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 (Figure 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 (Figure WR-10.3). 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 an 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 (Figure WR-11.2). Care must be taken in evaluating the hydrodynamic conditions of potential targets in this play type.

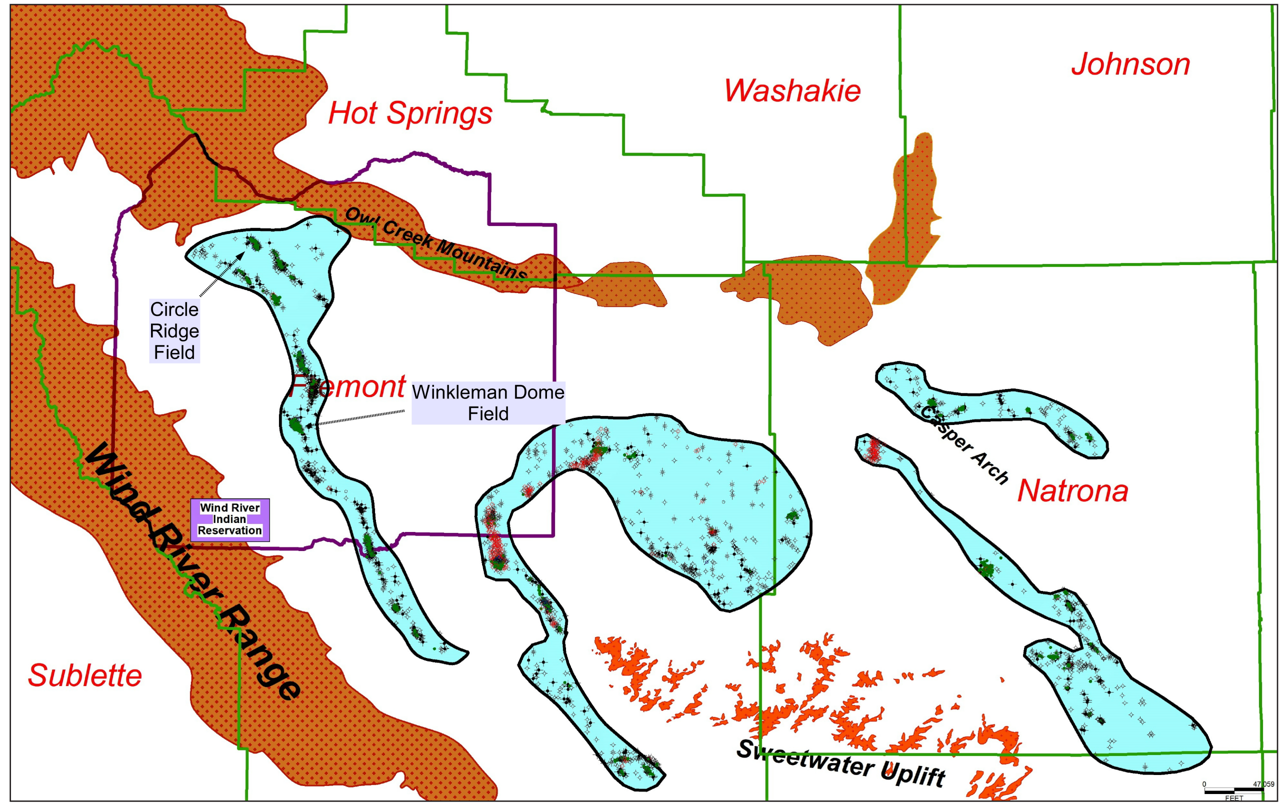

FIGURE WR-11.1. Play outlines for the Basin Margin Anticline Play in the Wind River Basin. Approximate locations of well penetrations in play area noted (modified after U.S.G.S. 1995 National Assessment).

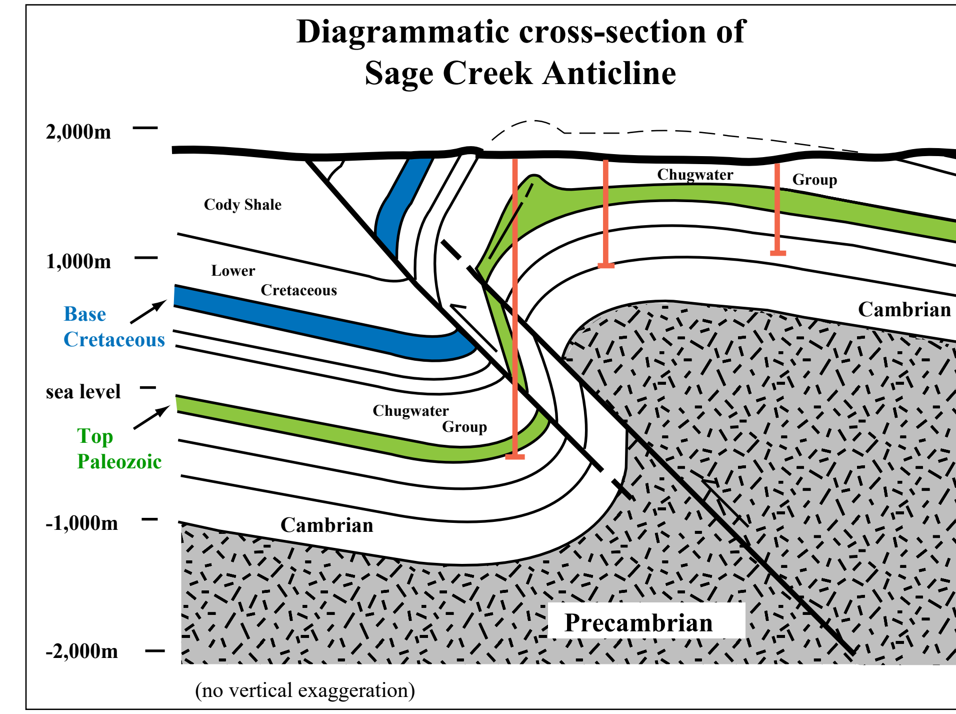

FIGURE WR-11.4. Basement-involved fold-thrust structure development. Subsidiary fault development, usually detachment features. Example of complex fault-propagation fold model typical of foreland uplifts (modified from Willis & Groshong, Jr., 1993).

Major Fields Located Within Reservation

Riverton Dome	4 MMBO	225 BCFG	Lander	17.5 MMBO
Steamboat Butte	95 MMBO	14 BCFG	Pavillion	321 BCFG
Winkleman Dome	92 MMBO	2.3 BCFG	Maverick Springs	18 MMBO
Circle Ridge	30 MMBO		Muddy Ridge	155 BCFG

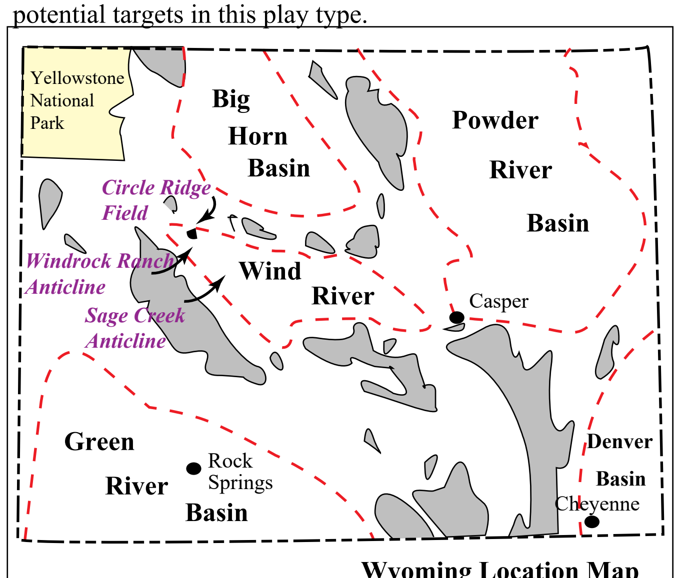

FIGURE WR-11.3. Location map for areas depicted on page (modified after Anderson & O'Connell, 1993).

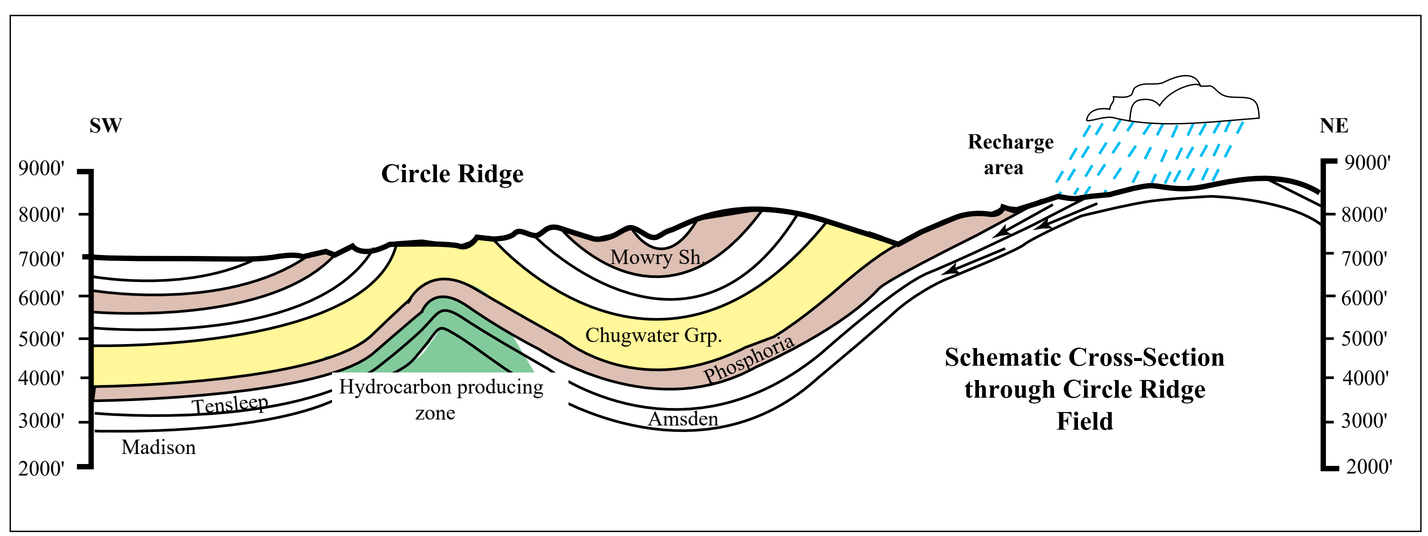

FIGURE WR-11.2. Generalized cross section from southwest to northeast through northern portion of Circle Ridge Anticline showing its topographic and hydrodynamic setting. Faults not shown; no vertical exaggeration (modified after Anderson & O'Connell, 1993).

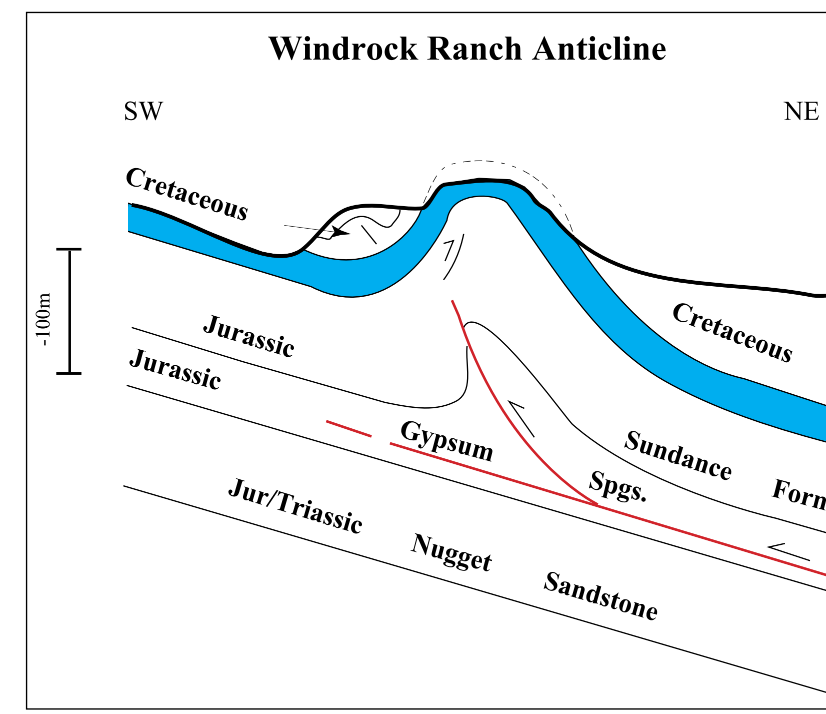

FIGURE WR-11.5. Example of basement-detached folding and faulting in Laramide-aged structures. Note development of smaller-scale anticline/syncline pair (pop-out anticline) developed in the center of syncline. Example of fold-thrust deformational style typical of foreland uplifts (modified after Willis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

BASIN MARGIN ANTICLINE PLAY (continued)

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-16.1). 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-16.2). 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-16.1 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-16.3 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.

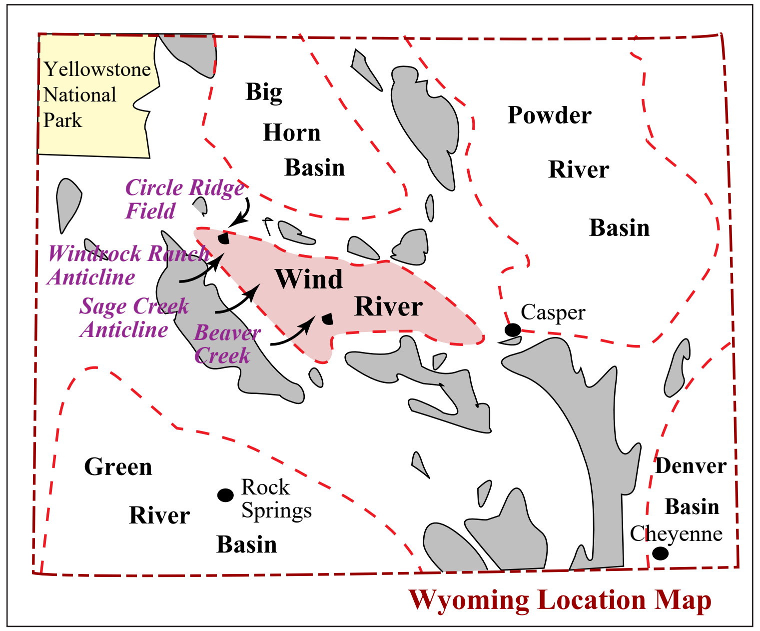

FIGURE WR-16.2. General location map showing position of Wind River Basin and Circle Ridge Field.

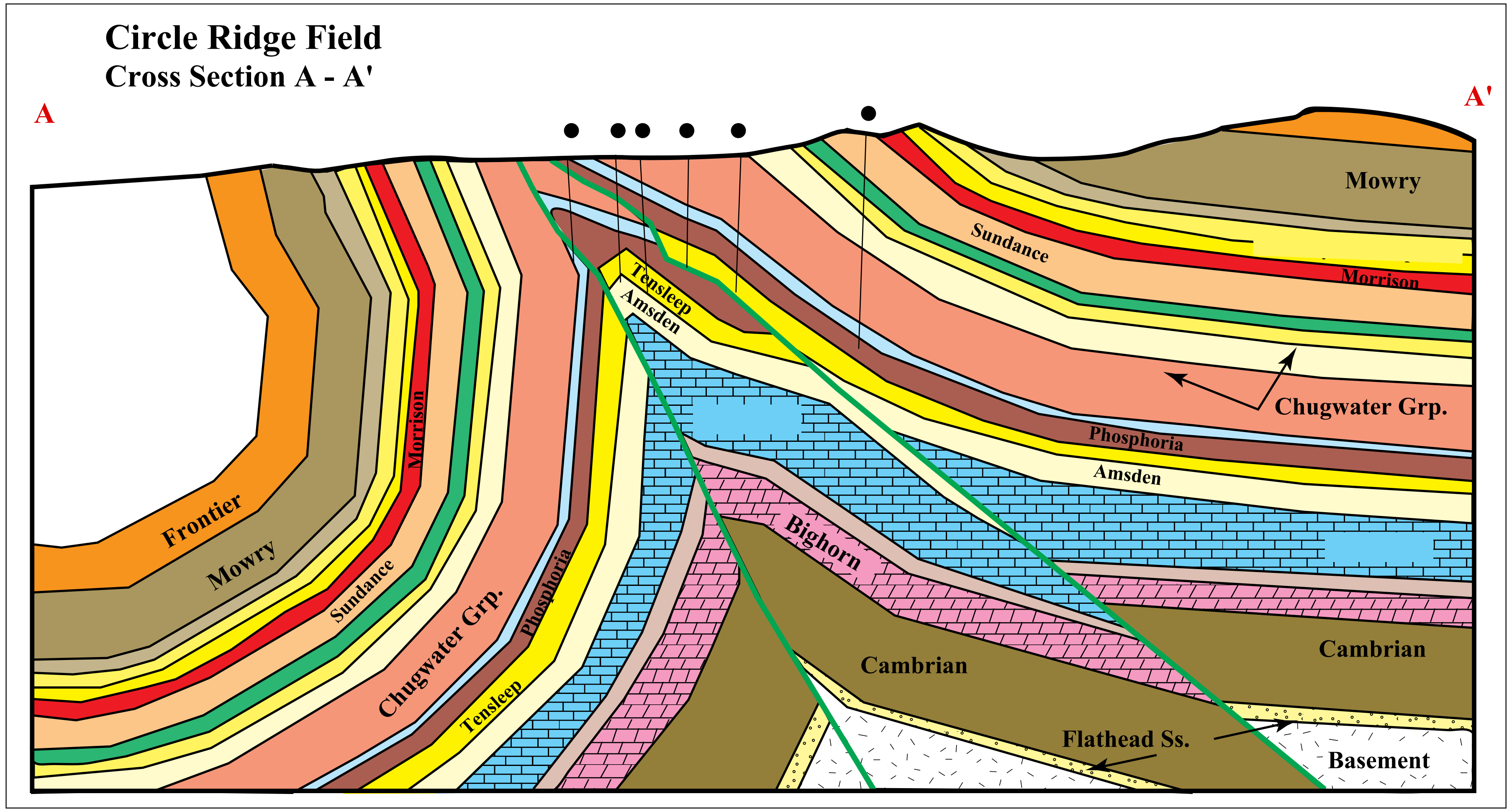

FIGURE WR-16.1. Stratigraphic/structural reconstruction of outcrop and well data through a northern cross-section of Circle Ridge Field. See Figure WR-12.2 for cross-section location. This field is typical of the basin margin anticline structures found in this play. Multiple reservoir horizons, compartmentalized reservoirs and flow units, and complex fluid pathways are common in this type of play (modified after Anderson & O'Connell, 1993).

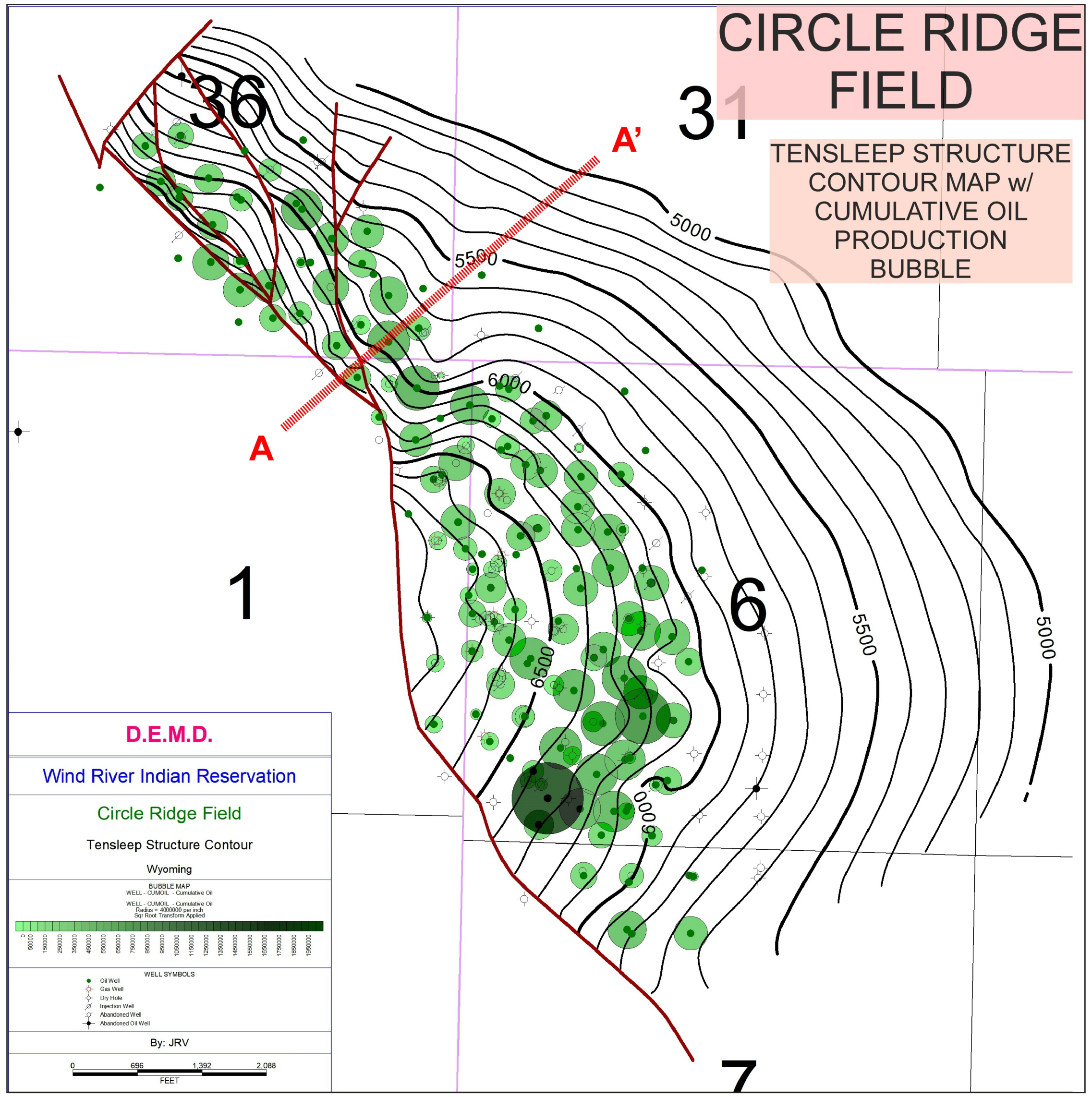

FIGURE WR-16.3. Structure contour map of Circle Ridge Field on top of the Tensleep Formation. Shows position of thrusts at depth, compartmentalized behavior of reservoirs, and fairly simple structural closure at 'deep' Tensleep level (modified after Anderson & O'Connell, 1993).

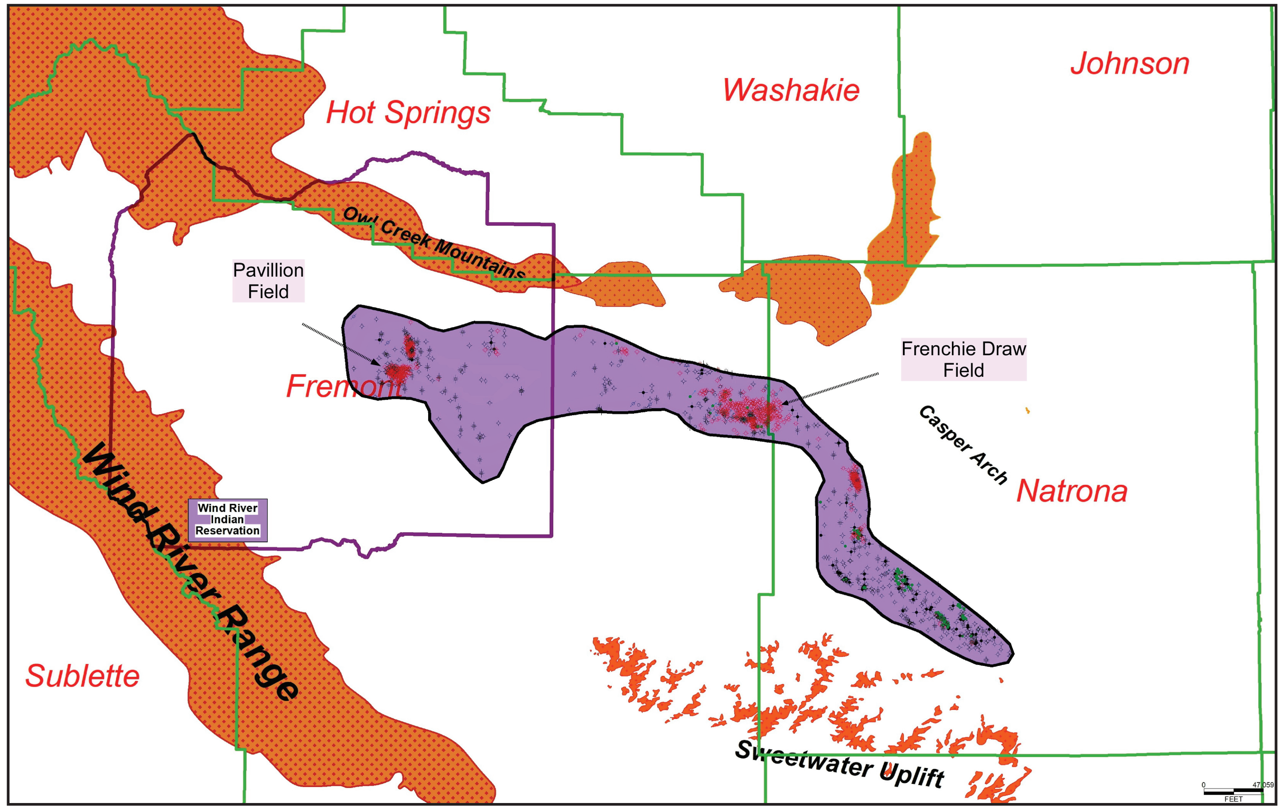

FIGURE WR-17.1. Well distribution, play outline, and location of the Deep Basin Structure Play in the Wind River Basin (modified after U.S.G.S. 1995 National Assessment).

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 (Figures WR-17.1 and 17.2). 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 the Lance, Fort Union, Wind River, and Mesaverde Formations (Figure WR-17.3). 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 remobilized 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. Pavillion (321 BCFG), Cooper Reservoir (56 BCFG), and Frenchie Draw (327 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.

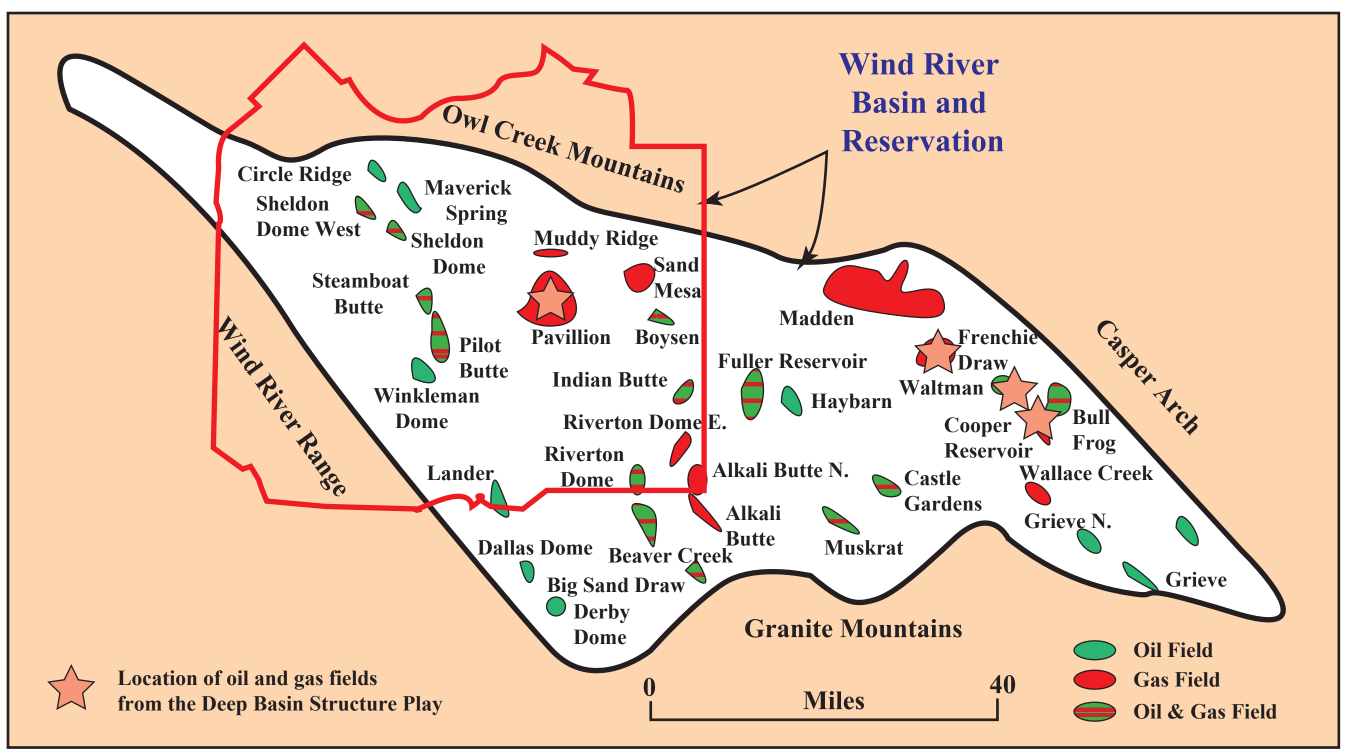

FIGURE WR-17.2. Major field distribution in the Wind River Basin. Fields producing from Deep Basin Structure plays noted (modified after Johnson & Rice, 1993).

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.

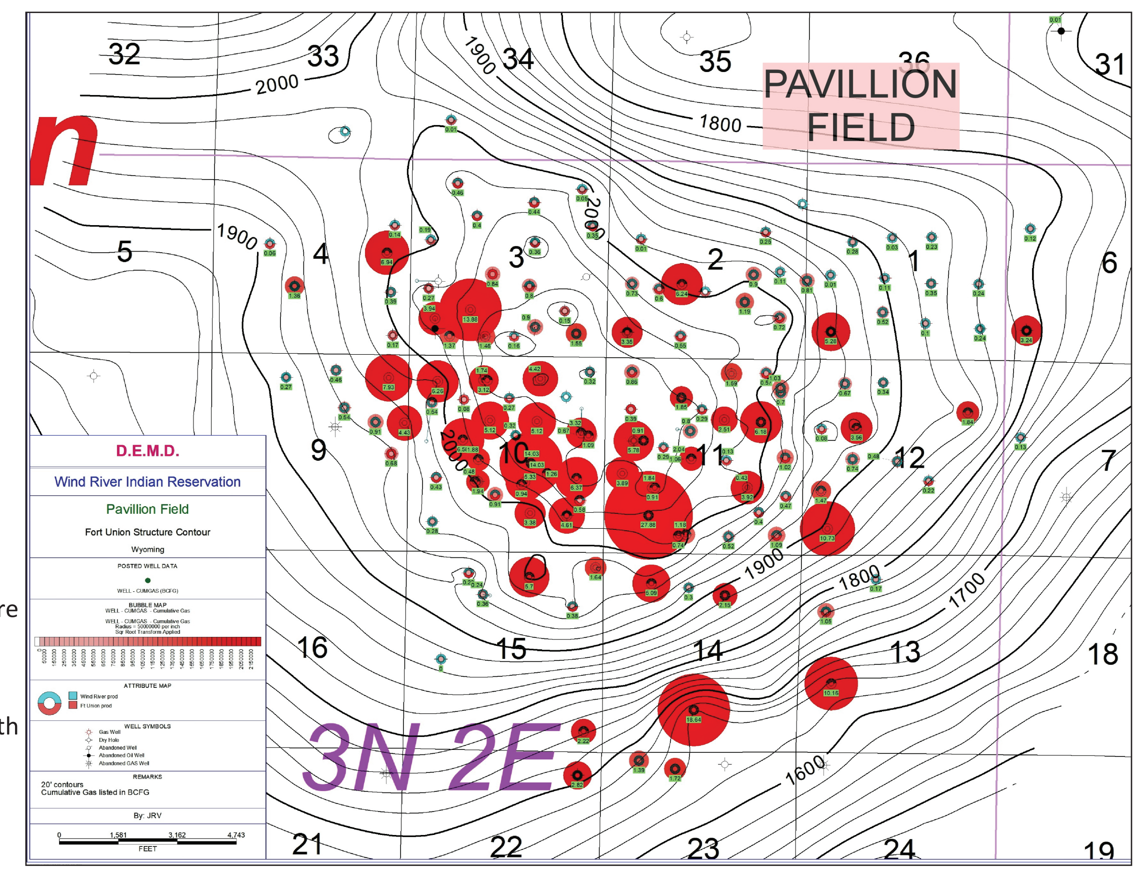

FIGURE WR-17.3. Structure contour map of Pavillion Field. Datum is top of the Fort Union Formation. This structure illustrates the typical domal - anticlinal nose structural orientation of this play type. Note absence of major fault horizons - blind thrust probably at depth (modified after Wyoming Geological Assoc., 1982). Cumulative gas bubble overlay. Gas is shown in BCFG.

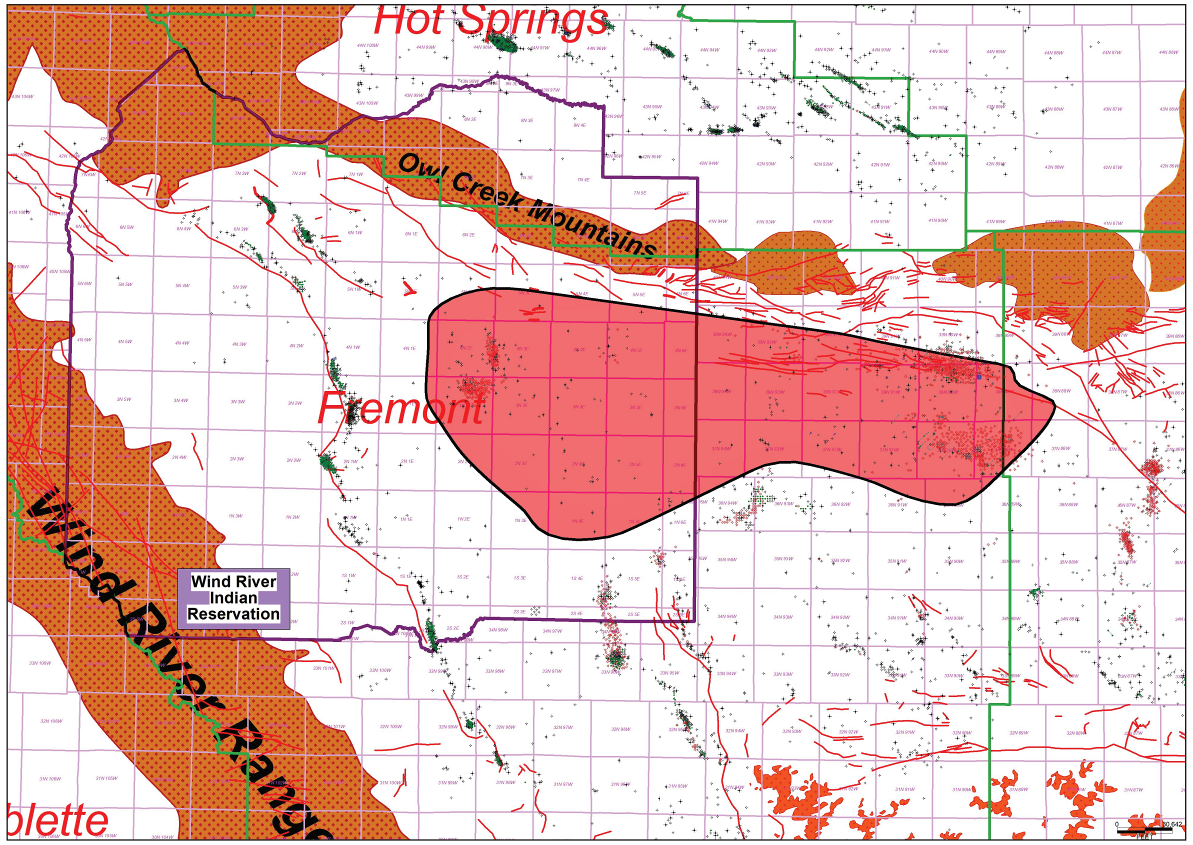

FIGURE WR-18.1. Play outline for the Basin-Center Gas Play showing distribution of dry holes, oil and gas wells, and reservation outline.

	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)

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 of the active generation of gas from source intervals in the deep part of the basin, which 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 moderate porosity and low permeability (Figure WR-18.2). 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-18.3. This play will only be viable if active generation is occurring to continuously replenish the reservoirs 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 index is usually reached at about 10,000 feet. Therefore, those Tertiary and Upper 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 market price of gas and the 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.

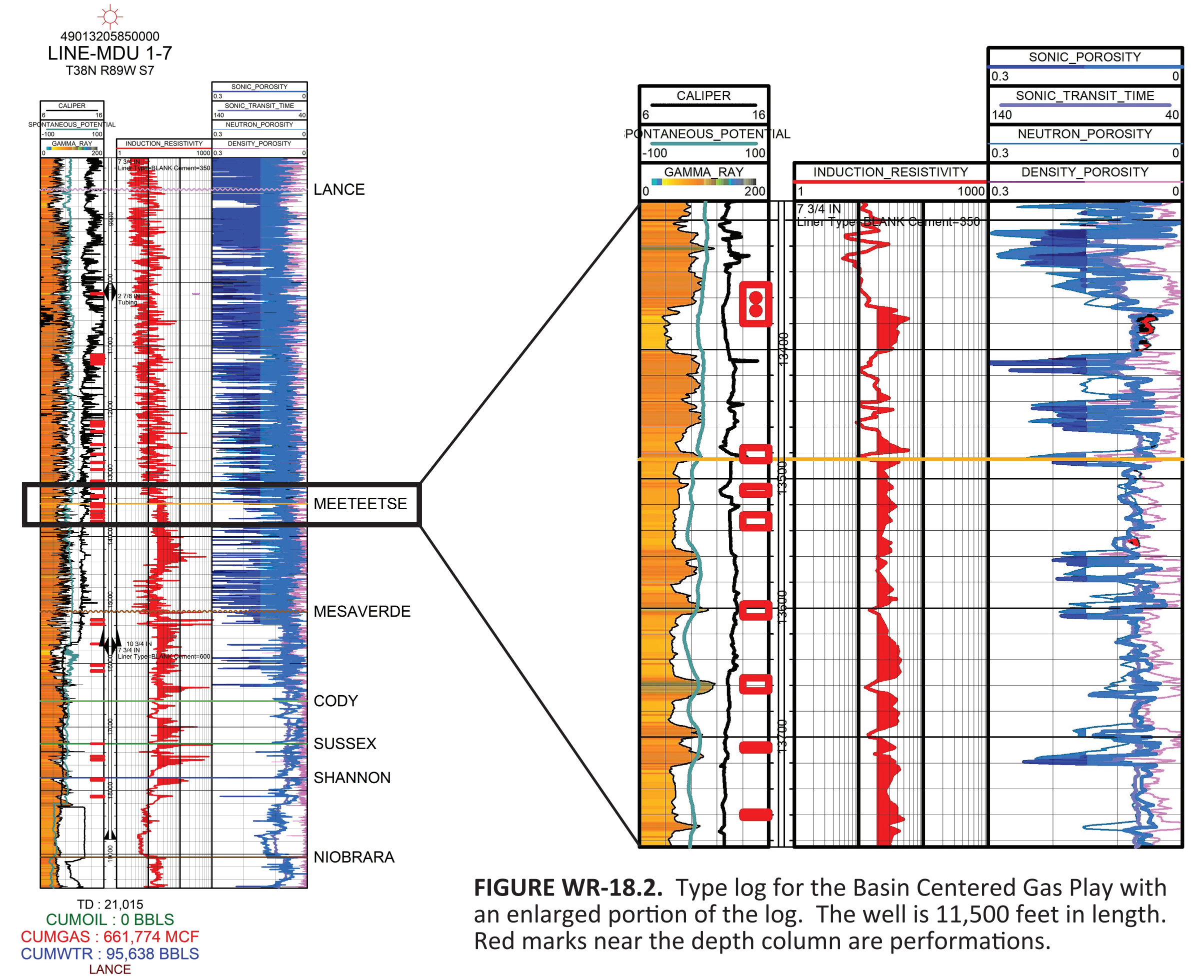

FIGURE WR-18.2. Type log for the Basin Centered Gas Play with an enlarged portion of the log. The well is 11,500 feet in length. Red marks near the depth column are performations.

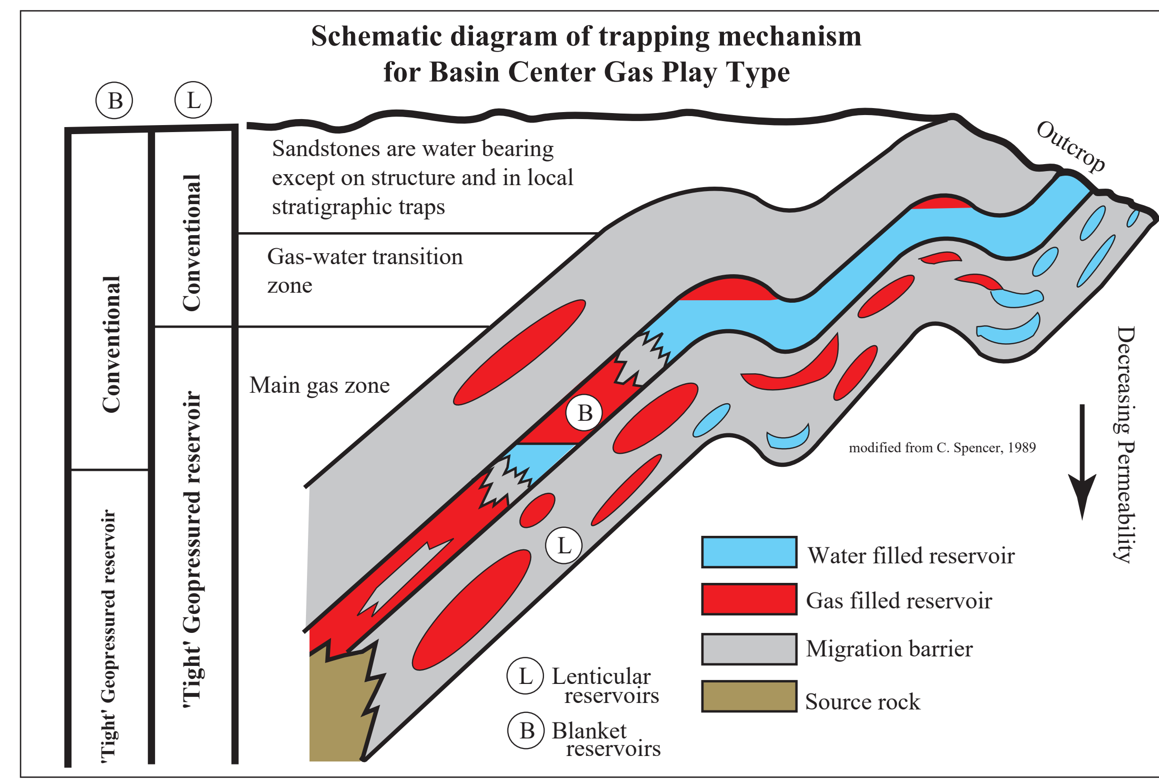

FIGURE WR-18.3. Generalized schematic cross-section showing general distribution of gas and water in conventional and 'tight' lenticular and 'tight' blanket reservoirs. Note that conventional reservoirs have gas-water contacts while the low-permeability reservoirs do not. A source interval that is still in the active generation stage is needed to charge and 'overpressure' the low-permeability reservoir horizons (modified after Spencer, 1989).

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