GEOLOGICAL SURVEY OF WYOMING

TIGHT GAS SAND INVENTORY OF WYOMING

by

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TIGHT GAS SAND INVENTORY OF WYOMING

Introduction

Domestic production of natural gas in the United States and Canada has declined approximately five trillion cubic feet during the past decade (Fig. 1). In the future, the rate of decline is expected to continue, but may be offset to some extent by new production from unconventional sources. Wyoming's natural gas production has fluctuated over the past decade, but is expected to increase substantially during the 1980's due to new discoveries of large reservoirs in the Overthrust Belt, Wind River and Green River basins (Fig. 2).

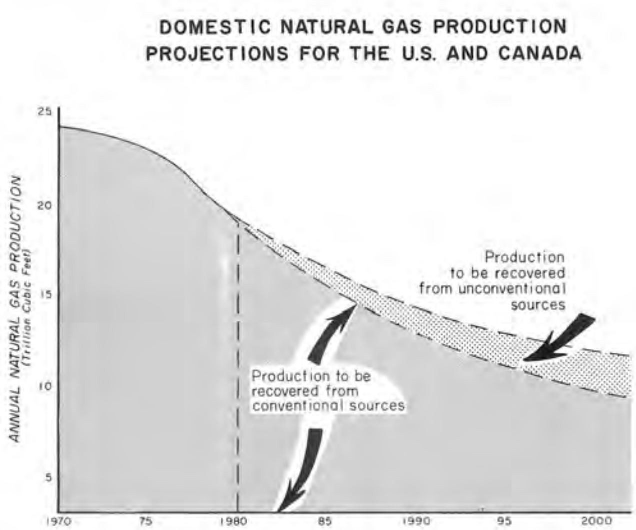


Figure 1

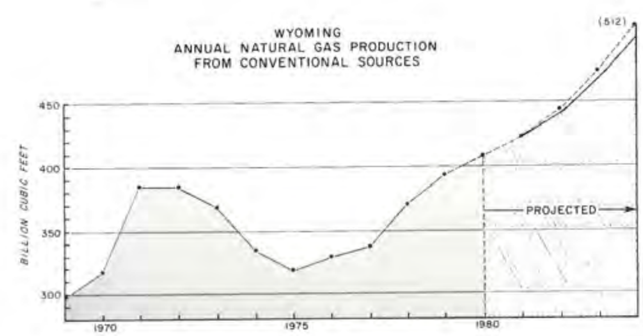


Figure 2

In the early 1970's agencies of the Federal government began gathering information and preparing recommendations that would encourage development of new techniques for the production of natural gas from unconventional sources (tight gas sands) through increased price incentives. A summary of their findings was published in 1978 as Volumes 1 - III, Enhanced Recovery of Unconventional Gas HCP/T2705-01 prepared by the Department of Energy.

During the past five years industry and government have continued to work cooperatively to identify areas within the nation that contain substantial amounts of natural gas and to determine what can be done through appropriate incentives to develop these unconventional supplies. The results of the studies are included in a five-volume report published in 1980 by the National Petroleum Council. Their conclusion is that development of significant tight gas sand reserves is about equally dependent upon industry's ability to obtain appropriate price increases, and the continuation of successful research and development programs. At present the Wyoming Oil and Gas Conservation Commission is processing tight gas sand designation applications from industry and making recommendations to the Department of Energy in accordance with the prescribed procedures. The data contained in these applications, pertinent to Wyoming, may be examined at the Commission office, 123 South Durbin, in Casper.

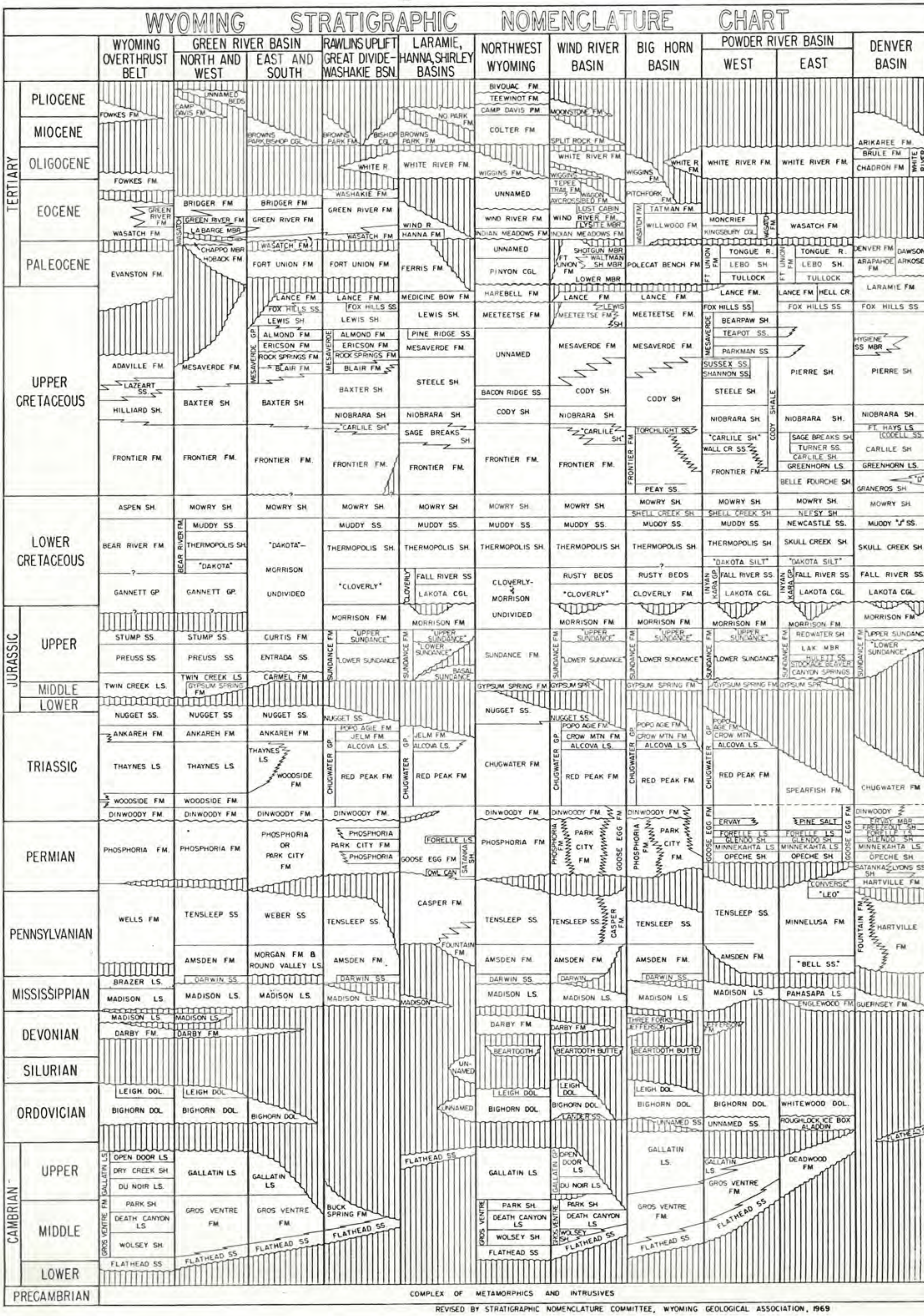
The following report was requested by the Wyoming State Legislature during the 1980 session in an attempt to identify those areas within the State where significant thicknesses of natural gas-bearing sandstones appear to fit the definition of "tight gas sands" as ordinarily understood in the industry, i.e., thin bedded, fine to very fine grained sandstones and siltstones wherein compaction and diagenetic alteration have reduced the average permeability of the gas-bearing section to 0.1 md or less. An additional consideration, and perhaps the most important, involves vertical communication between the thin beds and separate sand lenses beyond the limits of the bore hole. Industry's objective is to induce better communication through massive hydraulic fracturing or other means that will enhance permeability.

Wyoming presently produces 410 billion cubic feet of natural gas annually. This amount will steadily increase through the next decade and more than double by 1990 as market demand continues to escalate. For the most part, industry has pursued the larger reservoirs where conventional engineering practices are applicable. However, increased demand for natural gas coupled with higher market prices has over the past five years made it feasible to develop production in other parts of the stratigraphic section (Fig. 4) that previously would have been considered submarginal reservoirs or uneconomic ventures (Fig. 3).

GEOLOGIC PERIOD	PERCENTAGE OF NATURAL GAS PRODUCED IN 1979 FROM CONVENTIONAL RESERVOIRS		STRATIGRAPHIC INTERVALS WITH UNCONVENTIONAL NATURAL GAS RESERVOIRS
EOCENE		None	possible but unproven
PALEOCENE		6.91%	proven
CRETACEOUS	upper 59.48%	74.35	proven
	lower 14.87		proven
JURASSIC		5.54	probable
TRIASSIC		0.55	↑
PERMIAN		1.49	
PENNSYLVANIAN		6.35	
MISSISSIPPIAN		4.08	
DEVONIAN		None	very unlikely
SILURIAN		None	
ORDOVICIAN		None	
CAMBRIAN		0.12	↓

Figure 3. Geological Distribution of Natural Gas Production in Wyoming.

Figure 4


WYOMING STRATIGRAPHIC NOMENCLATURE CHART
WYOMING OVERTHRUST BELT
GREEN RIVER BASIN
NORTH AND WEST
EAST AND SOUTH
RAWLINS UPLIFT GREAT DIVIDE-WASHAKIE BSN.
LARAMIE, HANNA, SHIRLEY BASINS
NORTHWEST WYOMING
WIND RIVER BASIN
BIG HORN BASIN
POWDER RIVER BASIN
WEST
EAST
DENVER BASIN
TERTIARY
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
UPPER CRETACEOUS
LOWER CRETACEOUS
JURASSIC
UPPER
MIDDLE
LOWER
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
UPPER
MIDDLE
LOWER
PRECAMBRIAN
FOWKES FM.
GREEN RIVER FM.
WASATCH FM.
EVANSTON FM.
ADAVILLE FM.
LAZEART SS.
HILLIARD SH.
FRONTIER FM.
ASPEN SH.
BEAR RIVER FM.
GANNETT GP.
STUMP SS.
PREUSS SS.
TWIN CREEK LS.
NUGGET SS.
ANKAREH FM.
THAYNES LS.
WOODSIDE FM.
DINWOODY FM.
PHOSPHORIA FM.
WELLS FM.
BRAZER LS.
MADISON LS.
DARBY FM.
LEIGH DOL.
BIGHORN DOL.
GALLATIN LS.
OPEN DOOR LS.
DRY CREEK SH.
DU NOIR LS.
GROS VENTRE FM.
PARK SH.
DEATH CANYON LS.
WOLSEY SH.
FLATHEAD SS.
UNNAMED BEDS
CAMP DAVIS FM.
BRIDGER FM.
LABARGE MBR.
CHAPPO MBR.
HOBACK FM.
MESAVERDE FM.
BAXTER SH.
MOWRY SH.
MUDDY SS.
THERMOPOLIS SH.
"DAKOTA"
GYPSUM SPRING FM.
BROWNS PARK, BISHOP CGL.
FORT UNION FM.
LANCE FM.
FOX HILLS SS.
LEWIS SH.
ALMOND FM.
ERICSON FM.
ROCK SPRINGS FM.
BLAIR FM.
"DAKOTA"-MORRISON UNDIVIDED
CURTIS FM.
ENTRADA SS.
CARMEL FM.
WOODSIDE FM.
PHOSPHORIA OR PARK CITY FM.
WEBER SS.
MORGAN FM. & ROUND VALLEY LS.
DARWIN SS.
BISHOP CG.
WHITE R.
WASHAKIE FM.
NIOBRARA SH.
"CARLILE SH."
"CLOVERLY"
MORRISON FM.
"UPPER SUNDANCE"
LOWER SUNDANCE
SUNDANCE FM.
CHUGWATER GP.
JELM FM.
ALCOVA LS.
POPO AGIE FM.
RED PEAK FM.
PARK CITY FM.
TENSLEEP SS.
AMSDEN FM.
BUCK SPRING FM.
NO PARK FM.
WHITE RIVER FM.
WIND R.
HANNA FM.
FERRIS FM.
MEDICINE BOW FM.
PINE RIDGE SS.
STEELE SH.
SAGE BREAKS SH.
FALL RIVER SS.
LAKOTA CGL.
BASAL SUNDANCE
FORELLE LS.
GOOSE EGG FM.
SATANKA SH.
OWL CAN.
CASPER FM.
FOUNTAIN FM.
UN-NAMED
UNNAMED
BIVOUAC FM.
TEEWINOT FM.
CAMP DAVIS FM.
COLTER FM.
WIGGINS FM.
WIND RIVER FM.
INDIAN MEADOWS FM.
PINYON CGL.
HAREBELL FM.
MEETEETSE FM.
BACON RIDGE SS.
CODY SH.
CLOVERLY-MORRISON UNDIVIDED
DARBY FM.
BEARTOOTH
MOONSTONE FM.
SPLIT ROCK FM.
TEPEE TRAIL FM.
WAGON BED FM.
LOST CABIN
LYSITE MBR.
SHOTGUN MBR.
WALTMAN SH. MBR.
LOWER MBR.
RUSTY BEDS
CROW MTN. FM.
BEARTOOTH BUTTE
MESAVERDE FM.
PITCHFORK FM.
TATMAN FM.
WILLWOOD FM.
POLECAT BENCH FM.
TORCHLIGHT SS.
PEAY SS.
SHELL CREEK SH.
CLOVERLY FM.
THREE FORKS
JEFFERSON
MONCRIEF
KINGSBURY CGL.
TONGUE R.
LEBO SH.
TULLOCK
BEARPAW SH.
TEAPOT SS.
PARKMAN SS.
SUSSEX SS.
SHANNON SS.
COODY SHALE
WALL CR. SS.
INYAN KARA GP.
ERVAY
MINNEKAHTA LS.
OPECHE SH.
UNNAMED SS.
PAHASAPA LS.
NEFSY SH.
NEWCASTLE SS.
SKULL CREEK SH.
"DAKOTA SILT"
REDWATER SH.
LAK MBR.
HULETT SS.
STOCKADE BEAVER
CANYON SPRINGS
SPEARFISH FM.
PINE SALT
GLENDO SH.
MINNELUSA FM.
"BELL SS."
"LEO"
CONVERSE
ENGLEWOOD FM.
WHITEWOOD DOL.
ROUGHLOCK ICE BOX ALADDIN
DEADWOOD FM.
PIERRE SH.
TURNER SS.
GREENHORN LS.
BELLE FOURCHE SH.
ARIKAREE FM.
BRULE FM.
CHADRON FM.
DENVER FM.
DAWSON ARKOSE
ARAPAHOE FM.
LARAMIE FM.
HYGIENE SS. MBR.
FT. HAYS LS.
CODELL SS.
CARLILE SH.
GRANEROS SH.
MUDDY "J" SS.
FREEZEOUT SH.
LYONS SS.
HARTVILLE FM.
GUERNSEY FM.
COMPLEX OF METAMORPHICS AND INTRUSIVES
REVISED BY STRATIGRAPHIC NOMENCLATURE COMMITTEE, WYOMING GEOLOGICAL ASSOCIATION, 1969

In most instances the submarginal character of the reservoirs relates to the extremely low permeability of the rock and the lenticularity of the sands which restrict fluid communication even under very high pressure. Because of these circumstances economic production can only be established through expensive, unconventional methods that induce fracture permeability in the rock.

Undeveloped Natural Gas Occurrences and Reservoir Characteristics

Although estimates vary considerably as to the amounts of natural gas still to be developed in Wyoming, there is general agreement that the amounts are substantial in the deep basins in the western part of the State. The orders of magnitude in terms of trillions of cubic feet are as shown on Table 1. Of the amounts shown on the table as gas in place, most of it occurs in essentially impervious geologic sections that would qualify as tight gas sands based on the lithologic and stratigraphic character, over-pressurization and gas content, and individual reservoir performance based on drill stem test and production data.

Permeability data of individual gas-bearing sandstones, determined through laboratory analyses, was considered on a few of the tight gas sand zones; however, comparison of the values often measured in millidarcies (md) is not especially helpful in the context of this report. A special study SPE 7551 entitled "A Laboratory Study of Low Permeability Gas Sands" by Jones and Owens, AMOCO Production Co., indicates that rocks with very low permeability are affected by confining pressures to a greater degree than those having higher levels of permeability; and, that water saturation

TABLE 1 - AREAS IN WYOMING WITH SIGNIFICANT RESERVES OF NATURAL GAS
(See Plate 1 in pocket*)

	Total estimated gas in place in TCF	Technically recoverable gas in TCF	Stratigraphic intervals containing substantial amounts of natural gas in unconventional reservoirs
Greater Green River Basin	135	53-65	Sections 2000 to 2500 ft. thick within an overall interval 4000 to 10,000 ft. thick, including the Fort Union and Hoback formations, most of the Mesaverde Group, and individual zones in the Lower Cretaceous in parts of Uinta, Lincoln, Sublette, Fremont, Carbon, and Sweetwater counties.
Bighorn Basin	23	7-9	Sections 1500 to 2500 ft. thick within an overall interval 4000 ft. thick, including most of the Polecat Bench in the deeper part of the basin and the Mesaverde Group and its individual members to the east in parts of Park, Big Horn, Washakie, and Hot Springs counties.
Wind River Basin	15	4-10	Sections 1500 to 2500 ft. thick within an overall interval 6000 to 14,000 ft. thick, including much of the Fort Union, most of the sandstone facies in the Mesaverde Group and individual sandstone units in the Lower Cretaceous.

*f.n. A large colored copy of the Oil and Gas Fields Map, Scale 1 in. = 8 miles showing the location of existing oil and fields is enclosed with this report.

reduces permeability of tight gas sands in a manner quite different from the effect that it has on sandstones with greater permeability. In other words, permeability determinations of core plugs from tight gas sands are not reliable indicators of reservoir performance.

As a generalization, Wyoming's tight gas sands tend to exhibit matrix permeability characteristics similar to those of ordinary concrete: partly because of secondary authigenic crystals of calcite, silica, clay, or dolomite that tend to plug the pore throats. Photomicrographs showing the details of these microscopic features are available for examination at the Geological Survey.

In most instances, additional stress (confining pressure) has occurred within the rock after entrapment of the gas as evidenced by over-pressurization in parts of the stratigraphic section. Hairline fractures or bedding-plane splits that normally enhance natural permeability are rarely developed in tight gas sands. The following material describes those basins and stratigraphic intervals that could as a result of this assessment qualify for tight gas sand designation.

Greater Green River Basin - As shown on Plate 1 and cross-sections "A" through "E", there is more than 10,000 feet of Cretaceous and early Tertiary strata within the Greater Green River Basin that contains an estimated 135 trillion cubic feet of natural gas in place. Of this amount, 53-65 TCF is probably recoverable using present technology. The stratigraphy of the region is known and has been studied in detail as the result of more than 3500 test holes that were drilled during the past 25 years. Electrical logs, core and gas analyses, drill stem tests, pressure tests, and production histories, all indicate that most, if not all, of the stratigraphic section contains some gas.

Commercial production of natural gas from sandstones in both the Paleocene and Cretaceous section was established within the basin many years ago, as illustrated by the fields colored yellow and green on the large Oil and Gas Map of Wyoming (1980). Around the margins of these fields and at numerous other locations, thick gas-bearing sections have been encountered that lack sufficient sand development and permeability to result in commercially profitable wells under present price constraints.

The parts of the stratigraphic section that contain the gas include the sandstone facies of the Hoback Formation in the northwestern part of the basin, or the Fort Union Formation in the fields along the Colorado border in the southeastern (Washakie) part of the basin. In the south some of the fields also produce small amounts of gas from intervals within the Eocene Wasatch Formation. For purposes of this report the Fort Union or Hoback formations may be considered as equivalent stratigraphic units. Both stratigraphic sections are thin-bedded, well sorted, siltstone and very fine sandstone of continental and deltaic origin. There are innumerable, lenticular sandstones and occasionally slightly thicker, channel-fill deposits with very limited lateral extent. Few, if any, of the individual sandstones extend over a distance of more than a few square miles. The clay content of the sandstones varies considerably from place to place and is the dominant control over permeability. Authigenic chemical cements have also reduced porosity or rendered it ineffective from a reservoir point of view. Thin clay laminae are also interbedded with the sandstones and siltstones. For the most part, the permeability of the sandstones lacks vertical communication between individual lenses or even within the same beds. Although the beds have been extensively fractured and jointed, the incompetency of the beds and the mobility of the clay have rendered them ineffective as routes of fluid communication.

The thickest and most persistent sandstones of the Hoback and Fort Union formations rest unconformably upon the Cretaceous Lance Formation and onlap each other from the depositional centers of the basins out toward the margins. Although gas shows have been encountered within these sand lenses near the Colorado border and on the flanks of the Rock Springs Uplift, no significant production has thus far been established because of the lack of permeability.

In the Green River Basin (proper), the Mesaverde Group (See Fig. 5) is similar in many respects to the overlying Hoback and Fort Union formations. Tight lenticular siltstones and sandstones are interbedded with thin seams of clay, and there is a general lack of permeability. Farther east, along the east flank of the Rock Springs Uplift, the Mesaverde Group is interfingered with thin marine shales that thicken to the east and allow identification of the individual sandstone units in-between. Natural gas has been produced from individual sandstone lenses within the Lewis Shale interval, from the Almond sandstones, and from a few intervals in the Ericson and Rock Springs formations. The overall Mesaverde Formation

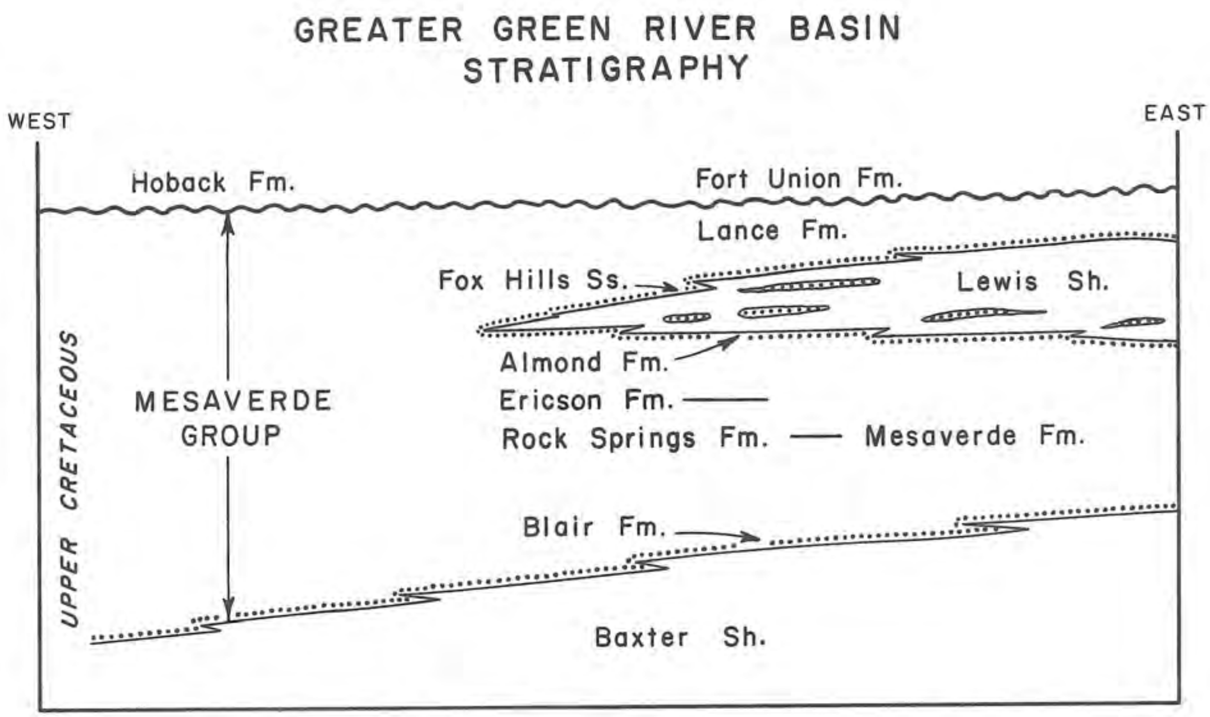


Figure 5

is over-pressured throughout the eastern part of the Greater Green River Basin, and can be expected to produce wherever adequate permeability can be developed through massive hydraulic fracturing. The entire Mesaverde Formation should be designated as a tight gas sand reservoir recognizing that there are "sweet spots" in which sandstones such as the Almond and Ericson facies are developed locally. The same is true for the thin sandstones within the Lewis Shale interval that are generally tight but have thin well-developed permeability in local areas.

With the exception of the Fox Hills Sandstone facies at the base of the Lance, which separates marine shales below from terrestrial deposits above, the Lance is essentially tight. At some time in the future there may be sufficient data to suggest that the Lance might also be designated as a tight gas sand, but at present there is insufficient evidence to evaluate its potential except at Pinedale Anticline in southern Sublette County.

In the past, Pinedale gas field, a twenty-mile long subsurface anticline that produces minor amounts of natural gas from the Hoback (Fort Union), Lance, and Mesaverde formations, was proposed as an experimental nuclear stimulation test site known as Project Wagonwheel. Substantial detail regarding the impervious nature of the gas-bearing strata have been thoroughly documented in PNE-WW-1 Project Wagon Wheel, Technical Studies Report, dated December 31, 1971, published by El Paso Natural Gas Company, El Paso, Texas; and in a feasibility study proposal entitled "Unconventional Natural Gas Production from Tight Sands in the Pinedale Unit, Sublette Co., Wyo.", Mountain Fuel Supply Co., Salt Lake City, Utah. The stratigraphic intervals involved with this gas sand production are shown on cross-section C-C' in the pocket of this report. Collectively, the data substantiates the concept that Pinedale Anticline is overcharged and contains several billion cubic feet of natural gas, but that efforts to induce fracturing and enhance permeability have been only marginally successful.

At a lower position within the Greater Green River Basin but still within the Upper Cretaceous section, natural gas has been produced from sandstone lenses in the Frontier interval as shown on the large colored Oil and Gas Field Map of Wyoming. At least two main sand facies can ordinarily be identified as the "First" and "Second" (or Third) Frontier. Besides the known productive areas along the western margin of the basin, on the Moxa Arch and on the Rock Springs Uplift, the Frontier can be expected to contain gas almost everywhere. Many more Frontier fields might be developed if massive frac completion techniques can be applied. From a practical standpoint, essentially all of the sandstones in the Frontier interval should qualify as tight gas sand reservoirs due to the lack of continuity of the permeability in clayey siltstones and very fine grained sandstones with clay interbeds.

In the lower Cretaceous throughout most of the Greater Green River Basin, there are two stratigraphic units, the "Muddy" and "Dakota" sandstones, that are known to be gas-charged along the southern part of the Moxa Arch, on the Rock Springs Uplift, and along the southern and eastern parts of the Washakie Basin. The stratigraphic terminology is slightly misleading in that the terms "Muddy" and "Dakota" are carry overs from well defined units of formation rank that are better known and understood in eastern Wyoming. Nevertheless, these are the names used by industry and understood by the majority of operators and regulatory agencies.

Both the Muddy and Dakota are thin sandy intervals averaging 10-50 feet thick wherein the lenses sometimes coalesce to form discrete beds. Both units exhibit only local sandstone development and can be more appropriately described as tight, sandy siltstone with varying amounts of clay and secondary mineral cement. With the exception of just a few very local areas, essentially all of the Muddy and Dakota reservoirs in this region should qualify as tight gas sands.

In summary, the Upper Cretaceous and Paleocene sandstones of the

Greater Green River Basin are:

1. Known to contain substantial quantities of natural gas in reservoir rocks that require massive hydraulic fracturing in order to be economic resources.
2. The vast majority of the sandstones occur as lenses with interbedded impervious clay beds.
3. The average permeabilities for the sandstone intervals that could be deemed productive are 0.1 md or less.
4. Vertical communication between individual sand lenses is essentially nil. All fractures and hairline cracks are naturally sealed.
5. Photographs of the pore throats within the sandstones taken with electron and petrographic microscopes indicate that natural permeability is rendered ineffective because of detrital clay-bloc, authigenic clay, and other mineral cements.
6. From the standpoint of economic practicality, all of these sandstones should be eligible for tight gas sand designation.

Wind River Basin - To date, no applications have been received by the State from industry requesting tight gas sand designation within the Wind River Basin of central Wyoming. Assessment of drill stem tests, reservoir pressures, and production records from wells in the deep part of the basin suggest that both the Paleocene Fort Union and the Upper Cretaceous Mesaverde, and Frontier formations may be eligible.

The large colored Oil and Gas Field Map of Wyoming (1980) shows the location and identifies the pay zones of the producing fields: Wind River and

Fort Union reservoirs are identified in yellow, the Upper Cretaceous reservoirs in light green. It should be noted that the color representation is only for the major reservoir. Many of the fields produce a little gas from all three reservoirs: Wind River, Fort Union, and Upper Cretaceous. There is insufficient evidence to consider the Wind River Formation for tight gas sand designation at this time.

Fort Union sedimentation in this area consists of a very thick heterogeneous mass of fluvial, lacustrine, deltaic, and paludal deposits of terrestrial origin that rest unconformably upon the Lance Formation. The basal sandstones onlap each other from the deepest part of the basin outward toward the margins. Sediments rich in organic matter that were deposited and compressed during Waltman time are believed to have contributed substantially to the natural gas content of the Fort Union.

Sandstones within the lower Fort Union are for the most part individual local lenses with random orientation. Some areas like Madden and Frenchie Draw fields have more sandstone distributed throughout the section than others, and this relationship has contributed to over-pressurization within the sands and more prolific pay zones. Apart from the sweet spots already discovered in the producing fields there are great thicknesses of section distributed over vast areas that should qualify as tight gas sands.

The underlying Lance Formation ranges in thickness from a few hundred feet to more than 6000 feet. To date there is insufficient evidence to support tight gas sand designation for the Lance although some field wells have perforations open in this interval and production has been obtained.

Natural gas has been produced from the Meeteetse and Mesaverde section in the eastern part of the Wind River Basin. The interval is gas charged and over-pressured in most places but lacks sufficient sand development and permeability to establish economical reservoirs alone. Where the Mesaverde interval has been perforated, the gas serves to supplement other pay zones in the overlying Lance and/or Fort Union.

The Meeteetse and Mesaverde intervals consist of terrestrial (continental) sediments with littoral transition zones both above and below the marine Lewis Shale. The best developed sandstone facies are within the littoral transition zones in the east half of the basin. The vast majority of the sandstones are thin bedded discontinuous lenses of very fine-grained sandstone with abundant clay and silt. Intra- and inter-bed permeability is very low and ineffective unless frac treatments are applied, and even then only massive hydraulic fracturing has proven effective. The Meeteetse-Mesaverde stratigraphic interval qualifies as a tight gas sand by any definition that might be applied.

In the lower part of the Upper Cretaceous there is another sandstone interval, the Frontier Formation, that has proven productive in a number of fields in the central and eastern parts of the basin. It should be pointed out, however, that Frontier reservoirs alone have not proven to be economically attractive at present market prices. In most of the small fields the gas in the Frontier supplements the production obtained from the Mesaverde and Fort Union. From the data available the Frontier interval is over-pressured, but lacks sufficient sandstone development and permeability to be an attractive exploration target. In the opinion of the writer, the Frontier interval has the appropriate characteristics to qualify as a tight gas sand.

There may also be other zones in the lower Cretaceous such as the Muddy, Dakota, and Lakota, that may qualify for tight gas sand designation in specific parts of the basin. Commercial production has already been established in a few small fields, but essential data is not available at this time.

Bighorn Basin - Within the deeper parts of Bighorn Basin of north-central Wyoming there are several stratigraphic intervals that seem worthy of tight gas sand designation, although data is minimal. These intervals include more than 4000 feet of section in the Polecat Bench (Paleocene Fort Union equivalent), Meeteetse-Mesaverde, and the lower Cretaceous Frontier. To date the only production of consequence is from the Frontier interval in a few small fields along the northern margin and eastern half of the basin. There is no significant oil or gas production from the Polecat Bench or Meeteetse-Mesaverde intervals in the Bighorn Basin at present. There are, however, wells that encountered shows of gas, and one single-well field near McCullock Peak that reportedly has open perforations in the "Fort Union" and Meeteetse intervals.

From the standpoint of sedimentation and stratigraphy, the general character of the Polecat Bench is similar in most respects to the Fort Union elsewhere in Wyoming. The overall section is extremely thick as shown on cross-section G-G', and consists of a heterogeneous mixture of clay and siltstone interbedded with very thin discontinuous sandstone stringers. The section lacks any significant sandstone development and from a practical standpoint has no measurable permeability. In at least a few areas the section is charged with gas, but there is insufficient data to suggest that it is over-pressured.

The Meeteetse-Mesaverde interval is also charged with gas, but lacks sufficient permeability to attract exploration incentive. For the most part the section is composed of terrestrial sediments except in the thin transition zones with the marine Cody Shale below and the marine Lewis Shale above. Much of what is illustrated as "Meeteetse" on the eastern end of cross-section G-G' is actually Lewis Shale, but the stratigraphic complexities cannot be illustrated at this scale. As a general statement all of the Meeteetse-Mesaverde interval, as well as the thin "Eagle" sandstones that are occasionally developed in the top of the Cody, should be given tight gas sand designation.

In the lower part of the Upper Cretaceous the Frontier Formation is much better known. Many of the producing fields in the basin produce gas in relatively small quantities from this stratigraphic interval. Three sandy zones are recognizable throughout most of the basin that are ordinarily referred to as the "First", "Second", and "Third" Frontier sandstones. An understanding of the distribution of individual sandstones within the interval is far too complex to describe in this report. The individual beds are characteristically lenticular and extend over areas of only one or two square miles. Clay beds, clay laminae, and clay in the matrix of the sandstones make permeability extrapolation into adjacent areas virtually impossible. There are sweet spots in some of the fields where conventional completion practices have been effective in the Frontier. There are also many hundreds of square miles within the basin that are completely untested, or where the reservoir characteristics can only be enhanced through massive hydraulic fracturing.

From a completely practical point of view, all of the Frontier interval could and probably should be given tight gas sand designation.

In summary, most of the deeper, interior part of the Bighorn Basin remains virtually unexplored. Tight gas sand designation is recommended for the lower half of the Polecat Bench (Fort Union), all of the Meeteetse-Mesaverde interval, and the Frontier Formation, in order to encourage renewed exploration interest in this area.

Summary of Findings

The piecemeal approach to tight gas sand designation originally interpreted by industry based on recommendations by FERC, Department of Energy, is basically inappropriate in Wyoming, and will eventually lead to a hodgepodge of separate tracts defined differently by different companies. Under these recommendations tracts may or may not overlap, and they may or may not include the same potential reservoir beds. The end result is creating confusion and an excessive workload on industry and government alike that is completely unnecessary. It would be more practical to define tight gas sand areas on the basis of the geometry of the sedimentary basins and then stipulate the stratigraphic intervals that are to be included with the understanding that there will be some areas discovered that have better sand development than others. The prime objective of the tight gas sand program should be to encourage exploration in basins where industry's efforts have lagged, and to encourage research and development of well completion technology.

The findings of this investigation indicate quite clearly that the Greater Green River, Wind River, and Bighorn basins contain several thousands of feet of gas charged, but impervious, sedimentary rocks that require massive hydraulic fracturing in order to become reservoirs of economic significance. At some later date there may be sufficient subsurface data to include parts of the stratigraphic section in the deeper parts of the Powder River and Hanna basins, but for the present adequate data is lacking.

Tight Gas Sand Proposals on File

During the past year industry has exhibited interest in developing tight gas sand projects in Wyoming. Six companies have submitted formal proposals to the Wyoming Oil and Gas Conservation Commission. The proposed areas and formation designation are outlined on Plate 1, and may be identified as follows:

AMOCO - Mesaverde Formation underlying parts of the Red Desert and Washakie basins and the Wamsutter Arch in Sweetwater and Carbon counties. This proposal has been proposed to and accepted by FERC.

AMOCO - Frontier Formation underlying part of the Green River

Basin and Moxa Arch in Uinta, Lincoln, and Sweetwater counties. This proposal has been proposed to and accepted by FERC.

BENSON-MONTIN-GREER DRILLING CORP. - Frontier Formation in the eastern Washakie Basin in Carbon County. This application is presently under consideration by the State.

ENERGETICS, INC. - Frontier, Bear River and Dakota formations in part of the Green River Basin, in parts of Lincoln, Sweetwater and Sublette counties. This proposal is presently under consideration by the State.

COROLLO AND HAY (Mountain Fuel Resources, Inc.) - Fort Union and Mesaverde formations in the Pinedale Unit in the Green River Basin in Sublette County. This proposal has been approved by the State and is under consideration by FERC.

TEXAS OIL & GAS CORP. - Fox Hills Formation in the northwestern part of the Washakie Basin in Sweetwater County. This proposal has been approved by the State, but is awaiting supplemental data.

The status of these applications and new applications are periodically updated in Appendix A.

APPENDIX A: STATUS OF TIGHT GAS SAND APPLICATIONS SUBMITTED TO THE WYOMING OIL AND GAS CONSERVATION COMMISSION

WYOMING OIL AND GAS CONSERVATION COMMISSION — HIGH COST GAS (TIGHT FORMATION) — MAY 1981

APPLICANT	FORMATION	DOCKET	APPROX ACREAGE	AVERAGE DEPTH	AVERAGE RATE Mcf/D (PRE FRAC)	APPROVED BY STATE	APPROVED BY F.E.R.C.
AMOCO	FRONTIER	CAUSE 1 ORDER 1 DOCKET 65-80	894,720	11,263	235	YES	YES
TEXAS OIL & GAS CORP.	FOX HILLS	CAUSE 1 ORDER 2 DOCKET 69-80	193,920	7,400	25	YES	UNDER REVIEW
AMOCO	MESAVERDE	CAUSE 1 ORDER 2 DOCKET 92-80	2,634,880	10,170	214	YES	YES
COROLLO & HAY	FORT UNION	CAUSE 2 ORDER 1 DOCKET 120-80(A)	311,040	8,000	250	YES	YES
COROLLO & HAY	MESAVERDE	CAUSE 1 ORDER 1 DOCKET 120-80(B)	311,040			DENIED	
ENERGETICS	DAKOTA	CAUSE 1 ORDER 3 DOCKET 189-80	199,680			DENIED	
ENERGETICS	FRONTIER	CAUSE 1 ORDER 3 DOCKET 189-80	199,680	9,000	100	YES	FORWARDED TO F.E.R.C.
ENERGETICS	BEAR RIVER	CAUSE 1 ORDER 3 DOCKET 189-80	199,680	9,500	240	YES	FORWARDED TO F.E.R.C.
BENSON-MONTIN GREER	FRONTIER	CAUSE 1 ORDER 1 DOCKET 193-80	56,326	7,000	166	YES	FORWARDED TO F.E.R.C.
BELCO	BEAR RIVER	CAUSE 1 ORDER 1 DOCKET 53-81	222,720	9,500	150	UNDER REVIEW	
BELCO	FRONTIER	CAUSE 1 ORDER 1 DOCKET 53-81	222,720	8,900	250	UNDER REVIEW	

CURRENT BASE PRICE: $4.888 per MMBTU

WYOMING OIL AND GAS CONSERVATION COMMISSION — HIGH COST GAS (TIGHT FORMATION) — MAY 1981

APPLICANT	FORMATION	DOCKET	APPROX ACREAGE	AVERAGE DEPTH	AVERAGE RATE Mcf/D (PRE FRAC)	APPROVED BY STATE	APPROVED BY F.E.R.C.
BELCO	DAKOTA	CAUSE 1 ORDER 1 DOCKET 53-81	222,720			UNDER REVIEW	
AMOCO	LEWIS	CAUSE 1 ORDER 1 DOCKET 93-81	2,811,520	7,800	170	UNDER REVIEW	
HOUSTON OIL & MINERALS	FRONTIER	CAUSE 1 ORDER 1 DOCKET 113-81	7,260			SET FOR JUNE HEARING	
PACIFIC TRANSMISSION & SUPPLY	FRONTIER	CAUSE 1 ORDER 1 DOCKET 128-81	136,960			SET FOR JULY HEARING	
		CAUSE ORDER DOCKET					
		CAUSE ORDER DOCKET					
		CAUSE ORDER DOCKET					
		CAUSE ORDER DOCKET					
		CAUSE ORDER DOCKET					
		CAUSE ORDER DOCKET					
		CAUSE ORDER DOCKET					

CURRENT BASE PRICE: $4.888 per MMBTU

APPENDIX B: COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

Statistics summarized from data included in various company applications submitted to the Wyoming Oil and Gas Conservation Commission (Compiled by Robert L. Oliver).

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

AMOCO MESAVERDE PROPOSAL

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Initial Pressure (psig)
Champlin 222 Amoco C-1	SW15-19-93	9,110	9,115-48	0.1393	152,000	315,250	160	4300	NA
Champlin 237 Amoco C-1	SW 5-17-94	10,191	10,200-12 10,233-49	0.0178	304,416	447,773	12	431	5500
Champlin 242 Amoco B-1	SW35-20-93	9,567	9,570-9,600	0.0230	107,856	270,000	61	5222	5625
Champlin 242 Amoco C-1	SW 3-19-93	9,448	9,500-32	0.0629	133,686	315,000	NA	1280	5077
Champlin 242 Amoco E-1	SW13-19-93	9,092	9,190-9,205	0.0852	323,484	645,000	852	3939	5364
Champlin 242 Amoco F-1	SW25-20-93	9,836	9,838-70	0.0041	132,400	271,500	13	1180	5500
Champlin 242 Amoco G-1	SW27-20-93	9,645	9,908-14 9,940-46	0.0054	191,520	425,000	23	3192	5700
Champlin 261 Amoco C-1	SW 3-18-93	8,768	8,846-58 8,770-90	0.0323	338,000	647,568	732	1811	5336
Champlin 263 Amoco B-1	SW27-22-94	10,876	10,881-908	0.0181	161,740	230,000	284	1126	6250
Champlin 221 Amoco A-1	SW29-18-94	9,298	9,928-38	0.0142	187,000	336,000	NA	1031	5150
Champlin 226 Amoco E-1	SW23-18-93	8,668	8,691-95 8,766-68 8,803-05 8,905-08 8,918-23 9,038-43	0.0407	222,768	380,000	18	55	5020
Champlin 237 Amoco B-1	SW 3-17-94	9,816	10,047-58	0.0424	77,448	180,000	NA	465	5270
Champlin 237 Amoco D-1	SW17-17-94	10,656	10,992-11,000 11,008-20	0.0370	122,892	262,776	762	807	5810
Champlin 242 Amoco D-1	SW11-19-93	9,244	9,654-67	0.3067	191,100	321,869	682	531	5750

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

AMOCO MESAVERDE PROPOSAL (cont.)

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Initial Pressure (psig)
Champlin 270 Amoco B-1	SW31-23-94	11,285	11,700-10	0.0676	68,838	55,366	134	220	5650
Champlin 533 Amoco A-1	SW13-22-93	12,176	12,308-18	0.0125	26,000	30,000	40	178	7654
Champlin 567 Amoco A-1	SW15-19-96	8,912	9,120-28	0.0592	100,000	207,500	29	53	3423
Five Mile Gulch No.3	SW35-21-93	10,468	10,714-22 10,672-88 10,664-68	0.0270	117,180	180,000	29	1019	6256
Salazar No.2	SW11-16-95	12,052	12,150-60	0.0175	124,656	228,114	70	431	7110
USA Amoco Q No.1	SW28-23-94	10,570	12,072-90	0.0322	33,800	40,860	95	724	6800
USA Amoco S No.1	SW22-20-94	9,546	9,949-59 9,968-80	0.0477	280,014	680,000	226	414	6072
USA Amoco T No.1	SW 4-20-93	10,075	10,490-800 10,514-20	0.0020	331,506	597,000	35	700	5750
USA Amoco T No.1	SW 4-20-93	10,025	10,574-80 10,604-24	0.0018	None	None	31	None	6153
Champlin 450 Amoco A-1	SW21-23-94	11,910	11,912-18 11,931-47	0.0050	None	None	5	None	6450
Siberia Ridge No.5	SW 3-21-94	10,582	10,586-606	0.0258	122,000	206,000	NA	990	6200
Siberia Ridge No.6	SW 9-21-94	10,486	10,438-42 10,453-56 10,472-78 10,496-500	0.0070	138,400	285,000	NA	350	5900
Champlin 336 Amoco A-1	SW21-17-94	10,620	10,976-92	0.0134	122,000	280,000	3	254	5948

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS
AMOCO MESAVERDE PROPOSAL (cont.)

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Initial Pressure (psig)
Champlin 451 Amoco A-1	SW17-21-94	10,228	10,384-93 10,407-11 10,450-65	0.0194	248,000	554,160	142	2830	6442
Monument Lake No.3	SW29-22-92	12,108	12,296-309 12,359-72	0.0070	298,000	695,000	317	260	5729
USA Amoco R No.1	SW20-21-94	10,006	10,110-21	0.0403	410,000	853,000	220	192	5648
Champlin 573 Amoco A-1	SW 3-21-90	8,912	13,114-34 13,098-106	0.0048	75,000	152,000	NA	9	6733
Monument Lake No.3	SW29-22-92	12,108	12,111-27	0.0085	110,000	290,000	18	0	6100
Champlin 237 Amoco B-1	SW 3-17-94	9,816	10,105-11 10,140-52	0.0231	77,450	180,000	9	476	5200
Champlin 237 Amoco D-1	SW17-17-94	10,656	10,812-20 10,885-90	0.0495	123,000	264,000	44	807	5810
Champlin 270 B-1	SW31-23-94	11,285	11,403-08 11,440-50	0.0179	62,000	111,000	90	31	6150
Champlin 237 Amoco D-1	SW 5-17-94	10,191	10,805-19	0.0226	55,600	80,000	21	166	5708
Champlin 237 Amoco A-1	SW 7-17-94	10,570	11,884-912 11,954-70 11,978-94	0.0109	300,000	666,000	NA	740	7401
Buck Draw No.1	SW29-21-91	11,382	11,815-28	0.0089	None	None	NA	None	6015
Champlin 237 Amoco D-1	SW17-17-94	10,656	10,992-11,000 11,008-20	0.2404	28,000	139,000	750	255	5347
Champlin 270 Amoco B-1	SW31-23-94	11,285	11,788-98	0.0293	None	None	150	None	6528

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

AMOCO MESAVERDE PROPOSAL (cont.)

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Flow Pressure (psig)
Champlin 278 Amoco D-1	SW 1-18-93	8,658	9,022-44	0.0278	55,900	63,000	26	639	5540
Champlin 440 Amoco A-1	SW11-17-98	8,586	9,040-56	0.0106	252,000	600,000	NA	75	3752
Champlin 536 Amoco A-1	SW 1-21-92	12,088	12,530-44	0.0943	65,000	100,200	635	536	7057
Creston III Unit #5-24	24-18-92	7,430	-	-	-	-	-	-	-
Creston III Unit #6-4	4-18-91	NA	7,036	NA	249,500	497,800	NA	(Not completed)	
Latham #1-14	14-20-93	NA	10,222	NA	270,900	479,000	17	322	40
Echo Springs #2-4	4-19-93	9,550	9,550	NA	250,300	569,300	10	840	830
Echo Springs #1-2	2-19-93	9,470	9,477	NA	430,500	495,900	363	3,277	650
Standard Draw #1-2	2-18-93	8,665	8,671	NA	188,000	264,000	263	5,800	2,800
Standard Draw #3-16	16-18-93	8,855	8,858	NA	214,600	452,000	NA	3,334	3,350
Tierney II Unit #6-32	32-20-93	NA	9,628	NA	265,000	588,500	65	(Not completed)	
Tierney II Unit #4-22	22-19-94	NA	9,567	NA	111,600	208,400	90	2,109	800
Tierney II Unit #1-23	23-19-94	9,425	9,455	NA	252,600	411,100	470	970	675
Tierney II Unit #7-24	24-19-94	NA	9,508	NA	-	-	-	-	-
Tierney II Unit #2-26	26-19-94	9,480	9,516	NA	142,200	253,200	NA	1,474	700
Tierney II Unit #5-34	34-19-94	8,460	-	-	-	-	-	-	-
Wamsutter State #1-16	16-21-94	10,325	10,332	NA	140,000	215,000	NA	1,048	2,330
Wamsutter Unit #A-7	28-21-94	9,970	9,970	NA	66,500	23,000	NA	1,226	1,000
Wamsutter Unit #A-6	29-21-94	9,865	9,869	NA	79,200	27,000	NA	1,080	3,170

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS
AMOCO MESAVERDE PROPOSAL (cont.)

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Flow Pressure (psig)
Wamsutter Unit #A-5	32-21-94	9,688	9,688	NA	97,900	30,000	NA	1,350	3,770
Wamsutter Unit #A-4	1-20-95	9,640	9,646	NA	55,400	23,900	466	2,209	4,050
Wamsutter Unit Fed. #1-6	6-20-94	9,787	9,787	NA	181,700	247,500	260	519	1,650
Wamsutter Fed. #1-8	8-20-94	9,753	9,753	NA	150,000	258,000	NA	821	775
Wamsutter Unit #A-1	12-20-95	9,594	9,594	NA	120,600	75,600	538	4,181	2,770
Wamsutter Unit Fed.#1-18	18-20-94	9,636	9,636	NA	69,700	152,600	150	1,420	1,000
Tierney II Unit #1-23	23-19-94	9,420	11,145-55	NA	44,000	62,500	NA	250	150
			9,791-803; 9,915-31	NA	98,600	148,100	NA	nil	-
			9,455-59; 9,464-68	0.026	110,000	200,500	470	970	675
			9,546-54; 9,585-97						
			9,649-62; 9,665-68						
Tierney II Unit #4-22	22-19-94	NA	9,567-80	NA	38,000	54,000	NA	2,109	800
			9,766-76	0.025	73,600	154,400	90		
Echo Springs #2-4	4-19-93	9,550	9,550-74	NA	100,800	240,000	NA		
			9,828-49; 9,940-52	NA	82,000	198,000	NA	840	830
			10,288-301	0.002	67,500	131,300	10	nil	-

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

TEXAS OIL & GAS FOX HILLS PROPOSAL

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Flow Pressure (psig)
#1 Amoco Antelope Flats	35-17-99	6,994	6,992-7,120	0.004	104,958	18,000	TSTM	110	NA
TXO North Bitter Creek #1 Fed	2-16-99	7,580	7,436-883	NA	103,300	150,000	TSTM	540	NA
TXO Antelope Flats #1 State	36-17-99	7,020	7,191-274	NA	92,610	139,612	Not tested	675	NA
Continental Bitter Creek Unit #3	36-17-99	7,600	7,844-61 7,720-44 7,602-14 7,634-42	NA	NA	NA	300-85	500	NA
Continental Bitter Creek Unit #3-2	3-16-99	7,700	7,865-96	NA	NA	NA	447-333	1,380	NA

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

BENSON-MONTIN-GREER FRONTIER PROPOSAL

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Flow Pressure (psig)
B-M-G J-31X	31-16-90	7,035	NA	0.07	2,000	None	160	745	254
True 31-31	31-16-90	7,470	NA	NA	None	26,000	65-110	100	NA

COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

ENERGETICS 2ND FRONTIER PROPOSAL

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Flow Pressure (psig)
32-15 Fed	15-25-110	10,405	10,582-602	NA	57,000	65,000	15	1442	NA
32-22 Fed	22-25-110	10,362	10,363-520	NA	121,400	77,000	No Test	1656	NA
32-27 Fed	27-25-110	10,345	10,398-474	NA	46,500	59,000	No Test	2276	NA
32-28 Fed	28-25-110	9,500	Open Hole	NA	None	None	782	782	NA
32-33 Fed	33-26-110	10,328	10,461-81	NA	76,000	135,000	TSTM	115	NA
Horn Canyon 32-34 Fed	34-25-110	10,522	10,522-70	NA	32,850	50,000	24	172	NA
23-14 Fed	14-25-111	9,230	9,347-66	NA	46,000	56,000	66	250	NA
32-26 Fed	26-25-110	10,434	10,558-72 10,578-98	NA NA	75,000 24,000	11,500 16,000	TSTM	227	NA
44-9 Fed	9-25-110	10,015	10,096-112	NA	73,000	None	23	NA	NA
Lincoln Road Unit 8	34-25-111	8,870	Open Hole	NA	71,200	120,000	NA	600	NA

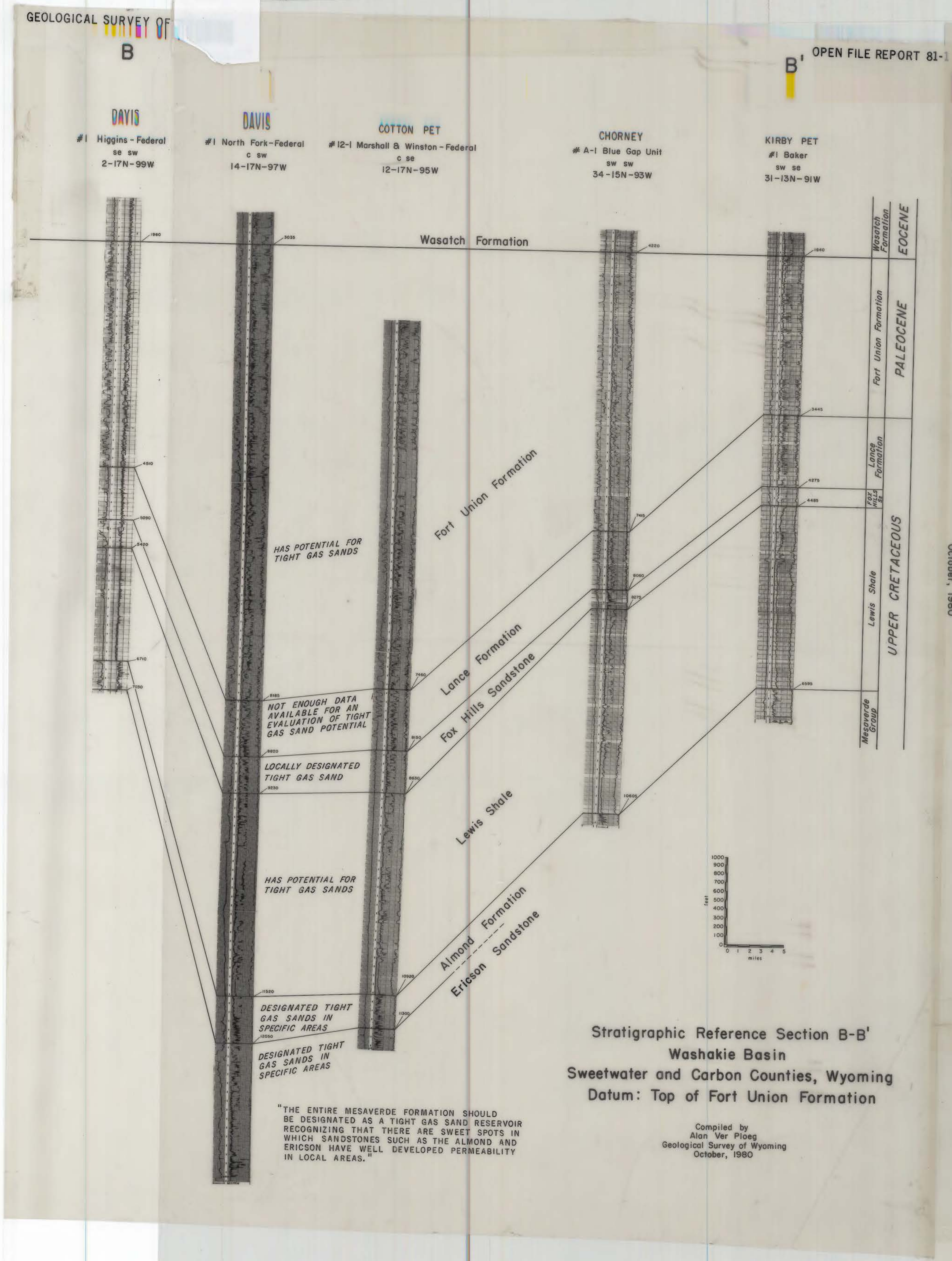
COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS
ENERGETICS BEAR RIVER PROPOSAL

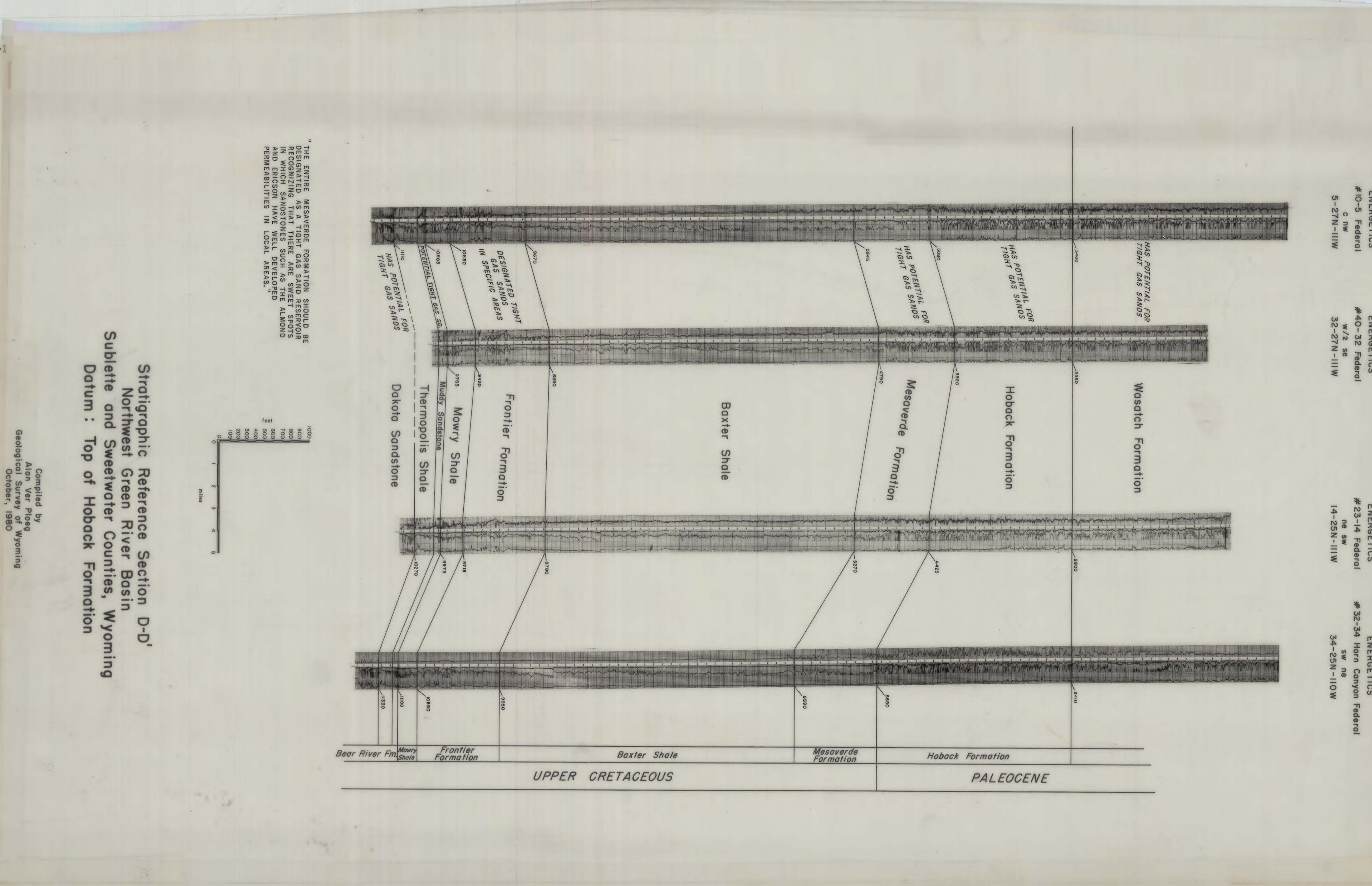
Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Flow Pressure (psig)
10-19 Fed	19-27-111	9,621	9,621-44	NA	40,000	63,750	No test	348	NA
10-30 Fed	30-27-111	9,428	9,432-74	NA	73,000	120,000	No test	1409	NA
40-30 Fed	30-27-111	9,484	9,484-98	NA	54,000	79,000	60	1496	NA
40-32 Fed	32-27-111	9,660	9,666-84	NA	65,000	100,000	223	500	NA
10-29 Fed	29-27-111	9,686	9,693-730	NA	64,750	79,000	628	4400	NA
40-29 Fed	29-27-111	9,815	9,821-36	NA	67,200	95,000	166	935	NA
10-5 Fed	5-27-111	10,687	10,692-726	NA	42,000	53,500	TSTM	550	NA
30-15 Fed	15-27-111	10,926	10,934-72 11,076-94	NA	74,200	84,000	TSTM	211	NA
10-20 Fed	20-27-111	9,974	9,974-90	NA	48,000	66,000	250	1807	NA
10-32 Fed	32-27-111	9,516	9,522-40	NA	75,000	130,000	107	407	NA
30-4 Fed	4-26-111	9,680	9,684-700	NA	81,100	130,000	108	100	NA
10-28 Fed	28-27-111	10,094	10,094-125	NA	75,000	133,000	274	NA	NA
40-20 Fed	20-27-111	9,963	9,963-77	NA	61,250	75,000	260	NA	NA
10-17 Fed	17-27-111	10,106	10,106-22	NA	75,000	131,000	507	NA	NA
40-7 Fed	7-27-111	9,582	9,587-627 9,741-56	NA	86,000	212,000	639	NA	NA
10-8 Fed	8-27-111	10,093	10,098-112	NA	75,200	135,800	121	NA	NA
40-6 Fed	6-27-111	9,953	9,958-76	NA	75,000	133,000	357	NA	NA

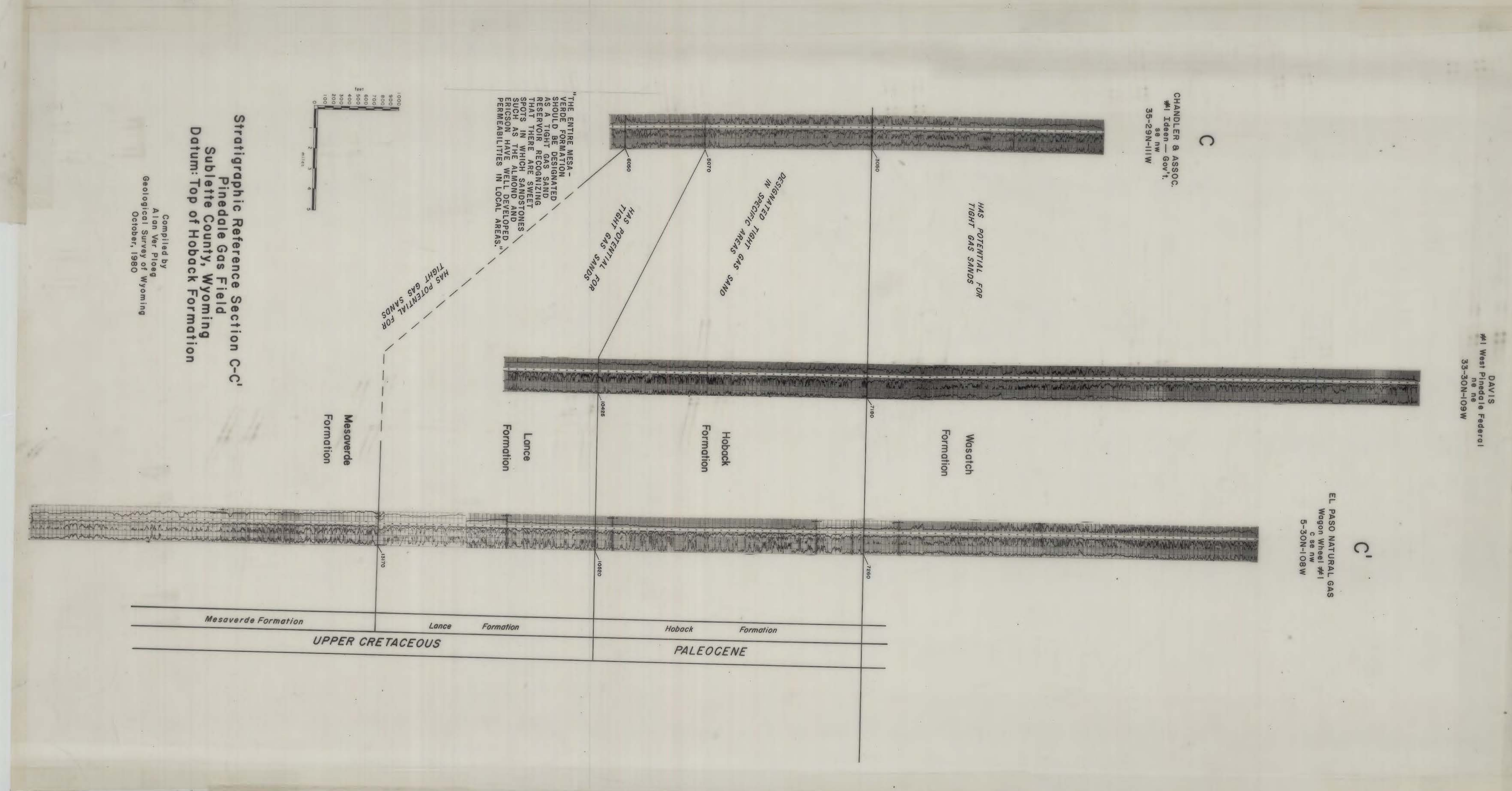
COMPLETION STATISTICS FOR TIGHT GAS SAND RELATED WELLS

ENERGETICS DAKOTA PROPOSAL

Well Name	Location	Formation Top	Perforations (feet)	Gas Permeability (md.)	Quantity of Fracturing Fluid (Gallons)	Quantity of Proppant (Pounds)	Pre-treatment Rate at Atm. Pressure (MCF/day)	Post Treatment Rate (MCF/day)	Flow Pressure (psig)
32-15 Fed	15-25-110	11,360	11,373-83	NA	60,000	71,000	TSTM	1442	NA
32-22 Fed	22-25-110	11,278	11,408-18	NA	32,000	49,000	No test	1656	NA
32-27 Fed	27-25-110	11,224	11,256-66	NA	64,000	70,000	500	2276	NA
32-28 Fed	28-25-110	NA	Open Hole	NA	None	None	NA	782	NA
32-33 Fed	33-26-110	11,278	11,455-66	NA	83,000	120,000	TSTM	115	NA
32-34 Fed	34-25-110	11,334	11,334-48	NA	1,500	None	TSTM	172	NA
23-14 Fed	14-25-111	10,155	NA	NA	None	None	NA	250	NA
32-26 Fed	26-25-110	11,374	11,398-414 11,461-69 11,500-22	NA NA NA	25,000 40,000 75,000	20,000 15,000 130,000	116	227	NA
41-21 Fed	21-25-110	10,882	10,894-902 10,958-66	NA	72,775	71,550	216	510	NA
44-9 Fed	9-25-110	10,918	10,925-33	NA	72,500	67,500	21	NA	NA
Unit 8	34-25-111	NA	Open Hole	NA	None	None	178	600	NA


GEOLOGICAL SURVEY OF
B
B'
OPEN FILE REPORT 81-1
DAVIS
#1 Higgins - Federal
se sw
2-17N-99W
DAVIS
#1 North Fork-Federal
c sw
14-17N-97W
COTTON PET
#12-1 Marshall & Winston-Federal
c se
12-17N-95W
CHORNEY
A-1 Blue Gap Unit
sw sw
34-15N-93W
KIRBY PET
#1 Baker
sw se
31-13N-91W
Wasatch Formation
Fort Union Formation
Lance Formation
Fox Hills Sandstone
Lewis Shale
Almond Formation
Ericson Sandstone
HAS POTENTIAL FOR TIGHT GAS SANDS
NOT ENOUGH DATA AVAILABLE FOR AN EVALUATION OF TIGHT GAS SAND POTENTIAL
LOCALLY DESIGNATED TIGHT GAS SAND
HAS POTENTIAL FOR TIGHT GAS SANDS
DESIGNATED TIGHT GAS SANDS IN SPECIFIC AREAS
DESIGNATED TIGHT GAS SANDS IN SPECIFIC AREAS
"THE ENTIRE MESAVERDE FORMATION SHOULD BE DESIGNATED AS A TIGHT GAS SAND RESERVOIR RECOGNIZING THAT THERE ARE SWEET SPOTS IN WHICH SANDSTONES SUCH AS THE ALMOND AND ERICSON HAVE WELL DEVELOPED PERMEABILITY IN LOCAL AREAS."
Wasatch Formation
EOCENE
Fort Union Formation
PALEOCENE
Lance Formation
Lewis Shale
UPPER CRETACEOUS
Mesaverde
Stratigraphic Reference Section B-B'
Washakie Basin
Sweetwater and Carbon Counties, Wyoming
Datum: Top of Fort Union Formation
Compiled by
Alan Ver Ploeg
Geological Survey of Wyoming
October, 1980


D
D'
ENERGETICS
#10-5 Federal
5-27N-111W
ENERGETICS
#40-32 Federal
32-27N-111W
ENERGETICS
#23-14 Federal
14-25N-111W
ENERGETICS
#32-34 Horn Canyon Federal
34-25N-110W
OPEN FILE REPORT 81-1
GEOLOGICAL SURVEY OF WYOMING
Wasatch Formation
Hoback Formation
Mesaverde Formation
Baxter Shale
Frontier Formation
Mowry Shale
Thermopolis Shale
Dakota Sandstone
HAS POTENTIAL FOR TIGHT GAS SANDS
DESIGNATED TIGHT GAS SANDS IN SPECIFIC AREAS
"THE ENTIRE MESAVERDE FORMATION SHOULD BE DESIGNATED AS A TIGHT GAS SAND RESERVOIR RECOGNIZING THAT THERE ARE SWEET SPOTS IN WHICH SANDSTONES SUCH AS THE ALMOND HAVE WELL DEVELOPED PERMEABILITIES IN LOCAL AREAS."
Bear River Fm.
Mowry Shale
Frontier Formation
Baxter Shale
Mesaverde Formation
Hoback Formation
UPPER CRETACEOUS
PALEOCENE
Stratigraphic Reference Section D-D'
Northwest Green River Basin
Sublette and Sweetwater Counties, Wyoming
Datum: Top of Hoback Formation
Compiled by
Alan Ver Ploeg
Geological Survey of Wyoming
October, 1980


C
C'
CHANDLER & ASSOC.
#1 Eden-Gov't.
35-29N-111W
DAVIS
#1 West Pinedale Federal
33-30N-109W
EL PASO NATURAL GAS
5-30N-108W
GEOLOGICAL SURVEY OF WYOMING
OPEN FILE REPORT 81-1
Wasatch Formation
Hoback Formation
Lance Formation
Mesaverde Formation
HAS POTENTIAL FOR TIGHT GAS SANDS
DESIGNATED TIGHT GAS SAND IN SPECIFIC AREAS
HAS POTENTIAL FOR TIGHT GAS SANDS
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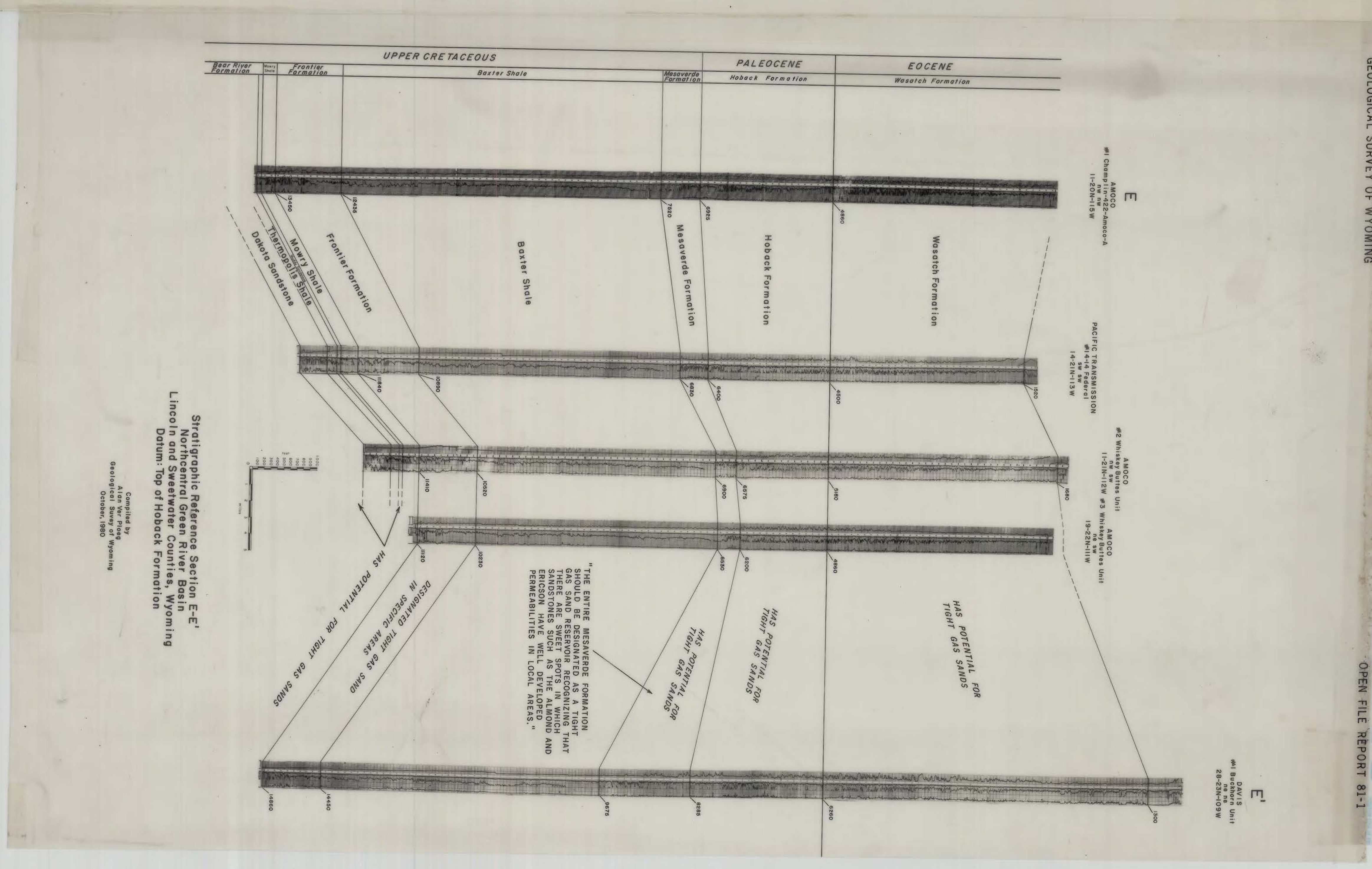
"THE ENTIRE MESAVERDE FORMATION SHOULD BE DESIGNATED AS A TIGHT GAS SAND RESERVOIR RECOGNIZING THAT THERE ARE SWEET SPOTS IN WHICH SANDSTONES SUCH AS THE ALMOND HAVE WELL DEVELOPED PERMEABILITIES IN LOCAL AREAS."
Mesaverde Formation
Lance Formation
Hoback Formation
UPPER CRETACEOUS
PALEOCENE
Stratigraphic Reference Section C-C'
Pinedale Gas Field
Sublette County, Wyoming
Datum: Top of Hoback Formation
Compiled by
Alan Ver Ploeg
Geological Survey of Wyoming
October, 1980


UPPER CRETACEOUS
PALEOCENE
EOCENE
Bear River Formation
Frontier Formation
Baxter Shale
Mesaverde Formation
Hoback Formation
Wasatch Formation
E
E'
GEOLOGICAL SURVEY OF WYOMING
OPEN FILE REPORT 81-1
Wasatch Formation
Hoback Formation
Mesaverde Formation
Baxter Shale
Frontier Formation
Mowry Shale
Thermopolis Shale
Dakota Sandstone
HAS POTENTIAL FOR TIGHT GAS SANDS
HAS POTENTIAL FOR TIGHT GAS SANDS
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DESIGNATED TIGHT GAS SAND IN SPECIFIC AREAS
HAS POTENTIAL FOR TIGHT GAS SANDS
"THE ENTIRE MESAVERDE FORMATION SHOULD BE DESIGNATED AS A TIGHT GAS SAND RESERVOIR RECOGNIZING THAT THERE ARE SWEET SPOTS IN WHICH SANDSTONES SUCH AS THE ALMOND AND ERICSON HAVE WELL DEVELOPED PERMEABILITIES IN LOCAL AREAS."
Stratigraphic Reference Section E-E'
Northcentral Green River Basin
Lincoln and Sweetwater Counties, Wyoming
Datum: Top of Hoback Formation
Compiled by
Alan Ver Ploeg
Geological Survey of Wyoming
October, 1980

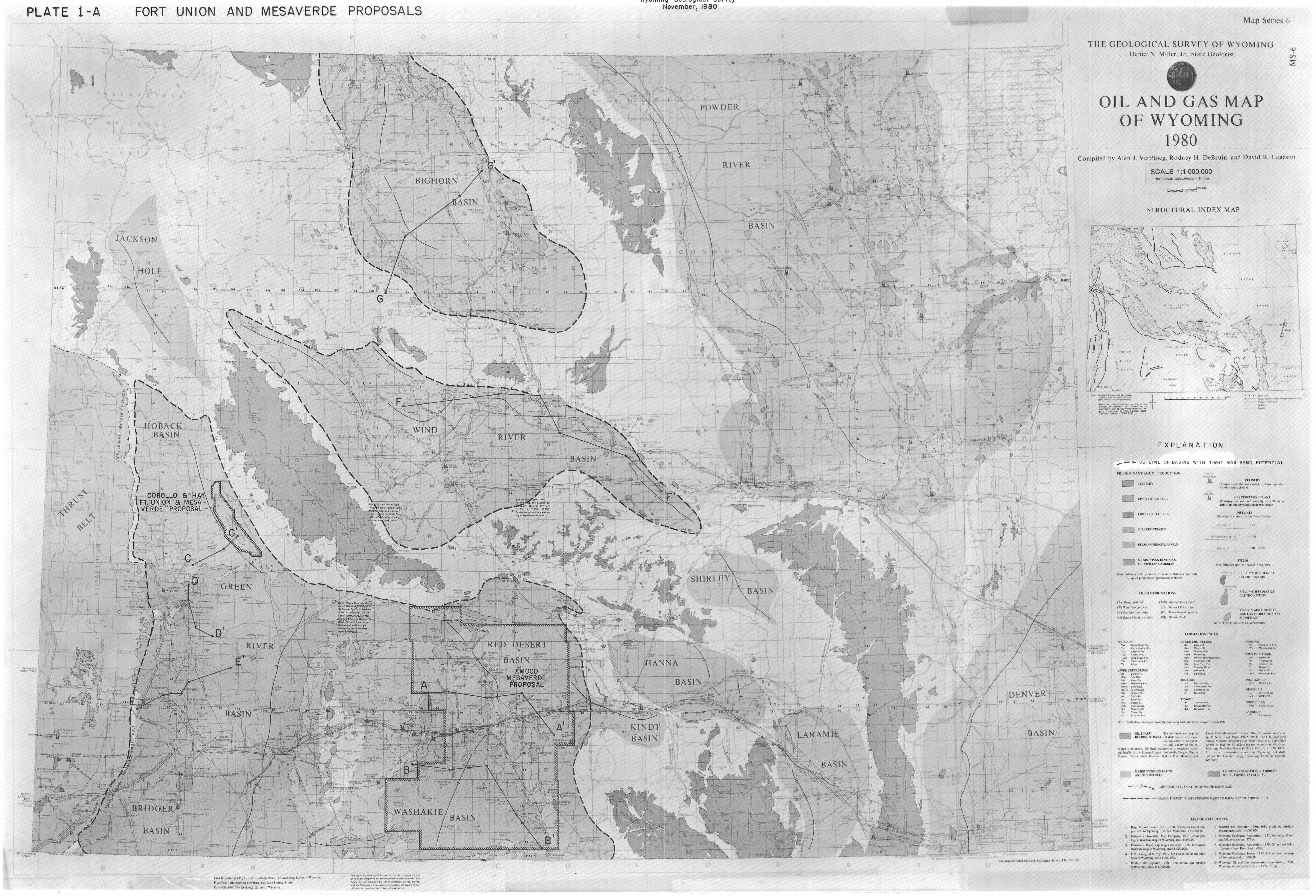
TIGHT GAS SANDS INDEX MAP

Compiled by
Alan J. Ver Ploeg
Wyoming Geological Survey
November, 1980

GEOLOGICAL SURVEY OF WYOMING

OPEN FILE REPORT 81-1, PLATE 1-A

PLATE 1-A FORT UNION AND MESAVERDE PROPOSALS



TIGHT GAS SANDS INDEX MAP

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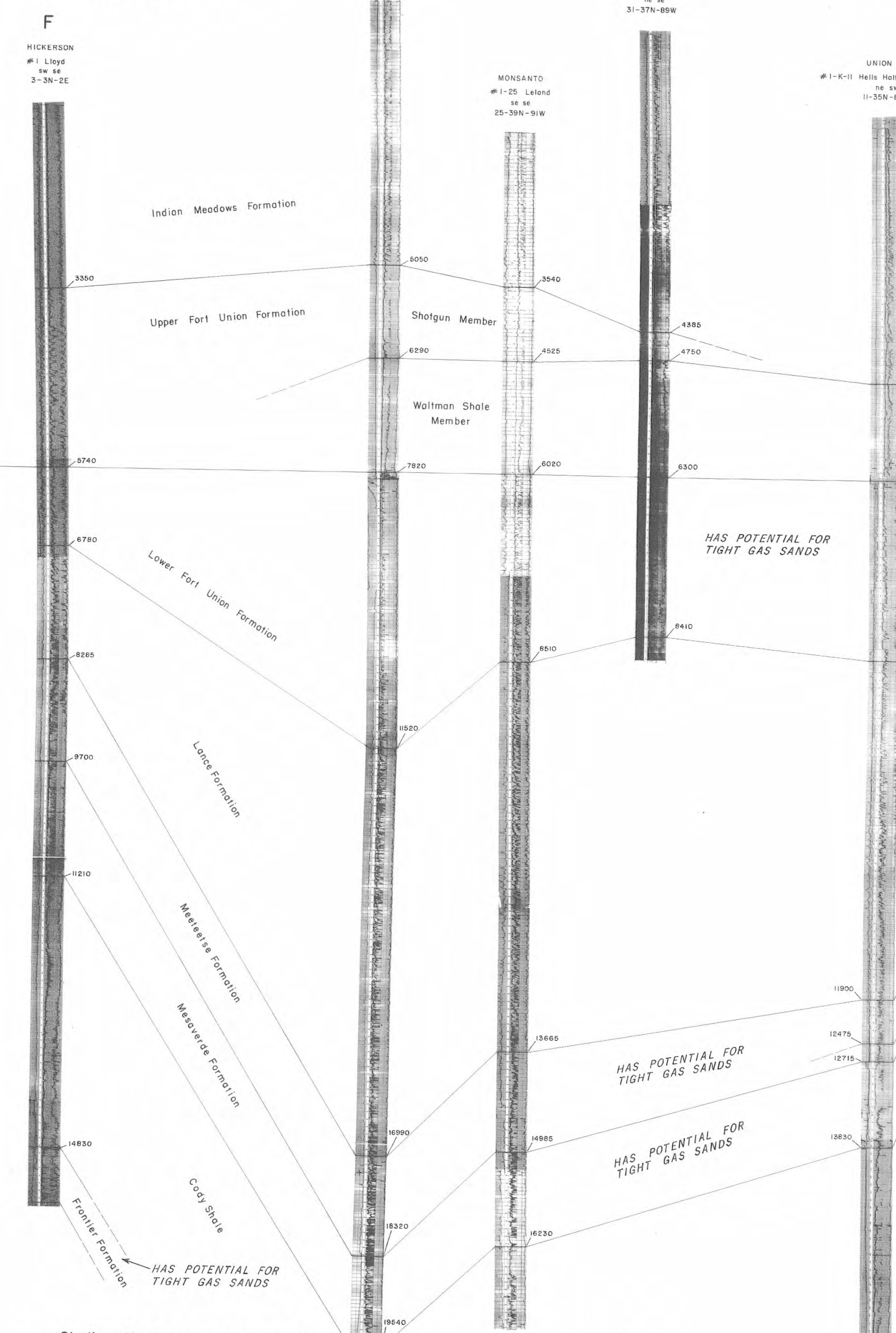
Wyoming Geological Survey
November, 1980

GEOLOGICAL SURVEY OF WYOMING

OPEN FILE REPORT 81-1, PLATE 1-C

PLATE 1-C LEWIS PROPOSAL



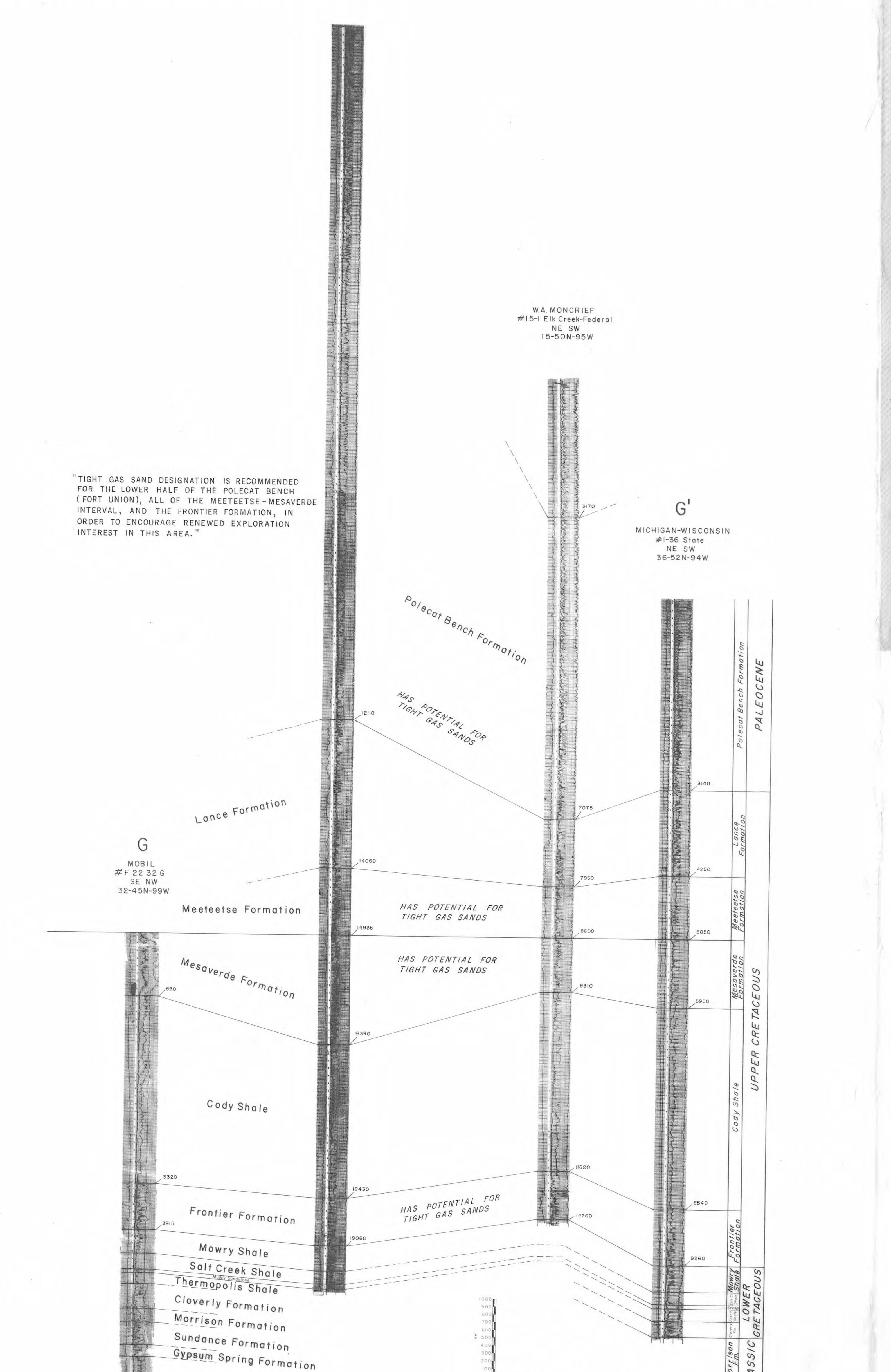
Stratigraphic Reference Section F-F'
Wind River Basin
Fremont and Natrona Counties, Wyoming
Datum: Top of Lower Fort Union Formation

Compiled by Alan Ver Ploeg, Geological Survey of Wyoming, October, 1980

"ASSESSMENT OF DRILL STEM TESTS, RESERVOIR PRESSURES, AND PRODUCTION RECORDS FROM WELLS IN THE DEEP PART OF THE BASIN SUGGEST THAT THE PALEOCENE FORT UNION, THE UPPER CRETACEOUS MESAVERDE AND FRONTIER FORMATIONS MAY BE ELIGIBLE."

"THERE MAY ALSO BE OTHER ZONES IN THE LOWER CRETACEOUS SUCH AS THE MUDDY, DAKOTA, AND LAKOTA, THAT MAY QUALIFY FOR TIGHT GAS SAND DESIGNATION IN SPECIFIC PARTS OF THE BASIN."

"TIGHT GAS SAND DESIGNATION IS RECOMMENDED FOR THE LOWER HALF OF THE POLECAT BENCH (FORT UNION), ALL OF THE MEETEETSE-MESAVERDE INTERVAL, AND THE FRONTIER FORMATION, IN ORDER TO ENCOURAGE RENEWED EXPLORATION INTEREST IN THIS AREA."



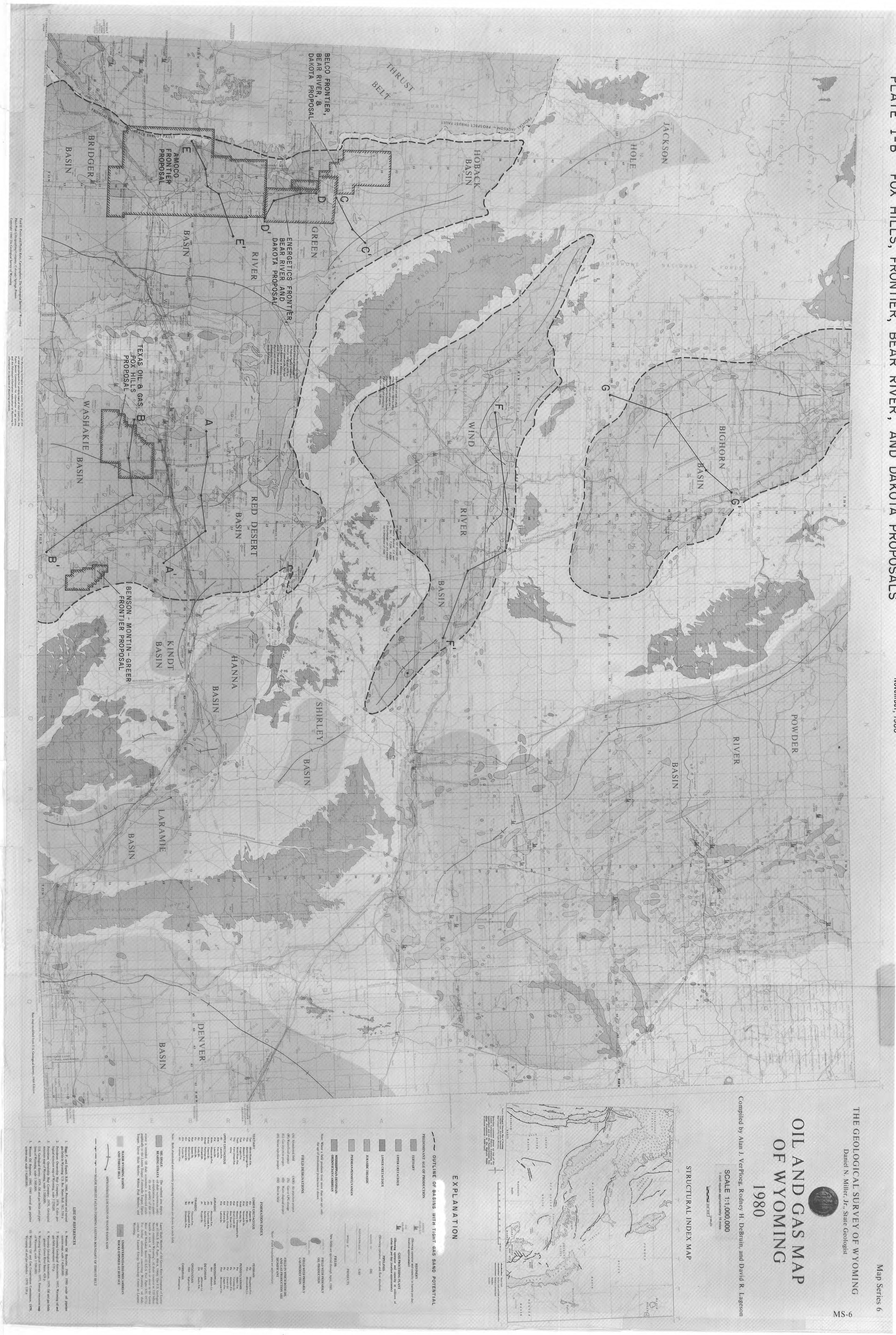
Stratigraphic Reference Section G-G'
Big Horn Basin
Hot Springs, Park, and Big Horn Counties, Wyoming
Datum: Top of Mesaverde Formation

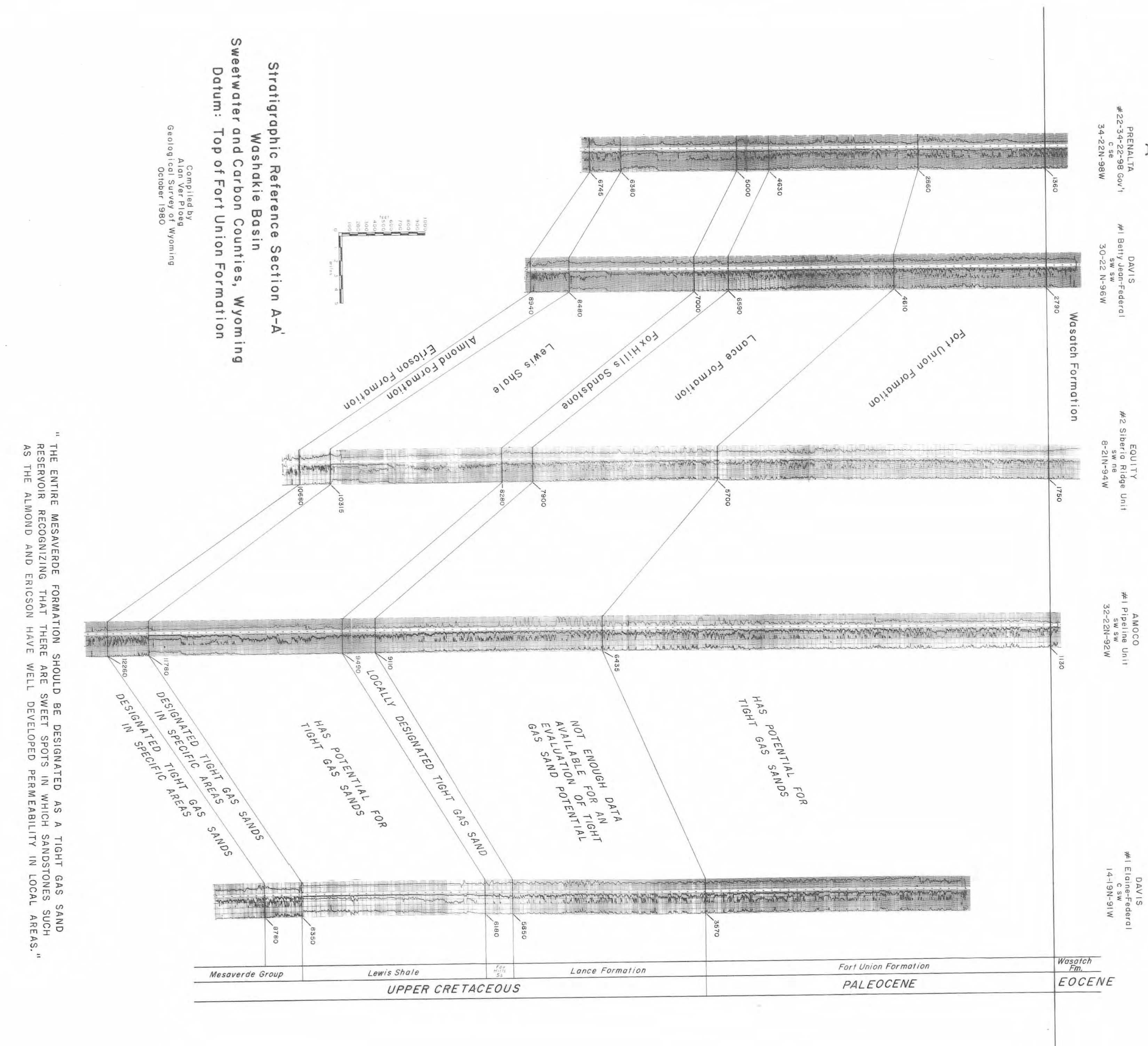
Compiled by Alan Ver Ploeg, Geological Survey of Wyoming, October, 1980

TIGHT GAS SANDS INDEX MAP

PLATE 1-B FOX HILLS, FRONTIER, "BEAR RIVER," AND DAKOTA PROPOSALS

Compiled by Alan J. Ver Ploeg, Wyoming Geological Survey, November, 1980





Stratigraphic Reference Section A-A'
Washakie Basin
Sweetwater and Carbon Counties, Wyoming
Datum: Top of Fort Union Formation

Compiled by Geological Survey of Wyoming, October 1980

"THE ENTIRE MESAVERDE FORMATION SHOULD BE DESIGNATED AS A TIGHT GAS SAND RESERVOIR RECOGNIZING THAT THERE ARE SWEET SPOTS IN WHICH SANDSTONES SUCH AS THE ALMOND AND ERICSON HAVE WELL DEVELOPED PERMEABILITY IN LOCAL AREAS."