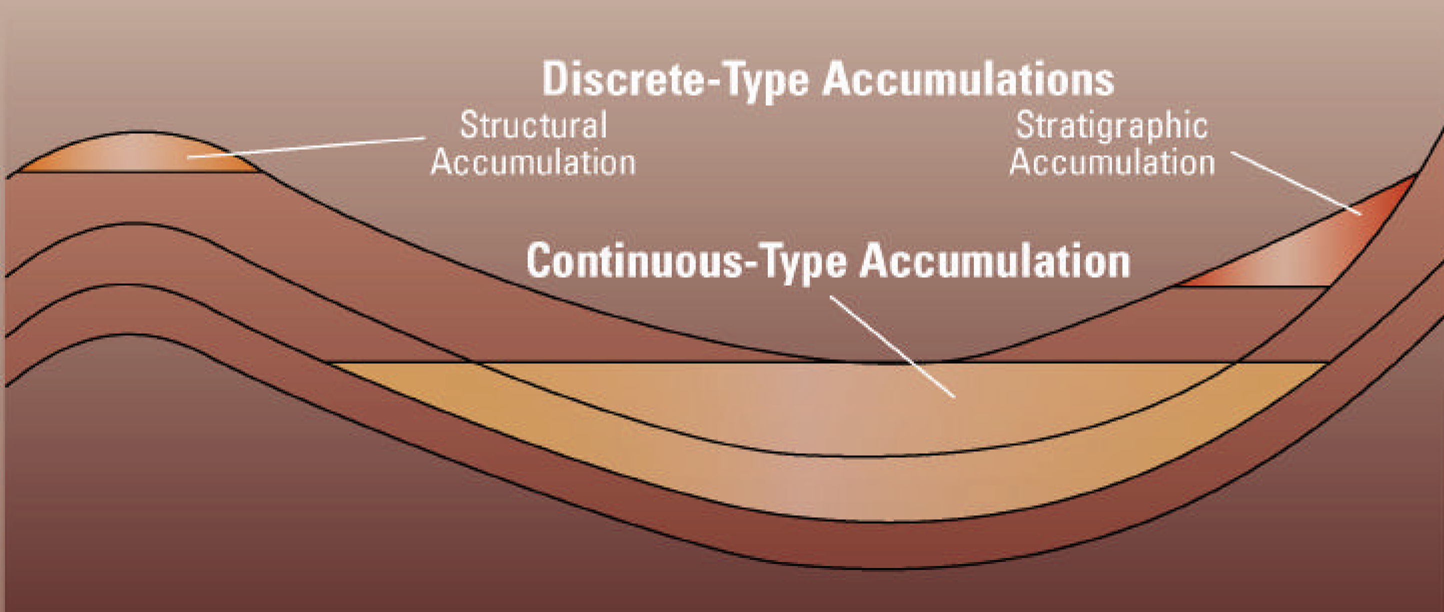
Potential for Deep Basin-Centered Gas Accumulation in Hanna Basin, Wyoming

Geologic Studies of Basin-Centered Gas Systems

U.S. Geological Survey Bulletin 2184-A



U.S. Department of the Interior
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By Michael S. Wilson, Thaddeus S. Dyman, *and* Vito F. Nuccio

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Edited by Vito F. Nuccio *and* Thaddeus S. Dyman

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By Michael S. Wilson,[1] Thaddeus S. Dyman,[2] *and* Vito F. Nuccio[2]

Abstract

The potential for a continuous-type basin-centered gas accumulation in the Hanna Basin in Carbon County, Wyoming, is evaluated using geologic and production data including mud-weight, hydrocarbon-show, formation-test, bottom-hole-temperature, and vitrinite reflectance data from 29 exploratory wells.

This limited data set supports the presence of a hypothetical basin-centered gas play in the Hanna Basin. Two generalized structural cross sections illustrate our interpretations of possible abnormally pressured compartments. Data indicate that a gas-charged, overpressured interval may occur within the Cretaceous Mowry, Frontier, and Niobrara Formations at depths below 10,000 ft along the southern and western margins of the basin. Overpressuring may also occur near the basin center within the Steele Shale and lower Mesaverde Group section at depths below 18,000 to 20,000 ft. However, the deepest wells drilled to date (12,000 to 15,300 ft) have not encountered overpressure in the basin center. This overpressured zone is likely to be relatively small (probably 20 to 25 miles in diameter) and is probably depleted of gas near major basement reverse faults and outcrops where gas may have escaped. Water may have invaded reservoirs through outcrops and fracture zones along the basin margins, creating an extensive normally pressured zone.

A zone of subnormal pressure also may exist below the water-saturated, normal-pressure zone and above the central zone of overpressure. Subnormal pressures have been interpreted in the center of the Hanna Basin at depths ranging from 10,000 to 25,000 ft based on indirect evidence including lost-circulation zones. Three wells on the south side of the basin, where the top of the subnormally pressured zone is interpreted to cut across stratigraphic boundaries, tested the Niobrara Formation and recovered gas and oil shows with very low shut-in pressures.

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Introduction

The primary purpose of this report is to describe the potential for a continuous-type basin-centered gas accumulation in the Hanna Basin of south-central Wyoming (fig. 1) using the published literature and computerized well and reservoir data files. The U.S. Geological Survey (USGS) is currently reevaluating the potential for basin-centered gas accumulations in high-priority basins in the United States in order to accommodate changing geologic perceptions and new data since the completion of the U.S. Geological Survey 1995 National Petroleum Assessment. This effort, which is being conducted with funding from the U.S. Department of Energy, may result in the identification of new continuous-type assessment units and petroleum systems. These potential basin-centered gas accumulations vary qualitatively from low to high risk and may or may not survive rigorous geologic scrutiny leading toward a full geologic assessment based on assessment units and petroleum systems.

This report on the Hanna Basin is one of several reports that will be published as U.S. Geological Survey Bulletins. Data relating to the existence of basin-centered gas accumulations is summarized in each of these reports. No attempt is made, however, to identify potential assessment units and petroleum systems or to actually assess gas resources for potential assessment units. These reports are specifically meant to describe the geologic and production characteristics of potential assessment units.

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Continuous-Type Accumulations

Continuous-type accumulations are large single fields having spatial dimensions equal to or exceeding those of con-

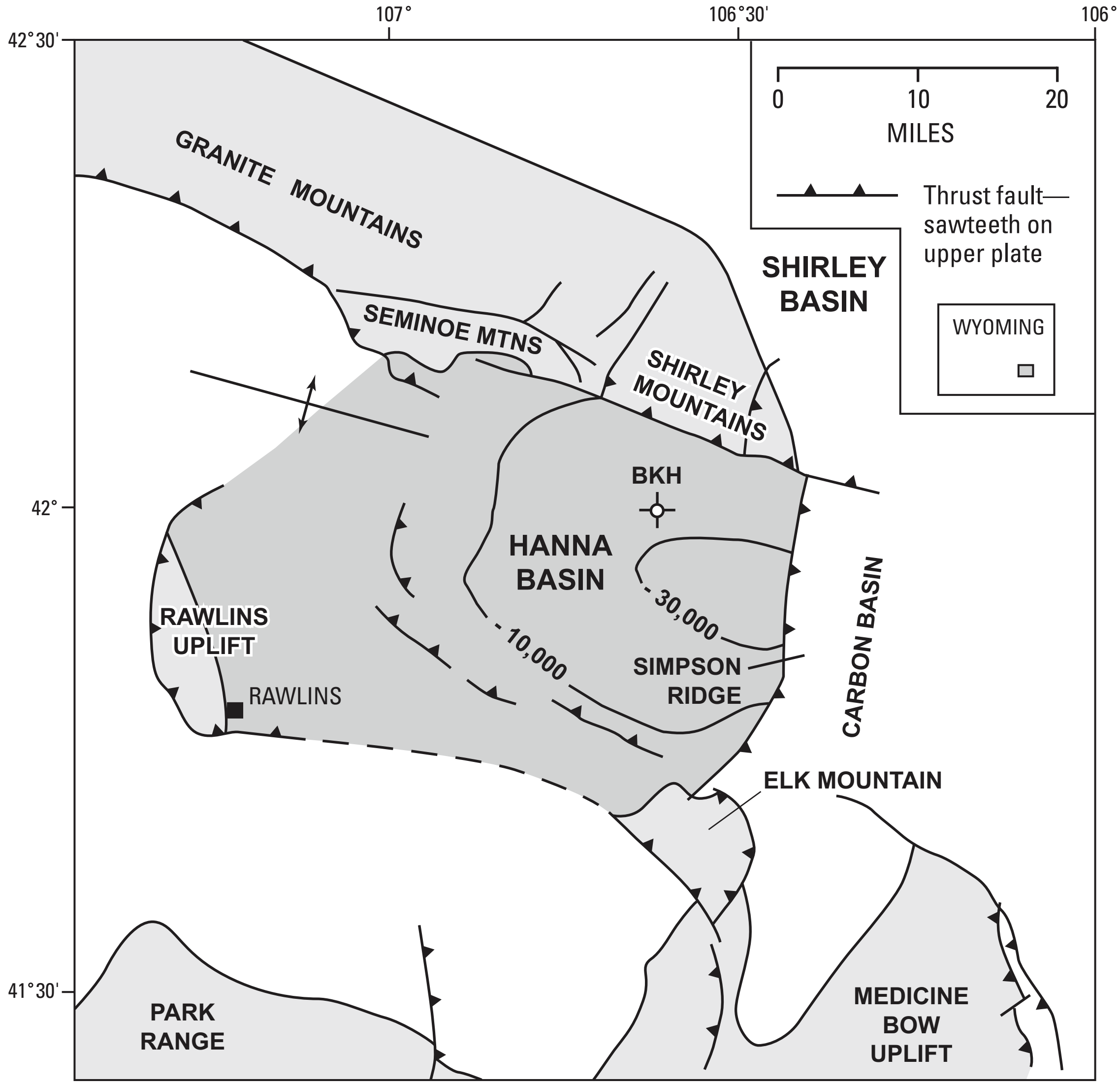

Figure 1. Map showing the location of the Hanna Basin (dark shading), surrounding uplifts (light shading), major faults, depth in feet to Precambrian basement in the basin center, and location of the Brinkerhoff Hanna Unit No. 1 well (BKH). Modified from Perry and Flores (1997, p. 52).

ventional fields. They cannot be represented in terms of discrete, countable units delineated by downdip hydrocarbon-water contacts (as are conventional fields). The definition of continuous-type accumulations used here is based on geology rather than on government regulations defining low-permeability (tight) gas. Common geologic and production characteristics of continuous-type accumulations include their occurrence downdip from water-saturated rocks, lack of obvious traps or seals, relatively low matrix permeability, abnormal pressures, large in-place hydrocarbon volumes, and low recovery factors (Schmoker, 1996).

Continuous-type plays were treated as a separate category in the U.S. Geological Survey 1995 National Petroleum Assessment and were assessed using a specialized methodology (Schmoker, 1996). These continuous-type plays are geologically diverse and fall into several categories including coal-bed gas, biogenic gas, fractured-shale gas, and basin-centered gas accumulations. This report focuses on basin-centered gas.

Basin-Centered Gas Accumulations

Basin-centered gas accumulations form a special group of continuous-type gas accumulations and differ significantly in their geologic and production characteristics from conventional accumulations. They have the following characteristics:

1. They are geographically large and cover from tens to hundreds of square miles in areal extent, typically occupying the central, deeper parts of sedimentary basins.
2. They lack downdip water contacts, and thus hydrocarbons are not held in place by the buoyancy of water.
3. Reservoirs are abnormally pressured.
4. Gas is the pressuring phase of the reservoir.
5. Water production is usually low or absent, or water production is not associated with a distinct gas-water contact.
6. Reservoir permeability is low—generally less than 0.1 millidarcy (mD).
7. Reservoirs are overlain by normally pressured rocks containing both gas and water.
8. Reservoirs contain primarily thermogenic gas.
9. Migration distances are not thought to be great.
10. Structural and stratigraphic traps are of minor importance.
11. Reservoirs are commonly compartmentalized.
12. Multiple fluid phases contribute to seal development in reservoirs.
13. The tops of basin-centered accumulations occur within a narrow range of thermal maturities, usually between vitrinite reflectance values of 0.75 and 0.9 percent.

Many gas accumulations may have only some of the above characteristics, and classification as a basin-centered accumulation may become highly subjective.

Assessment of Basin-Centered Gas Accumulations

Assessment of basin-centered gas (and other continuous-type) accumulations is based on the concept that a continuous accumulation can be regarded as a collection of hydrocarbon-bearing cells. In the assessment unit, cells represent spatial subdivisions defined by the drainage area of wells. Cells may be productive, nonproductive, or untested. Geologic risk, expressed as assessment-unit probability, is assigned to each play. The number of untested cells in an assessment unit and the fraction of untested cells expected to become productive (success ratio) are estimated, and a probability distribution is defined for estimated ultimate recoveries (EUR's) for those cells expected to become productive. The combination of geologic probability, success ratio, number of untested cells, and EUR probability distribution yields potential undiscovered resources for each assessment unit. Refer to Schmoker (1996) for a detailed discussion of continuous-type accumulations and their assessment.

In 1995, the U.S. Geological Survey defined 100 continuous-type oil and gas plays in sandstones, shales, chalks, and coals for all depth intervals. Of the 100 identified plays, 73 were gas plays. Eighty-six of the 100 identified plays were quantitatively assessed. Estimates of undiscovered technically recoverable gas resources from all continuous-type plays—excluding coal-bed gas plays—range from 219 trillion ft^3 (TCF) (95th fractile) to 417 TCF (5th fractile), with a mean estimate of 308 TCF. Much of this resource is attributed to basin-centered gas plays.

Four categories of continuous-type basin-centered gas plays can be identified with respect to new data and perceptions since the U.S. Geological Survey 1995 National Petroleum Assessment: (1) plays that were assessed in 1995, but need to be updated because of new data; (2) plays that were identified incorrectly as conventional or continuous in 1995; (3) plays that were identified as continuous in 1995 but not assessed because of a lack of data; and (4) new continuous-type accumulations that were not identified in 1995. Basin-centered gas plays were not assessed or identified in 1995 in many basins including the Wind River, Raton, Albuquerque, Bighorn, Crazy Mountains, and Hanna Basins of the Rocky Mountain region; the Anadarko and Arkoma Basins of the southern Midcontinent region; and the Colville Basin of northern Alaska.

Geologic Setting of Hanna Basin

The Hanna (fig. 1) is a deep Laramide basin located northeast of the city of Rawlins in south-central Wyoming (Perry and Flores, 1997). The basin is flanked by Precambrian-cored uplifts including the Shirley and Seminoe Mountains to the north, Simpson Ridge to the east, the Medicine Bow and Park Range uplifts to the south, and the Rawlins uplift to the west. Precambrian basement is about 30,000 to 40,000 ft deep in the eastern part of the basin (Hansen, 1986). The Hanna Basin is considered a pull-apart basin; its tectonic history has been summarized by LeFebre (1988) and Perry and Flores (1997). Strike-slip and reverse faulting along the Shirley Mountain thrust occurred during Late Cretaceous and early Paleocene time (early Laramide), whereas uplift of the Medicine Bow Mountains and Rawlins uplift occurred during late Paleocene and Eocene time (late Laramide).

Stratigraphic units in the Hanna Basin are shown in figure 2. The Cambrian through Jurassic section is less than 2,500 ft thick and includes the Cambrian Flathead Sandstone, Mississippian Madison Limestone, Pennsylvanian Casper Formation, Triassic Jelm and Chugwater Formations, and the Jurassic Nugget Sandstone and Sundance and Morrison Formations. The Lower and lower Upper Cretaceous fluvial and marine section includes the Cloverly Formation, Thermopolis Shale, Muddy Sandstone, and Mowry Shale. Upper Cretaceous marine and deltaic units include the Frontier Formation, Niobrara Formation, Steele Shale, Mesaverde Group, Lewis Shale, Fox Hills Sandstone, and Medicine Bow Formation. Fluvial and deltaic sediments of the Tertiary Hanna and Cretaceous

STRATIGRAPHIC UNITS IN THE HANNA BASIN			
PERIOD/EPOCH		STRATIGRAPHIC UNIT	Approximate Thickness (feet)
TERTIARY (part)	EOCENE	Hanna Formation	19,000
	PALEOCENE	Ferris Formation	
CRETACEOUS	LATE	Medicine Bow Formation Fox Hills Sandstone	6,000
		Lewis Shale	2,100
		Mesaverde Group	2,600
		Steele Shale	3,000
		Niobrara Formation	1,200
		? Frontier Formation	800
		Mowry Shale	200
	EARLY	Muddy Sandstone	60
		Thermopolis Shale	80
		Cloverly Formation	200
JURASSIC		Morrison Formation	375
		Sundance Formation Nugget Sandstone	300
TRIASSIC		Jelm and Chugwater Formations	700
PERMIAN		Goose Egg Formation	400
PENNSYLVANIAN		Casper Formation	400 300
MISSISSIPPIAN		Madison Limestone	500
CAMBRIAN		Flathead Sandstone	65
PRECAMBRIAN		granitic and metamorphic basement	

Figure 2. Stratigraphic chart showing names and average thicknesses of stratigraphic units recognized in the Hanna Basin, Wyoming. Modified from Kaplan and Skeen (1985, p. 224).

and Tertiary Ferris Formations filled the basin as it subsided rapidly during Laramide uplift and are almost 19,000 ft thick in the basin center (Hansen, 1986). Several thousand feet of sediment have probably been removed by erosion from the basin since Miocene time, based on the presence of regional unconformities.

Exploratory Drilling

The Hanna Basin has been lightly explored for oil and gas, including coal-bed methane. The lack of exploration is due in part to the “checkerboard” lease position in which alternate sections have been held by the Union Pacific Railroad Corporation (Stone, 1966). Most of the early exploratory wells tested fault-fold structures along the flanks of the basin (Johnson and Flores, 1998), and only a few deep wells have been drilled in the basin center. A few minor oil and gas fields have been discovered, including the Rock River, Allen Lake, Big Medicine Bow, Cedar Ridge, Chapman Draw, Melton, and Simpson Ridge fields (Mapco, 1999). Figure 3 shows lines of cross section and well locations for 29 representative exploration wells. The Denver Earth Resources Library, Denver, Colo., provided much of the data used here, including geologic maps, well logs, and scout cards.

Evidence for Normal Pressures

Drilling-mud-weight, drill-stem-test, bottom-hole-temperature (table 1), and vitrinite reflectance data were examined for evidence of abnormal pressures that might indicate the presence of a basin-centered gas accumulation. Figures 4 and 5 illustrate our interpretations of the approximate boundaries of normal and abnormal pressure zones in the Hanna Basin based on the limited well data available.

The Cambrian through Jurassic stratigraphic section is interpreted to be regionally water saturated and normally pressured largely due to the absence of significant hydrocarbon-generating source rocks. Several exploratory wells recovered water with near-normal pressure gradients during tests of the Jurassic Morrison and Pennsylvanian Tensleep Formations (fig. 3, symbol CKS). Some oil shows were encountered in the Triassic Chugwater Formation and Jurassic Nugget Sandstone. These shows are probably due to early (pre-Laramide) migration of oil generated from the Permian Phosphoria Formation in western Wyoming. Laramide tectonic movements disrupted and breached many of the pre-Cretaceous oil traps, and noncommercial oil shows are common in the Paleozoic section.

Water-producing Paleozoic through Tertiary reservoirs with near-normal pressure gradients (0.40 to 0.47 psi/ft) have been encountered at depths of less than 8,000 ft along the western, southern, and southeastern margins of the basin, and at depths of less than 12,500 ft in the basin center (table 1). The Frontier-Cloverly section was tested in three wells on the west flank of the basin (table 1, symbols MHS, CKS, and SFM), and shut-in pressures from drill-stem tests indicate near-normal pressure gradients ranging from 0.35 to 0.47 psi/ft in this part of the basin. Several tests of the Mesaverde Group and Ferris Formation (table 1) also recovered water with near-normal pressure gradients. One of the deepest wells in the basin, the Forgotson-Nortex HBJVU No. 1-25 well (fig. 3, FGN) reached a total depth of 15,322 ft in the lower Mesaverde Group using only 8.9 pounds per gallon (ppg) mud. Overpressures were not reported in this well. Drill-stem tests at 12,500 and 10,200 ft recovered water, and shut-in pressures indicate normal pressure gradients of 0.41 psi/ft.

These results indicate extensive water-saturation at depths less than 12,500 ft in the basin. The normally pressured zone (figs. 4 and 5) is interpreted to be an envelope extending from outcrops on the basin margins through the basin center at shallow depths, and from outcrops through the basin bottom within the Cambrian- through Jurassic-age section. Major fault zones and outcrops surrounding the basin may have allowed extensive water invasion and (or) gas leakage.

Evidence for Subnormal Pressures

Zones of subnormal pressure (±0.3 psi/ft) have been found below water-saturated, normal-pressure zones and above central overpressure zones in several other basin-centered gas accumulations in the Rocky Mountain region (Meissner, 2000; Wilson and others, 1998). The subnormally pressured zones are generally interpreted to have been previously overpressured during peak gas expulsion, but loss of gas due to cooling, erosional unloading, and escape along fractures and fault zones has allowed pressures to decline to subnormal levels. Identification of subnormally pressured zones in exploration wells is often difficult because water-based drilling mud often overbalances the low-pressure gas reservoirs. Gas shows may be suppressed (Wilson and others, 1998) and formation damage may have occurred due to mud invasion. Drill-stem tests may be ineffective or inconclusive in the damaged intervals. Low or flat mud-log gas readings, problems with lost circulation, and drill-stem tests that recovered gassy mud with low shut-in pressures are often subtle clues indicating subnormally pressured zones.

Subnormal pressures have been interpreted in the central part of the Hanna Basin (figs. 4 and 5) at depths ranging from 10,000 to 25,000 ft based on indirect evidence including lost circulation reported at 11,800 ft in the Amoco Seminoe Reservoir No. 1 well, where 8.8 ppg mud was used. This mud may have overbalanced a low-pressure zone (fig. 3, ASR).

Temperatures high enough for gas generation have been

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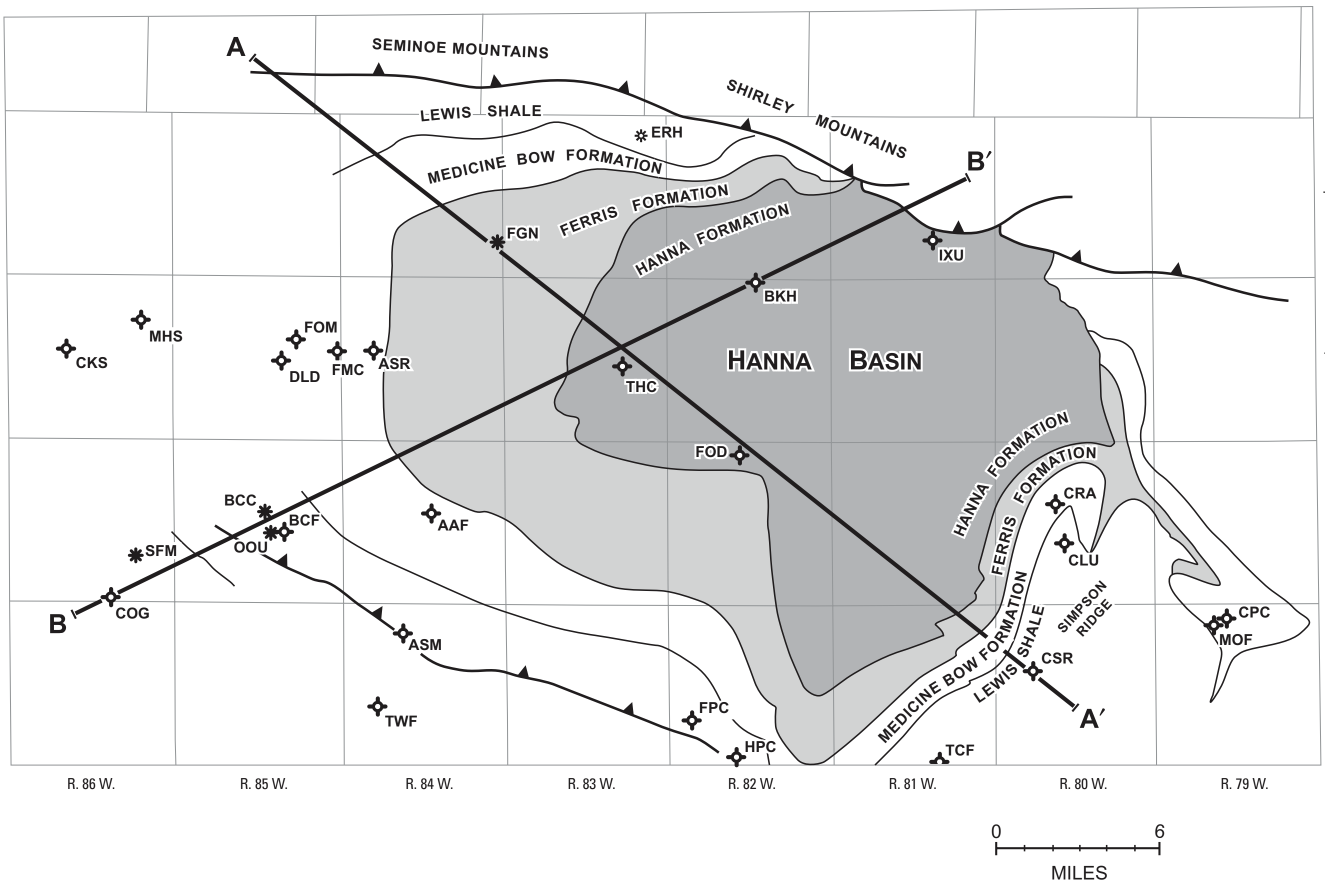

Figure 3. Map showing structural elements, outcrop patterns, locations of cross sections (figs. 4 and 5), and locations of 29 representative exploration wells in the Hanna Basin, Wyoming. Modified from Hansen (1986, p. 485) and MAPCO (1999, maps WA5 and WA6). Three-letter code identifies well name as shown in table 1.

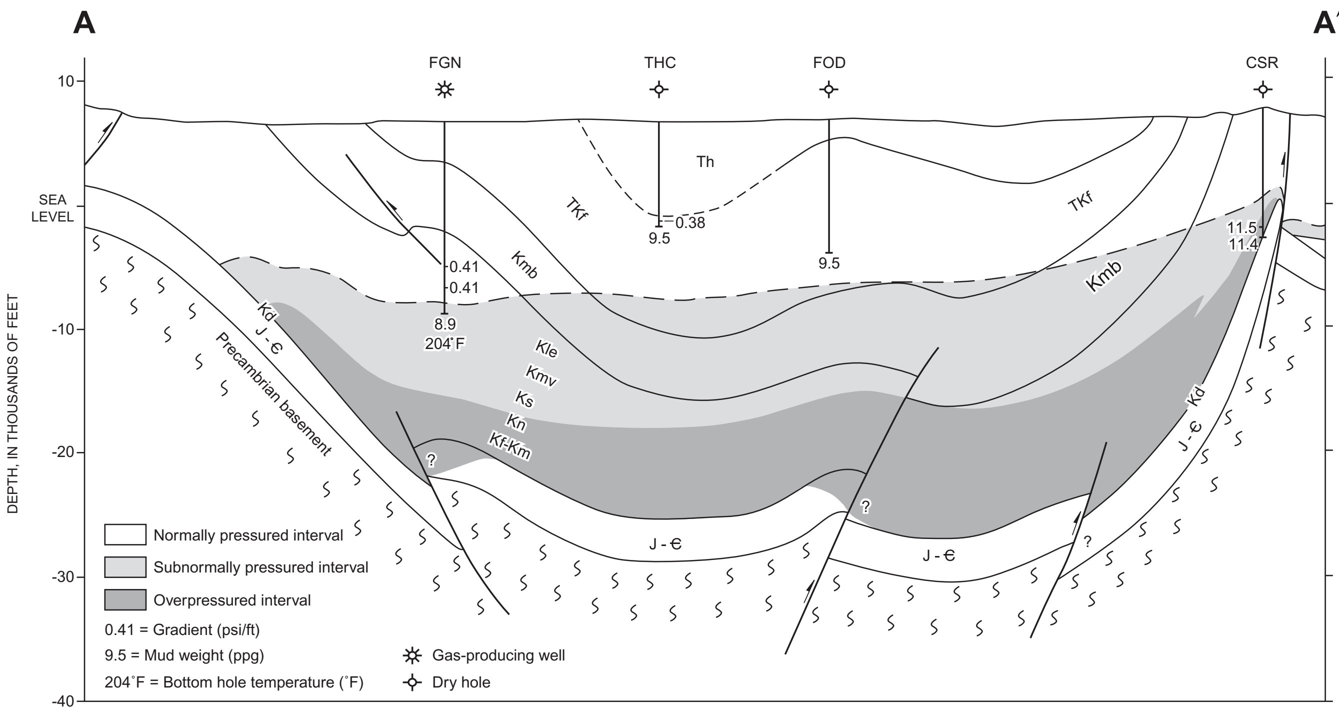

Figure 4. Cross section A-A′ showing generalized structure of the Hanna Basin and approximate boundaries of the normal, subnormal, and overpressure zones based on interpretations of vitrinite reflectance measurements and well data. See figure 3 for location of cross section. See table 1 for explanation of codes used to identify wells. Th, Tertiary Hanna Formation; TKf, Tertiary-Cretaceous Ferris Formation; Kmb, Cretaceous Medicine Bow Formation; Kle, Cretaceous Lewis Shale; Kmv, Cretaceous Mesaverde Group; Ks, Cretaceous Steele Shale; Kn, Cretaceous Niobrara Formation; Kf, Cretaceous Frontier Formation; Km, Mowry Shale; J-Є, Jurassic through Cambrian rocks.

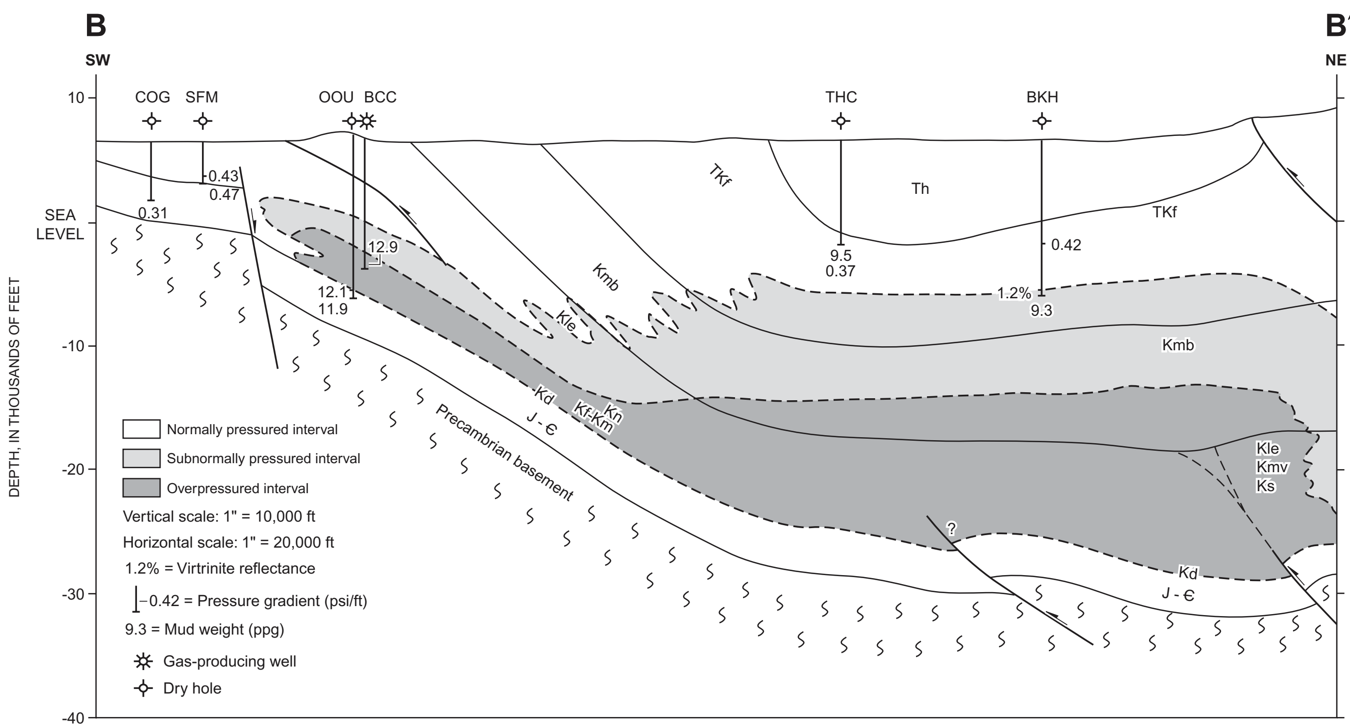

Figure 5. Cross section B-B′ showing generalized structure of the Hanna Basin and interpreted boundaries of normal, subnormal, and overpressure zones, based on interpretations of vitrinite reflectance measurements and well data. See figure 3 for location of cross section. See table 1 for explanation of codes used to identify wells. Th, Tertiary Hanna Formation; TKf, Tertiary-Cretaceous Ferris Formation; Kmb, Cretaceous Medicine Bow Formation; Kle, Cretaceous Lewis Shale; Kmv, Cretaceous Mesaverde Group; Ks, Cretaceous Steele Shale; Kn, Cretaceous Niobrara Formation; Kf, Cretaceous Frontier Formation; Km, Mowry Shale; J-Є, Jurassic through Cambrian rocks.

Table 1. Mud weights, bottom-hole temperatures and drill-stem test results for 29 representative exploration wells in the Hanna Basin, Wyoming, based on well logs and scout cards available at the Denver Earth Resources Library, Denver, Colo.

[Fm., formation; ppg, pounds per gallon; NDXO, neutron-density crossover; Dpor, density porosity; pr., pressure; TD, total depth of well; MCFD, thousand ft^3 of gas per day; BHT, bottom hole temperature; psi/ft, pounds per square inch per foot; Ro, vitrinite reflectance in percent; DST SIP, standard drill-stem test shut-in pressure; sgcm, slight gas cut mud; Ss, sandstone; Mm, Mississippian Madison Formation; PPt, Pennsylvanian Tensleep Formation; PPa, Pennsylvanian Amsden Formation; Jm, Jurassic Morrison Formation; Jn, Jurassic Nugget Sandstone; Kn, Cretaceous Niobrara Formation; Ks, Cretaceous Steele Shale; Kmv, Cretaceous Mesaverde Group; TKf, Tertiary-Cretaceous Ferris Formation]

Well Name	Symbol	Sec.	T.	R.	Year	T D feet	Fm at TD	Mud ppg	Depth feet	BHT deg F	DST SIP psi	Depth feet	Gradient psi/ft	Comments
Amoco Alkali Flat Unit No. 1	AAF	15	22 N.	84 W.	1978	9,870	Ks	9.6	9,805	165				No tests. Some NDXO effects. Normal pressure ??
Amoco Seminoe Reservoir 1	ASR	17	23 N.	84 W.	1977	12,100	Kmv	9.1 8.8	9,791 12,097	160 178	2,273	8,850	0.26	DST recovered 1,900 feet of sgcm water. Normal pressure ? Cored 11,720-780 feet, lost circulation. Subnormal pressure ?
Amoco St Mary's Unit No. 1	ASM	9	21 N.	84 W.	1974	15,553	Mm	9.0 10.0 10.9	5,968 11,266 14,850	102 181 217				Perforated Niobrara at 10,470-10,560 feet. Abandoned. Probably overpressured in Niobrara & Frontier.
Apache U.S.Golden No. 1	ACG	22	22 N.	79 W.	1969	9,238	Jm	9.2	9,199	158				No tests reported. Niobrara may be subnormally pressured ?
Brinkerhoff Hanna Unit No. 1	BKH	3	23 N.	82 W.	1972	12,500	TKf	9.2 9.3	10,700 12,498		2,695 241 1,588	6,350 9,080 10,350	0.42 very low very low	Normal pressure gradient at 6,350 feet? Few shows. Ro < 0.7% above 10,000 feet. Dpor = 5-13%. Ro = 1.2% near TD. Subnormal pressure?
Byron Oil Cedar Ridge No. 1	BCC	15	22 N.	85 W.	1982	10,672	Kn	12.9	10,648	160				12.9 ppg mud, overpressure? Perforated Shannon Ss. (Steele Sh.).
Byron Oil Cedar Ridge No. 1	BCF	22	22 N.	85 W.	1980	10,302	Kn	8.9 10.9	6,185 10,288	109 136				10.9 ppg mud. Perforated Niobrara and Shannon Ss. (Steele Sh.).
Chambers Klaenhammer No. 1	CKS	16	23 N.	86 W.	1976	9,240	PPt	10.5	9,240	140	2,685 2,538 3,809	6,220 7,150 9,180	0.43 0.37 0.41	DST Frontier recovered gassy mud. Probably normal pressure. DST Dakota (Cloverly) recovered 3,750 feet of water. Normal pressure. DST Tensleep recovered 7,100 feet of sulfur water. Normal pressure??
Champlin UPRR 44-5 No. 1	CPC	5	21 N.	79 W.	1982	11,351	Jm	9.2	11,338	185				Flowed gas and water from Morrison. Normal pressure.
Coastal COGC-UPRR No. 1	CLU	21	22 N.	80 W.	1990	10,050	Kf	9.9 12.0 10.0	6,300 7,200 10,050	164				Gas kicks, 12 ppg mud. Overpressured Niobrara Formation Steep dips, stuck pipe, two sidetracks. Abandoned.
Colorado Oil No. 1 Gov't	COG	34	22 N.	86 W.	1958	4,842	PPt				1,523	4,825	0.31	DST Tensleep rec. 100 feet of water. Normal pressure?
Continental Simpson No. 1	CSR	17	21 N.	80 W.	1957	10,514	Kf	11.5 11.4	9,870 10,513	110 157				Gas shows, mud weight = 11.4 ppg in Niobrara. Fault zone. Niobrara section is probably overpressured. Abandoned.
CRA CRA-UPRR No. 16-1	CRA	16	22 N.	80 W.	1968	5,013	Kmv	9.2	4,890	94	2,082	4,990	0.42	DST Kmv recovered 316 feet of water. Normal pressure.
Dillard Unit No. 41-22	DLD	22	23 N.	85 W.	1963	4,924	Kmv				1,817 1,968	4,450 4,740	0.41 0.42	DST Kmv recovered 2,694 feet of water. Normal pressure. DST Kmv recovered 4,355 feet of water. Normal pressure. Abandoned.
ERG HSR No. 34 RD-1	ERH	2	24 N.	83 W.	1978	5,126	Kmv	9.2 9.3	4,548 5,126	100				Low BHT. Probably normal pressure.
Ferguson PCR 63X-30 No. 1	FPC	30	21 N.	82 W.	1966	7,277		9.6 10.0	3,665 7,277	114 111				No tests. No formation tops listed on card.
FMC Sandstone Unit No. 1-13	FMC	13	23 N.	85 W.	1980	7,078	Kmv	9.6	7,078	127	2,953	7,000	0.42	DST Kmv rec. 6,173 feet of water. Normal pressure.
Forest Oil Dana Unit No. 1	FOD	4	22 N.	82 W.	1955	10,706	TKf	9.5	10,706	154				Ferris is probably normally pressured.
Forest Oil Miller No. 14-1	FOM	14	23 N.	85 W.	1956	7,910	Kmv	9.5 9.8	6,369 7,906	127	450	7,060	very low	DST Kmv recovered 60 feet gas-cut mud. Subnormal pressure?
Forgotson-Nortex HBS No. 1	FGN	25	24 N.	84 W.	1982	15,322	Ks	8.7 9.0 8.9	10,023 12,686 15,190	176 204	4,232 5,164	10,300 12,500	0.41 0.41	DST Kl rec. 3,712 feet water. Normal pressure. DST Kmv recovered 11,061 feet gas, water and mud. Misrun? Kmv is probably normal pressure, subnormal near TD?
Humble Pass Creek No. 1	HPC	33	21 N.	82 W.	1969	16,850	PPa	9.8 9.0	6,908 16,850	110 240	4,931	13,200	0.37	DST Ksh flowed gas 44 MCFD, rec. 1,675 feet of oil Kmv is probably normal pr. Niobrara may be subnormal.
INTEX UPRR No. 10-27	IXU	27	24 N.	81 W.	1960	9,587	Kmb	9.2 9.8	6,095 9,497	115 143				Gas show noted at 9,220 feet. No cores or tests, TD in Medicine Bow. Abandoned.
Mobil F-14-4-G	MOF	4	21 N.	79 W.	1958	12,623	PPt	10.1 10.0	10,321 11,246	148 172	4,962	11,070	0.45	10.1 ppg mud through Niobrara-Frontier. Several cores. Overpressures? DST Jn flowed gas, subnormal & normal pressures (?)
Murphy Haystack No. 1	MHS	14	23 N.	86 W.	1951	7,472	Jm	9.7 9.8	6,841 7,466	147	2,000 1,160	6,400 7,330	0.31 very low	DST Frontier recovered 50 feet gassy mud. Subnormal pressure ? DST Dakota (Cloverly) recovered 1,440 feet of water, trace oil. Normal pressure.
Ohio Oil Unit No. 1	OOU	22	22 N.	85 W.	1954	13,177	Jm	9.7 10.9 12.1 11.9	6,755 10,126 11,796 12,213	160 184				Gas kick, DST flowed gas from Niobrara. Abandoned. Niobrara-Frontier Shale is probably overpressured.
Sinclair Federal Melton No. 1	SFM	26	22 N.	86 W.	1961	3,215	Jm				962 1,485	2,245 3,150	0.43 0.47	DST Frontier recovered 1,316 feet of water. Normal pressure. DST in Dakota recovered gas and mud. Normal pressure.
True Oil Curry Federal No. 44	TCF	34	21 N.	81 W.	1970	6,950	Jm	10.6 11.0	6,124 6,950	125				No tests. Niobrara-Frontier may be overpressured. High mud weight.
True Oil Hanna Unit C No. 2	THC	23	23 N.	83 W.	1973	8,623	TKf	9.5	8,623		3,146	8,390	0.38	DST recovered 560 feet muddy water. Probably normal pressure.
Total Walcott Fed No. 1-20	TWF	20	21 N.	84 W.	1985	5,172	Kn	9.2	5,176	152	509	4,400	very low	Niobrara is probably subnormally pressured.

reported from deep wells in the Hanna Basin. A temperature of 204°F was reported from a drill-stem test at 11,871 to 15,322 ft in the Forgotson Seminoe Unit No. 1-25 (fig. 3, FGN), indicating that temperatures are high enough for a basin-centered gas accumulation to exist. However, the drilling mud used in this well was only 8.9 to 9.0 ppg and overpressures were not encountered. These rocks might have been overpressured previously, but pressures may have declined to subnormal levels due to cooling and leakage of gas through fractures and outcrops updip to the northwest. Subnormal pressure is interpreted below 15,000 ft in this well (fig. 4).

Measured vitrinite reflectance values in the Brinkerhoff Hanna Basin Unit No. 1 well (fig. 3, BKH) vary from less than 0.7 percent above 10,000 ft to 1.23 percent at 12,845 ft (Law, 1984; Perry and Flores, 1997). Source rocks are thermally mature below 10,000 ft; however, normal mud weights were used in this well (9.2 ppg at 10,700 ft and 9.3 ppg at 12,498 ft) indicating that overpressuring probably does not exist. A drill-stem test at 10,302 to 10,380 ft recovered gassy mud with a very low shut-in pressure (1,588 psi), indicating a tight, damaged, or low-pressure zone. Subnormal pressures are highly likely in this depth range.

Three wells on the south and west margins of the basin (fig. 3, MHS, TWF, and HPC) tested the Niobrara and Frontier Formations and recovered gas and (or) oil shows with very low shut-in pressures. The top of the subnormally pressured zone (figs. 4 and 5) is interpreted to cut across stratigraphic boundaries near the basin margins, and these wells may have penetrated the subnormally pressured zone where it cuts across the Niobrara-Frontier-Mowry section.

Evidence for Overpressured Zones

Drilling-mud-weight data (table 1) indicate that the Niobrara-Frontier-Mowry section may be moderately overpressured at depths below 10,000 ft along the western and southern margins of the basin. Gas shows and mud weights as high as 12.9 ppg were reported at the Byron Cedar Ridge No. 1 well (fig. 3, BCC)—reported mud weight was as high as 12.1 ppg at the Ohio Oil Unit No. 1 (fig. 3, OOU) while drilling through the Niobrara section. Several other wells along this trend also encountered gas shows and gas kicks and used 10- to 12-ppg drilling mud through the Niobrara-Frontier interval (fig. 3, BCF, ASM, TCF, CSR, MOF, and CLU). Mud-log descriptions indicate that this interval consists of calcareous shale beds and thin, low-permeability sandstones with poor reservoir quality. Gas kicks may have occurred in locally fractured zones with unusually high permeability. Several completion attempts using perforations and artificial fracture stimulation in cased holes were unsuccessful at establishing commercial production from the Niobrara Formation in the area. This gas-saturated, fractured shale reservoir may require special completion methods.

Overpressuring was not encountered in any of the deep exploratory wells drilled near the center of the basin. The Forgotson-Nortex No. 1-25 well (FGN) reached a total depth of 15,322 ft in the lower Mesaverde Group using 8.9 ppg mud. This well may have penetrated subnormally pressured rocks near total depth. The limited well data available show no evidence of gas-charged overpressures within the Upper Cretaceous Mesaverde Group, Lewis Shale, Medicine Bow Formation, or in the Cretaceous and Tertiary Ferris or Tertiary Hanna Formations in the basin center. Based on these results, the top of the overpressure zone is interpreted to extend downdip from the Byron, Ohio, and Continental wells (fig. 3, BCC, OOU, CSR) and across the center of the basin at depths of 18,000 to 25,000 ft (figs. 4 and 5). This deep overpressured zone appears to have a diameter of approximately 20 to 25 miles.

Basin modeling indicates that source rocks in the Niobrara-Frontier-Mowry interval are thermally mature in the deep basin and have generated large volumes of oil and gas (Beirei and Surdam, 1986; Beirei, 1987). However, transformation models suggest that hydrocarbon generation may have peaked during Paleocene and Eocene time due to the rapid deposition of many thousands of feet of the Ferris and Hanna Formations within a 15 million year time span. Gas generation may have slowed or ceased during post-Eocene time as a result of uplift and erosion, and the overpressure zone may have receded from its maximum extent.

Discussion: Basin-Centered Gas in the Deep Hanna Basin?

The unusually high mud weights used in wells penetrating the Niobrara-Frontier-Mowry section along the southern and western margins of the basin indicate some potential for a basin-centered gas accumulation. Similar overpressures in the Niobrara-Frontier-Mowry section have been described in the Piceance Basin in western Colorado by Wilson and others (1998), in the Washakie Basin of south-central Wyoming by Kristinik and Lorenz (2000), and in the Wind River Basin by Johnson and others (1996). The interpreted boundaries of the normally pressured and subnormally pressured zones in the Hanna Basin fit the patterns of typical basin-centered gas accumulations. Basin modeling by Beirei (1987) suggests that the Niobrara-Frontier-Mowry section has probably reached (or even exceeded) the gas-generation window in the deep basin. This part of the section may have been extensively dewatered and charged with gas.

The Hanna Basin is relatively small compared to other basins in the Greater Green River Basin of southwestern Wyoming. It is surrounded by basement uplifts along fault zones that have thousands of feet of displacement. Gas may have escaped via several major fault and fracture zones or through outcrops along the margins of the basin. Extensive water invasion may be occurring along the major fault zones, and formerly abnormal pressures may be reverting to normal pressures. The interpreted pressure boundaries (figs. 4 and 5) suggest extensive normal and subnormal pressures and a relatively small (and very deep) overpressured zone.

No wells have been drilled deep enough to validate the concept of a central overpressured zone. Core analyses and measured permeability data were not found in the well data collection. Well-log analyses by Schlumberger (noted on the Brinkerhoff No. 1 density log) indicate that sandstone porosities range from 5 to 13 percent at depths of 10,600 to 12,400 ft. These values are typical for Cretaceous and Tertiary tight gas sands in Wyoming. Porosity and permeability ranges for thin sandstones in the Frontier Formation are unknown but probably resemble those reported by Kristinik and Lorenz (2000) for Frontier sandstones at the Sidewinder 4-H well in the Washakie Basin (9 to 12 percent, 0.04 to 0.001 mD). The fractured Niobrara, Frontier, and Mowry reservoirs are technically challenging reservoirs that have not yet been commercially productive in other known basin-centered gas accumulations. New technologies may be needed to produce gas from these deep, thermally mature, Cretaceous, shale-rich reservoirs in the Hanna and other Rocky Mountain basins.

Conclusions

Data for deep wells in the Hanna Basin show evidence for a shallow, normally pressured section, subnormal pressures at intermediate depths, and a gas-charged overpressured zone within the Niobrara-Frontier-Mowry section along the southern and western margins of the basin. This overpressured zone may be part of a larger, continuous gas accumulation that extends through the basin center at depths below 18,000 to 25,000 ft. No evidence was found for overpressuring in wells penetrating the Upper Cretaceous Mesaverde Group and Lewis and Medicine Bow Formations, and Cretaceous and Tertiary Ferris and Tertiary Hanna Formations, at depths of less than 15,000 ft.

Basin modeling by Beirei (1987) indicates that Cretaceous-age source rocks in the deep basin reached thermal maturity relatively quickly due to rapid burial below 18,000 ft of the Paleocene Hanna and Upper Cretaceous and Paleocene Ferris Formations. Gas generation probably peaked in Paleocene and Eocene time and may have slowed or ceased during late Tertiary time.

Only a few deep wells have been drilled in the center of the Hanna Basin, and the deepest well drilled to date (Forgotson-Nortex No. 1, 15,322 ft total depth) did not encounter overpressured zones. An overpressured zone may have receded from its maximum extent due to erosional unroofing, cooling, and gas leakage via faults, fractures, and outcrops. The present diameter of a deep overpressured compartment may be only 20 to 25 miles. A relatively thick zone of subnormal pressure has been interpreted where previously overpressured strata have lost gas pressure.

The interpretations proposed in this report remain speculative due to the limited data available for the Hanna Basin. However, available data suggest a pattern favoring the presence of a basin-centered gas accumulation similar to accumulations in other basins of the Rocky Mountain region (Wilson and others, 1998).

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