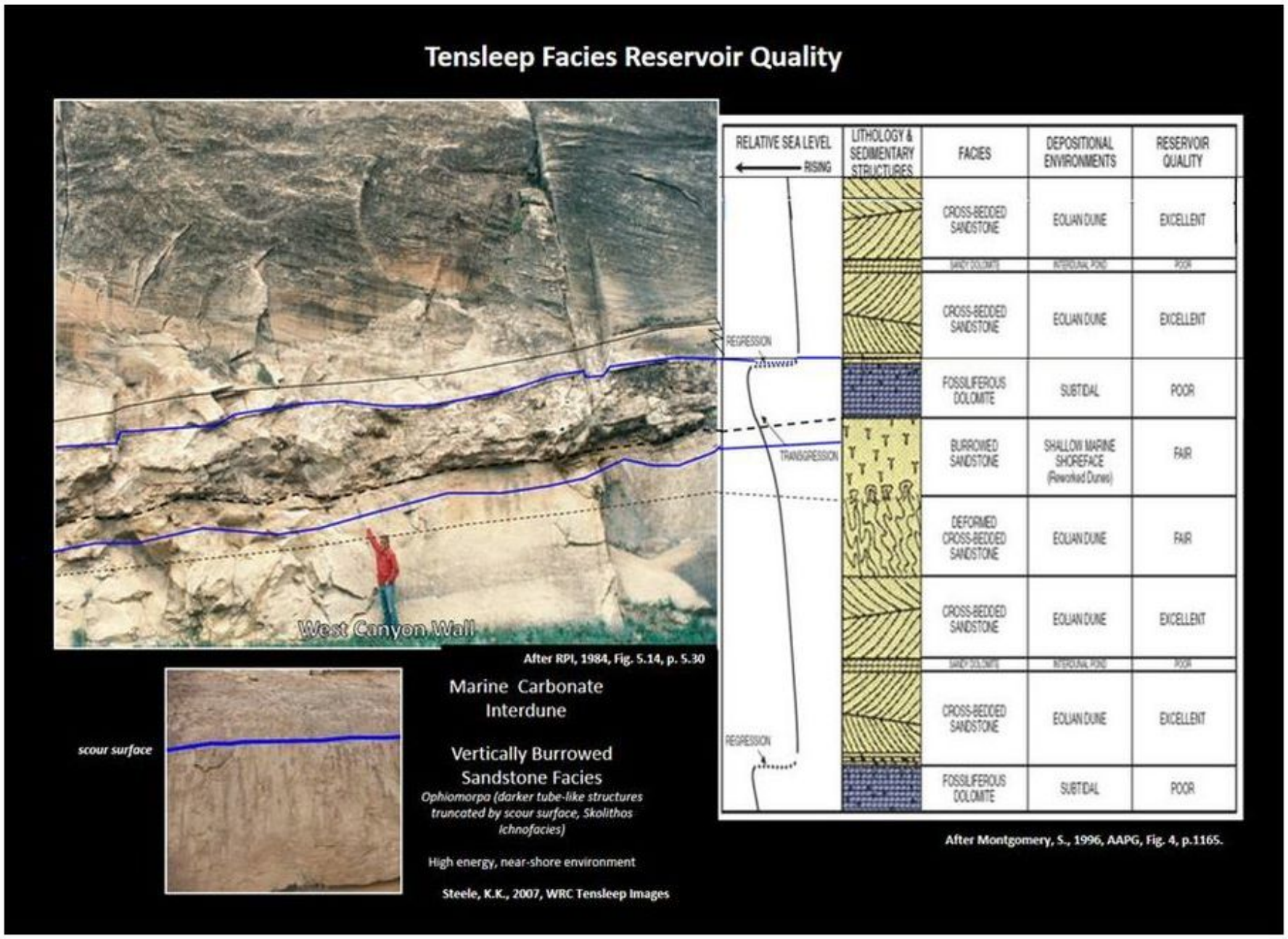
Lithofacies	Mean ϕ	Mean k	Direction	Symbol
Massive SS	15.04	198.63	V	○
Massive SS	15.04	190.1	H	●
Plane-lam SS	14	155.55	V	△
Plane-lam SS	14	87.96	H	▲
Plane-XB SS	14.73	149.43	V	□
Plane-XB SS	14.73	112.17	H	■
Sd Sabkha	9.07	13.85	V	◇
Sd Sabkha	9.07	11.46	H	◆
Carb Sabkha	4.78	2.1	V	◇
Carb Sabkha	4.78	1.09	H	◆
Dolomite	2.52	0.63	V	⊠
Dolomite	2.52	0.36	H	⊠

Data from: Shebl, R.A., 1996, PhD Dissertation, Colorado School of Mines



Porosity/Permeability distribution in Bighorn Basin reflects volume of lithofacies at location

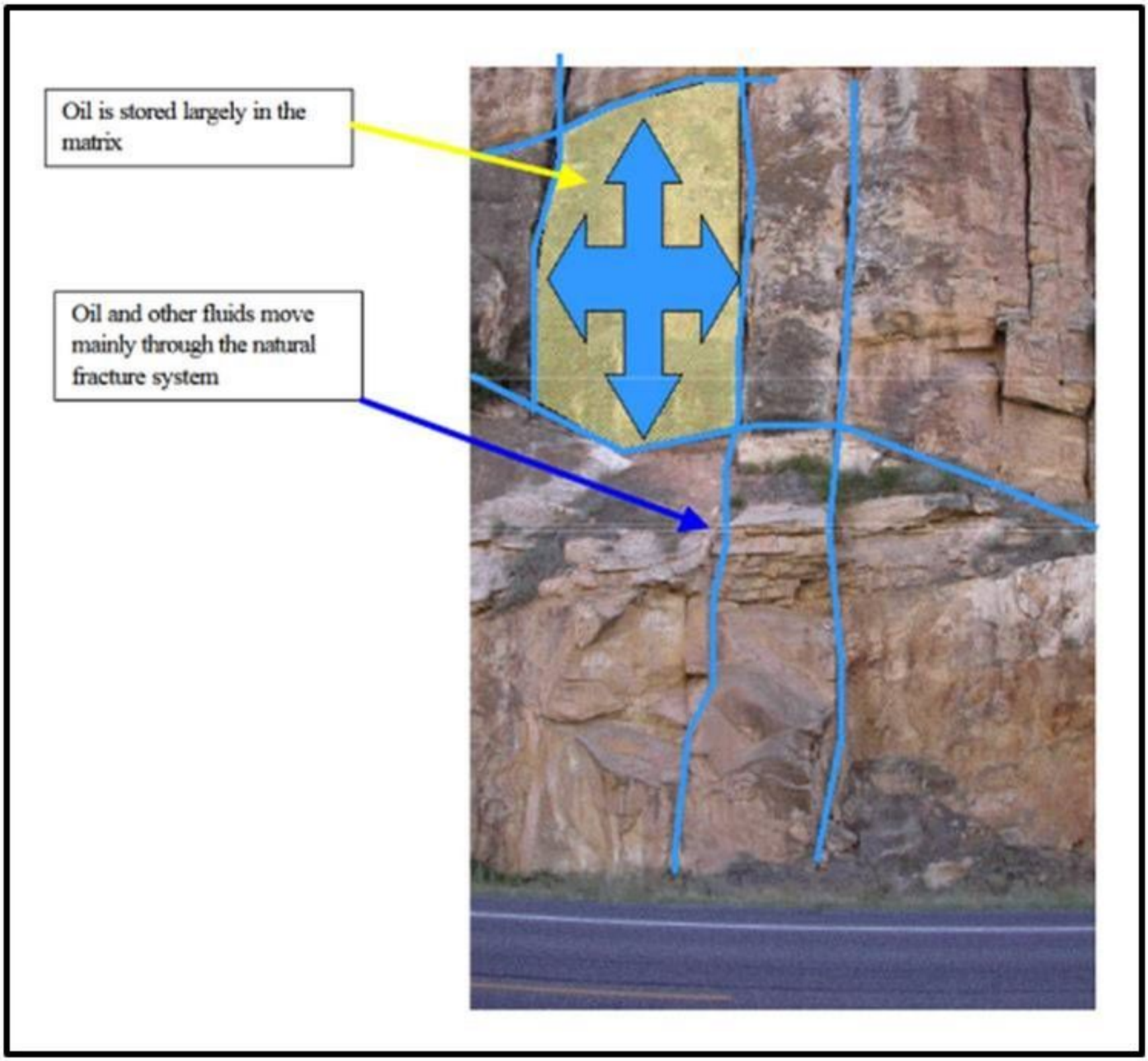
Tensleep reservoir characteristics by lithofacies development in the Bighorn Basin.
Image: Steele, K.K. (data from WGA, 1989)



Upper Tensleep hydrocarbon reservoir properties, Wind River Canyon. Photo is about 0.3 miles south of the Phosphoria/Tensleep contact.

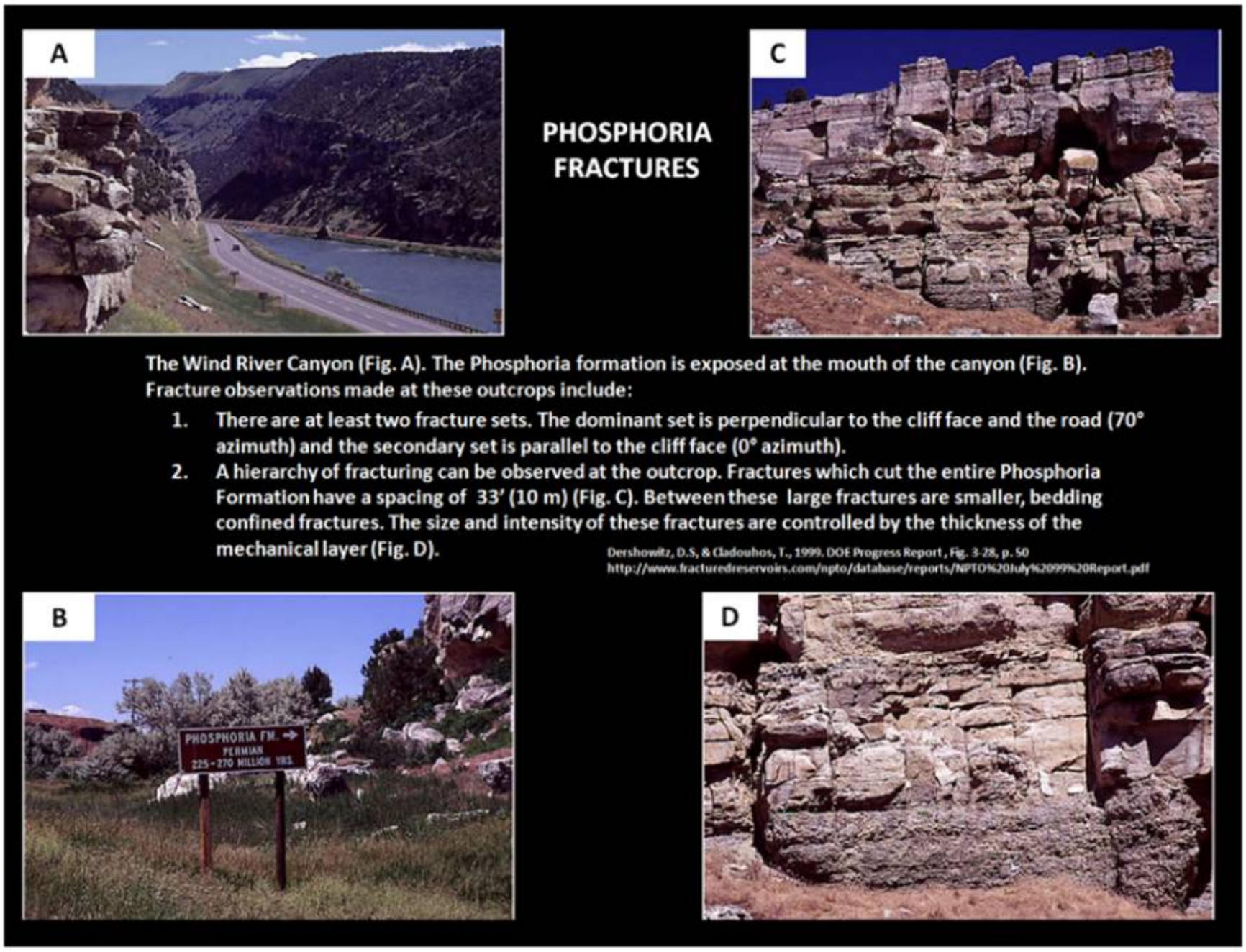
Images: Top Right: After RPI, 1984, Tensleep/Phosphoria, Bighorn Basin, Fig 5.14, p. 5.30; Right: After Montgomery, S., 1996, AAPG, Fig. 4, p.1165; Bottom Left: Steele, K.K., 2009, WRC Pt Image

Natural fractures occur from stresses applied to the rock. Fracture characteristics reflect the rock properties of the formation and the orientation to the stress field. The majority of fractures found within the Permian and Pennsylvanian units resulted from the Laramide mountain building event that reached the Bighorn Basin about 70 million years ago.



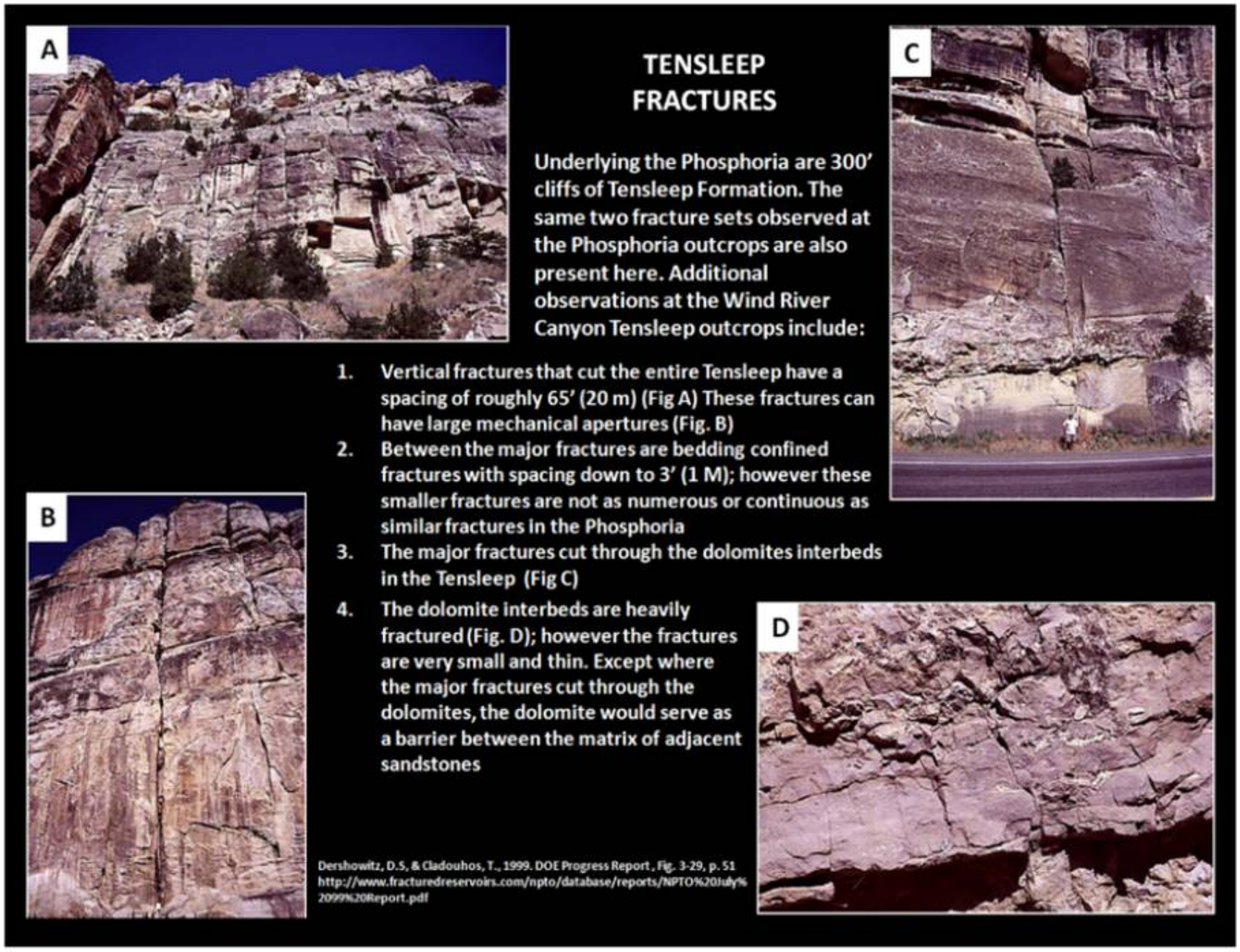
Outcrop of Tensleep Formation, Wind River Canyon, Wyoming, illustrating roles of matrix as storage and natural fractures as permeability.

Image: LaPointe et al., 2002, DOE Final Technical Report, Fig. 1.3 p.



Laramide fractures exposed in Ervay Member of Permian Phosphoria Formation, Wind River Canyon.

Images: Dershowitz, D.S, & Cladouhos, T., 1999. DOE Progress Report, Fig. 3-28, p. 50
http://www.fracturedreservoirs.com/npto/database/reports/NPTO%20July%2099%20Report.pdf
(http://www.fracturedreservoirs.com/npto/database/reports/NPTO%20July%2099%20Report.pdf)

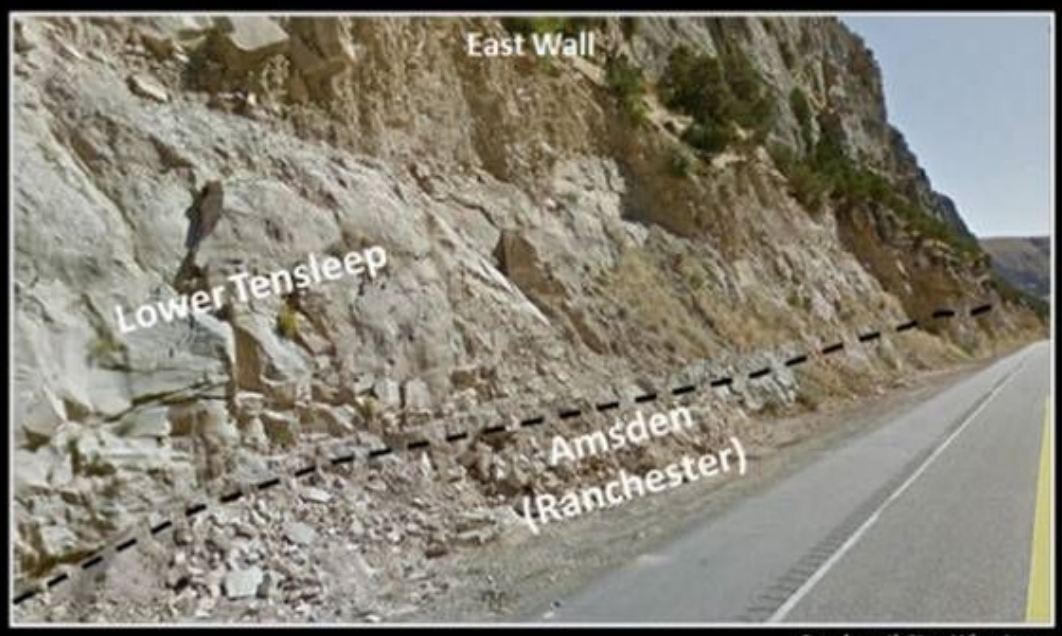


Laramide fractures exposed in the Pennsylvanian Upper Tensleep Formation, Wind River Canyon.

Images: Dershowitz, D.S, & Cladouhos, T., 1999. DOE Progress Report, Fig. 3-29, p. 51
http://www.fracturedreservoirs.com/npto/database/reports/NPTO%20July%2099%20Report.pdf
(http://www.fracturedreservoirs.com/npto/database/reports/NPTO%20July%2099%20Report.pdf)

1.0	5.6	0.2	12.2

Amsden turnout. Stop 3. Examine Tensleep/Amsden contact. The lower Tensleep consists predominately of interbedded marine sandstones and carbonates with some discontinuous, flooded and reworked eolian sandstones.



Google earth Street View Image

After RPI, 1985, Fig. 3.11, p. 3.15

View of the Amsden/Tensleep boundary at Wind River Canyon. Tensleep sand has filled solution features at the upper surface of the Ranchester Limestone Member.

Steele, K.K., 2007, WRC Amsden Images

Interbedded caliches and silty green shales in the upper part of the Ranchester Limestone Member of the Amsden Formation.

Tensleep/Amsden contact, Wind River Canyon.
Images: Top: Google Earth Street View; Bottom Left: After RPI, 1984, Tensleep/Phosphoria, Bighorn Basin, Fig. 3.11, p. 3.15; Right: Steele, K.K., 2009, WRC Pa Image.

The Amsden formation consists of three members. The uppermost Ranchester Limestone ranges from 100 to 200 feet thick and is and sequence of alternating shallow marine fossiliferous sandy dolomite with interbedded shale units and supratidal cherty dolomite. The supratidal units show signs of exposure with paleosol development. This member grades upward into the Lower Tensleep. The middle Horseshoe Shale Member is 0 to 50 feet of generally slope forming red mudstone and siltstone that is poorly exposed. The Darwin Sandstone Member is brown-grey, fine-grained, cross-bedded sandstone that ranges from 0-80 (?) feet. The Darwin is sporadically located within the canyon on the Madison erosion surface. Where Darwin is absent the middle Horseshoe Shale Member overlies the Madison unconformity.

0.2	5.8	0.2	12.0	Approximate top of Pennsylvanian Darwin Sandstone. This buff and rusty weathering sandstone outcrops on the west (R/L) side of the canyon. The thickness of this unit varies up to 80 feet depending on the amount of relief on the solution topography of the Madison Limestone on which it was deposited. The Darwin has produced oil in a number of fields in the Bighorn Basin.

Left: Darwin Sandstone Member of Amsden Formation and Madison Limestone contact shown by white rectangle. Unconformity contact shown by red dashed line. Right: Close-up of Darwin Sandstone at US 20 mile post 125.9. Geologic notation: Pp: Permian Phosphoria Formation, Pt: Pennsylvanian Tensleep Formation, Par: Ranchester Member of Pennsylvanian Amsden Formation, Pah: Horseshoe Shale Member of Pennsylvanian Amsden Formation, Pad (?): possible Darwin Sandstone Member of Pennsylvanian Amsden Formation, Mm: Mississippian Madison Formation.

Images: Annotated Google Earth Street View

Continue Wind River Canyon Road Log at Wind River Canyon Part Two (http://www.geowyo.com/wind-river-canyon-part-2.html)