WIND RIVER RESERVATION

List of Topics

OVERVIEW

WIND RIVER RESERVATION

The Shoshone and Arapahoe Tribes

TRIBAL HEADQUARTERS: Fort Washakie, Wyoming
GEOLOGIC SETTING: Wind River Basin

General Setting

Currently, the Wind River Indian Reservation contains about 3500 square miles of land. The reservation stretches from the northern part of the Owl Creek mountains to Sand Draw in the South. To the east it begins just west of Shoshone and extends westward to the town of Dubois. There are approximately 2,500 Shoshone and approximately 5,000 Arapaho on the reservation.

Government

The Wind River Reservation is governed as follows: Each tribe has its own General Council that meets about three times a year. A General Council is composed of each member of the tribe 18 years and older and is similar to a town meeting. The General Council of each tribe has delegated certain powers to the Business Council, but retains most major decision making authority.

The Arapaho Business Council and the Shoshone Business Council each have six members. Each tribe elects six members for a two year term. Each Business Council elects a chairman. Together, these twelve members comprise the Joint Business Council (JBC) of the Shoshone and Arapaho Tribes. The Joint Business Council is directly responsible for the day to day activities on jointly owned resources and joint programs of the tribes.

Wind River Indian Reservation Tax Structure

On December 12, 1978, the Joint Business Council (JBC) of the Shoshone and Arapaho Tribes enacted Ordinance Number 39, effective April 2, 1979. The Ordinance imposed a one-half of one percent (0.5%) Privilege of Doing Business Tax on the market value of gas produced, saved and/or sold or transported from the field where produced within the exterior boundaries of the reservation. Subsequently, the JBC amended Ordinance Number 39 on March 10,1982 and increased the tax rate from one-half of one percent (0.5%) to four percent (4.0%).

None of the oil and gas companies operating on the reservation at that time paid the tax. Several of the major oil and gas producers filed suit against the Tribes challenging their authority to impose taxes on their production. On May 7, 1982 the Federal District Court in Cheyenne ordered the companies to start paying the tax into an escrow account under its control. Although, the JBC enacted the Ordinance back in 1978, no revenues flowed to the Tribes until June of 1986.

On May 6, 1986, the United States District Court dismissed the suit against the Tribes, due to a previous United States Supreme Court decision which allowed Indian Tribal Governments the authority to tax within their boundaries. Since, that time the JBC and the Wind River Tax Commission have collected millions of dollars to support and finance the services it provides to its citizens.

On June 19, 1987, the JBC, again amended Ordinance Number 39. The amended Ordinance created the Wind River Tax Commission. In addition, the JBC increased the tax rate from four percent to four percent plus amounts paid to Wyoming and its subdivisions. The state of Wyoming imposes a six percent (6.0%) severance, a one-half of one percent conservation and approximately seven percent in ad valorem taxes. Thus, the total tribal tax would be closer to seventeen percent (17.0%). However, the JBC realized by increasing the tax rate, it would drive the operators off the reservation. Therefore, the JBC decided to allow a credit to the operator/producer for amounts paid to Wyoming and has issued credits of over $12,000.000

Due to the declining economy and declining production of the aging fields, revenues to the JBC from taxation has been on a dramatic decline. In addition, due to the increased population of its non-Indian and corporate citizens, the JBC was and is in dire need of increased revenues in order to provide essential government services, medical services, basic transportation, housing, police protection, fire protection, and solid waste disposal. The demand for these basic infrastructure services far exceeds the severance tax revenues.

However, the JBC realizes that it cannot continue to raise its tax rates in order to meet this demand. Therefore, it has been lobbying the Congress to effect some type of change in federal law that will aid Indian Tribes in their efforts to induce economic activity on Indian Reservations.

The JBC has been lobbying for investment tax credits, employment tax credits and have even lobbied for apportionment of state and tribal taxes. However, in the last three years, the JBC has had no success with this campaign. Other energy producing tribes and industry have also lobbied for these incentives, but with no success.

In addition, the Tribes have joined one taxpayer on the Reservation in a lawsuit against the state of Wyoming. The agreement between the Tribes and this taxpayer comes under the 1982 Indian Mineral Development Act. Other companies that would like to do oil and gas business with the Tribes should seriously consider entering into these type of agreements, if they want to avoid dual taxation.

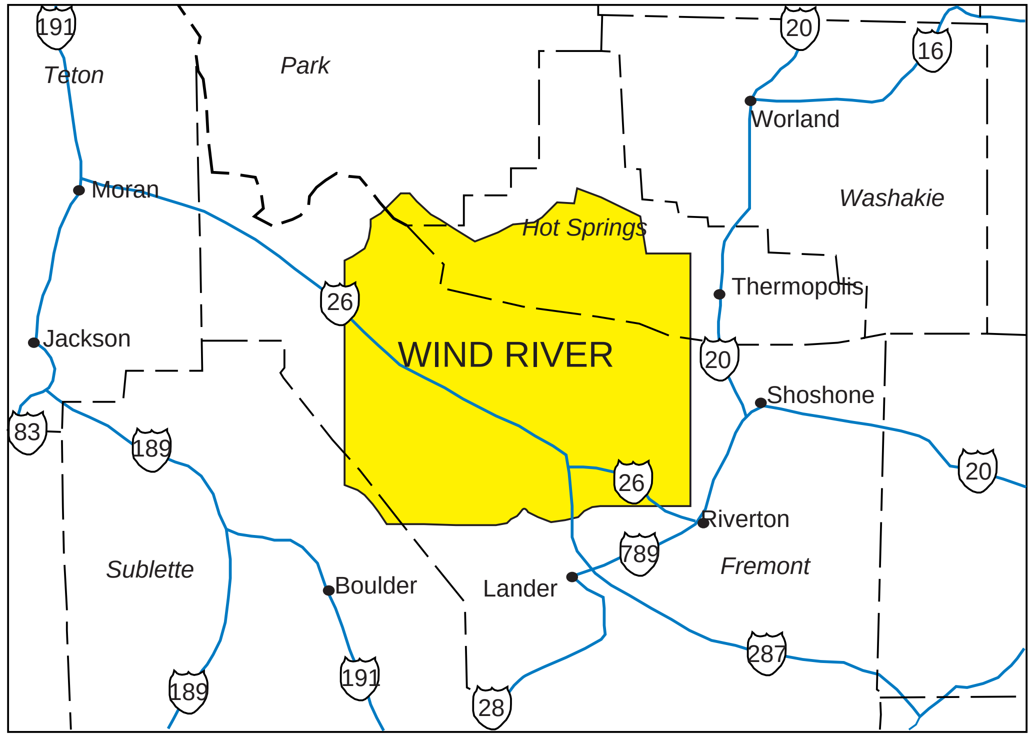
Finally, the Tribes have been negotiating with Wyoming for several years concerning the dual taxation problem. However, after the Cotton Petroleum decision, Wyoming's position on this problem appears to be stronger. But it is important to differentiate the facts of that case with the facts of the case mentioned above. The most important difference being the type of agreement entered into between the tribes and the company. The Tribes are pushing for a solution of the dual taxation problem on the Wind River Indian Reservation, which would serve as a model for all of Indian country.

Contacts

The Joint Business Council feels it is in the best interest of their people to fully develop their oil and gas resources in an efficient, economic, and environmentally sound method. The Joint Business Council will accept proposals at your earliest convenience. The Joint Business Council along with staff of the Wind River Tax Commission, the Shoshone Oil and Gas Commission and the attorneys will evaluate all proposals within thirty days of submittal. The Joint Business Council will then act on the recommendation of the staff and attorneys within thirty days of the committee's action.

For additional information, please mail your request and/or proposal to the following:

Joint Business Council
Shoshone and Arapaho Tribes
c/o Wind River Tax Commission
P.O. Box 830
Fort Washakie, Wyoming 82514



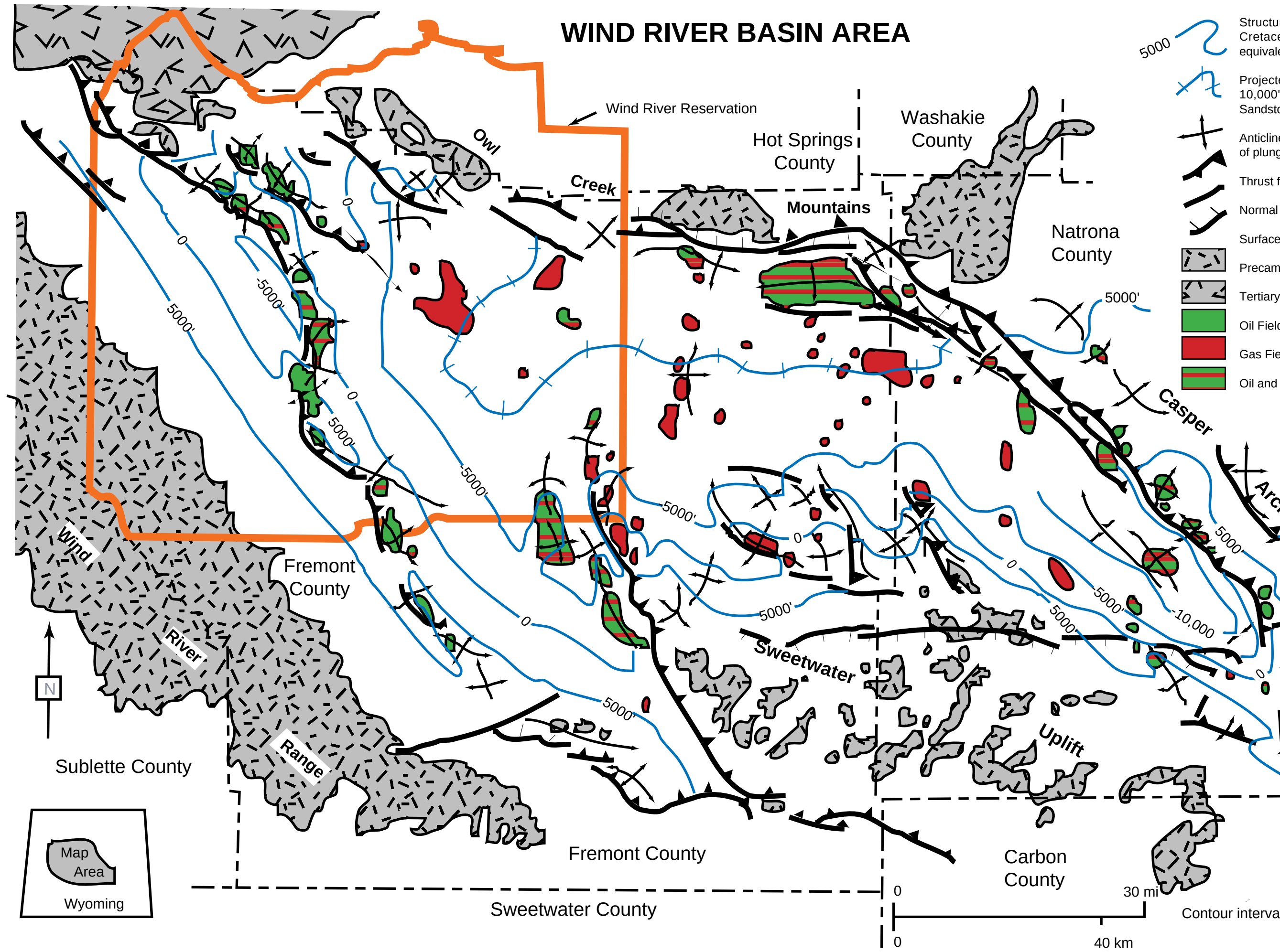


Figure WR 2.1 - Tectonic features, structure and field distribution map (after Johnson & Rice, 1993.)

Wind River Basin - Petroleum System Overview

The Wind River Basin is a northwest-southeast trending asymmetrical intermontane basin of the Rocky Mountain Foreland, located in central Wyoming. Province boundaries are defined by fault-bounded Laramide uplifts that surround it. These include the Owl Creek Mountains to the north, Wind River Mountains to the west, Casper arch to the east, and the Sweetwater Uplift to the south. The Wind River Basin Province is about 200 mi. long and 100 mi. wide, encompassing an area of about 11,700 sq. mi. Actual basinal area not capped by eroded Precambrian and/or Paleozoic rock is approximately 7,500 sq. mi. The Wind River Reservation comprises almost half of this basinal area, 3,500 sq. mi. All of the major petroleum systems and play types have been encountered in the reservation area. Approximately 0.55 BBO , 35 MMBNGL, and 2.9 TCFG are known to have been produced from the entire basin since 1884.

A nearly complete stratigraphic section, Cambrian through Tertiary in age fill the sub-basins located within the reservation area of the Wind River Basin. Sevier-aged and Cretaceous epicontinental seaway basins have been complexly folded, thrusted, and faulted during the Laramide orogenic event (initiated latest Cret.-earliest Paleocene). Basement involved and detached structural features create intricate and complicated stratigraphic correlations throughout the Wind River Basin. Early paleozoic platform carbonates and fringing patch reefs of a mainly carbonate province become siliciclastic-dominated by latest Paleozoic time. Sandstone reservoirs of the Permian Phosphoria Formation and Pennsylvanian Tensleep produce the bulk of the petroleum within the reservation area. Locally, many of the other Cretaceous sandstone reservoirs produce significant quantities of oil and gas. Black shales of the Phosphoria and Mowry formations are considered the source of the petroleum for much of the Wind River basin reservoirs. Deeply buried Cretaceous and Tertiary coals are probably the source of significant amounts of thermogenic methane (gas) found in Cretaceous/Tertiary reservoirs.

Stratigraphic Column
Wind River Reservation Area

				Source horizon
Cenozoic	Paleogene & Neogene		Undifferentiated	
	TERTIARY	Eocene	Wind River Fm	
			Indian Meadows Fm	
		Paleocene	Fort Union Fm	S
Mesozoic	CRETACEOUS	Upper	Lance Fm	
			Meeteese Fm	
			Mesaverde Ss	
			Cody Sh	
			Frontier Fm	
		Lower	Mowry Sh	S
			Muddy Ss	
			Thermopolis Sh	S
			Cloverly Fm	
	JURASSIC		Morrison Fm	
			Sundance Fm	
			Gypsum Springs Fm	
			Nugget Ss	
	TRIASSIC		Chugwater Gp	
			Dinwoody Fm	
Paleozoic	PERMIAN		Phosphoria Fm	S
	PENNSYLVANIAN		Tensleep Ss	
			Amsden Fm	
	MISSISSIPPIAN		Madison Ls	
	ORDOVICIAN		Bighorn Dol	
	CAMBRIAN		Gallatin Ls	
			Gros Ventre Fm	
			Flathead Ss	
PRECAMBRIAN			Undifferentiated	

S Source horizon

Oil / Gas: Production from reservoirs in approx. proportions

Figure WR 2.3 - Stratigraphic column for Wind River Basin (Willette, D., 1996).

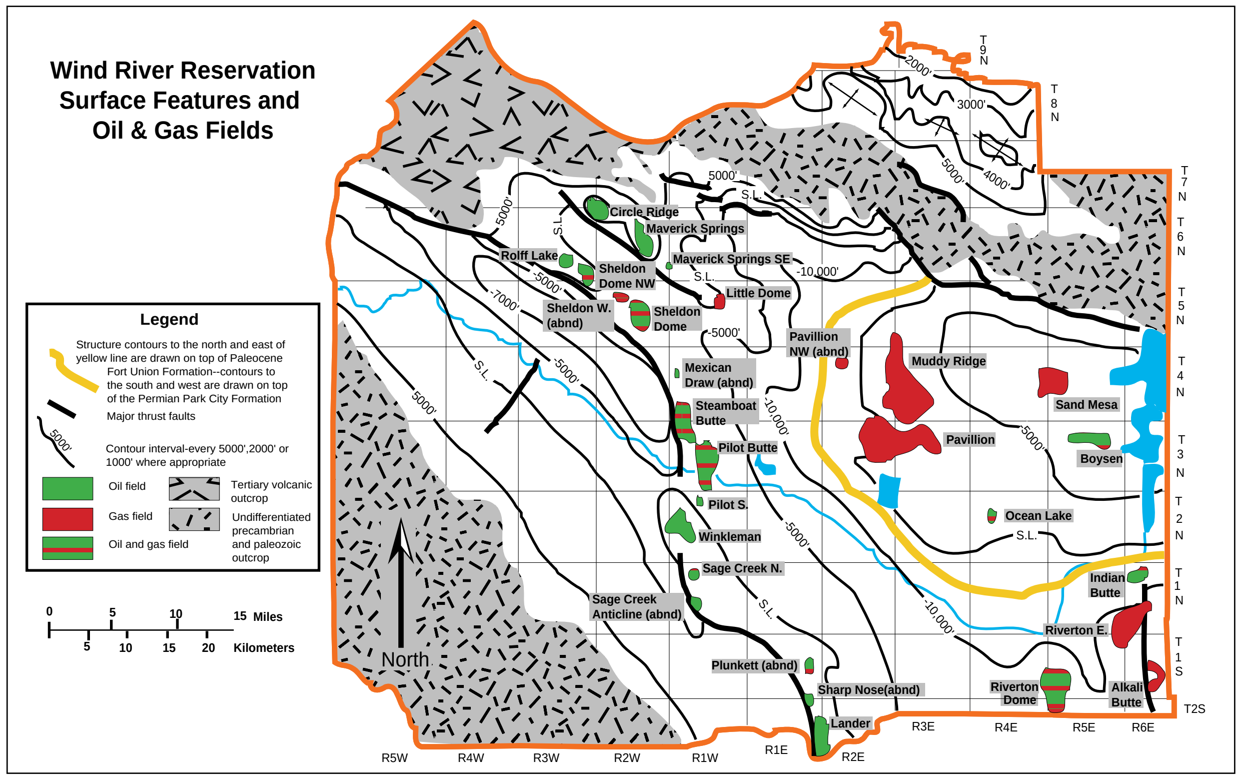


Figure WR 2.2 - Reservation area and distribution of oil and gas fields. The reservation area contains many of the large surface structural features drilled early in the exploration history of the Wind River Basin; Sage Creek Anticline (1886) and Lander fields(1912) for example. Major structural features both shallow and deep account for significant production from the reservation area. Winkleman Dome and Steamboat Butte have each produced over 90 MMBO. Circle Ridge has produced over 34MMBO. Pilot Butte, Maverick Springs, and Lander have each produced over 10 MMBO. Gas production from Riverton Dome and Pavillion fields exceed 175 BCFG per field. Deep basin gas and subthrust plays provide the bulk of the future petroleum potential. (after Johnson and Rice, 1993).

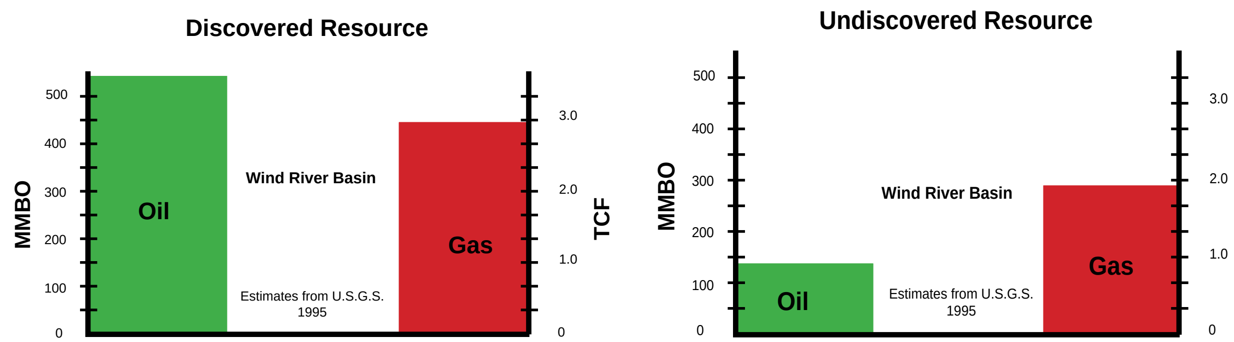


Figure WR-2.4. These graphs depict the estimates for discovered and undiscovered hydrocarbons within the Wind River Basin. The bulk of new discoveries should be gas with over 100 MMBO added to production as well. Historic ratios of oil versus gas discoveries will not apply in the future as exploration efforts will most likely target for new gas reserves (Willette & USGS, 1996).

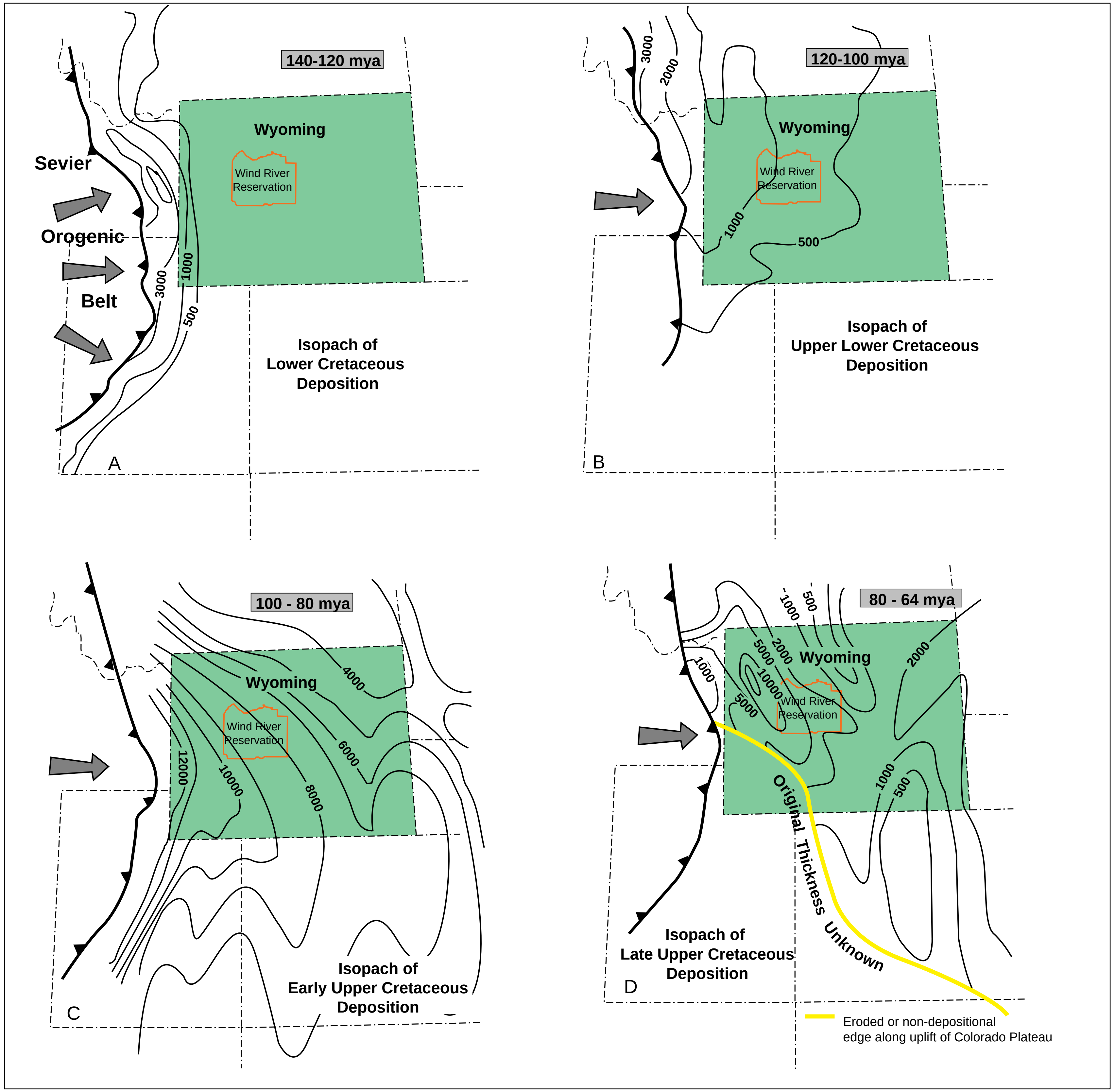


Figure WR 3.1 - Generalized patterns of deposition in the Rocky Mountain area during Cretaceous time. **A** - Mid Atlantic spreading caused uplift, thrusting, and folding in the Sevier orogenic belt, synorogenic sediments were thick adjacent to the Sevier uplift and very thin elsewhere. **B** - Continued westward plate movement is reflected in uplifts on the western plate margin, thick deposits adjacent to the overthrust belt, and thin deposits over a wide area of the foreland. **C** - Early uppermost Cretaceous deposition is thickest adjacent to the overthrust belt; a thicker section of marine sediments may reflect a general downwarping of the foreland area. **D** - During latest Cretaceous and early Paleocene, the spreading rate between North America and Eurasia was greatly increased. Early Laramide buckling of the basement in the foreland began to occur, and foreland uplifts formed north-south parallel to the overthrust belt (after Gries, R. 1983).

Regional Geology

The Wind River Basin occupies the geographic center of Wyoming and is surrounded by some of Wyoming's highest mountains. The Wind River Mountains (13,500+ feet in elevation) form the western boundary of the basin against which several major southwest verging thrust systems abut. The northern margin of the basin is constrained by the Owl Creek and southern Big Horn Mountains, while the southern basin margin is marked by the Granite Mountains. The eastern edge of the basin is delineated by the more subtle topography of the Casper arch which separates the Wind River basin from the Powder River basin. The basin is 180 miles long, northwest to southeast and is 75 miles wide north to south. The reservation area comprises most of the northwestern and central portions of the basin. The predominant pattern of deposition for both the Paleozoic and Mesozoic intervals consist of complexly interbedded sandstone and shales. Only the lower Paleozoic section contains carbonate and evaporite deposits.

Paleozoic and early Mesozoic Geologic History

During Paleozoic and early Mesozoic time all of central Wyoming was part of the stable shelf lying east of the Cordilleran orogenic belt. Deposition upon the shelf occurred primarily in shallow seas. Because of the broad shelfal, area widespread facies changes and unconformities resulted from relatively minor sea level fluctuations.

Combined thickness of Cambrian-aged deposits range from 1025' in the western edge of the basin to approximately 775' in the east. The Flathead Sandstone and the Gros Ventre Formations consist of predominantly clastic deposits while the Upper Cambrian Gallatin Limestone provides the first evidence of carbonate depositional conditions within the shallow, shelfal environment.

Ordovician-aged sediments of the Wind River Reservation are represented only by the Bighorn Dolomite. Estimates in thickness range from 125-300 feet and the dolomite thins to the east and southeast and is absent in the southeast corner of the reservation due to an erosional unconformity. Devonian rocks are thin to absent across the reservation area. The Madison Limestone comprises most of the Mississippian-aged sediments within the reservation. It ranges between 500-700 feet in thickness with the upper portion containing karst features.

During Pennsylvanian and Permian time, marine deposition became progressively more terrestrially influenced. The Amsden Formation consists of dolomite, shale, sandstone, and limestone ranging between 250-350 feet thick. The Tensleep Sandstone is a known reservoir interval containing massive to cross-bedded shelf and eolian sandstone deposits between 200-400 feet thick. By Permian time, the reservation area alternated between terrestrial shoreline and restricted carbonate depositional environments. The Phosphoria Formation contains an organic-rich source interval, dolomite, shale, and limestone deposits between 200-300 feet thick.

Lower Triassic deposits contain the Dinwoody Formation (50-150 feet thick), dominantly terrestrial Chugwater Group deposits (800-1000') containing typical 'red bed' continental sediments, and the Nugget Sandstone. The upper Triassic/lower Jurassic Nugget Formation is a known reservoir interval consisting of large-scale, cross-bedded eolian deposits. The formation is as thick as 300 feet, thins to the northeast, and is absent in the northern part of the reservation area. Jurassic deposition reflects both nearshore marine and fluvial conditions in the area. The Gypsum Spring and Sundance Formations contain oolitic limestone, glauconitic sandstone, gypsum and anhydrite ranging between 250-350 feet thick. The Morrison Formation consists of fluvial sandstone, siltstones, and shales and contains well known dinosaur bone-beds.

Cretaceous Geologic History

Lower Cretaceous sediments reflect the first pulse of foreland basin development in the reservation area. Effects from the Sevier orogenic event located to the west are mainly restricted to relatively thin, fine-grained shale deposition in this area (Figure 3.1). The Cloverly Formation ranges between 250-450 feet thick and consists of 'weathered' thin sandstone deposits and paleosols representing coastal plain deposition. The Thermopolis and Mowry Shale Formations represent the initiation of clastic, marine epeiric sea conditions.

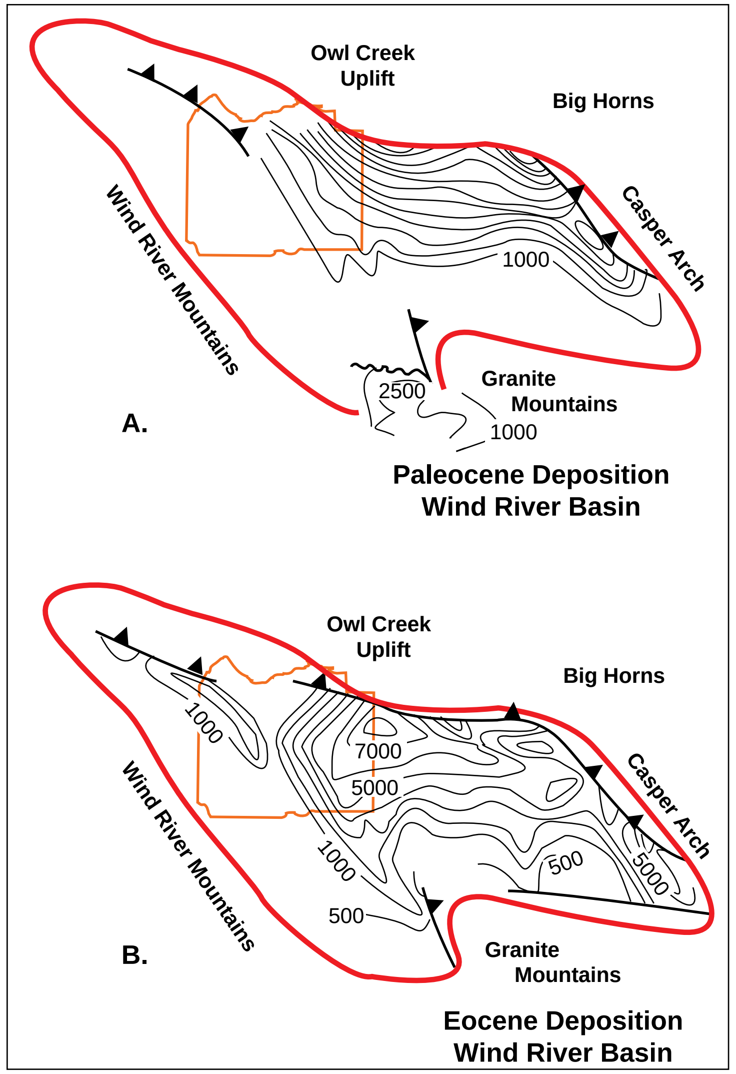


Figure WR-4.1 - Depositional patterns of Eocene and Paleocene time slices in the Wind River Basin. **A.** - Fine grained (non-synorogenic) Paleocene sediments were thickest at the south end of the Big Horn Mountains and in a deep trough on the north side of the Wind River Basin. **B.** - Eocene deposition reflected the denudation of the Owl Creek and other surrounding uplifts with coarse-grained conglomerate and clasts of Paleozoic and Precambrian rocks (after Gries, R., 1983).

Cretaceous Geologic History *(Continued)*

As the foreland area developed and the basin began to downwarp due to crustal loading, thick piles of sediment began to accumulate in front of the thrust sheets (Figure WR-3.1). The early Late Cretaceous Frontier Formation, an important oil/gas producing formation, ranges in thickness between 600-1000 feet. As downwarping continued, the clastic- marine Cody Shale was deposited. Accumulation ranges between 2500-5000 feet in thickness.

Terrestrial conditions were re-established in the reservation area by the time the Mesaverde Formation was deposited. Containing fluvial and shoreline sandstones, coal, and carbonaceous shale, the formation ranges between 1000-2000 feet in thickness but is absent in the southwest part of the reservation due to later uplift and erosion. The overlying Meeteetse Formation contains depositional environments similar to the Mesaverde, but the interbedded coal horizons are much thicker. Plant remains and dinosaur bones have been found in this formation and it can be up to 1400 feet in thickness.

As the basement buckled and uplifted during latest Cretaceous time, denudation of these highlands started to occur. The Lance Formation contains the first evidence of clasts from Paleozoic and Cambrian rocks deposited in lenticular conglomeratic horizons. While the thickness of the interval is highly variable, it can range up to 1200 feet in thickness.

Cenozoic Geologic History

On the margins of the Wind River Basin the Paleocene Fort Union Formation unconformably overlies the Late Cretaceous Lance Formation but in the northern and central troughs, fluvial and alluvial fan deposition continued (Figure WR 4.1). Earliest Eocene deposits of the Indian Meadows Formation contain abundant alluvial fan and channel sandstones and conglomerates. Mesozoic and Paleozoic rock clasts are common and landslide/slide block masses from these thrust sheets are present as well. By the time of the Wind River Formation deposition, Precambrian rock fragments are abundant and reflect exposure of the igneous/metamorphic cores of the uplifts (Figure WR 4.1). The thickness of the Wind River Formation ranges from a few feet at the basin margin, to over 6000 feet in the northern part of the reservation area. Oligocene and younger sediments consist of a thin veneer of volcanic tuffs, volcanic breccia and sandstone deposits. Quaternary glacial till and outwash gravel are present in the southwestern part of the reservation.

Structural Evolution of Wind River Basin

Complex Laramide orogenic events produced a structural fabric in the Wind River area that produced polyphase structural re-orientations of major elements. However, studies of all the major Laramide Rocky Mountain basins and uplifts show similar patterns of development. The Laramide orogenic event was triggered by the opening of the mid-atlantic ridge and movement of the North American craton along a westward directed line of motion during latest Cretaceous time. The ridge-opening accelerated in Paleocene/Eocene time and movement of the craton became directed southwestward.

Most structural analyses indicate that little or no vertical movement occurred on east-west trending structures in latest Cretaceous/Paleocene time. However, substantial activity on northwest-southeast trending structures is likely and produced westward verging, linear thrust sheets (Figure WR-4.2). It is possible that east-west trending strike-slip faults also developed along zones of basement weakness.

Development of east-west trending thrust sheets occurred during maximum compression (southward directed) in Eocene time. Detailed surface mapping has shown Eocene east-west trending thrusts and folds truncate or are superimposed on earlier Laramide north- and northwest-trending thrusts and folds (Figure WR-4.2).

Early Laramide (latest Cretaceous) erosion was mostly from north-south trending arches and ranges (Gries, R.,1983). Eroded material included previously deposited Mesozoic shale, limestone, dolomite, and sandstone. As uplift continued in early Paleocene, Paleozoic rock fragments became incorporated in fluvial/alluvial sedimentation. Thick sections of lower - middle Eocene coarse, boulder conglomerates adjacent to the east-west trending ranges are evidence of major uplift during the late phase of the Laramide orogeny (Fig. WR-4.1).

Most foreland basins have thicker sections of Eocene syn-orogenic sedimentary rocks than Paleocene and uppermost Cretaceous, an indication perhaps of greater tectonism at the end of the Laramide orogeny than during the earlier phases (Gries, R., 1983).

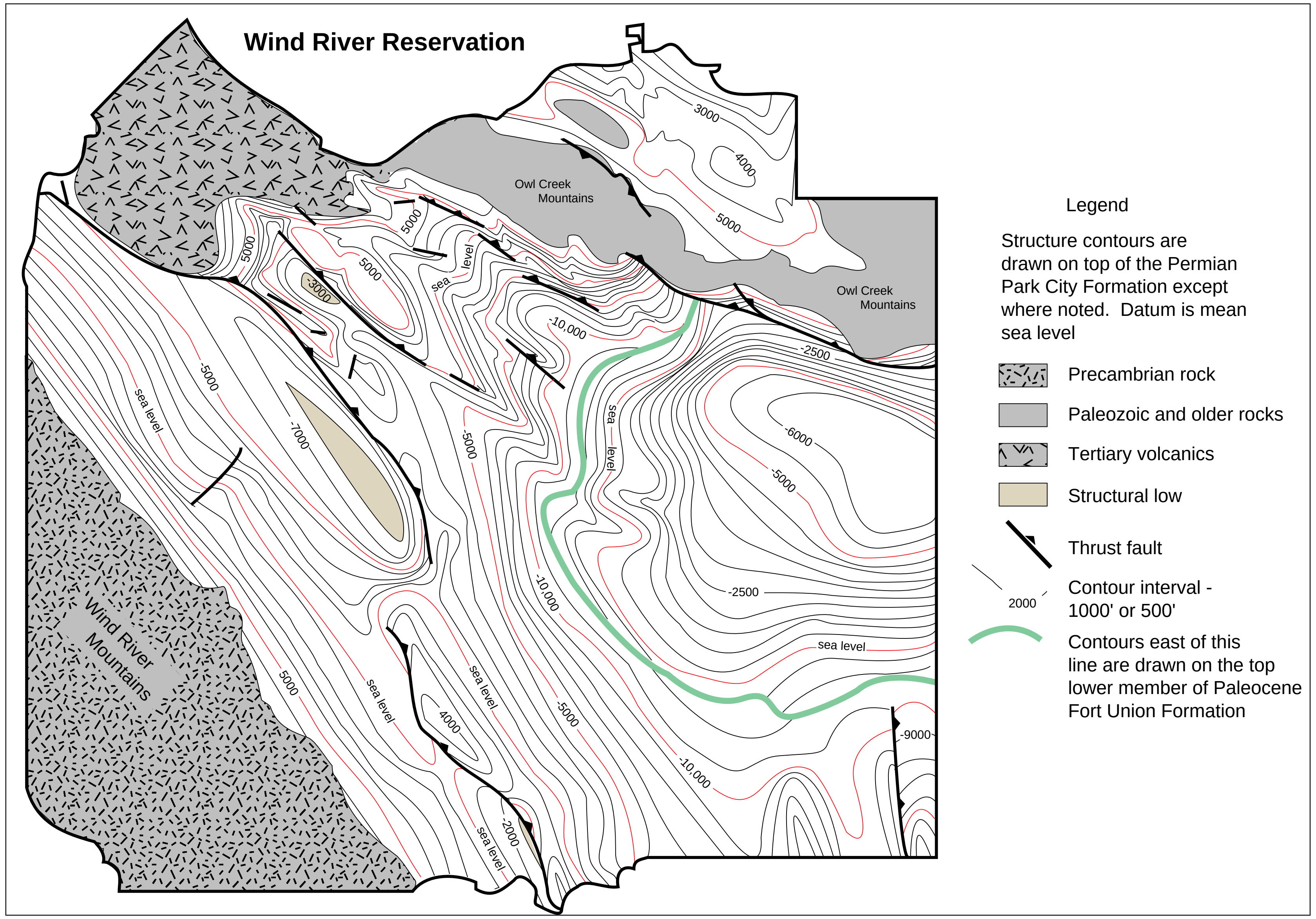


Figure WR-4.2 - Structure map of Wind River Reservation area (after Keefer, W., 1993).

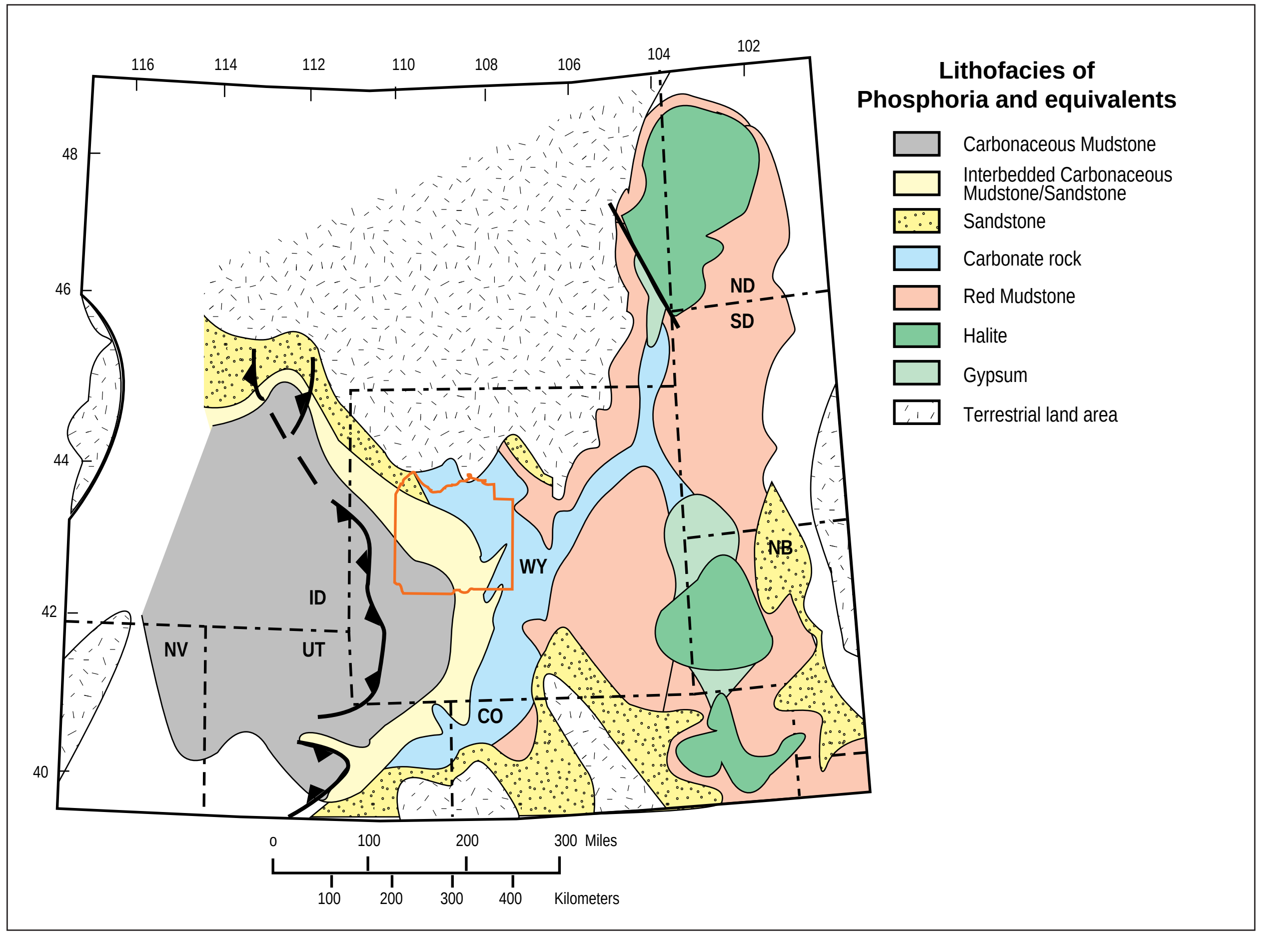


Figure WR-5.1 - Lithofacies of Phosphoria (Meade Peak Mbr) and equivalent rocks in Wyoming and adjacent areas. Note position of reservation relative to carbonaceous mudstone and organic-rich carbonate horizon (after Maughan, 1984).

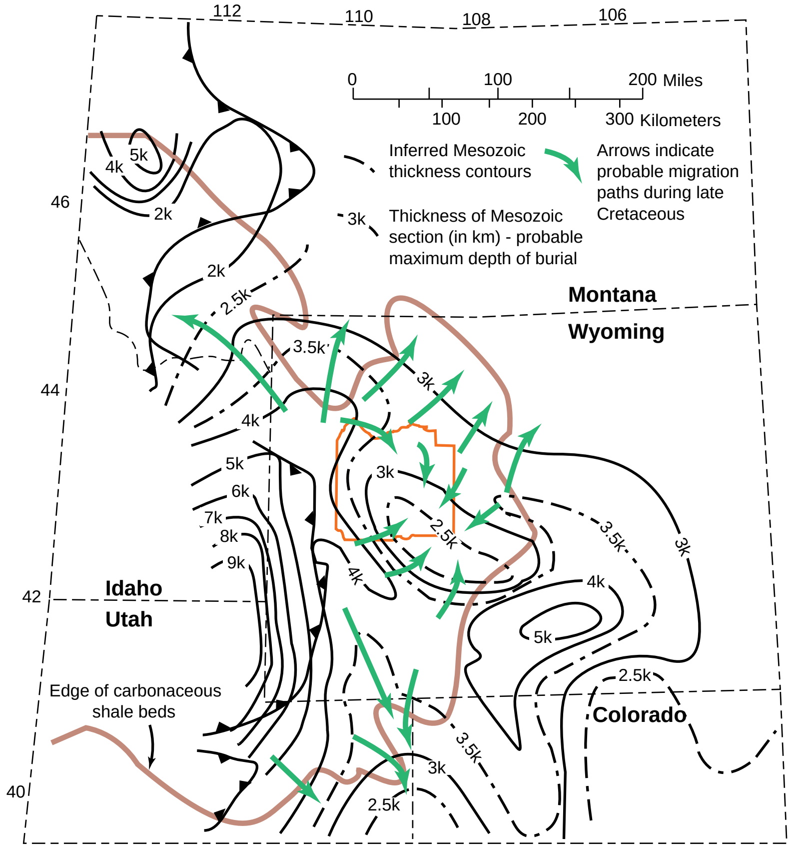


Figure WR-5.2 - Inferred maximum depth of burial of Phosphoria Formation based on thickness of Mesozoic section. Solid lines indicate thickness of Mesozoic in kilometers, dashed lines are inferred. Arrows indicate probable migration paths during late Cretaceous time. Barbed lines are leading edge of Cordilleran overthrust belt (Maughan, 1984).

Petroleum Systems Overview

In the Wind River Basin area, there are three and possibly four source rock petroleum systems that have generated or are generating hydrocarbons. The reservation area is ideally situated to explore at least three of these systems. Thrusting during the Laramide orogenic event has obscured evidence regarding migration pathways, lithofacies relationships, and even a clear determination of geothermal gradient in some areas. However, some generalizations can be made.

A major source rock interval in the Wind River Basin is the Permian Phosphoria Formation which contains two organic-rich shale members called the Meade Peak and Retort intervals. These rocks were formed at the periphery of a foreland basin between the Paleozoic continental margin and the North American cratonic shelf (see Fig. WR-5.1). Restricted circulation patterns, increased biologic activity due to zones of upwelling, and resultant anoxia contributed to the preservation of algal organic matter.

Petroleum generation from the Phosphoria Formation ranges between 24.6 - 30.7x10^6 metric tons according to various authors. Reservoirs such as the Tensleep, Chugwater Group, and Nugget Sandstone contain oils which have been typed back to the Phosphoria. The bulk of the oil seems to have been generated from the carbonaceous mudstone strata (see Fig. WR-5.1).

Both organic-rich members of the Phosphoria occur within the reservation boundaries (Retort and Meade Peak). The average TOC of the Meade Peak has been calculated to be 2.4%, with some beds containing as much as 30% organic carbon by weight. Average TOC from the Retort member ranges from 4.2-4.9%, maximum values are about 10 weight percent total organic carbon.

Hydrocarbon generation resulted from the effects of deep burial in westernmost Wyoming and adjacent areas (see Fig. WR-5.2). Fluids were generated during passage of the source rocks through the oil/condensate window corresponding to burial depths between 2.2 - 4.5 km. Relatively unimpeded migration pathways (both lateral and vertical) occurred during Late Cretaceous time just prior to the Laramide orogeny (Fig. WR-5.2).

The lower Cretaceous Mowry shales and their equivalents are major source rocks in the northern Rocky Mountain - Great Plains region. They are one of the major sources of hydrocarbon in the Jurassic Nugget Sandstone of southwestern Wyoming, lower Cretaceous Muddy Sandstone, and other Cretaceous sandstone reservoirs.

In the reservation area, the Mowry shale may range between 500 - 600 feet in thickness. A significant percentage of the interval includes non-source lithofacies such as oxic, bioturbated mudstone, sandstone and siltstone. Typically, only the basal Mowry can be considered a source facies due to the presence of anoxic, laminated mudstone.

The Mowry shales contain a mixture of predominantly type II and type III organic matter (see Fig. WR-5.4). These organic matter types represent a mixing of terrestrial and marine organic matter. Organic matter suites with this composition are typical of shallow, epicontinental seas. In general, the Mowry section within the reservation area contains a higher percentage of terrestrially derived organic matter (more gas prone) than the shales deposited within the axial portion of the Mowry seaway.

Areas of anomalously low TOC values in the Mowry coincide with the deeper parts of Laramide structural basins which developed after the deposition of these shales. Regional variations in the TOC content may reflect in part a reduction of the TOC by thermal maturation or abrupt variations in the precursor organic facies (see Fig. WR-5.3).

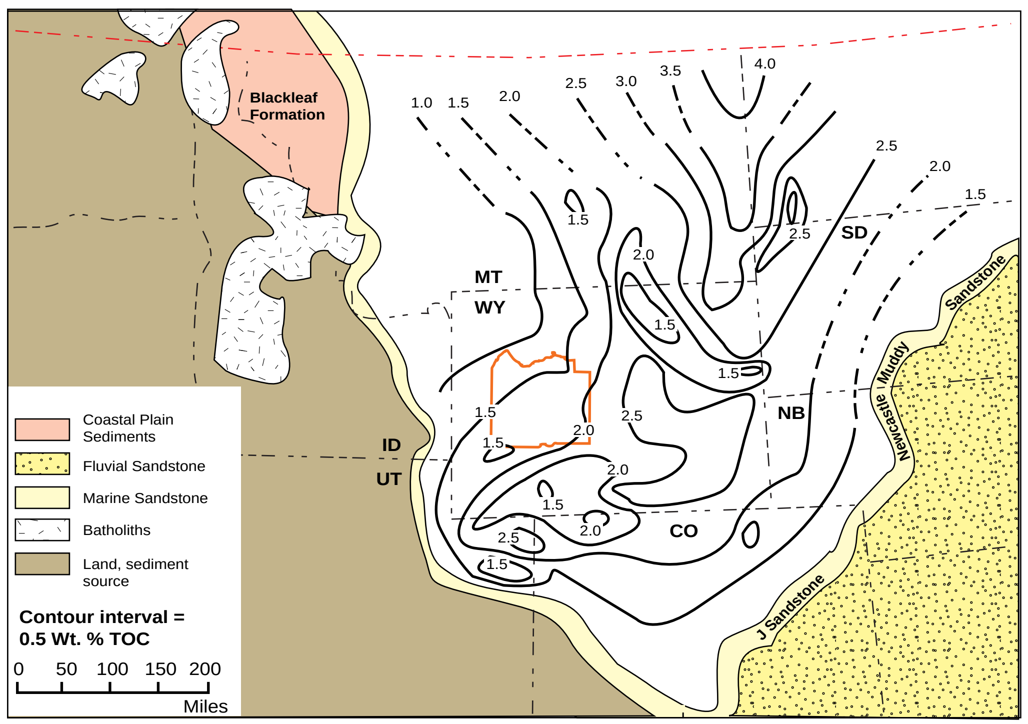


Figure WR-5.3 - Regional distribution of total organic carbon (TOC) in the Mowry Shale. Anomalously low TOC values may coincide with lithofacies variation or position with the deeper portions of Laramide structural basins where significant generation/expulsion has occurred (from Burtner & Warner, 1984).

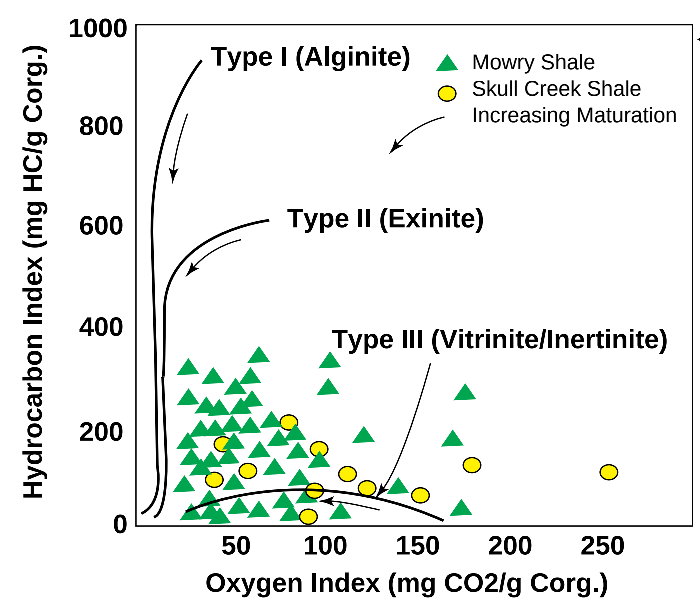


Figure WR-5.4 - Plot of whole rock HI vs. OI for Mowry and Skull Creek Shale samples. Samples contain a mixture of dominantly type II and type III kerogen. Oil and a strongly gas prone source rock would be the result (after Burtner & Warner, 1984).

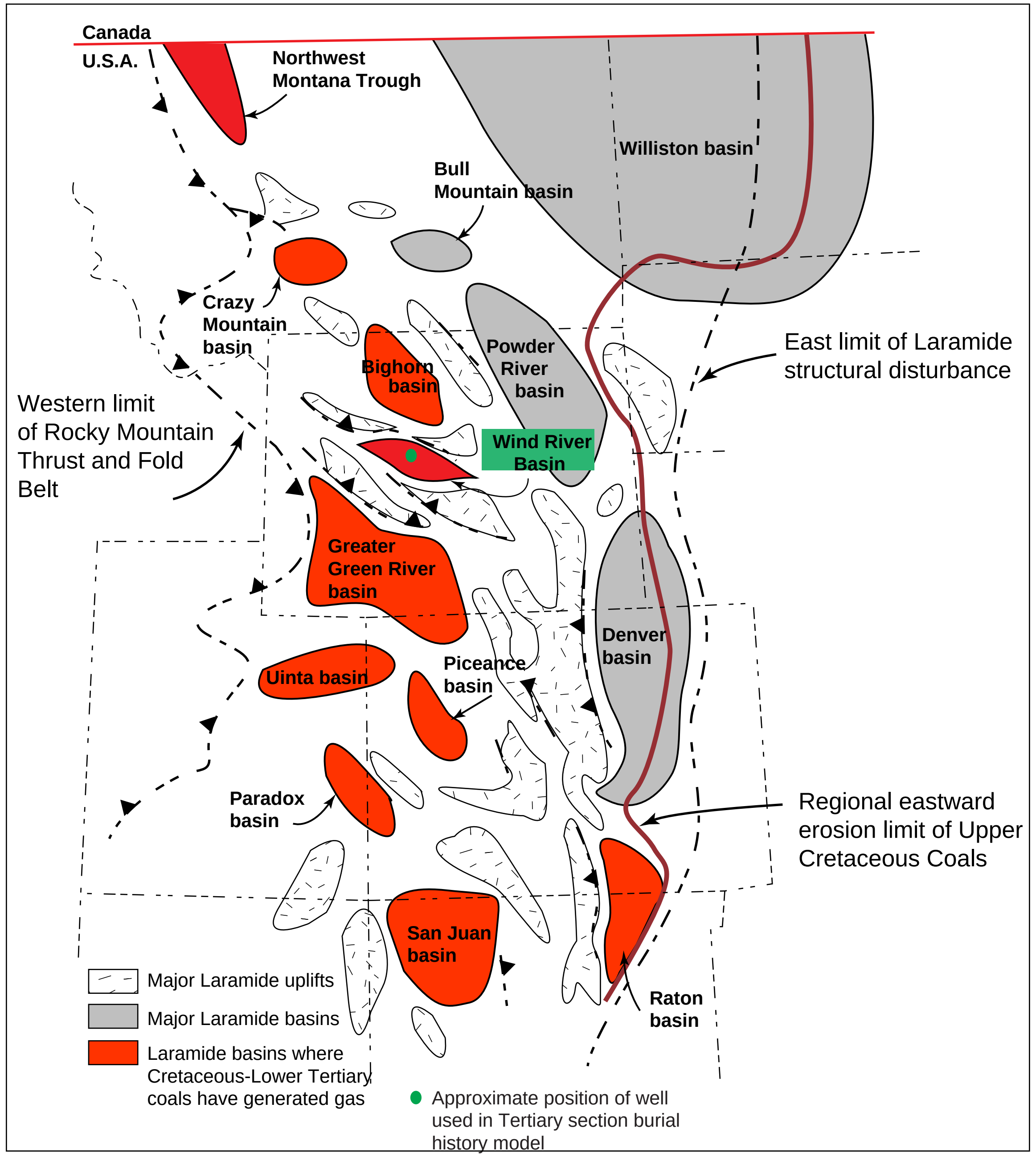


Figure WR-6.1 - Generalized map showing the distribution of major Laramide structural basins and uplifts in the Rocky Mountain region. Eastward limit of Uppermost Cretaceous coal deposition is shown along with those basins which have reached sufficient maturity to generate gas from these coal deposits (after Meissner, F., 1984).

The major Tertiary oil source rock in the Wind River Basin is the Waltman Shale member of the Fort Union Formation. The Waltman Shale contains a mixture of both types II and III kerogen, with total organic carbon content values as high as 7.0 wt%. Mean Ro values for samples taken from the modeled well range from .61-.9% (Figure WR-6.4). In general, oil generation is thought to begin around the .60 Ro value.

Using a constant heat flow value that matched measured Ro values, a burial and temperature history of the stratigraphic interval was modeled (Figure WR-6.3). The maturity level for the Waltman Shale ranged between .70-.90% Ro corresponding to burial depths between 7000-10,000'. Maximum burial temperatures reached 250 degrees Farh. at about 15 Ma before present. Based on this information, the Tertiary Waltman Shale has reached the proper maturity level to have generated hydrocarbons near the basin center. In addition, for the interval that was buried to around 11,000' may have reached the critical threshold to initiate gas generation.

This potential source interval may charge subthrust plays, basin-center plays, as well as conventional fold/thrust structural traps.

3) The Uppermost Cretaceous/Lower Tertiary section of the reservation area contain several potential source horizons; either organic-rich shales or thin-bedded coals. Oil and gas produced from the Fort Union reservoirs, as well as oil shows in the Wind River Formation were probably generated from these intervals. In addition, Lance Formation shows and reservoired hydrocarbons may also be source from these zones.

Figure WR-6.1 depicts the distribution of basins in which thermogenic gas has been generated from Tertiary or Upper Cretaceous coals, generally under deep burial conditions. These coals contain typical type lll gas-generating kerogen. These coals could charge conventional sandstone reservoirs as well as unconventional 'tight' sandstones (basin-center accumulations). In addition, the coals may also provide a viable exploration target.

Humic coals are capable of both generating and storing significant amounts of dry methane gas. Methane generation commences within the high volatile bituminous A coal rank, where volatile matter content is 37.8% and vitrinite reflectance is 0.73% (Meissner, 1984). Lowland areas adjacent to the Cretaceous Seaway provided environments conducive to the formation of lagoonal swamps, shoreline paralic swamps, channel-overbank swamps, and restricted lacustrine swamps. Later Laramide orogenic activity has eroded some of these horizons while preserving others under thick volumes of Tertiary sediment (Figure WR-6.2).

In addition to coaly intervals, at least one shale horizon in the Tertiary section may have the organic-richness to generate hydrocarbons (Figure WR-6.2). In the reservation area, the Waltman Shale has been modeled using known well data and vitrinite measurements. Approximate location of this well is located in Figure WR-6.1.

System	Series		Stratigraphic Unit or event	Thickness (in feet)	Ages (Ma)
Tertiary	mid-Mio. to present		uplift and erosion	-3,380	15 - 0
	Miocene		Split Rock Formation	900	24 - 15
	Oligocene		White River Formation	500	36 - 24
	Eocene		Post lower Eocene rocks-undivided	1,980	55 - 38
			Wind River and Indian Meadows Formations undifferentiated	4,625	
	Paleocene	Fort Union Formation	Shotgun Member	2,175	59 - 55
			Waltman Shale Member	840	60 - 59
			Lower member	1,350	66 - 60

Figure WR-6.2 - Stratigraphic column of Tertiary stratigraphy in the reservation area of the Wind River Basin. Position of potential source interval is depicted in brown (after Nuccio, V., 1994).

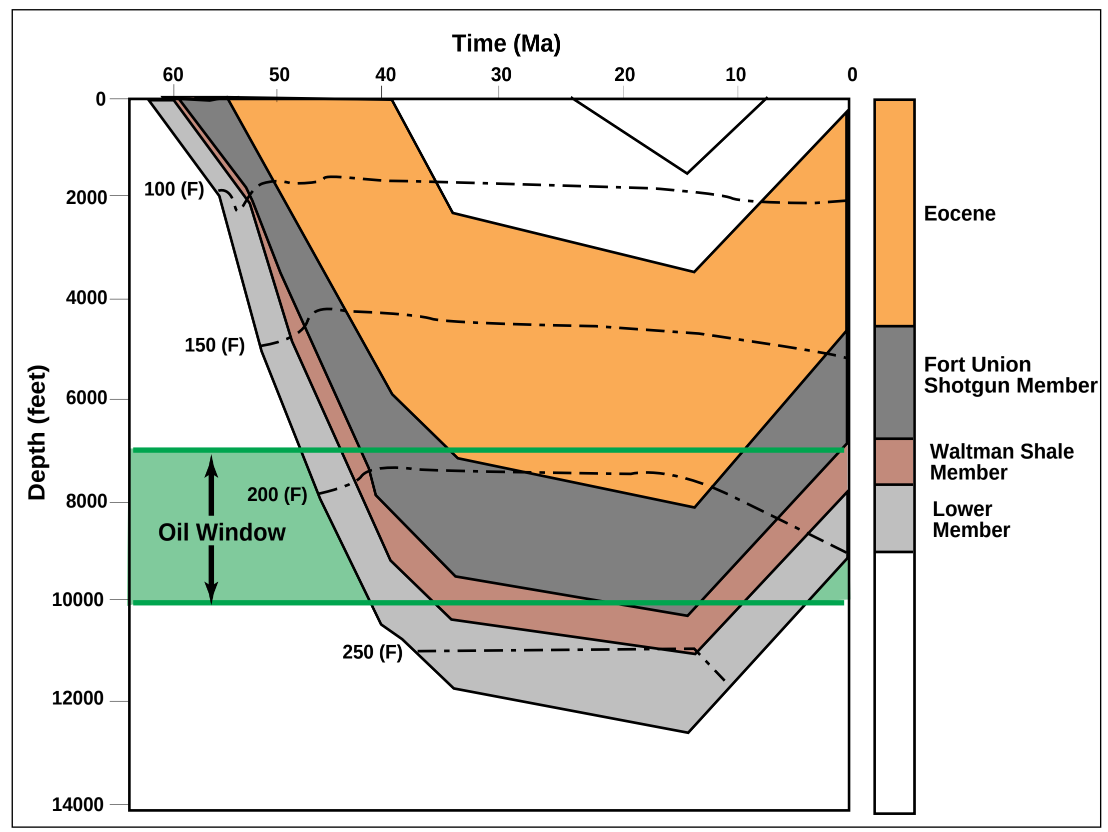


Figure WR 6.3 - Burial history diagram depicting oil generation window relative to position of the Waltman Shale. Diagram illustrates the probable generation of hydrocarbons from this zone under basin center burial conditions. Position of well from which this data was modeled is located on Figure WR-6.1 (after Nuccio, V., 1994).

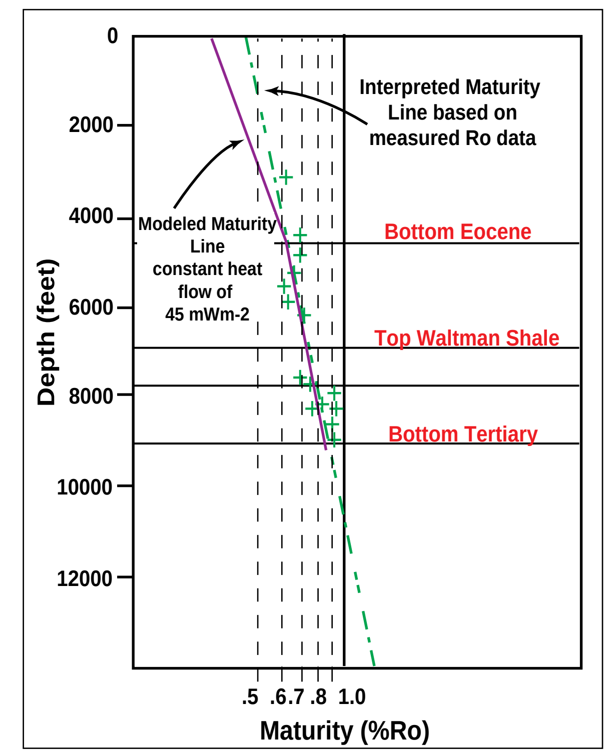


Figure WR-6.4 - Measured and modeled Ro data from well located on Figure WR 6.1. Data was input into burial history model to generate range of oil generation from the Waltman Shale (from Nuccio, V., 1994).

WIND RIVER BASIN SCHEMATIC ILLUSTRATION OF POTENTIAL HYDROCARBON TRAPPING MECHANISMS AND PLAY TYPES

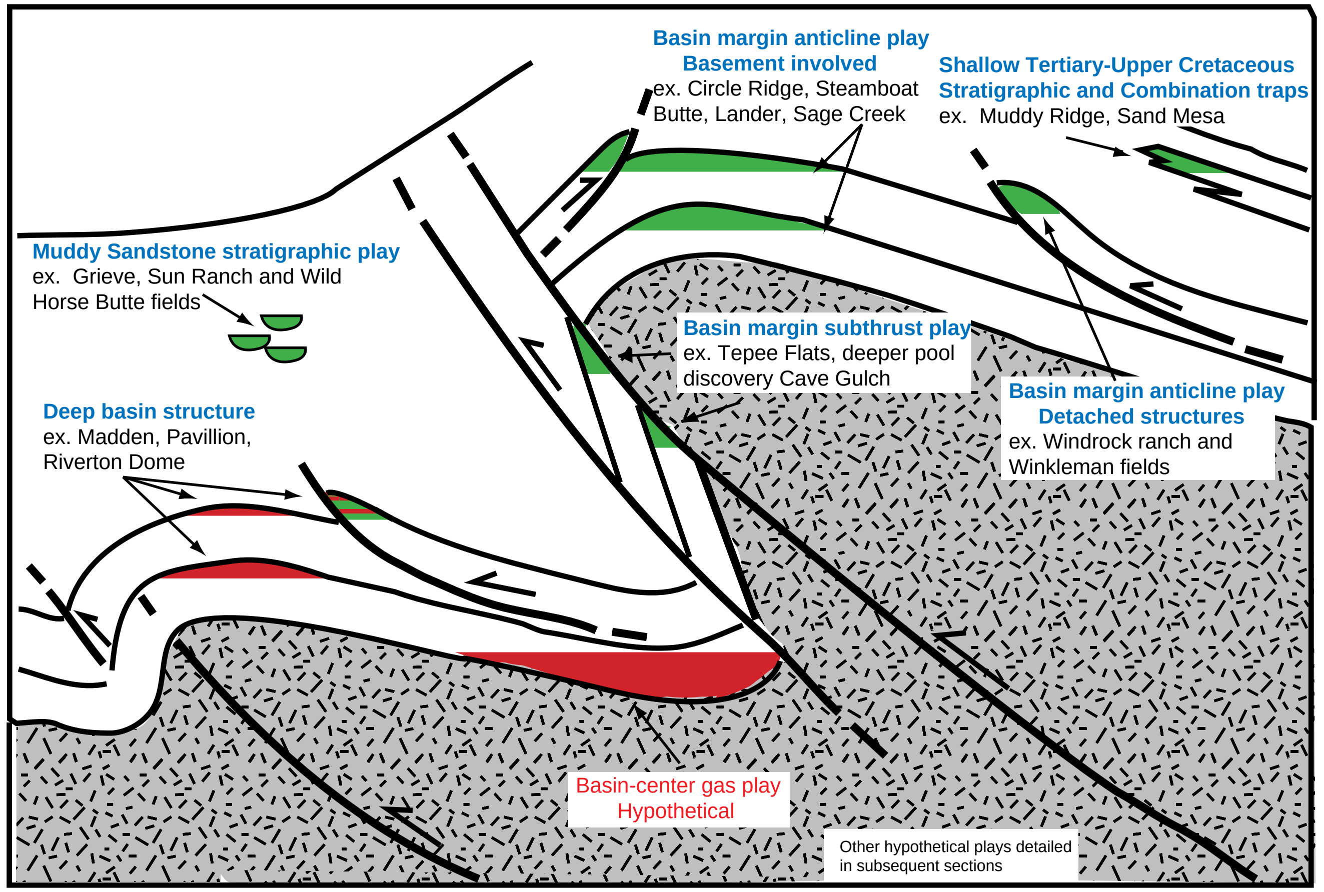


Figure WR 7.1 - Schematic illustration of play types showing distribution of hydrocarbons (modified from Willis & Groshong, 1993)

Play Types - Wind River Basin

1. Basin Margin Subthrust
2. Basin Margin Anticline
3. Deep Basin Structure
4. Muddy Sandstone Stratigraphic
5. Phosphoria Stratigraphic
6. Bighorn wedge-edge pinch-out
7. Flathead-Lander and equivalent sandstone stratigraphic
8. Madison Limestone stratigraphic
9. Darwin-Amsden sandstone stratigraphic
10. Triassic and Jurassic stratigraphic
11. Shallow Tertiary-Upper Cretaceous stratigraphic
12. Cody and Frontier stratigraphic
13. Basin-Center gas unconventional/hypothetical conventional

Reservation: **Geologic Province:** **Province Area:** **Reservation Area:**	**Wind River** **Central Wind River** **Wind River Basin (11,700 sq. miles)** **3500 sq. miles**	**Total Production (by province-1996)** **Oil:** **Gas:** **NGL:**	**Wind River Basin** **550 MMBO** **2.8 TCFG** **32 MMBNGL**

Undiscovered resources and numbers of fields are for Province-wide plays. No attempt has been made to estimate number of undiscovered fields within the Wind River Reservation

Play Type	USGS Designation	Description of Play	Oil or Gas	Known Accumulations	Undiscovered Resource (MMBOE) mean vol. oil, mean vol. gas, mean size, non assoc.	Play Probability (chance of success)	Drilling depths	Favorable factors	Unfavorable factors
Basin Margin Subthrust **1**	3501	Laramide basin-margin thrusting has trapped oil/gas in upturned, overturned, folded, and faulted Phanerozoic strata below the overthrust wedge. Multiple reservoir horizons	Both	50-200 BCF	31.1 MMBO (mean) 152 BCF (mean) 9.4 MMBO (mean field size) 6 BCF nonassociated gas	1	3,000 - 12,000 ft	1) confirmed play; new, ongoing exploration effort 2) thermally mature source rocks in portion of reservation 3) source rocks and reservoir present 4) multiple horizon exploration targets	1) seismic delineation may prove difficult 2) field size could be small 3) drilling mobilization may be difficult 4) drilling may be difficult
Basin Margin Anticline **2**	3502	Anticlinal noses and domes forned during the Laramide orogenic event. Best development along shallow margins of basin. Multiple reservoir horizons and structural configuration	Both	420 MMBO 525 BCFG	19 MMBO (mean) 54 BCF (mean) 3.6 MMBO (mean field size) 2 BCF nonassociated gas	1	3,000 - 9,000 ft	1) confirmed play; production within reservation 2) thermally mature source rocks 3) source rocks and reservoir present 4) seismic delineation is useful	1) mature field development, new field development unlikely 2) chance of hydrodynamic flushing of small structures 3) possible small target size
Deep Basin Structure **3**	3503	Intrabasin anticlinal, domal and fold nose structures within the deep,axial portion of the basin. Forned,enhanced during the Laramide Orogeny with possible older precursors. Multiple reservoir targets.	Gas/condensate	15 MMBO 1.3 TCFG	8.3 MMBO (mean) 390 BCF (mean) 3.1 MMBO (mean field size) 7 BCF nonassociated gas	1	9,000 - 14,000 ft	1) confirmed play; production exists on/near reservation 2) source rocks in oil-gas window, generation of gas probable 3) source rocks and reservoir present 4) seismic may be very useful	1) trapping mechanisms may be subtle, stratigraphic in part 2) new targets may be of smaller areal extent 3) increased depths enhances drilling difficulties/expense

Table WR 7.2 - Summary of play information.

Reservation:	**Wind River**	**Total Production (by province-1996)**	**Wind River Basin**
Geologic Province:	**Central Wind River**	**Oil:**	**550 MMBO**
Province Area:	**Wind River Basin (11,700 sq. miles)**	**Gas:**	**2.8 TCFG**
Reservation Area:	**3500 sq. miles**	**NGL:**	**32 MMBNGL**

Undiscovered resources and numbers of fields are for Province-wide plays. No attempt has been made to estimate number of undiscovered fields within the Wind River Reservation

Play Type	USGS Designation	Description of Play	Oil or Gas	Known Accumulations	Undiscovered Resource (MMBOE) Oil Volume, Gas Volume, Field Size	Play Probability (chance of success)	Drilling depths	Favorable factors	Unfavorable factors
Muddy Sandstone Stratigraphic **4**	3504	Unconformity bounded pinch-outs of discontinuous Muddy Sandstone intervals provide trapping mechanisms. Stratal framework is complex and distribution controlled by paleotopography and sea-level fluctuations.	Both	32 MMBO 160 BCFG	58.6 MMBO (mean) 350 BCF (mean) 7.3 MMBO (mean Field size) 4 BCF nonassociated gas	1	4,000 - 12,000 ft	1) confirmed play; production within reservation 2) thermally mature source rocks 3) source rocks and reservoir present 4) seismic delineation possible 5) sequence stratigraphic interpretations useful	1) discontinuous, complex reservoir target 2) rough topography 3) narrow play area 4) seismic may not be helpful
Phosphoria Stratigraphic **5**	3506	Porous, detrital carbonate tidal channels of the Ervay member of the Phosphoria form possible reservoirs. Fine-grained carbonates/shales provide lateral and vertical seals. The reservoirs are adjacent to mature/organic-rich source rock.	Oil	> 1 MMBOE	12 MMBO (mean) no gas volume 4.5 MMBO (mean field size)	.80	7,000 - 13,000 ft	1) confirmed play near reservation area 2) thermally mature source rocks 3) source rocks and reservoir interbedded 4) favorable migration pathways	1) limited production from interval 2) reservoir facies may not be present in reservation area 3) limited well penetrations to interval
Bighorn wedge-edge pinch-out **6**	3509	Wedge-edge pinch-outs of the Ordovician Bighorn Dolomite which abut against the base of the Madison Limestone could provide a trapping mechanism. Dolomites can contain abundant intergranular porosity.	unknown	no information available	very high risk, no calculated estimates	.05	8,000 - 13,000 ft	1) Thermally mature source rocks 2) Porosity could range up to 18% 3) 'Bright' seismic character, easy to identify horizon	1) No production within reservation 2) variable, discontinuous porosity 3) lack of well control 4) small areal extent of targets 5) seismic may not be useful
Flathead-Lander & equiv. sandstone **7**	3510	Stratigraphic pinch-outs of Cambrian Flathead and Ord. Lander Sandstones could provide a trapping mechanism. Variable reservoir quality.	unknown	no information available	very high risk, no calculated estimates	.05	10,000 - 14,500 ft	1) continuous sandstone lenses 2) thermally mature source rocks 3) high volume reserves if present	1) lack of well control 2) complex migration pathways 3) porosity highly variable 4) stratigraphic play, seismic of limited use 5) drilling depths/expense
Madison Limestone Stratigraphic **8**	3511	Porosity variation and topography related to karst development within the Madison Limestone could be a viable exploration target.	unknown	no information available	high risk, no calculated estimates	.10	7,000 - 11,500 ft.	1) karst related porosity typically high 2) thermally mature source rocks 3) seismic may be very useful in picking karst horizons 4) 'bright' seismic reflector	1) lack of well control 2) complex migration pathways 3) porosity highly variable 4) stratigraphic play, seismic may not be useful in structurally very disturbed areas 5) drilling depths/expense
Darwin - Amsden Stratigraphic **9**	3512	Stratigraphic entrapment of hydrocarbons in discontinuous sandstones of the Penn. Darwin and Amsden Formations may be possible. Unknown to variable reservoir quality	unknown	no information available	high risk, no calculated estimates	.10	7,000 - 11,000 ft.	1) sandstone porosity variable, but could range up to 16% 2) thermally mature source rocks 3) large, areal extent of sandstone lenses	1) porosity highly variable 2) complex migration pathways 3) no established production 4) stratigraphic play, seismic may not be useful in structurally very disturbed areas
Triassic & Jurassic Stratigraphic **10**	3513	Stratigraphic traps may exist in truncations and pinchouts of Triassic and Jurassic aged sandstones. Complex stratigraphy, but possible good reservoir quality.	unknown	no information	high risk - no calculated estimates	.10	6,000 - 10,000 ft	1) porosity may be high 2) thermally mature source rocks 3) source rocks and reservoir present 4) seismic delineation possible 5) sequence stratigraphic interpretations usful	1) discontinuous, complex reservoir target 2) rough topography 3) narrow play area 4) seismic may not be helpful
Shallow Tertiary-Upper Cretaceous **11**	3515	Stratigraphic and modified structure/stratigraphic trapping mechanisms in arkosic/lithic sandstones of Tertiary and Upper Cretaceous age. Humic-rich source rocks adjacent to possible reservoirs.	Oil/gas	> 1 MMBOE	no oil volume 72 BCF (mean) unknown (mean field size) 3.0 BCF nonassociated gas	.70	2,500 - 8,000 ft	1) confirmed play near reservation area 2) thermally mature source rocks 3) source rocks and reservoir interbedded 4) favorable migration pathways	1) limited production from interval 2) areal extent of target may be small 3) seismic may not be useful in structurally distrubed areas
Cody and Frontier Stratigraphic **12**	3518	Deep basin stratigraphic traps of Upper Cretaceous Cody and Frontier fine-grained sandstones. Mowry shale source horizons interfingered within sandstones.	unknown	no information	high risk, no calculated estimates	.10	8,000 - 13,000 ft	1) Thermally mature source rocks 2) Porosity could range up to 15% 3) clastic, sandstone reservoirs	1) No production within reservation 2) variable,discontinuous porosity 3) lack of well control 4) small areal extent of targets 5) seismic may not be useful
Basin Center Gas **13**	3505	Extensive and continuous overpressured gas accumulations trapped in low permeability Paleocene and uppermost Cretaceous reservoirs in deep parts of basin. Characterized by overpressuring due to active generation of gas.	gas	no information	high risk, no calculated estimates but volumes of gas in excess of 2 TCF possible	.20-.70	11,000 - 14,500 ft	1) continuous accumulations 2) thermally mature source rocks 3) high volume reserves if present	1) lack of well control 2) complex migration pathways 3) porosity / permeability - low 4) stratigraphic play, seismic of limited use 5) drilling depths/expense

Table WR 9.1 - Play summary information.

unconventional/hypothetical play
conventional play

PLAY TYPE 1

Basin Margin Subthrust Play

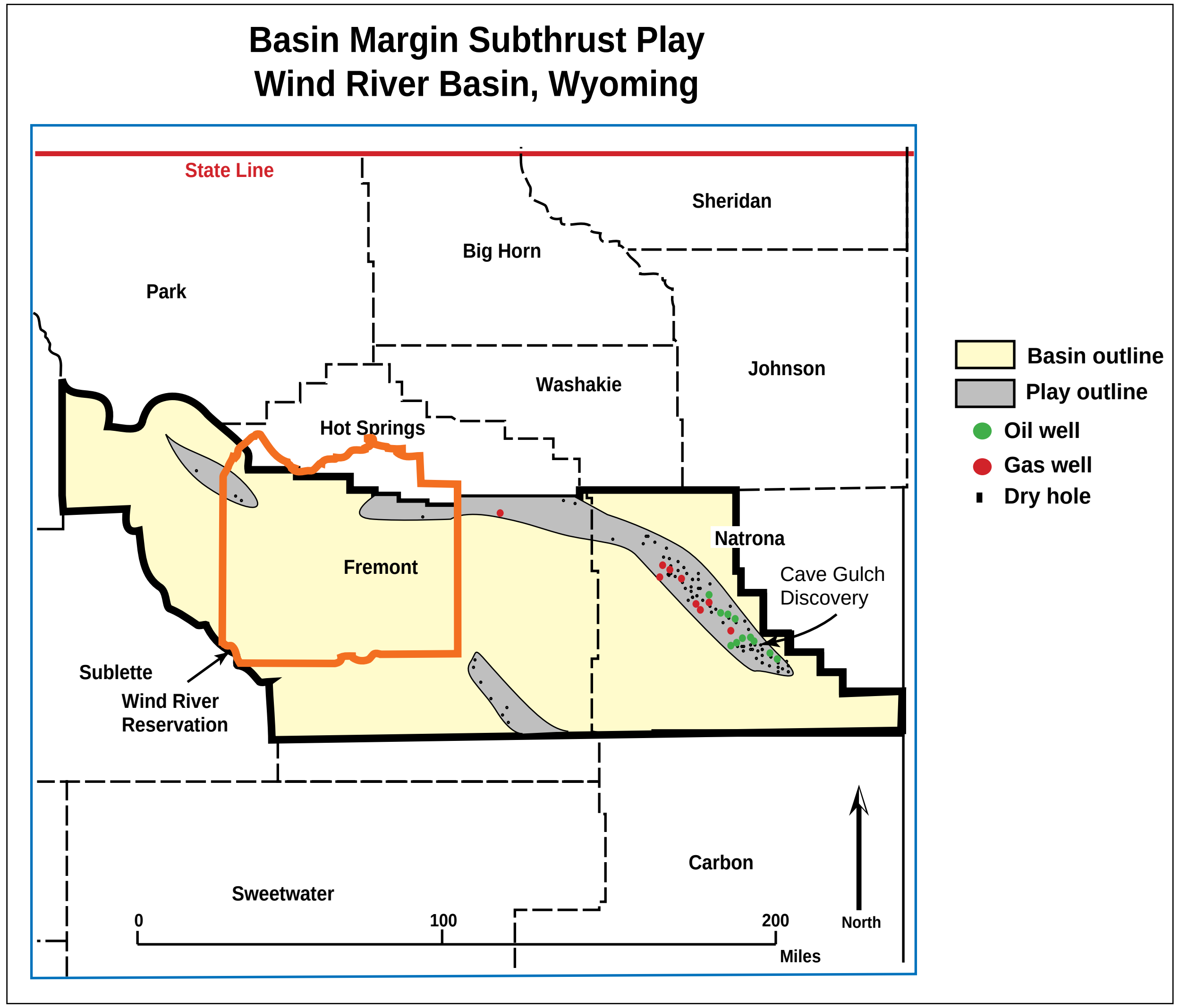


Figure WR-10.1 - Play outline for the Wind River Basin Margin Subthrust Play. Approximate location and type of penetrations in play outline located on figure. County and reservation outline depicted as well (from U.S.G.S. 1995 National Assessment).

Laramide basin-margin thrusting has trapped oil and gas in upturned, overturned, folded, and faulted Phanerozoic strata below the overthrust wedge. The limits of this demonstrated play are defined by the leading edge of basin-margin thrust faults and an assumed overhand displacement of 6 mi. This is a currently developing exploration play (Cave Gulch discovery) with previous exploration success limited to the Tepee Flats field. The Tepee Flats field is currently producing gas from the Frontier Formation at a depth of about 12,200 ft. with a known recoverable of 9.0 BCFG (see Figures WR 10.2 & 10.3). Since this play has only been marginally explored, significant new reserves could be anticipated from this play type. The Cave Gulch discovery attests to the economic viability of this concept with known recoverable estimates ranging from 50-200 BCFG (Fig. WR-10.1). Sparse information has been published regarding this new discovery but it is thought that relatively 'shallow' (>10,000 feet) Upper Cretaceous reservoirs contain the gas reserves. In the reservation area, little exploration has occurred over the potential subthrust areas.

Reservoir type and quality are highly variable since any of the buried Mesozoic and Paleozoic potential reservoir horizons could be involved. Principal reservoirs include the Pennsylvanian Tensleep, Permian Phosphoria carbonates, and Upper Cretaceous Frontier, Mesaverde, and Lance Formations. Source horizons could be from the Phosphoria, Mowry, or Tertiary Fort Union Formations. It is likely that the shallower horizons would receive significant contributions from the Upper Cretaceous/Tertiary source intervals due to the simpler migration pathways.

Because Laramide thrust faults have thrust thick wedges of Precambrian rocks over younger Paleozoic and Mesozoic intervals, the depth of burial of the source intervals is usually great enough for source rocks to have generated hydrocarbons locally or for hydrocarbons to have migrated from mature areas in deeper parts of the basin during/after Laramide deformation (Figure WR 10.3). Some pre-Laramide migration may have taken place, moving hydrocarbons into reservoirs before tectonic development of the basin-margin folds and faults. In this case, stratigraphic traps could have formed prior to basin-margin thrusting and folding. Subsequent structural development could have re-mobilized previously trapped hydrocarbons or kept the previous trap intact with a structural overprint enhancing the original trapping mechanism.

Petroleum is trapped where structures with closure occur beneath the basin-margin thrust and is sealed by associated rocks or by impermeable rocks of the hanging wall thrust sheet. In the thrusting process the underlying beds are folded and often upturned or overturned with fault slivers typically present (Figure WR-10.3). Oil and gas may also be trapped in these upturned, overturned, faulted, and folded strata. Depth of production is highly variable, ranging from more than 20,000 ft. on the structurally steepest side of the asymmetrical basin to less than 10,000 ft. in other basin-margin areas.

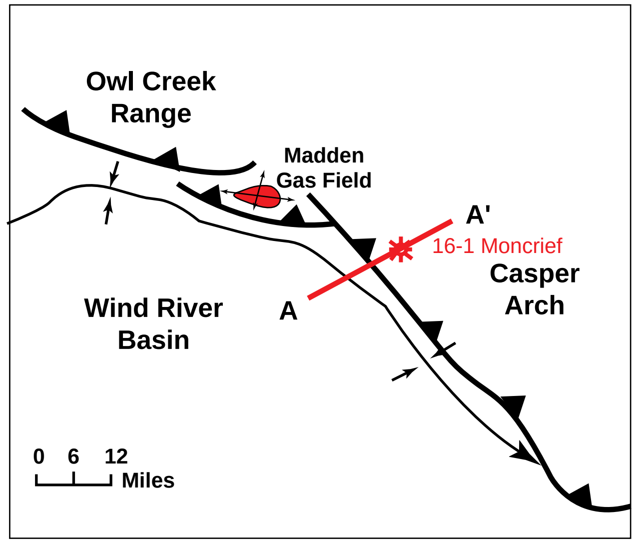


Figure WR-10.2 - Location of adjacent Subthrust play example along the eastern margin of the Wind River Basin (from Gries, 1983).

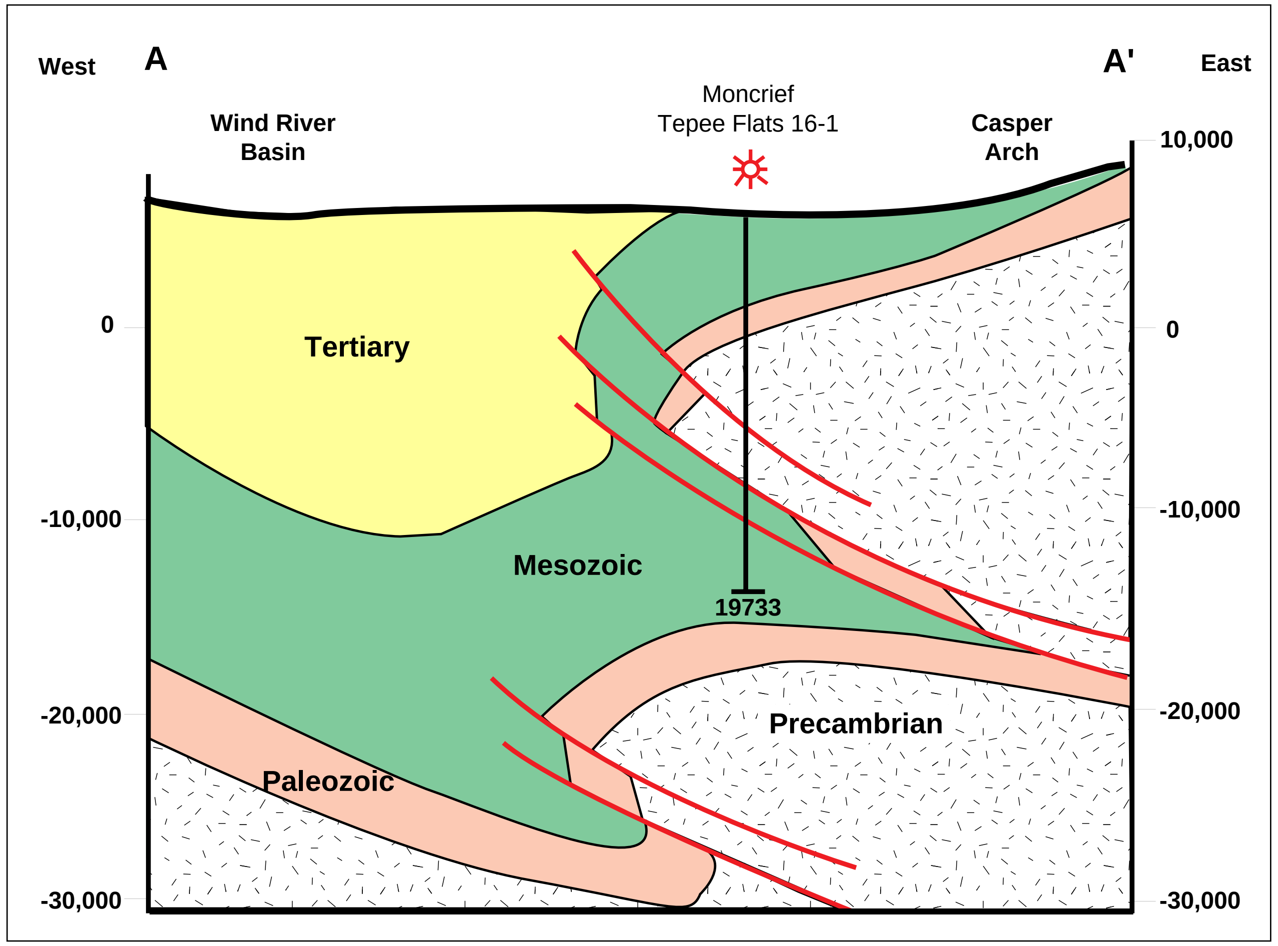


Figure WR-10.3 - Subthrust structure on Casper arch could be similar to Madden field northwest of Moncrief 16-1 Tepee Flats discovery well. This structure is an symmetric fold related to compression of Owl Creek Range. Similar subthrust structure may be present in the reservation area (after Gries, 1983).

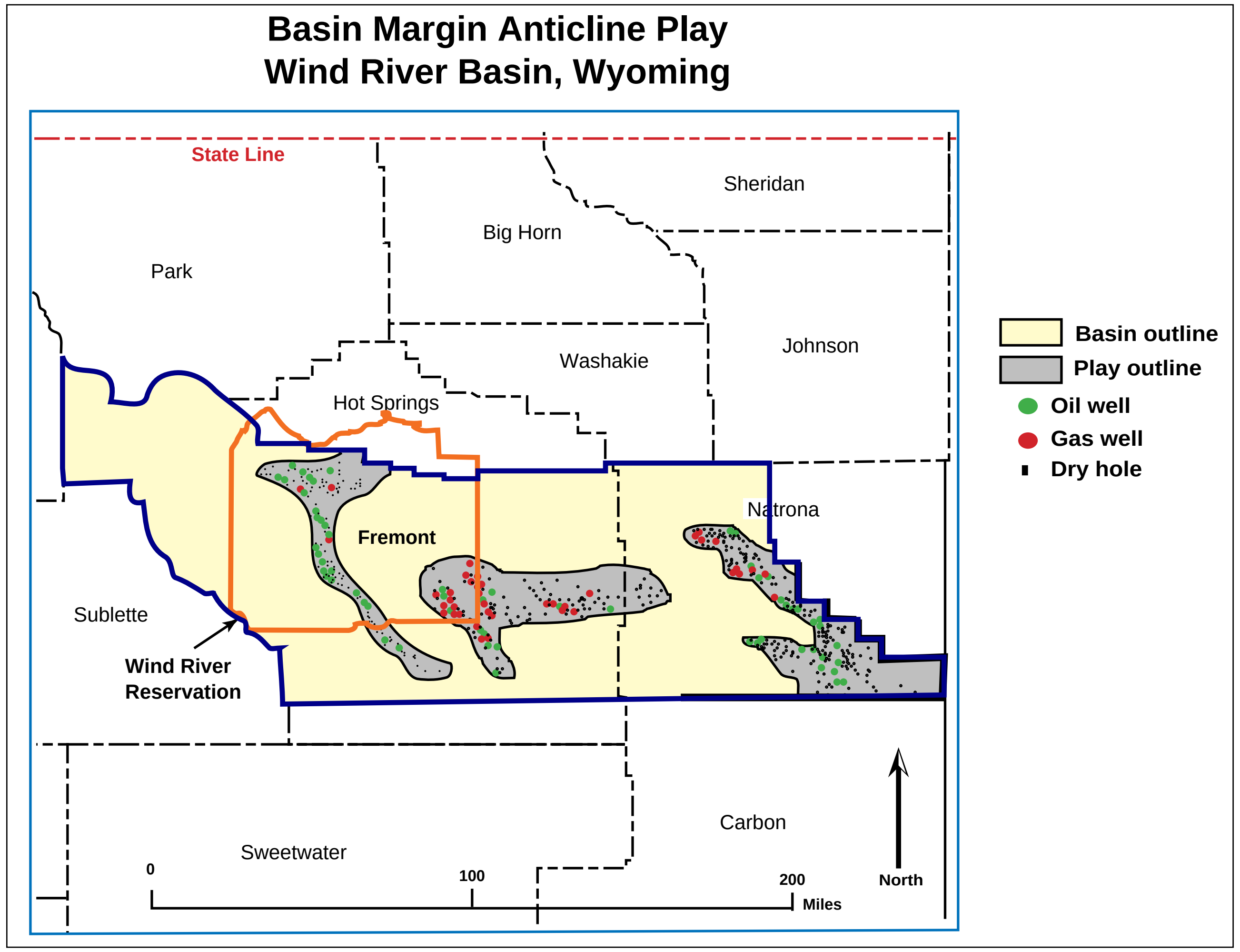


Figure WR-11.1 - Play outlines for the Basin Margin Anticline Play in the Wind River Basin. Approximate locations of well penetrations in play area noted (from U.S.G.S. 1995 National Assessment).

PLAY TYPE 2

Basin Margin Anticline Play

This mature exploration play is defined by the occurrence of oil and gas trapped in anticlines and domes, in many cases faulted, and in faulted noses that formed during major thrust movement in the Laramide orogeny. These structures are best developed along the shallow margins of the basin, with production ranging from about 1,000 ft. to 14,000 ft. The inner boundary of the play is located at the approximate basinward limit of basin-margin anticlines (Fig. WR-11.1). The outer boundary is drawn at the outcrop edge of the Tensleep Formation.

Basement-involved and basement-detached thrusting has produced complex folded/faulted anticlines, domes, and synclines. These surface features were drilled early (1900-1950's) in the exploration history of the Wind River Basin. Figure WR-11.4 shows an example of a typical basement-involved thrust/fold pair showing development of subsidiary faults and upturned fault sliver. In this case, the Sage Creek Anticline has only produced minimal hydrocarbons. Figure WR-11.5 shows the development of a typical detachment structure; detachments usually occur in Triassic or Jurassic-aged sediments.

Major fields have been discovered in these complex thrust/fold structures. Circle Ridge contains multiple reservoir horizons ranging from the Madison to Phosphoria Formations (Figure WR-11.2). This is typical for this play type. Because of the shallow nature of some of these structures and close proximity to outcrop, tilted oil/water contacts are common due to flushing from nearby recharge areas (Fig. WR-11.2). Care must be taken in evaluating the hydrodynamic conditions of potential targets in this play type.

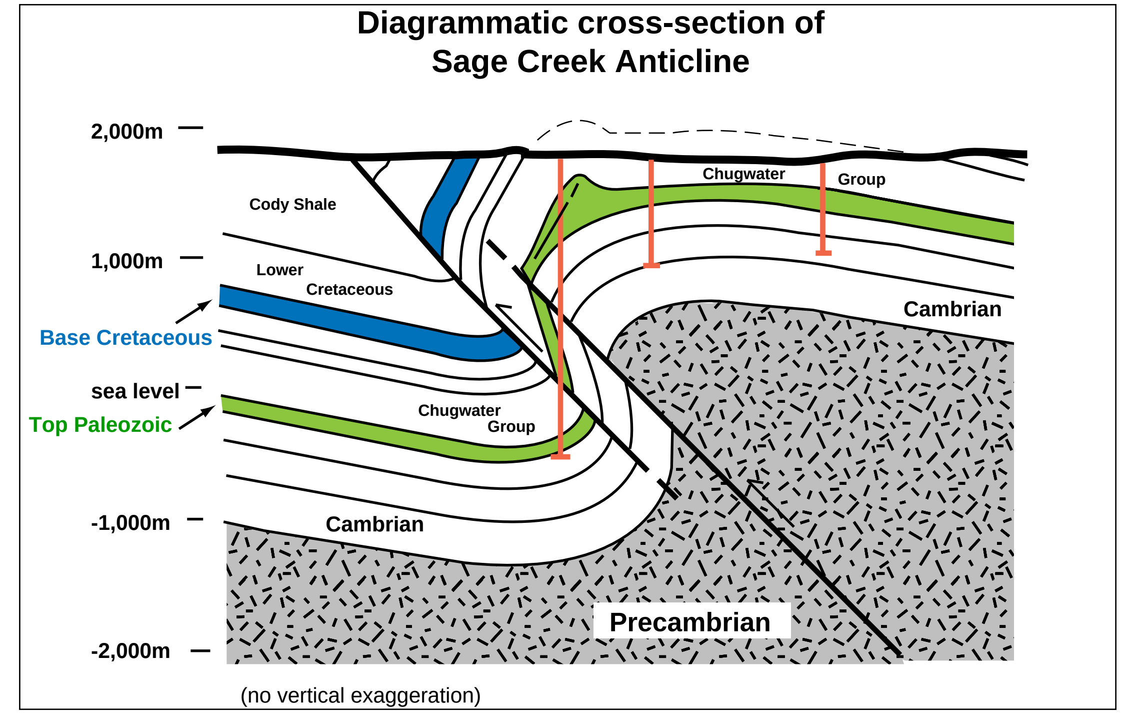


Figure WR-11.4 - Basement-involved fold-thrust structure development. Subsidiary fault development, usually detachment features. Example of complex fault-propagation fold fold model typical of foreland uplifts (modified from Willis & Groshong, Jr., 1993).

Major Fields located within Reservation

Riverton Dome	180 BCFG, 510 MBO	Lander	20 MMBO
Steamboat Butte	95 MMBO	Pavillion	174 BCFG
Winkleman Dome	98 MMBO	Maverick Springs	10 MMBO
Circle Ridge	29 MMBO	Muddy Ridge	29 BCFG

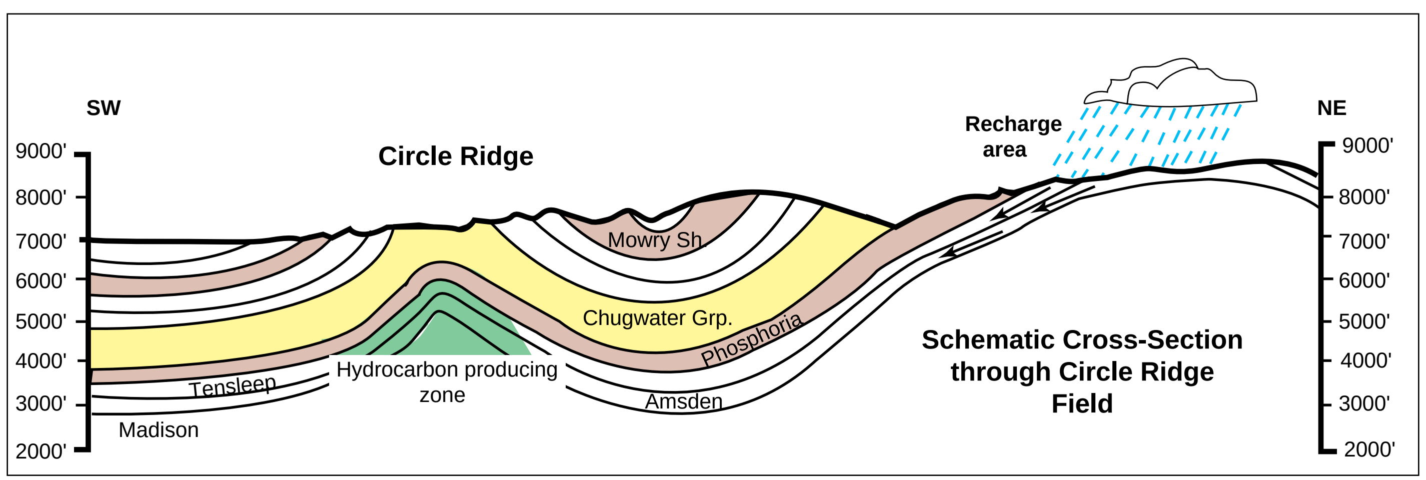


Figure WR-11.2 - Generalized cross section from southwest to northeast through northern portion of Circle Ridge Anticline showing its topographic and hydrodynamic setting. Faults not shown; no vertical exaggeration (after Anderson & O'Connell, 1993).

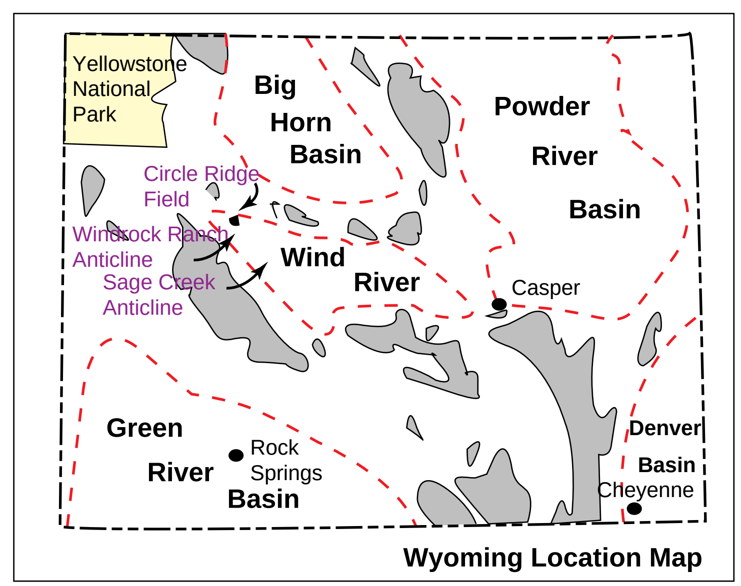


Figure WR-11.3 - Location map for areas depicted on page (after Anderson & O'Connell, 1993).

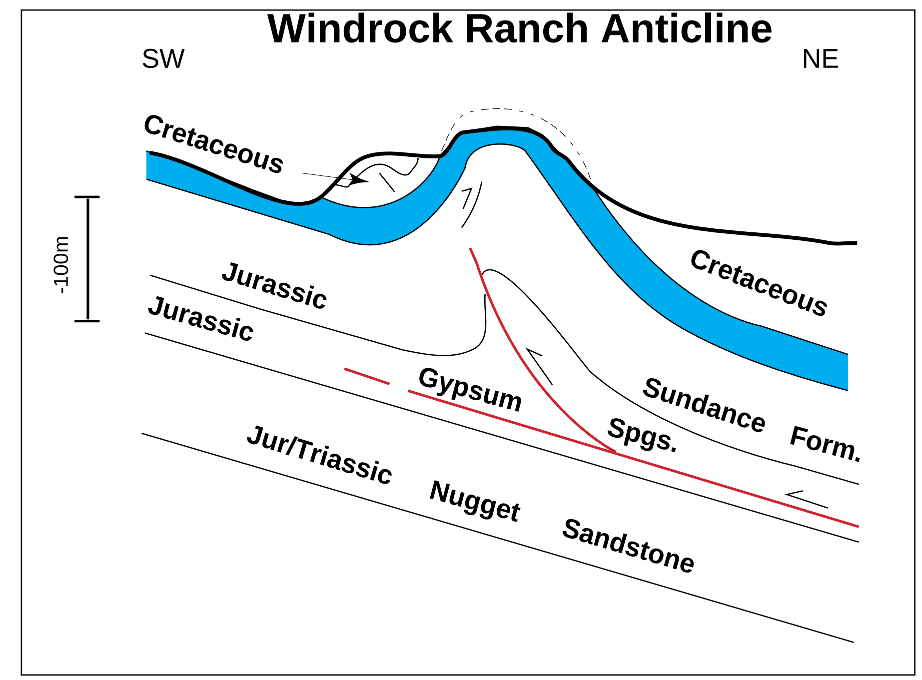


Figure WR-11.5 - Example of basement-detached folding and faulting in Laramide-aged structures. Note development of smaller-scale anticline/syncline pair (pop-out anticline) developed in the center of syncline. Example of fold-thrust deformational style typical of foreland uplifts (after Willis & Groshong, Jr., 1993).

PLAY TYPE 2 (continued)

Basin Margin Anticline Play

Examples from the Circle Ridge Field illustrate the nature of this particular play type within the Wind River Basin. Producing formations range in age from Mississippian through Cretaceous and include Madison, Tensleep, Phosphoria, Sundance, Nugget, Cloverly, Muddy, Frontier, Cody, and Mesaverde Formations (see Figure WR-12.3). Primary production has been from the Madison, Tensleep, and Phosphoria Formations. Many of the fields have multiple pay zones and some show common oil-water contacts involving several of the Paleozoic reservoirs. Sandstone is the dominant reservoir lithology.

Paleozoic reservoirs contain hydrocarbons derived from a distinct Phosphoria source facies. Two fields in the western part of the basin, Circle Ridge and Beaver Creek, produce oil from the Madison Limestone (see Figure WR-12.1). Properties of the oil in these two fields are nearly identical to those of the Tensleep and Phosphoria oil in the same area, indicating that the oil may have been derived from the younger Phosphoria source or re-mobilized from younger reservoir horizons. Figure WR-12.3 depicts the structural position of the Phosphoria in relation to other reservoir horizons; additional throw in the structure could easily juxtapose Madison against known source intervals or reservoirs.

Pre-Laramide generation and long-distance migration from western Wyoming prior to basin formation, followed by remigration during the Laramide Orogeny, is a possibility for charging lower Paleozoic reservoirs. However, local generation of deeply buried Cretaceous source rocks is a likely mechanism for charging reservoirs as well.

Structural closure in faulted anticlines, domes, and noses is the predominant trapping mechanism for this play. Figure WR-12.2 illustrates the typical thrust/fold structural pattern found in this play type. The shallower portions of these structures tend to become structurally more complex due to subsidiary fault development along the major thrust horizons. While the deeper, larger areas of structural closure may have been thoroughly explored, the smaller, shallower structural compartments should offer significant potential for future exploration.

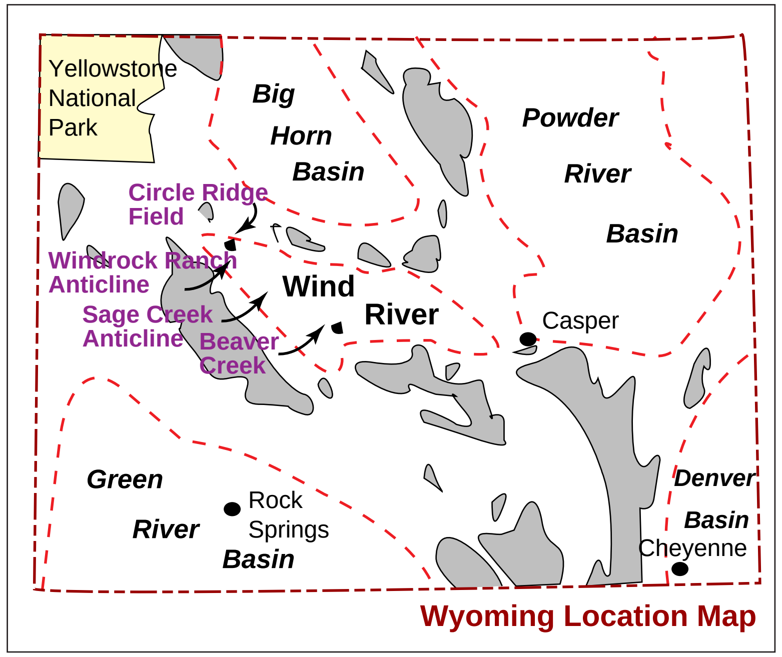
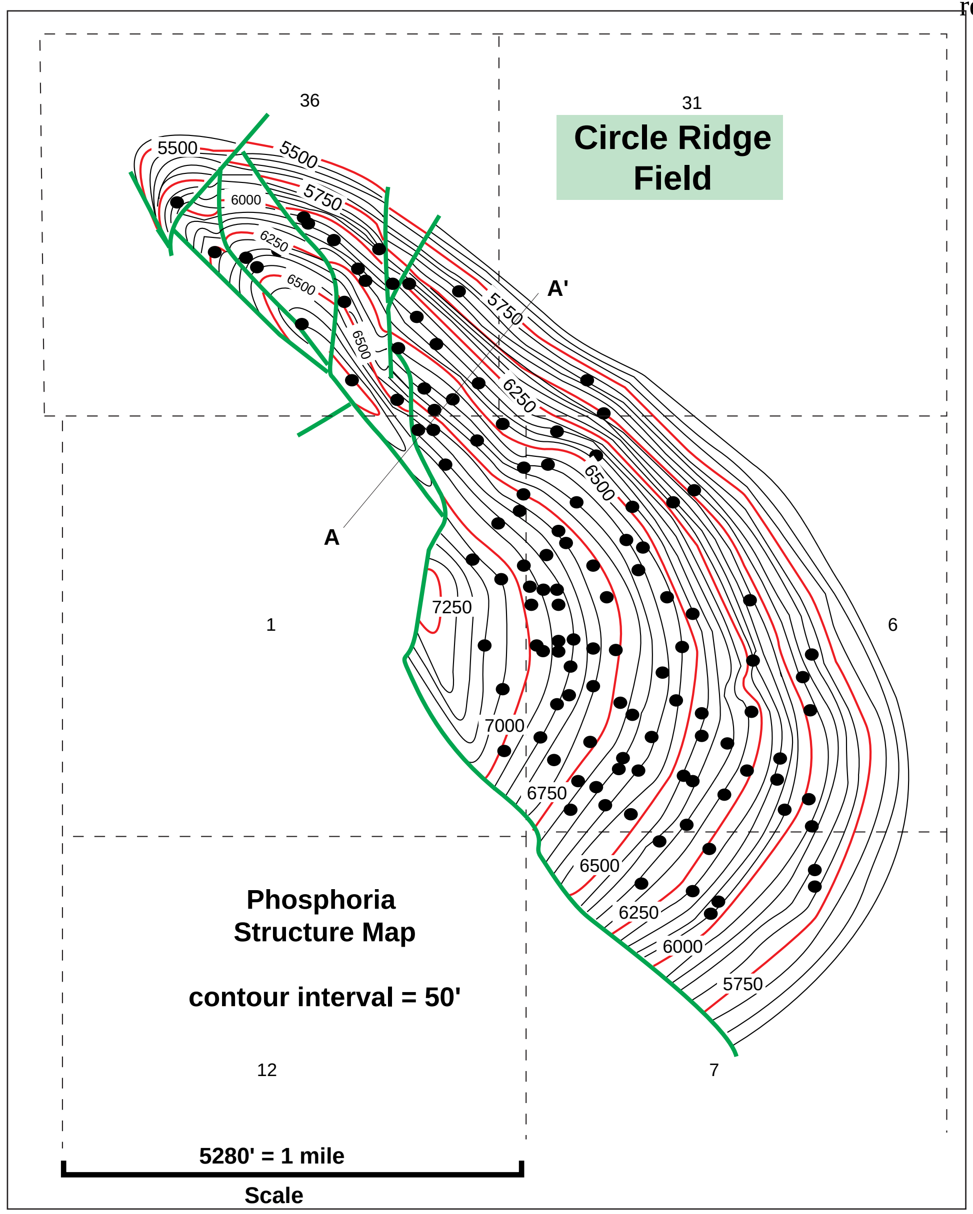


Figure WR-12.1 - General location map showing position of Wind River Basin and Circle Ridge Field.



◀ **Figure WR-12.2** - Structure contour map of Circle Ridge Field on top of the Phosphoria Formation. Shows position of thrusts at depth, compartmentalized behavior of reservoirs, and fairly simple structural closure at 'deep' Phosphoria level (after Anderson & O'Connell, 1993).

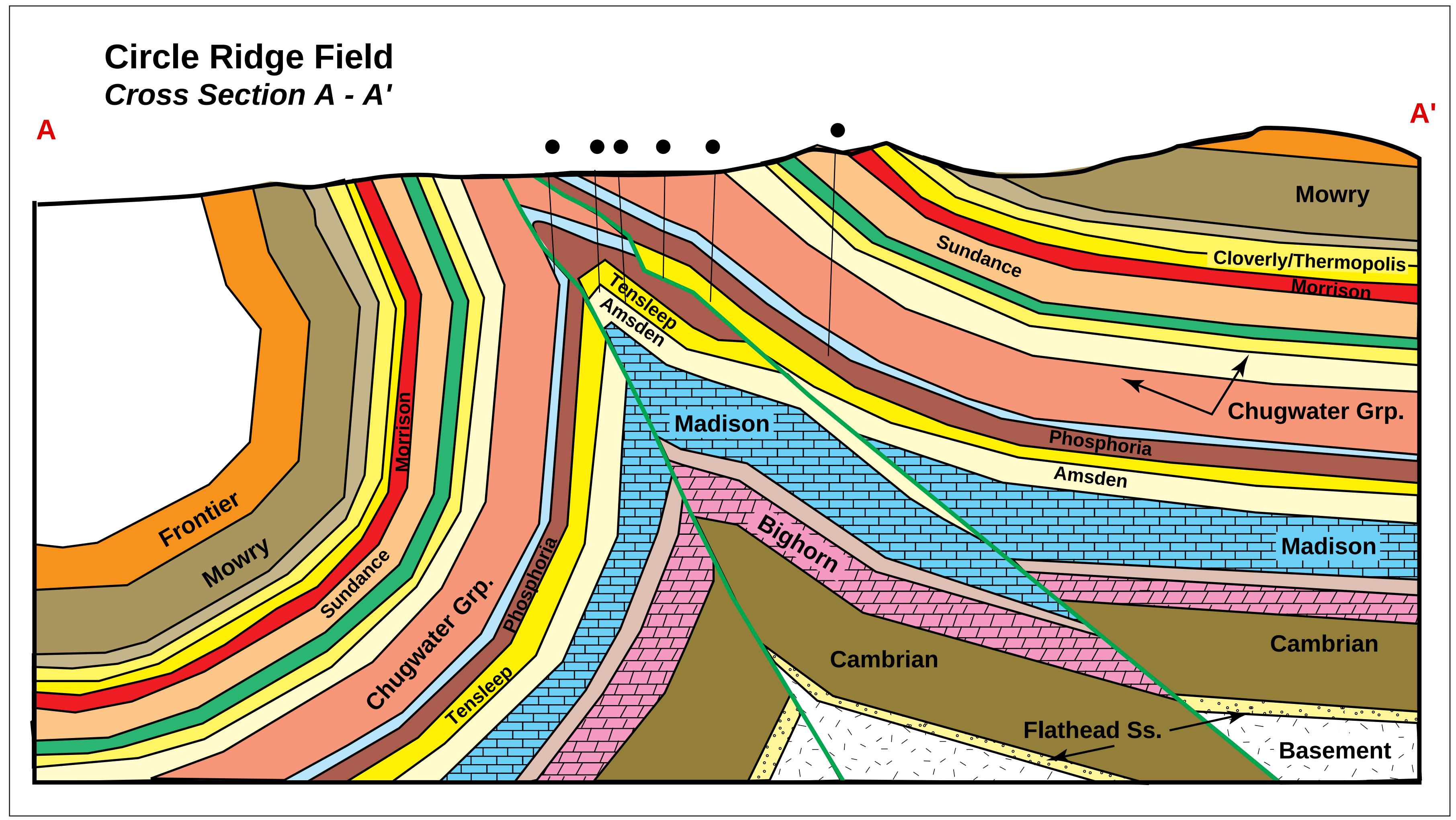


Figure WR-12.3 - Stratigraphic/structural reconstruction of outcrop and well data through a northern cross-section of Circle Ridge Field. See Figure WR 12.2 for cross-section location. This field is typical of the basin margin anticline structures found in this play. Multiple reservoir horizons, compartmentalized reservoirs and flow units, and complex fluid pathways are common in this type of play (modified after Anderson & O'Connell, 1993).

Deep Basin Structure Play
Wind River Basin, Wyoming

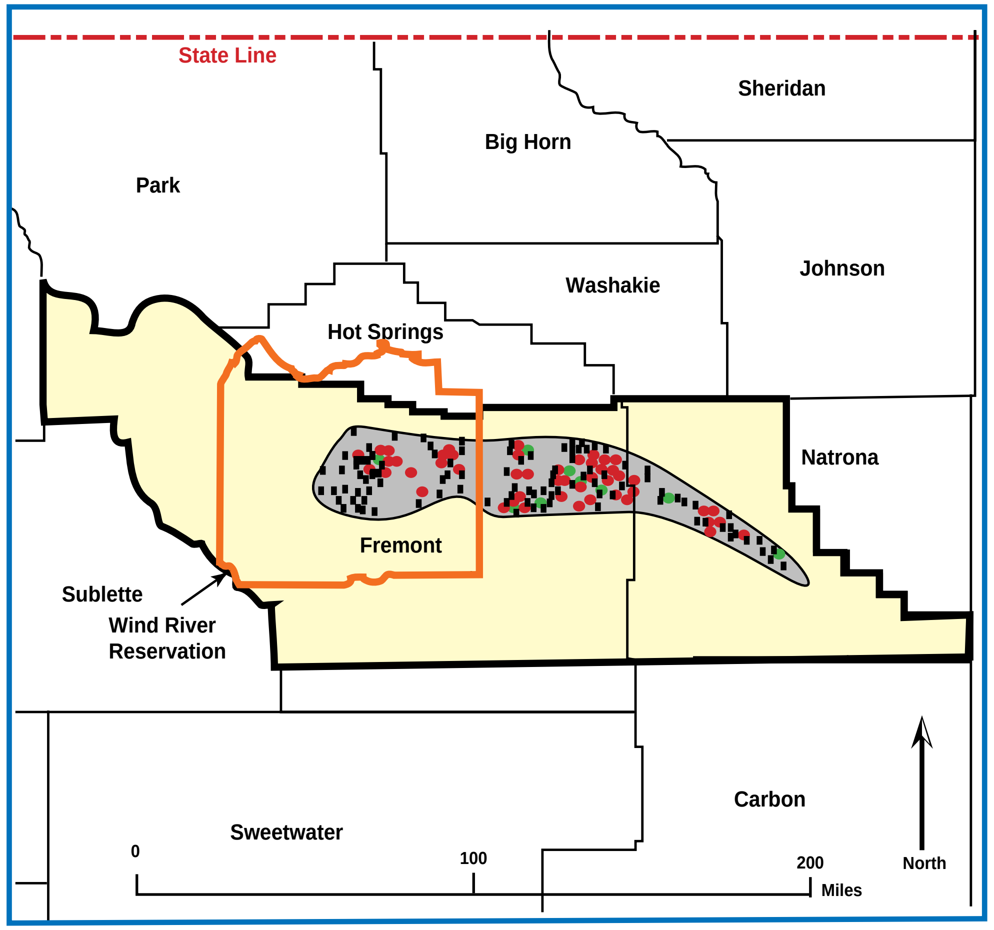


Figure WR-13.1 - Well distribution, play outline, and location of the Deep Basin Structure Play in the Wind River Basin (from U.S.G.S. 1995 National Assessment).

PLAY TYPE 3

Deep Basin Structure

This is a demonstrated gas play with entrapment in large intrabasin anticlinal, domal, and fold nose structures within the deep axial portion of the basin. The boundary of this play is defined on the north by the leading edge of the northern basin-margin thrust fault and on the south and west by the deep limit of the Basin Margin Anticline Play.

Reservoir rocks range in age from Mississippian to Eocene. The bulk of the gas production has been from Lance, Fort Union, Wind River, and Mesaverde Formations. However, deeper drilling has encountered significant reserves in the Mississippian Madison and Pennsylvanian Tensleep Formations. Porosity and permeability reduced through compaction/cementation with deeper burial, may be re-enhanced by fracturing and secondary cement dissolution. Early migration and entrapment may have preserved some of the original porosity. Even if the hydrocarbons have been re-mobilized due to movement associated with the Laramide Orogeny, the porosity and permeability may have been preserved. This would allow subsequent migration into reservoir intervals from source rocks that initiated generation/expulsion in late Paleocene through to the present time.

Most fields have multiple pool production from a great range of depths and thicknesses. Most individual reservoir intervals range between 25-50 feet in thickness. Reservoirs may be overpressured; for example most Tertiary and Mesozoic strata on the Madden structure are overpressured but nearly normal pressure gradients occur near the top of the Paleozoic interval.

Most of the productive reservoir intervals are interbedded with source rocks. This facilitates migration and entrapment of the hydrocarbons. Indigenous source rocks are found in the Permian Phosphoria, Cretaceous Mowry, and Tertiary Fort Union (including Waltman shale) Formations. Early Paleocene generation from the Fort Union sources has been modeled using vitrinite reflectance data. Generation probably continues to present and accounts for some of the overpressured intervals encountered in some fields.

Potential for undiscovered resources may be good-excellent in this play due to deeper pool discoveries. Madden Field (825 BCFG), Pavillion (174 BCFG), Waltman-Bull Frog (96 BCFG), and Frenchie Draw (46.5 BCFG) all have the potential for deeper reservoir horizons. In fact, many of the currently discovered fields do not include Paleozoic units such as the Madison Limestone, which is a major new reservoir at Madden Field.

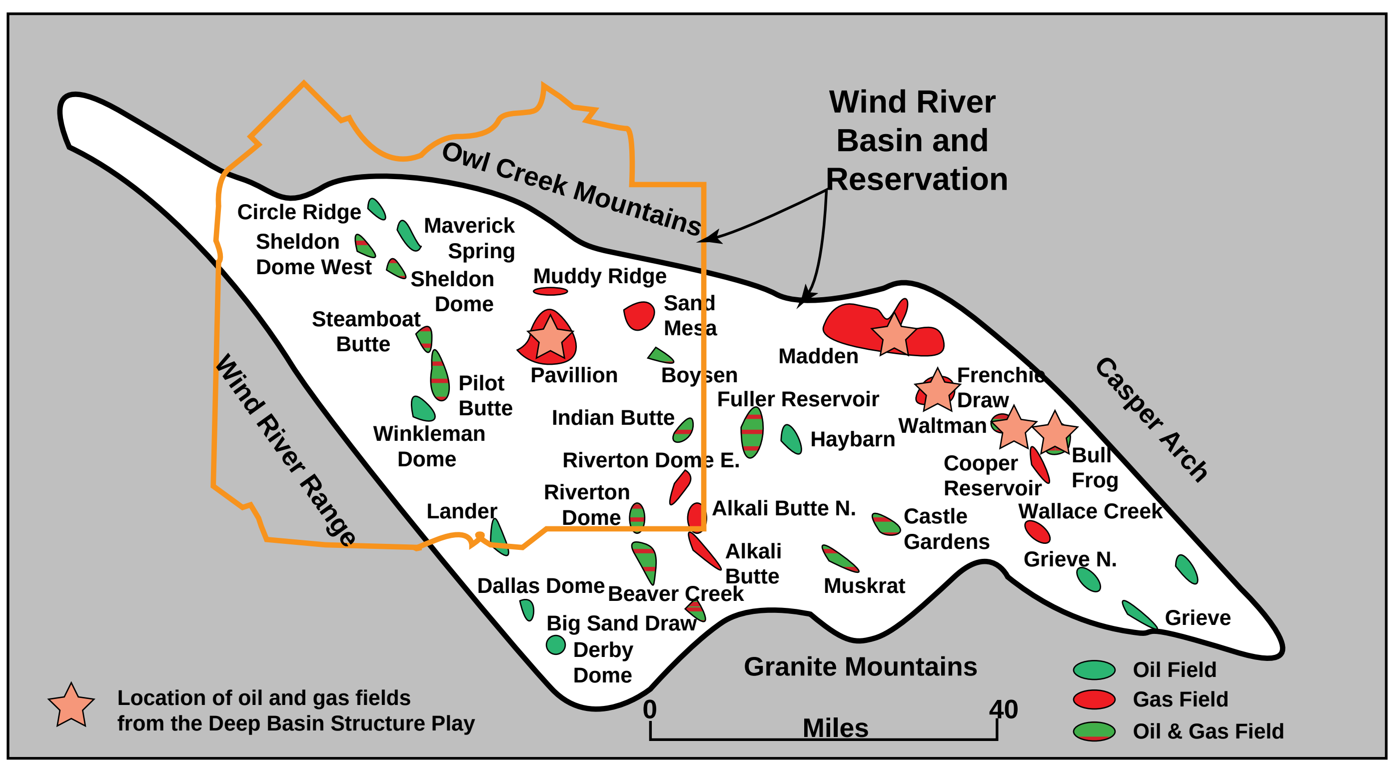


Figure WR-13.2 - Major field distribution in the Wind River Basin. Fields producing from Deep Basin Structure plays noted (from Johnson & Rice, 1993).

Pavillion Field
Wind River Basin
Datum - Fort Union Formation

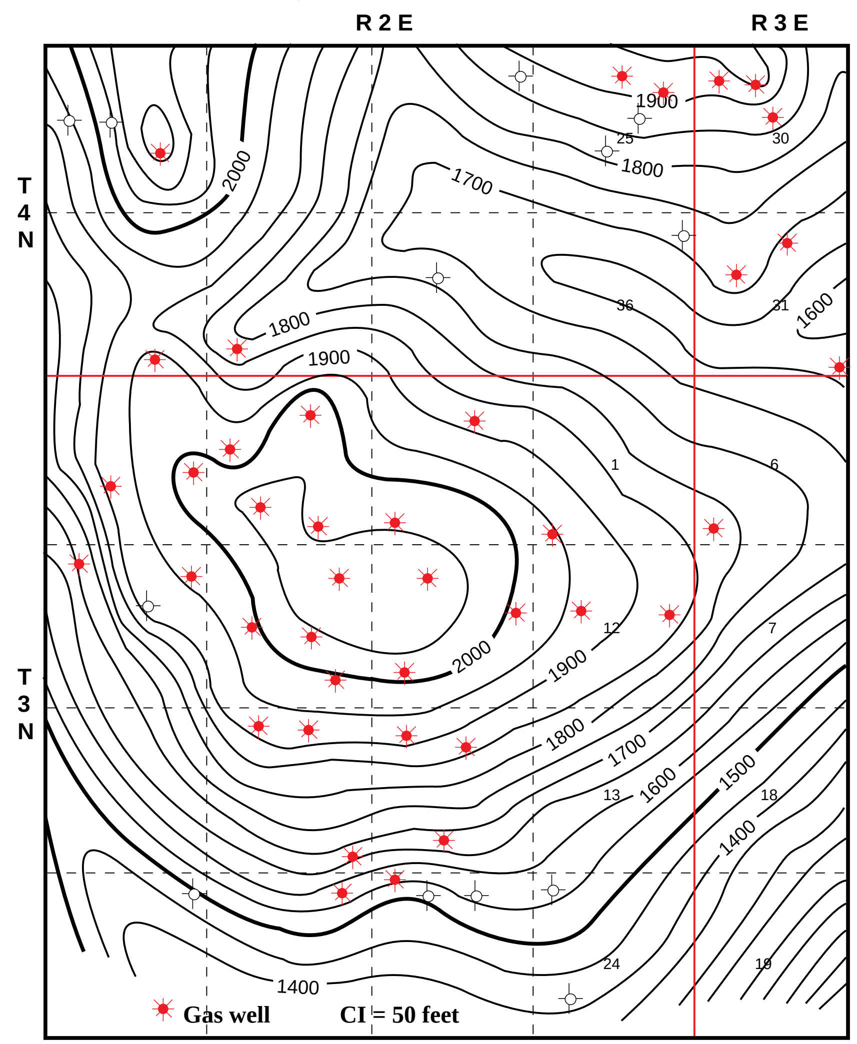


Figure WR-13.3 - Structure contour map of Pavillion Field. Datum is top of the Fort Union Formation. This structure illustrates the typical domal - anticlinal nose structural orientation of this play type. Note absence of major fault horizons - blind thrust probably at depth (after Wyoming Geological Assoc., 1982).

Pavillion Field Parameters

Formations:	Fort Union & Wind River Fm.
Lithology:	sandstone
Porosity:	20% av., range 4-28%
Permeability:	av. 3 md, range from 0.1 - 300 md
Pay thickness:	6-50 feet
Oil/Gas column:	400-500 feet
Gas/Oil Ratio:	almost 100% dry methane gas
Depths:	3000-12,000 feet subsea
Other:	Deeper pools in both Pavillion and Madden Fields have been found in the Miss. Madison, Cretaceous Frontier, Cody, and Mesaverde Formations.

PLAY TYPE 4

Muddy Sandstone Stratigraphic Play

This is a stratigraphic play with anticipated entrapment of oil/gas in updip pinchouts of discontinuous Muddy Sandstone bodies, deposited as a complex series of coastal/valley-fill sandstone horizons whose distribution is controlled by paleotopography and sea-level fluctuations. Actual outline of play area may be unknown due to subtle nature of some channel/coastline complexes on seismic (Figure WR-14.1).

The Muddy Sandstone and equivalent strata have produced more than 1.7 billion bbl of oil-equivalent hydrocarbons in the Rocky Mountain region. Production is controlled principally by unconformities formed during a relative sea level lowstand. Reservoirs are found in paleohills of older marine sandstones, younger valley fill and associated alluvial plain channel sandstones, and infilling transgressive marine deposits (see Figures WR-14.3 and WR-14.4).

Valley fill and channel reservoirs have produced at least 359 MMBOE, onlap cycles another 318 MMBOE, and older marine buried-hill reservoirs more than 269 MMBOE. The excellent reservoir characteristics and the high quality of oil (33-43 API gravity) make it a prime drilling objective. Porosity ranges from about 9% - 15% at depths to about 11,000 ft. Most reservoirs range between 20 - 52 ft. in thickness.

Migration from adjacent Mowry source rocks provides efficient pathways for fluid migration. This demonstrated play is heavily explored along the southern margin of the basin but is lightly explored in the central or western regions. Relatively new discoveries at Austin Creek (1988) and Sun Ranch (1987) indicate that additional exploration opportunities are possible.

The reservation area is ideally situated to capitalize on new target possibilities within this play. Application of improved seismic processing techniques, sequence stratigraphic principles, and fluid migration modeling could greatly enhance the future potential within this play type.

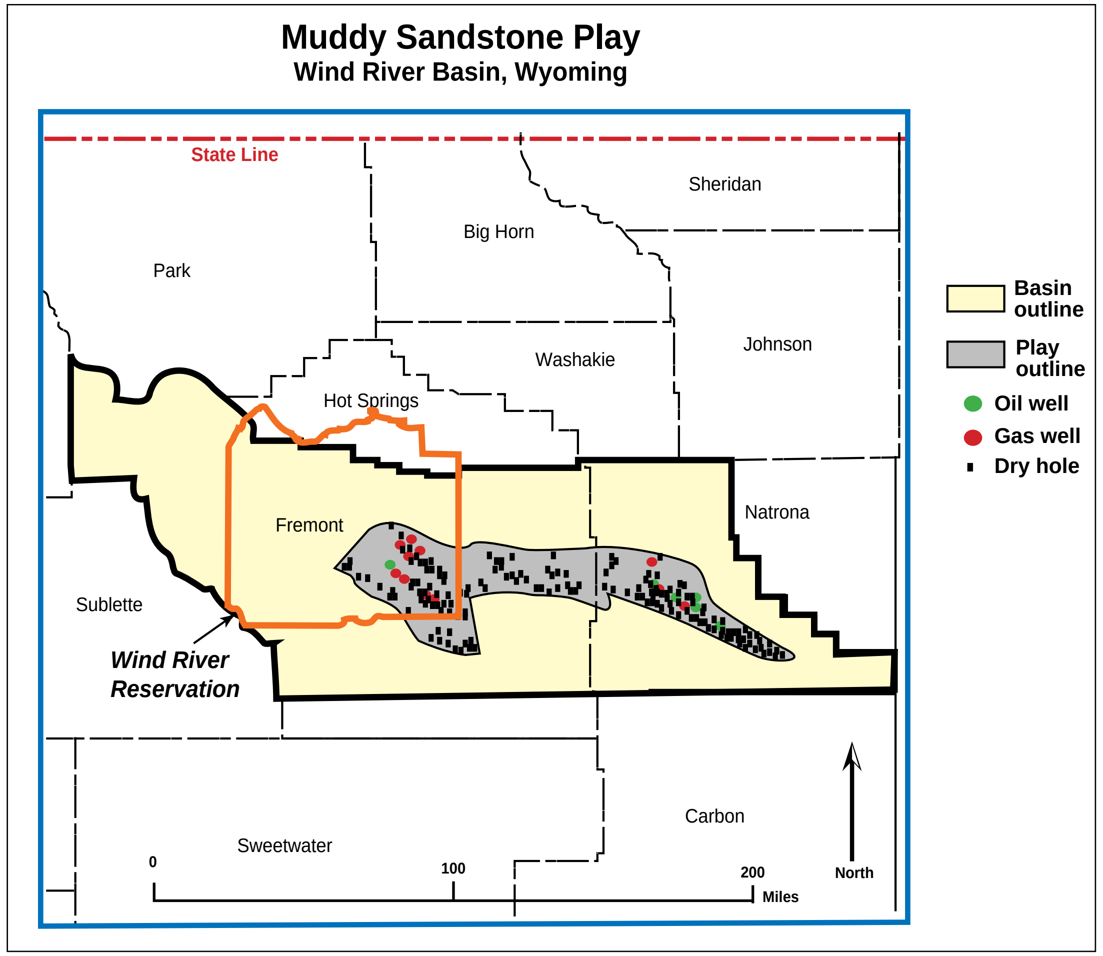


Figure WR-14.1 - Play outline for the Muddy Sandstone Play showing distribution of dry holes, oil and gas wells, and reservation outline (from U.S.G.S. 1995 National Hydrocarbon Assessment).

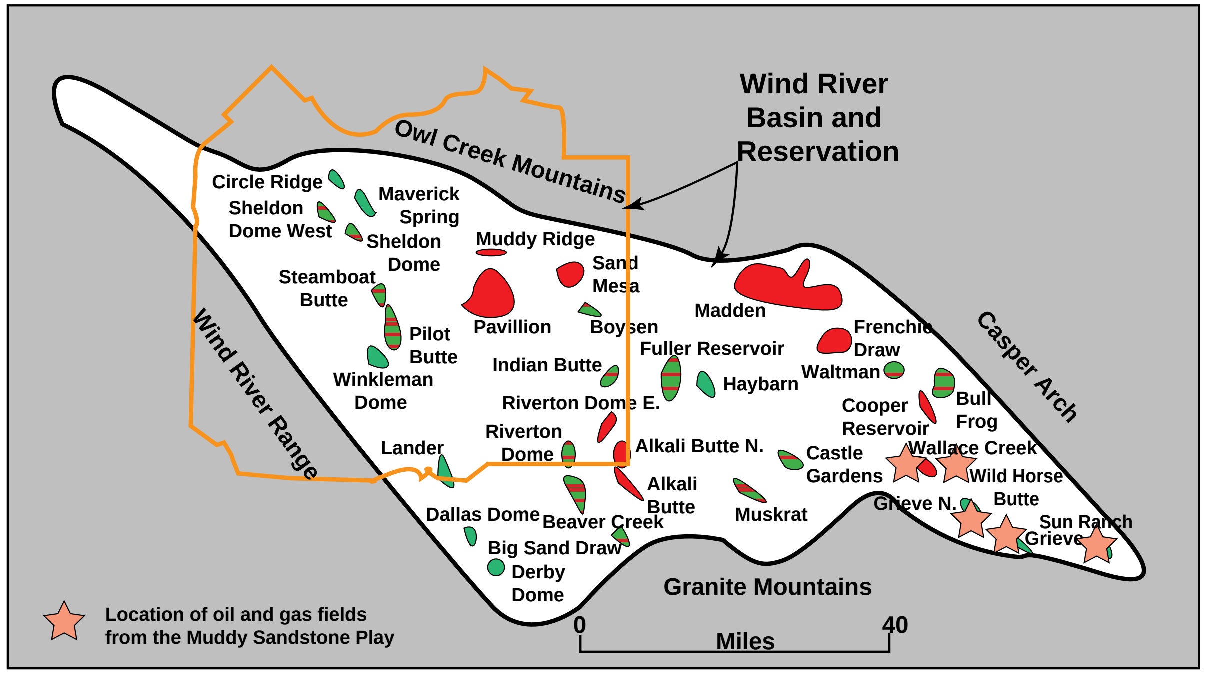


Figure WR-14.2 - Distribution of fields within the Wind River Basin that are producing from the Muddy Sandstone Play type. Small fields > 1 MMBO are not shown on diagram (modified from Johnson & Rice, 1993).

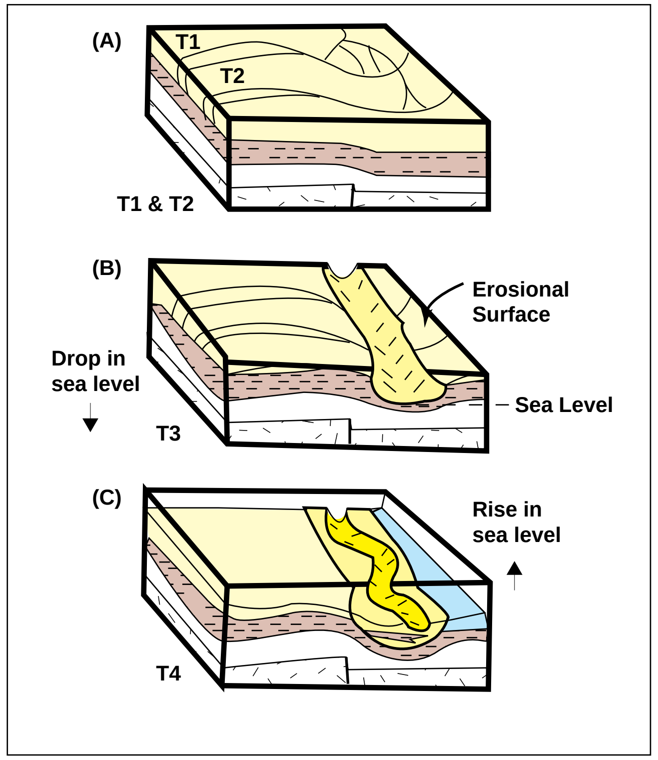


Figure WR-14.3 - Generalized alluvial valley model applicable to the Muddy Formation (Weimer, 1983). **(A).** Initial wave-dominated deltaic progradation during highstand **(B).** T3 time depicts truncation of older marine and deltaic deposits with continued sea level lowering **(C).** T4 time shows relative sea level rise and backfilling of valley networks with fluvial/ marine strata (Dolson, et al,1991).

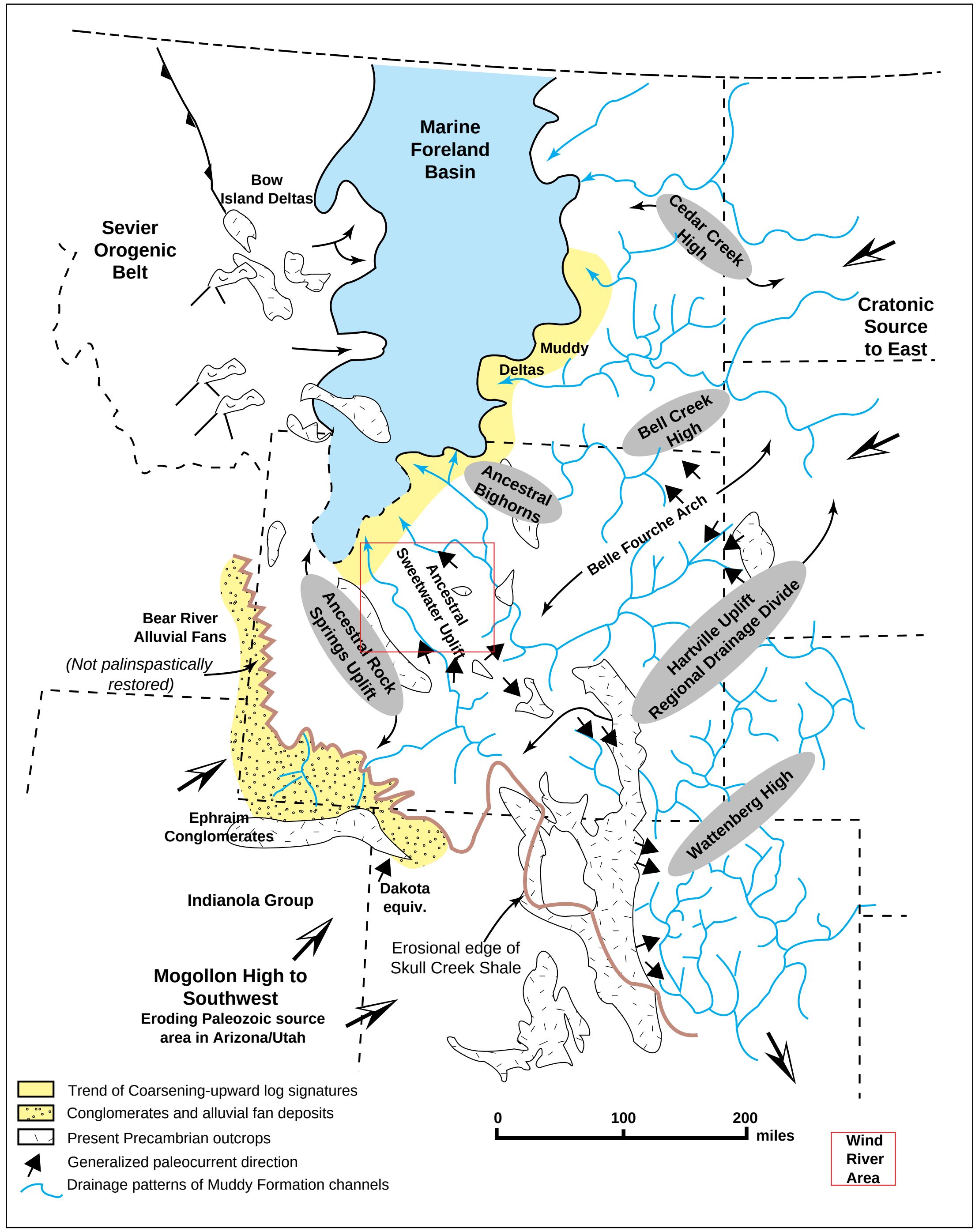


Figure WR-14.4 - Muddy Sandstone drainage networks developed at maximum sea level lowstand. Paleocurrent directions shown are derived from cross-bedding in fluvial strata. Note position of general reservation area relative to channel networks and deltas (from Dolson, et al, 1991).

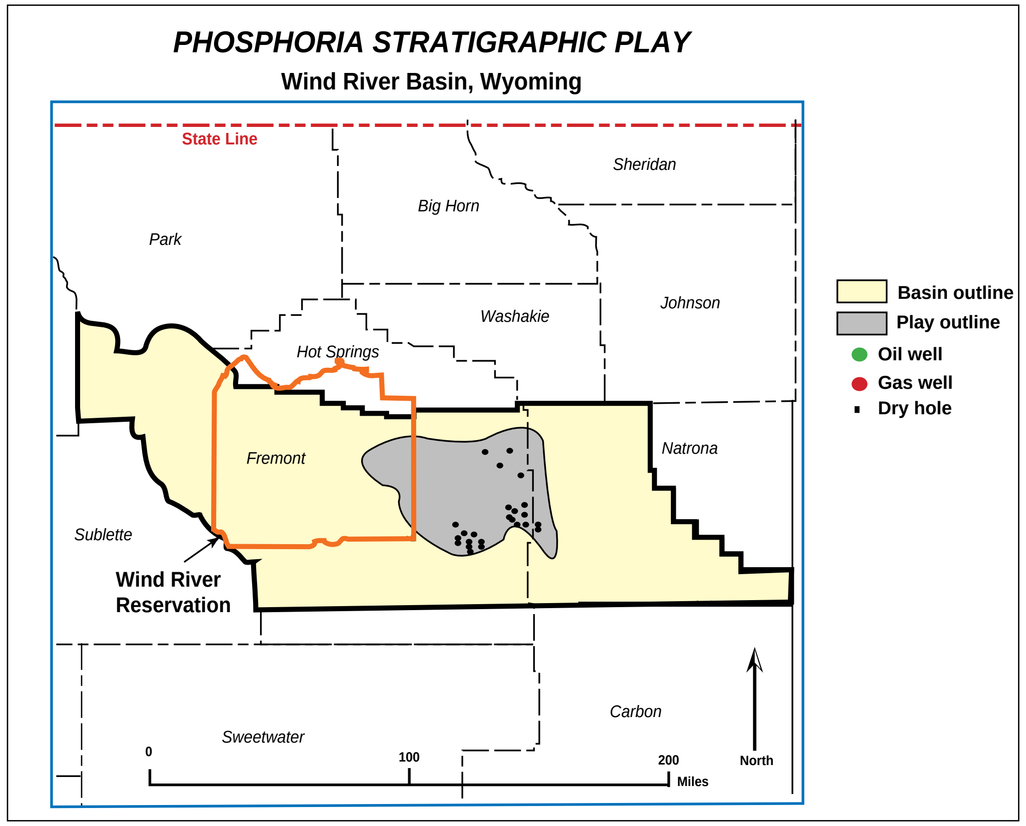


Figure WR-15.1 - Play outline for the Phosphoria Stratigraphic Play showing distribution of dry holes, oil and gas wells, and reservation outline (from U.S.G.S. 1995 National Hydrocarbon Assessment).

PLAY TYPE 5

Phosphoria Stratigraphic Play

High sulfur oil may be stratigraphically trapped in the Ervay Member of the Phosphoria Formation along a north-south transition zone from Phosphoria carbonates to the west and red shale and evaporites to the east (Fig. WR-15.2). The play area is located in the eastern Wind River Basin, limits of the play defined to the east by the eastern limit of the Ervay Member, to the west by the estimated limit of viable carbonate porosity, and to the north and south by Phosphoria outcrops (Fig. WR-15.1).

Potential reservoir intervals occur in the Ervay Member of the Phosphoria Formation. They are typically dolomitized grainstones and packstones, along with algal framework laminations containing abundant fenestrate porosity. These reservoir intervals formed in high-energy tidal and shoreline environments. Reservoir matrix porosities average about 10 percent, but are fracture enhanced due to generation of hydrocarbons in-situ. Reservoir thicknesses range between 25 - 75 feet.

The interbedded nature of the carbonate facies with known source facies in the Phosphoria may create efficient migration pathways into reservoir horizons. Exploration in this interval was initiated back in 1953 with the discovery of the Cottonwood Creek Field in the Bighorn Basin. This large field has known reserves of 59 MMBO and 42 BCFG. Subsequent discoveries in the Bighorn Basin have been small and infrequent. Exploration success in the Wind River Basin has been of limited extent, and only one or two very small accumulations have been found to date.

Stratigrapahic traps should occur near the edge of the carbonate facies in the Ervay Member; in porous, detrital reservoirs deposited within the high energy regimes of tidal channels on coastal tidal flat environments. Updip seals are provided by fine-grained carbonates of intertidal/supratidal origin. The facies change from carbonates to the west, to red mudstone/evaporites could be thought of as a regional/lateral sealing configuration. Depth to producing horizons could range from 2,000 - 20,000 feet.

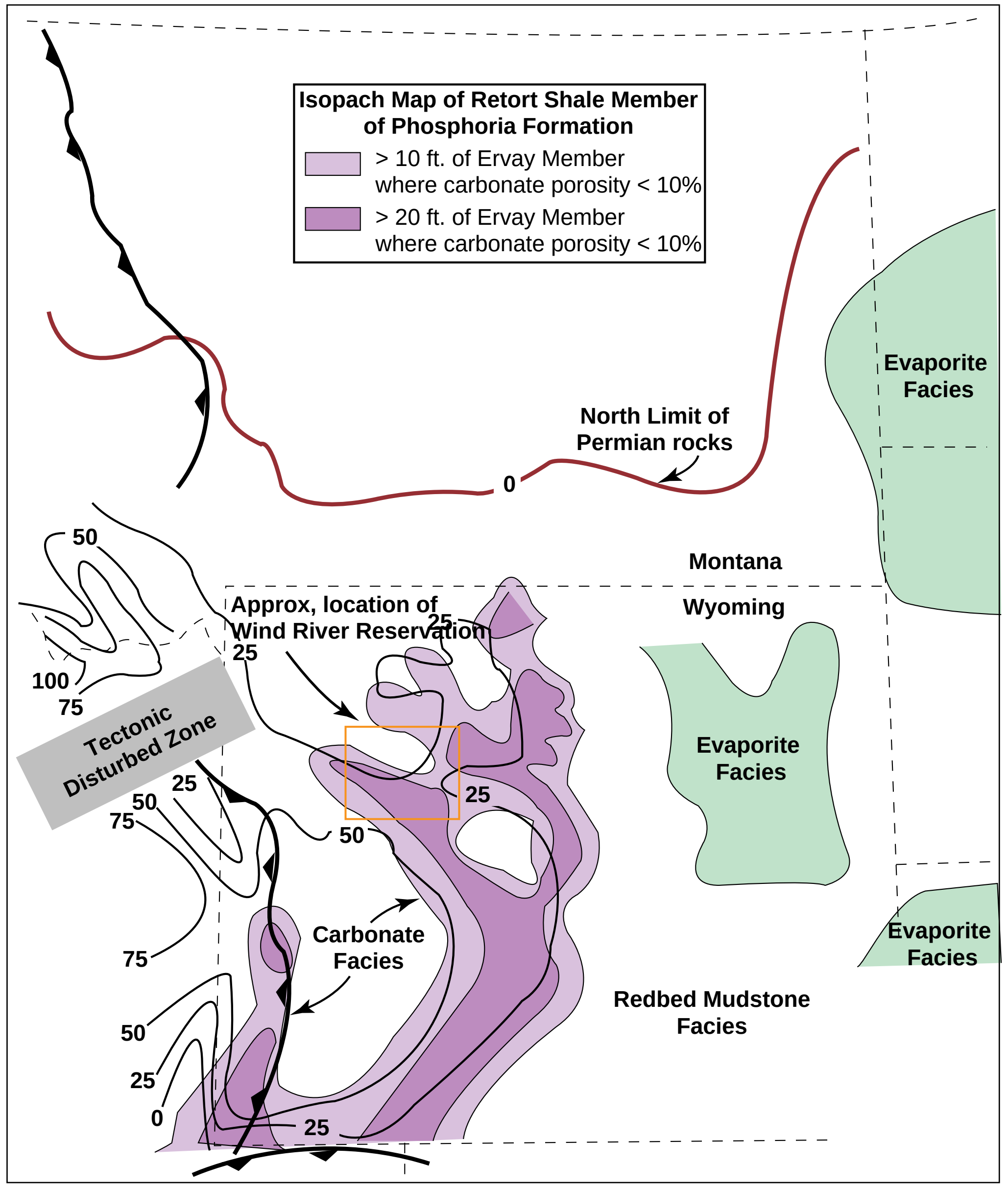


Figure WR-15.2 - Map showing thickness of Retort Phosphatic Shale Member of Phosphoria Formation (Lower Permian), and distribution of carbonate porosity greater than 10 percent in the Ervay Member (from J. Peterson, 1988).

PLAY TYPE 6

Bighorn Wedge-Edge Pinchout Play

This is a hypothetical play concept characterized by wedge-edge pinchouts of the Ordovician Bighorn dolomite against the base of the Madison Limestone (Fig. WR-15.3). This is a very high risk play with no known hydrocarbon occurrences or source rocks to occur near/within the potential trapping horizon.

Reservoirs in the Bighorn Dolomite could contain moderate-high porosities within an intergranular fabric. Dolomitized intervals within this formation are very common and anticipated to occur throughout most of the reservation area. Although regional truncation is demonstrated, the presence of traps at this unconformity horizon is undocumented.

PLAY TYPE 7

Flathead-Lander and Equivalent Sandstone Stratigraphic Play

This is a hypothetical play concept which involves hydrocarbons trapped in stratigraphic facies change/erosional truncation horizons within the Cambrian Flathead and Ordovician Lander Sandstones (Fig. WR-15.3). No known hydrocarbon occurrences or source intervals are known within these formations.

Potential reservoir intervals could occur in sandstones which are probably present throughout much of the reservation area. Quality of potential reservoirs may be poor due to diagenesis and compaction. The absence of known source intervals near these reservoir horizons implies that the chance of exploration success is minimal.

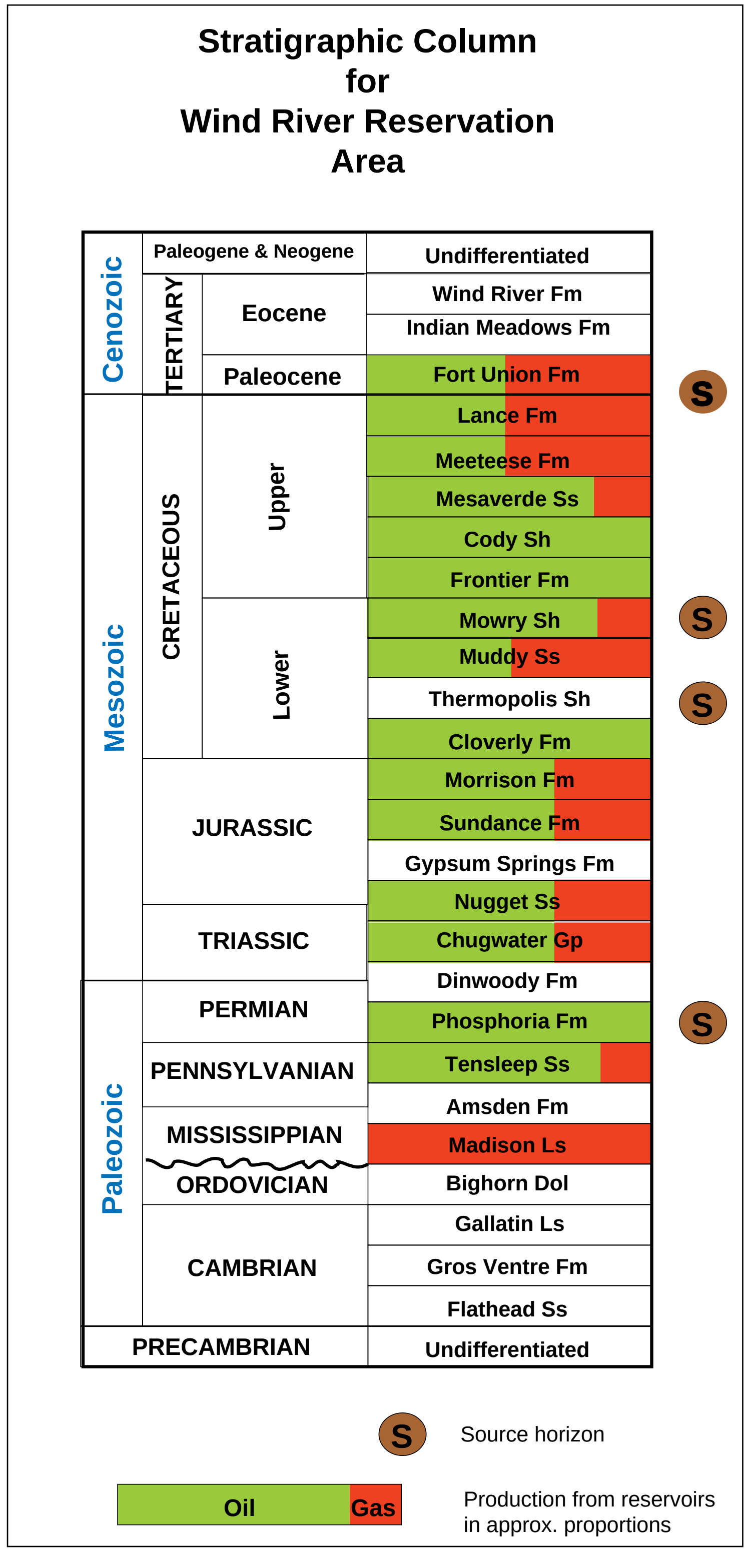


Figure WR-15.3 - Stratigraphic column for the Wind River Basin depicting general distribution of major source intervals and reservoir horizons.

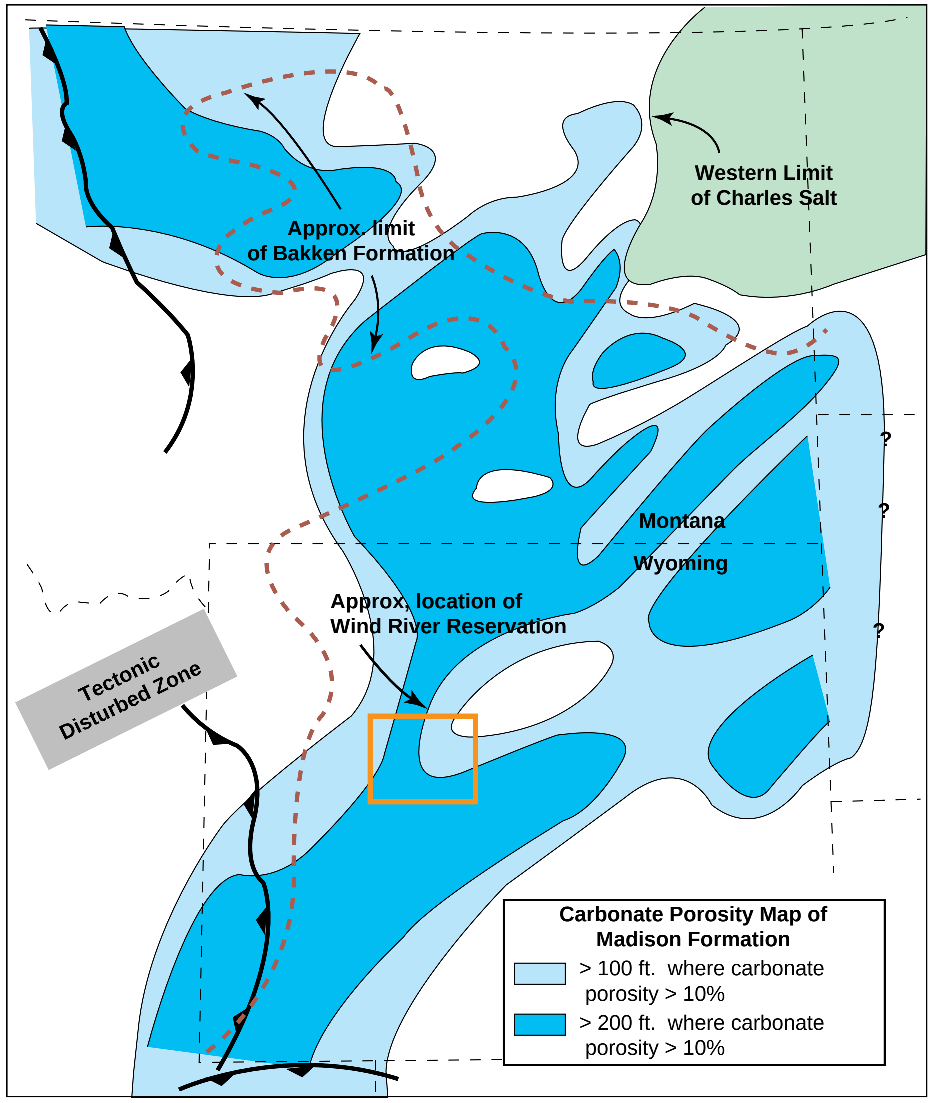


Figure WR-16.1 - Map showing distribution of net porosity greater than 10 percent in Madison carbonate rocks, approximate limit of Bakken Formation and equiv., and reservation area (after J. Peterson, 1988).

PLAY TYPE 10

Triassic and Jurassic Stratigraphic Play

This hypothetical play encompasses stratigraphic plays within the Chugwater Group, Nugget Sandstone, Sundance, and Morrison Formations. The Nugget Sandstone provides the best opportunity for commercial production from wedge-edge pinchouts and truncations in the eastern and northern portion of the Wind River Basin.

Potential reservoirs would include mostly sandstone with good porosity and permeability. Sealing horizons remain problematic as well as the presence of effective hydrocarbon charge.

Numerous shows and non-commercial accumulations have been found in these zones. They may act as migration pathways into other horizons. This play is classified as high risk and would require detailed stratigraphic/charge modeling to effectively explore for hydrocarbons from these intervals.

PLAY TYPE 8

Madison Limestone Stratigraphic Play

This hypothetical play encompasses possible hydrocarbons enclosed within or at the top of the Mississippian Madison Limestone. The trapping mechanism involves a combination of porosity variation and topography creation related to karst development.

Karstic, vuggy porosity carbonate intervals in the upper part of the Madison Limestone are expected throughout the play area (Figure WR-16.1). In some cases, these intervals may be fracture enhanced. The presence of sealing horizons above the Madison remain problematic. In addition, to charge these potential reservoirs requires fault juxtaposition of Phosphoria source against Madison. This requires advantageous timing of hydrocarbon generation, structural development, and migration.

No production exists utilizing this play concept within the Wind River Basin and the presence of effective traps has not been demonstrated. As a result, this play type is classified as very high risk owing to poor charge and trap potential. Detailed mapping of the Madison karst surface is required to evaluate the exploration potential within the reservation area.

PLAY TYPE 12

Cody and Frontier Stratigraphic Play

This hypothetical play would include deep oil and gas accumulations in stratigraphic traps from the Upper Cretaceous Cody and Frontier Formations. These sandstone/shale intervals are in thick marine sequences of shale and fine-grained sandstone.

Potential reservoir intervals of sheets of fine-grained sandstone are present throughout the reservation area. Although equivalent reservoirs are productive in structural settings, reservoir quality and effective traps in deeper, off-structural settings remain speculative.

Cretaceous source rock intervals in the Mowry Shale are interbedded with these potential reservoir horizons. A favorable hydrocarbon generation and migration history could charge these reservoirs if an effective trapping mechanism is present. The presence of traps of significant size have not been demonstrated. This play is characterized as high risk because of these issues.

PLAY TYPE 9

Darwin-Amsden Sandstone Stratigraphic Play

This hypothetical play consists of stratigraphic entrapment of oil in discontinuous sandstone lenses of the Pennsylvanian Darwin and Amsden Formations. Although no known traps exist within the Wind River Basin, these formations are productive elsewhere in structural settings.

Potential reservoir intervals in poor-moderately porous sandstones are believed to be present over most of the reservation area. Total interval thickness ranges between 100 - 300 feet (Figure WR-16.2). Variable quality of porosity and permeability are expected and may be modified by burial diagenetic processes.

Hydrocarbon charging of this interval is problematic and would require complex, structurally modified, migration pathways. In addition, poor seal quality is expected immediately above the horizon.

No production exists within this play type and it is classified as a high risk exploration target. Considerable variation of sandstone distribution and porosity exists within the interval; detailed facies mapping of the Amsden as well as detailed structural modeling would be required to effectively explore for hydrocarbons.

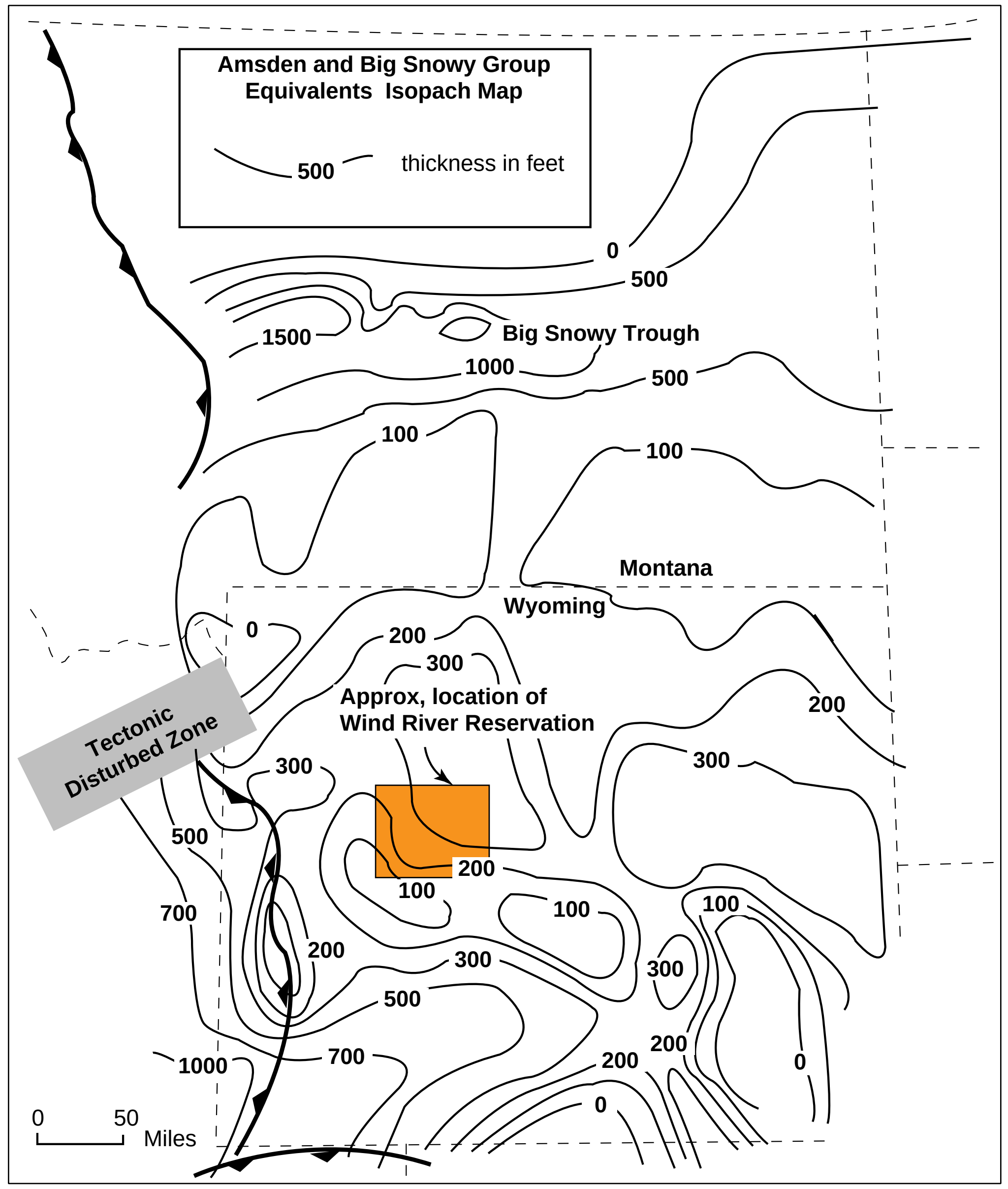


Figure WR-16.2 - Map showing thickness of Amsden Formation and Big Snowy Group equivalents (after J. Peterson, 1988).

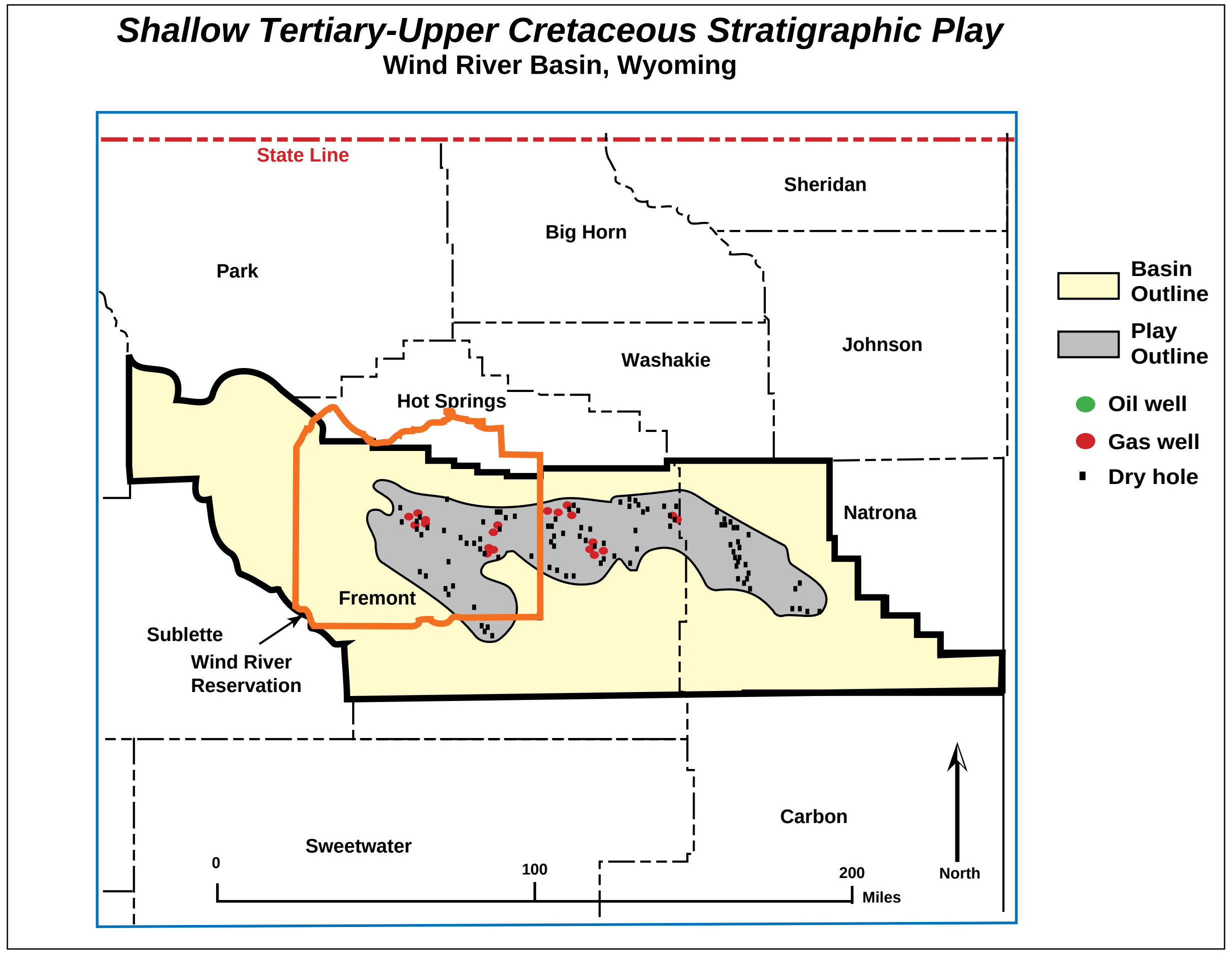


Figure WR-17.1 - Play outline for the Shallow Tertiary/Upper Cretaceous Stratigraphic Play showing distribution of dry holes, oil and gas wells, and reservation outline (from U.S.G.S. 1995 National Hydrocarbon Assessment).

PLAY TYPE 11

Shallow Tertiary/Upper Cretaceous Stratigraphic Play

Primarily a gas play, the shallow Tertiary and Upper Cretaceous reservoirs have also yielded liquids as well in these discontinuous, sandstone reservoirs. This play has been lightly explored for years and a number of small accumulations have been discovered within/outside the reservation area (Figures WR-17.1 and WR-17.2).

In general, the proven reservoirs include the Wind River, Fort Union, Lance and Mesaverde Formations (Figure WR-17.3). These clastic sandstone reservoirs have good-excellent porosity and permeability, however, most exhibit discontinuous, fluvial reservoir architecture (Figure WR-17.4). Source horizons are underlying/interbedded Cretaceous/Paleocene shales and coals. Humic-rich coal horizons may be contributing to the gas charge as well as other shale zones with abundant Type III kerogen mixtures (Figure WR-17.2). In some instances, oil from the Waltman Shale has accumulated in reservoirs of Upper Cretaceous through Eocene age.

Facies changes and local erosional unconformities associated with channel migration are the typical trapping mechanisms for these fluvial reservoirs. They are typically alluvial/fluvial sandstones that form localized channel bodies of limited areal extent (Figure WR-17.4). Traps are small and sometimes occur in combination with structural enhancement. Seals are provided by associated fine-grained overbank shales. Fluid migration is primarily vertical.

Stacking of multiple reservoir horizons is enhanced when the underlying Cretaceous Mesaverde Formation is unconformably overlain by younger Paleocene reservoirs. This also allows more efficient migration from source horizons within Upper Cretaceous/Paleocene intervals (Figure WR-17.5).

System	Series	Stratigraphic Unit or event	Thickness (in feet)	Ages (Ma)
Tertiary	mid-Mio. to present	uplift and erosion	-3,380	15 - 0
	Miocene	Split Rock Formation	900	24 - 15
	Oligocene	White River Formation	500	36 - 24
	Eocene	Post lower Eocene rocks-undivided	1,980	55 - 38
		Wind River and Indian Meadows Formations undifferentiated	4,625	
	Paleocene	Fort Union Formation: Shotgun Member	2,175	59 - 55
		Fort Union Formation: Waltman Shale Member	840	60 - 59
		Fort Union Formation: Lower member	1,350	66 - 60
Cretaceous	Upper	Lance Formation	2,200	74 - 66
		Meeteese Form.	800-1,000	79 - 74
		Mesaverde Form.	1,200-1,800	84 - 79

Figure WR-17.3 - Stratigraphic column of Tertiary/Upper Cretaceous stratigraphy in the reservation area of the Wind River Basin. Position of potential source interval is depicted in brown and intervals containing coal are depicted in dark gray (modified from Nuccio, V., 1994).

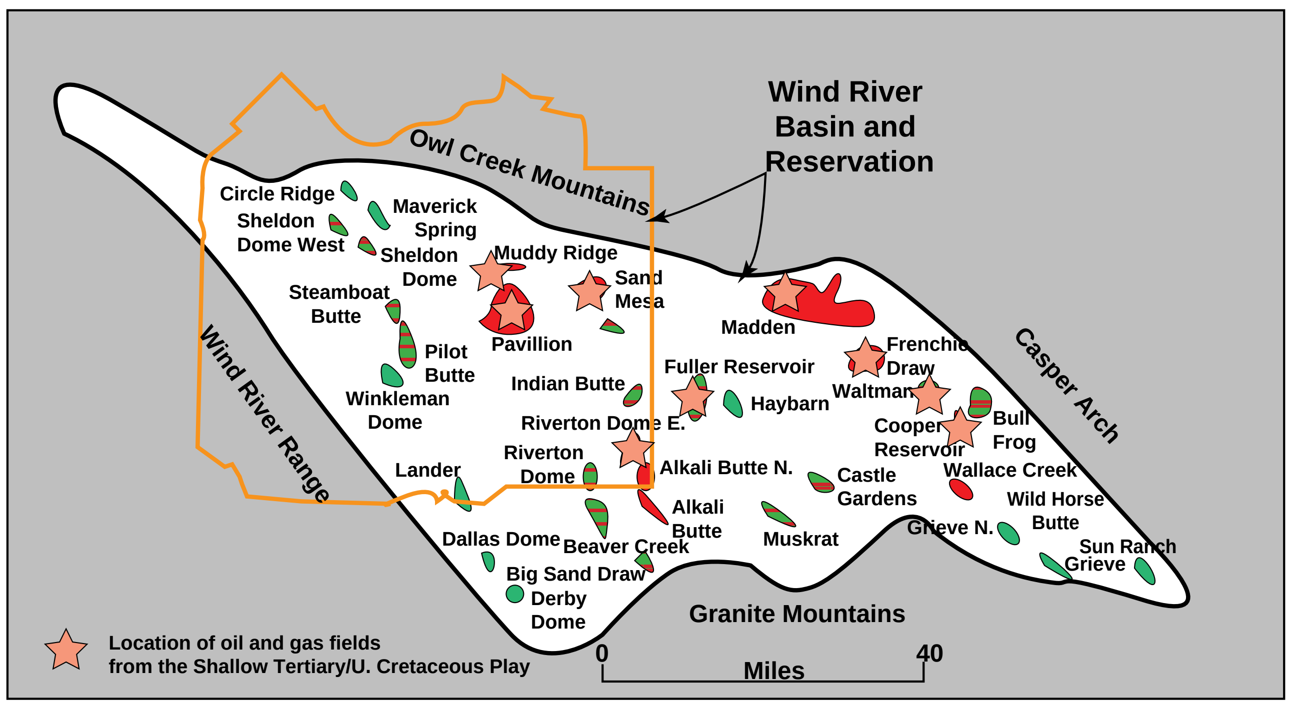


Figure WR-17.2 - Distribution of fields within the Wind River Basin that are producing from the Shallow Tertiary/Upper Cretaceous Play type. Small fields > 1 MMBO are not shown on diagram (modified from Johnson & Rice, 1993).

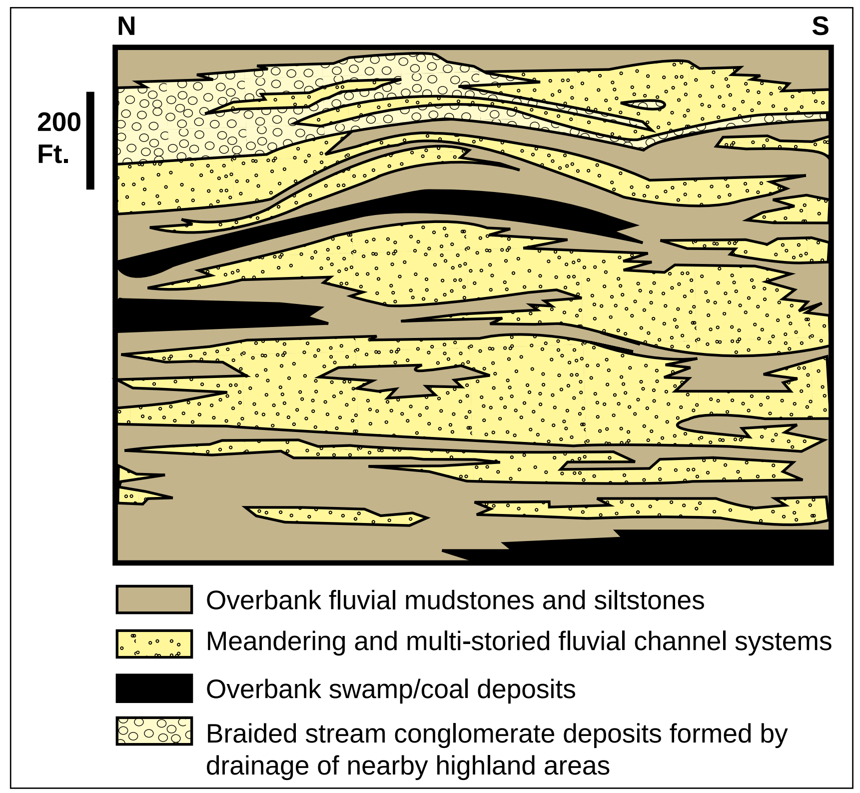


Figure WR-17.4 - Diagram showing typical stratigraphic framework and reservoir anisotropy of Paleocene Fort Union Formation. Note distribution of coal and potential reservoir intervals (modified from Flores & Keighin, 1993).

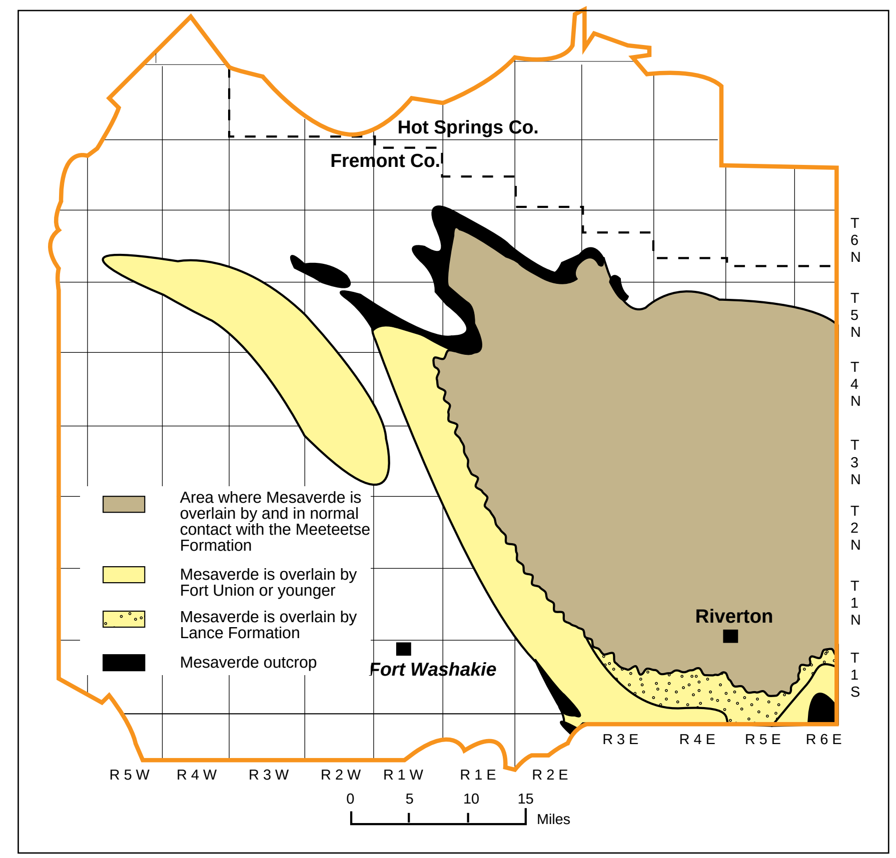


Figure WR-17.5 - Map showing distribution of Mesaverde Formation within the Wind River Reservation. Juxtaposition against shallower horizons facilitates migration of hydrocarbons (from Keefer & Johnson, 1993).

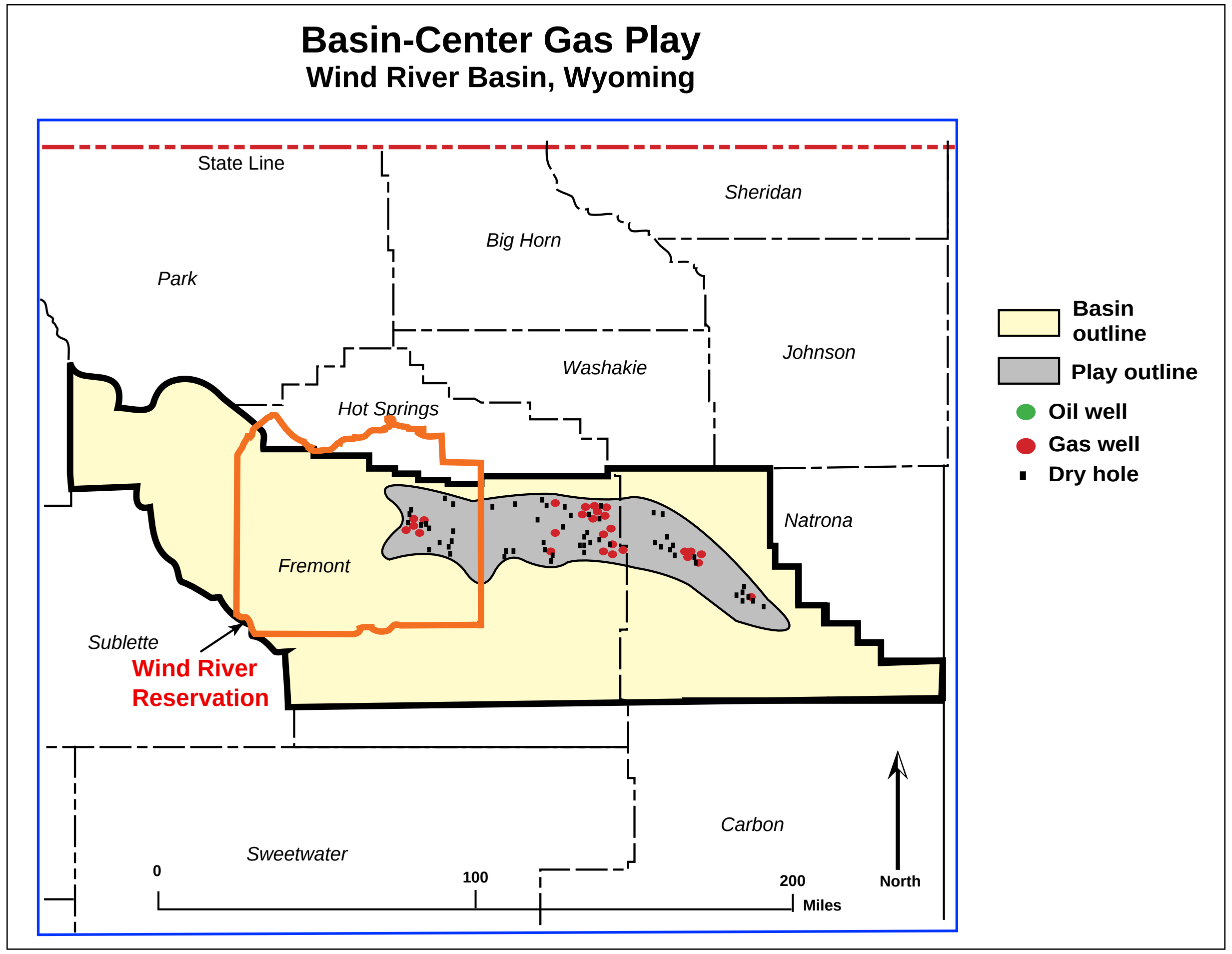


Figure WR-18.1 - Play outline for the Basin-Center Gas Play showing distribution of dry holes, oil and gas wells, and reservation outline (from U.S.G.S. 1995 National Hydrocarbon Assessment).

PLAY TYPE 13

Basin-Center Gas Play

This play is characterized by an extensive and continuous overpressured gas accumulation trapped in low permeability Paleocene and uppermost Cretaceous sandstone reservoirs in the deep parts of the Wind River Basin (Figure WR-18.1). The play exists because the active generation of gas from source intervals in the deep part of the basin creates overpressuring. This allows reservoirs to be charged that would otherwise be non-reservoir intervals due to low permeability and porosity.

Principal reservoirs are sandstone beds in the Fort Union, Lance and Mesaverde Formations. They are generally arkosic or lithic in composition, with poor to modest porosity and low permeability (Table WR-18.1). Within the reservation area the reservoirs could be of three types; alluvial-fluvial sandstone bodies with channels of limited areal extent, marine sandstone intervals with a more blanket-like character, and overbank siltstone/silty sandstone crevasse splay deposits.

Trapping mechanisms for this play concept are depicted in Figure WR-18.2. This play will only be viable if active generation is occurring to continuously replenish the reservoir intervals since most sealing intervals are 'leaky' with respect to gas in these environments. Transient sealing mechanisms are common in deep, basin-center accumulations.

Since active generation is occurring from most of the Tertiary/Upper Cretaceous humic-rich coals and shales, timing is extremely favorable with reference to the interbedded potential reservoir intervals. Overpressuring which is one result of the active generation of gas appears to generally coincide with Ro=1.0% burial indicator. This maturation indice is usually reached at about 10,000 feet. Therefore, those Tertiary andUpper Cretaceous intervals below this subsea elevation could be considered potential exploration targets.

The limiting factors regarding the development of these reservoirs are principally economic; the price of gas and expense associated in developing reservoirs with significant internal compartmentalization. Therefore, this play is considered high risk even though active generation from source intervals is occurring at the present time.

Table WR-18.1	Conventional Gas Sandstone	'Tight' Gas Blanket/Lenticular Sandstone (Low Pressure Reservoir)	'Tight' Gas Blanket Siltstone, Silty Shale (High Pressure Reservoir)
Porosity (%)	14 - 25+	3 - 12+	10 - 30+ in individual siltstone laminations
Porosity Type	Primary (intergranular), some secondary	Common secondary (microvug), some intergranular	Dominantly primary, some secondary
Porosity Communication	Good-excellent. short pore throats	Poor, relatively long, sheet/ ribbonlike capillary system	Good, short pore throats, but gas impeded by clays, small size of pores, and high Sw
Relative Clay Content in Pores	Low	High to moderate	Low to High
Water Saturation (%)	25 - 50	45 - 70+	40 - 90 approximate
In-Situ Permeability to Gas (md)	1.0 - 500+	0.1 - 0.0005	<0.1
Capillary Pressure	Low	Relatively high	Moderate
Grain Density (g/cm3)	2.65	2.65 - 2.74+ average; 2.68 - 2.71 in siltstone	Unknown, probably 2.65 - 2.70
Reservoir Pressure	Usually normal-underpressured	May be under-overpressured	Overpressured (relative)
Recovery of Gas in Place (%)	75 - 90	<15 - 50 estimated low for individual reservoirs	Unknown, probably low

(from C. Spencer,1989)

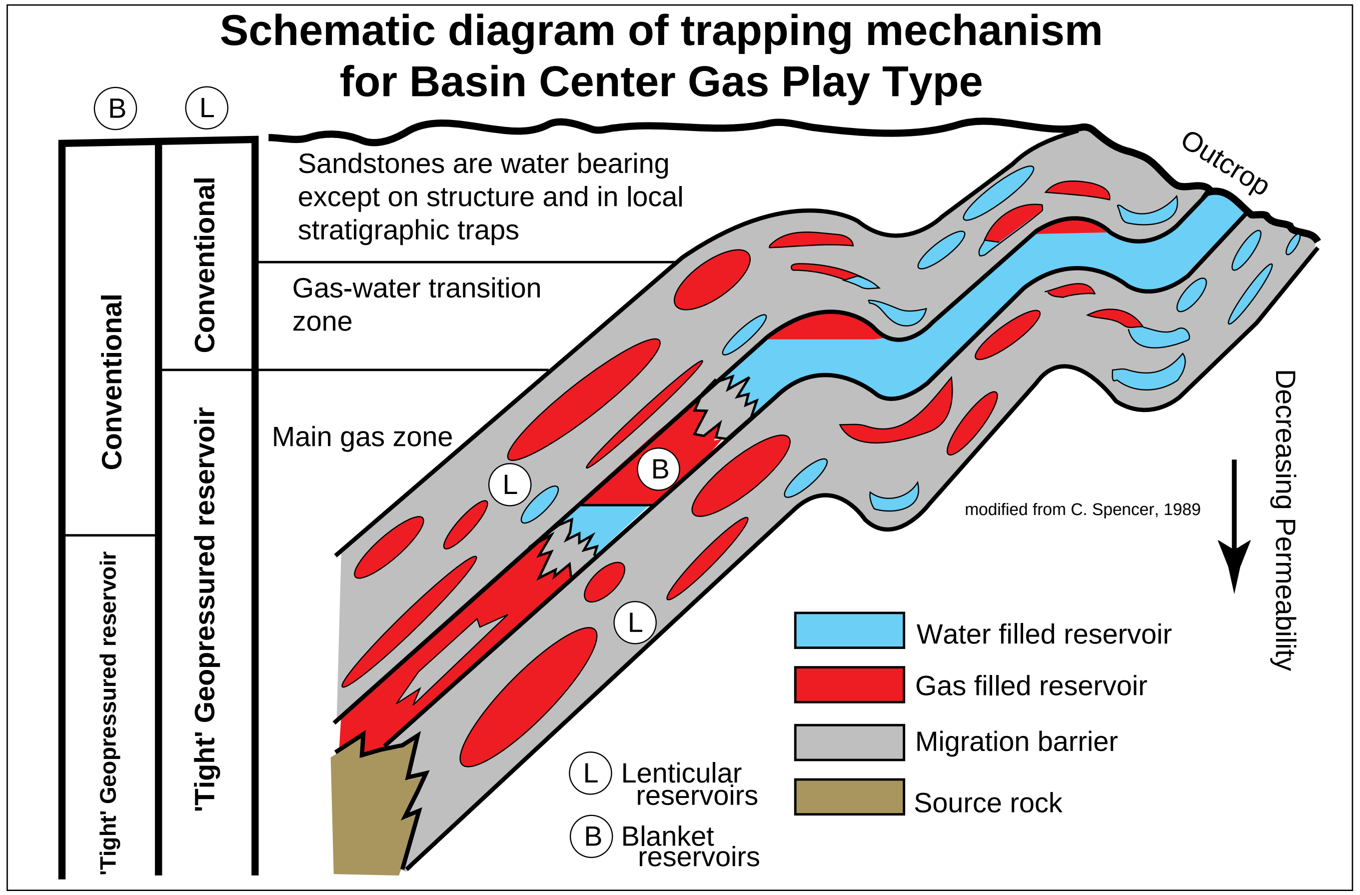


Figure WR-18.2 - Generalized schematic cross-section showing general distribution of gas and water in conventional and 'tight' lenticular and 'tight' blanket reservoirs. Note that conventional reservoirs have gas-water contacts while the low-permeability reservoirs do not. A source interval that is still in the active generation stage is needed to charge and 'overpressure' the low-permeability reservoir horizons (after C.W. Spencer, 1989).

Wind River
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