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OIL AND GAS FIELDS OF THE LOST SOLDIER-FERRIS DISTRICT WYOMING

BY

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AND

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OIL AND GAS FIELDS OF THE LOST SOLDIER-FERRIS DISTRICT, WYOMING.

By A. E. Fath and G. F. Moulton.

INTRODUCTION.

The finding of commercial quantities of oil by drilling on the Lost Soldier Flats, in south-central Wyoming, during the spring of 1916, marked the beginning of an oil and gas field development that has resulted in the discovery of the Lost Soldier, Ferris, Mahoney, G. P., Wertz, and O'Brien Springs fields, named in the order in which their productivity was proved. This district is generally referred to as the Lost Soldier-Ferris district, from the names of the two fields first discovered.

Surface indications of oil and gas are not to be found in the region, and it was not until geologists recognized the presence of well-developed domes in this district that the drilling of test wells was undertaken.

The oil and gas fields of this district are in a high, barren, and practically unsettled region, in which most of the land still forms a part of the Federal domain. The need for classifying these lands in accordance with the public-land leasing act of February 25, 1920, resulted in an examination of the region by the United States Geological Survey during the summer and fall of 1920. The geologic findings of this examination were deemed sufficiently interesting to warrant their publication, and the present report is the result.

SUMMARY OF GEOLOGIC RESULTS.

The stratigraphy of the region is similar to that set forth in earlier reports on the oil and gas fields of the Big Horn Basin and central and east-central Wyoming. The rocks represented include crystalline rocks of pre-Cambrian age and sedimentary rocks that range from Cambrian to Tertiary. The rocks of greatest importance, because of their possible yield of oil and gas, belong to the Cretaceous system and include the Cloverly formation, with a sand identified as Muddy sand at its top; the Mowry shale; the Frontier formation, with the Wall Creek and one to three other sands; and a producing sand that is thought to belong to the lower part of the Steele shale or the upper part of the Niobrara shale. Although all these formations yield either oil or gas or both within the district, they are not uniformly oil and gas bearing at all favorable localities. For instance, the Muddy sand yields oil in the Lost Soldier dome and gas in other places.

The pre-Cretaceous formations of the region also contain beds that could serve as reservoirs for oil and gas, and in other parts of the State oil and gas are found in some of these rocks. Strata that possibly contain oil and gas and lie within reach of the drill at some localities in the Lost Soldier-Ferris district include formations as low as the Madison limestone of Mississippian age.

The investigation determined that the Lost Soldier-Ferris district is an oil and gas area with rather sharply defined limits within which nine domes and anticlinal folds have been found. The district as a whole is the modified north end of the Rawlins uplift, a regional feature of major magnitude. The investigation has shown that most of the minor domes and anticlines that control the oil and gas accumulations in this district were formed at a much later date than the major Rawlins uplift, on which they are superimposed. The Rawlins uplift is of pre-Wasatch age, but the minor folds are of post-Wasatch age and perhaps may be as recent as post-Oligocene.

The outcropping formations are concealed by alluvial wash and windblown sand in a large part of the district. It has therefore been impossible to make an accurate structure contour map of the district except in small local areas. Of the nine minor upfolds that have been found, but two, the Lost Soldier and Bunker Hill domes, are sufficiently well indicated by the exposed rocks to show their general configuration and extent. The Lost Soldier dome yields oil from the Wall Creek and associated sands of the Frontier formation and from the deeper Mowry shale and the Muddy sand of Cloverly age. The Bunker Hill dome has not been adequately tested. The shallowest known oil-bearing stratum in this district lies at a depth of more than 5,000 feet on the Bunker Hill dome, and this alone can account for lack of immediate interest in testing the dome.

The Mahoney and Ferris domes are indicated by local exposures of Carlile and Niobrara shales encircled by the Steele shale, but present knowledge of their extent and configuration is based largely on information furnished by the drill. The Mahoney domes contain small quantities of gas in sands of Frontier age and large quantities of gas in the Muddy sand. The Ferris dome yields oil from the Mowry shale and large quantities of gas from the Muddy sand.

The locations of the Wertz and Sherrard domes are determined by dip and strike readings made on bedding planes in the Steele shale. The extent and configuration of their crests can not be determined except from information to be gleaned from future drilling operations. The Wertz "dome" contains small quantities of oil in the Mowry shale and large quantities of gas in the Muddy sand. Press reports seem to indicate that the Muddy sand contains also some oil. The Sherrard dome has been tested by two wells in which only a showing of oil was encountered. In view of the fact that the crest of this fold is concealed, it seems to the authors that the possibilities of this dome have not been sufficiently demonstrated by the test wells thus far drilled.

The O'Brien Springs anticline and the G. P. "dome" are indicated by rim-rock exposures of the Mesaverde formation. The crests of these two folds are completely concealed by dune sand. The O'Brien Springs anticline had been tested by but one well prior to February, 1922, and in this well two good showings of gas were encountered in sands of the Frontier formation. The G. P. "dome" yields oil from a sand that is considered to lie in the lower part of the Steele shale or the upper part of the Niobrara shale. Drilling operations thus far have not definitely proved the presence of "closure" on either of these folds.

The Separation Flats anticline probably represents the main axis of the Rawlins uplift as it extends northward across the Lost Soldier-Ferris district. Except in a very small area at its south end there are no rock exposures by which the location and configuration of the axis can be ascertained. The anticline has been tested by five wells, in which only small showings of gas were encountered, but in the opinion of the authors these wells were not so spaced as to constitute an adequate test of the fold.

FIELD WORK.

The field work for this report was done between the middle of July and November 1, 1920, by a party that originally consisted of the two authors, N. W. Bass, and C. Y. Hsieh. The senior author was in charge until September 5, after which the work was carried on under the direction of the junior author.

The geologic mapping was done by means of plane table and telescopic alidade. After the measurement of a base line, an expanding system of triangulation points was established, from which secondary locations were made by the three-point method, supplemented here and there with stadia traverse. Altitudes were carried throughout the field by vertical angles and were based on United States Geological Survey bench marks, of which two lines cross the district. One of these lines crosses the southeastern part of the district and is described in a Survey bulletin.[1] The other line, which is not described in any publication, extends along the southwest side of the district and is a

[1] Results of spirit leveling in Wyoming, 1896 to 1912: U. S. Geol. Survey Bull. 558, pp. 36, 40, 1914.

single-spur line run in 1907 by a United States Geological Survey party for use in classifying coal lands.[2] The adjusted elevations of this line of bench marks are given on the map (Pl. I). These two lines were tied in during the present investigation by vertical angles across the northern part of the district.

The formation boundaries and the positions and attitudes of key beds were mapped with accuracy where such information was vital, and at every point where a definite location was made the altitude also was determined. Detailed stratigraphic sections were measured at several localities, and by determining the intervals between key beds it was possible to draw structure contours (see Pl. I) throughout most of the district to represent the configuration of the top of the Wall Creek sand, which is the shallow producing sand on the Lost Soldier dome.

The absence of key beds in some places and their concealment by alluvium and dune sand over considerable areas in others made it difficult and in places impossible to determine the geologic structure accurately. In some localities where shale without key beds is so exposed in natural outcrop or in pits dug by hand that its bedding planes could be determined, measurements of the dip and strike were made, and these measurements are represented on the map by the usual dip and strike symbols. The value in critical localities of dip and strike determinations is so great that in many places where rock exposures are completely lacking several of the oil companies have dug shafts 20 feet or more deep through the alluvium and dune sand to bedrock, in order to obtain a single strike and dip determination that would indicate the position or direction of a domal or anticlinal crest. Most of the shafts dug for this purpose were filled with sand at the time of this investigation and hence supplied no information for this report.

In the preparation of this report the senior author wrote most of the text and the junior author did most of the work of compilation for the structure and geologic map (Pl. I).

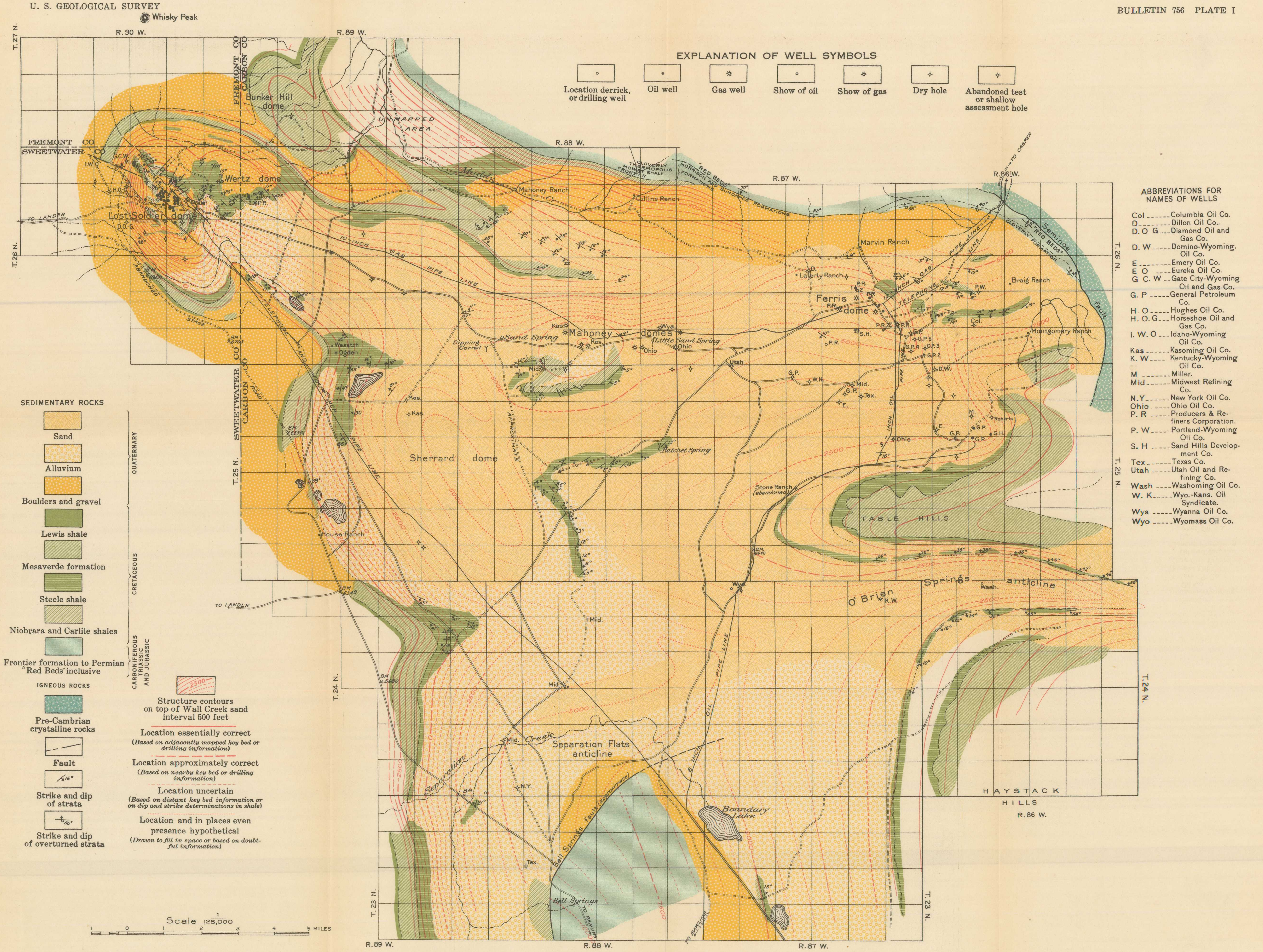
PREVIOUS GEOLOGIC INVESTIGATIONS.

The western and eastern marginal parts of the Lost Soldier-Ferris district were investigated by the United States Geological Survey in 1906 and 1907 to obtain data for coal-land classification, and the reports of these investigations [3] included maps showing the distribution of the formations in their respective regions.

It is probable that outside of these investigations no general examination of the region was attempted until, in the search by geolo-

[2] Smith, E. E., The eastern part of the Great Divide Basin coal field, Wyo.: U. S. Geol. Survey Bull. 341, pp. 220-242, 1909.

[3] Veatch, A. C., Coal fields of east-central Carbon County, Wyo.: U. S. Geol. Survey Bull. 316, pp. 244-260, 1907. Smith, E. E., The eastern part of the Great Divide Basin coal field, Wyo.: U. S. Geol. Survey Bull. 341, pp. 220-242, 1909.



MAP OF THE LOST SOLDIER-FERRIS DISTRICT, WYOMING

Showing the areal geology and structure of the Wall Creek sand gists for possible oil-bearing anticlines and domes, the presence of the Lost Soldier dome was recognized by a study of the map accompanying Smith's report. A test well proved the oil-bearing possibilities of this dome in the spring of 1916, and it is probable that commercial geologists immediately scanned the entire district. The results of their work, however, have never been published.

ACKNOWLEDGMENTS.

During the field investigation lodging and board were obtained at several ranches and drilling camps. These accommodations obviated the necessity of running a special camp or of driving out from Rawlins each day, and for this courtesy thanks are due to the ranchers and oil-company officials.

The officials and geologists of the oil companies were, as a rule, very generous in furnishing information regarding their wells and in discussing the geologic problems of the region. Geologic and development maps, together with well logs, were freely supplied. For such courtesies thanks are due to the following companies and officials: Bair Oil Co., C. A. Bonine, Columbia Oil Co., Emery Oil Co., General Petroleum Co., H. R. Harriman, Kasoming Oil Co., E. W. Krampert, Midwest Refining Co., Ohio Oil Co., Portland-Wyoming Oil Co., Producers & Refiners Corporation, Sand Hills Development Co., the Texas Co., Carroll M. Wagner, Wasatch Oil Co., R. E. Wertz, Wyanna Oil Co., and Wyoming-Kansas Oil Co.

The writers are especially grateful to Messrs. E. W. Krampert and C. A. Bonine for much detailed information and for their discussion of local geologic problems with which they alone were intimately familiar. The mapping of the sandstone bed in the upper part of the Steele shale across Range 86, on the flanks of the O'Brien Springs anticline, was supplied by Mr. Bonine.

The painstaking work of Mr. N. W. Bass in the field and in compiling a map of the Ferris dome area is gratefully acknowledged, and to Mr. Willis T. Lee thanks are due for detailed stratigraphic data which enabled the writers to make correlations with the sedimentary section of southeastern and east-central Wyoming.

GEOGRAPHY.

LOCATION AND ACCESSIBILITY.

The Lost Soldier-Ferris district is roughly triangular and contains about 455 square miles. It is in the northeast corner of Sweetwater County and the northwestern part of Carbon County, in south-central Wyoming. (See fig. 1.) It is most easily reached from Rawlins, 25 to 40 miles to the south, a division point on the Union Pacific Railroad and the county seat of Carbon County. The district can also be reached from Casper, 85 miles to the northeast, on the Chicago, Burlington & Quincy and Chicago & Northwestern railroads, and from Lander, the terminus of the Chicago & Northwestern Railway, about 100 miles to the northwest.

Rawlins, with a population of about 4,000 (3,969 in 1920), is the nearest and most accessible railroad point and is therefore the supply center for the entire district. Outside of Rawlins there is no place where meals and lodging can be obtained except at the camps of the oil companies or at the few scattered ranches.

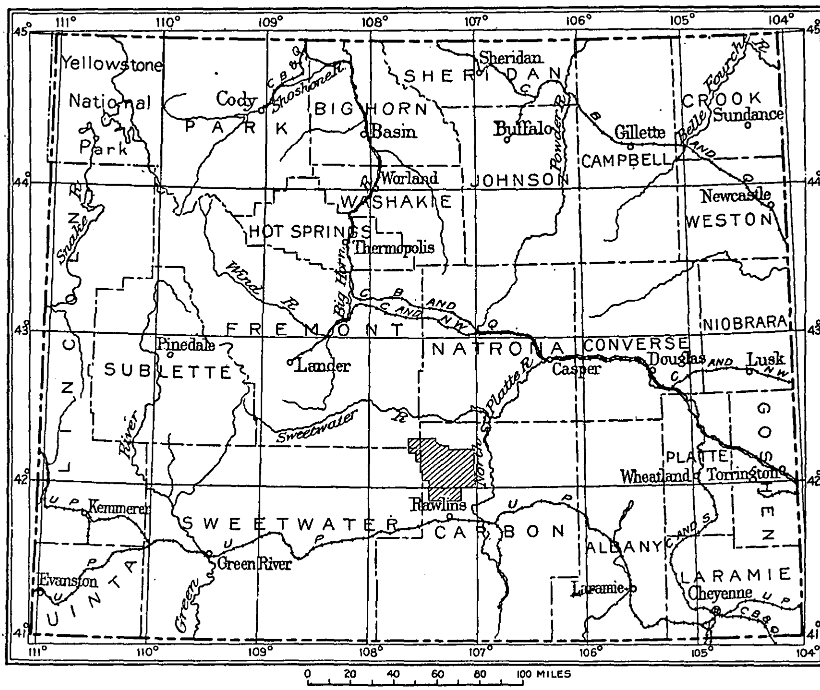


FIGURE 1.—Index map of Wyoming showing location of Lost Soldier area.

TOPOGRAPHY.

The Lost Soldier-Ferris district occupies the almost isolated east end of the Great Divide Basin, a high interior basin having no outward drainage, which lies between the two low divides that in this region represent the Continental Divide. Within the district this basin has a minimum altitude of about 6,420 feet at Boundary Lake and is nearly encircled by the Green, Ferris, and Seminoe mountains on the north and northeast, the Table and Haystack hills on the east and southeast, and the Rawlins Hills on the south. To the west the hogback escarpment rim of Mesaverde sandstone almost isolates the Lost Soldier-Ferris district from the main part of the Great Divide Basin, lying farther west. The Ferris Mountains on the north form a striking topographic feature, and their highest peak rises above 10,000 feet. (See Pl. III, *A*.)

The Ferris Mountains are separated from the basin proper by the valleys of Muddy and Sand creeks, which after leaving the area flow northward to join Sweetwater River. Outside of these valleys the basin has a smooth floor, which, however, in general rises very gently toward the northeast. The larger lakes in the basin lie in the southwestern part. The upward slope toward the northeast may be accounted for in part by the great blanket of wind-transported sand that covers this part of the district. (See Pl. II, *A*, *B*.) The source of this sand is to be found principally in the Tertiary sedimentary rocks that cover the surface to the west of this district, and the present position of the sand must be ascribed to the prevailing southwesterly winds. The continued accumulation of this sand has undoubtedly slowed down the erosion of this part of the district and thus caused the present northeasterly upward slope of the basin floor.

WATER SUPPLY.

The perennial streams of the district are limited to Muddy Creek and its mountainward tributaries and the headwaters of a few other drainage channels that head in the mountains at the north side of the district. During wet seasons and immediately after hard rains these channels carry the run-off toward the low spots of the basin, where there are several more or less alkaline lakes. The subsurface drainage along some of these channels is the source for the water supply of the camps and drilling operations.

Springs are found at a few places and are a boon to the industrial needs of the region, as well as to the traveler and to the livestock that grazes in the basin. Some of these springs supply sufficient water to fill small artificial ponds, and from these the water is piped for considerable distances to points where wells are being drilled.

There are numerous local depressions in the basin, and these range from those which contain water for only a few days after rainy spells and thereafter are simply dry lake beds to those in which the water is perennial and highly alkaline. Some of the alkaline lakes when nearly or completely dry present glaring white salt crusts and boggy bottoms. Several of these lakes are not shown on the map (Pl. I) because they do not lie in or near the localities where the geology was mapped.

VEGETATION.

The basin proper is an arid desert where the precipitation is very slight during the summer and where the snows of winter are insufficient to modify the desert character. The land surface sustains a small amount of vegetation, most of which consists of sagebrush. During relatively wet years the growth of grass is sufficient to support a few flocks of sheep and small bands o cattle and horses.

CULTURE.

The roads that connect the district with Rawlins, Casper (through Whisky Gap), and Lander are comparatively good, and those to Rawlins, over which most of the oil-field freight is carried, receive occasional attention in the way of grading and upkeep. Practically all the travel and hauling is done by automobile and motor trucks. The roads that connect the different fields and camps and especially the secondary roads in the sand-covered areas are not in permanent locations but are changed with the season or at the will of the travelers.

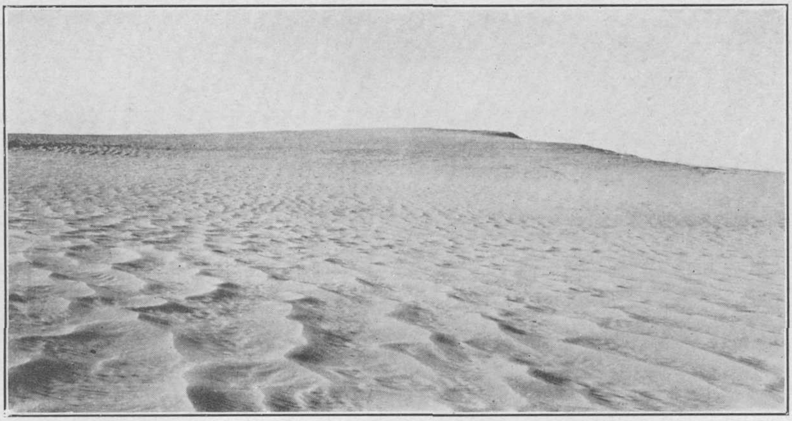
Prior to the advent of oil operators the only industry in the district consisted of a little stock and sheep grazing, such as the vegetation would sustain, combined with ranching in a few favorable places.

In the search by geologists for possible new oil fields the Lost Soldier dome was naturally the first to be found, as it is the only one in the district to be well delineated by an encircling rim of sandstone hogbacks. Soon after this dome had been proved to contain oil the entire district was combed for other favorable drilling localities, and this work resulted in the discovery of additional domes and anticlines. Drilling camps were soon established at many places in the district, old roads were improved, new ones were built, and now hundreds of people are living in this district where before a few ranchers and sheep herders constituted the entire population.

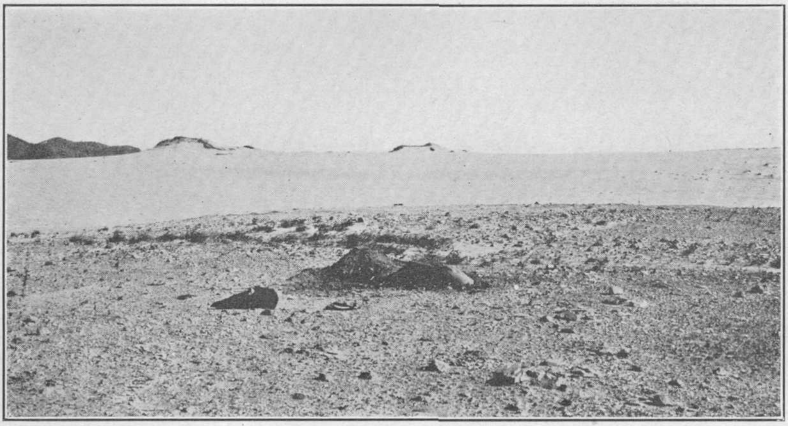
Early in the spring of 1919 a 4-inch pipe line was laid from the Union Pacific Railroad at Fort Steele to the Lost Soldier field, and in the fall of 1920 a second line paralleling the first from Fort Steele to a point near Boundary Lake was laid to the Ferris and G. P. fields. (See Pl. I.) In the fall of 1921 a pipe line 90 miles long was laid between the district and Casper to supply the refineries there with gas.

MARKETS FOR OIL AND GAS.

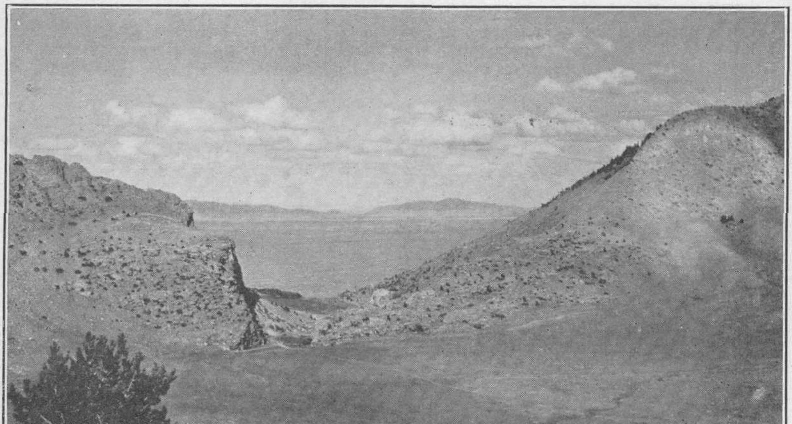
The law of supply and demand affects petroleum and natural gas very differently. The differences are largely inherent in the nature of the substances but depend also on the distance between the oil and gas fields and the markets. Petroleum can be stored and refined into hundreds of different products, and these products in turn can be stored, so that the interval between the time of production at the well and the time of consumption may range from a few weeks to many years. The refining and storing operations thus occupy what may be termed an elastic interval between production and consumption. For natural gas, on the other hand, no such elastic interval is possible. As storage is not feasible the gas takes an almost direct course from well to consumer, and the time between production and consumption ranges from a few minutes to a maximum of only a few days where it is transported to distant cities through long pipe lines.



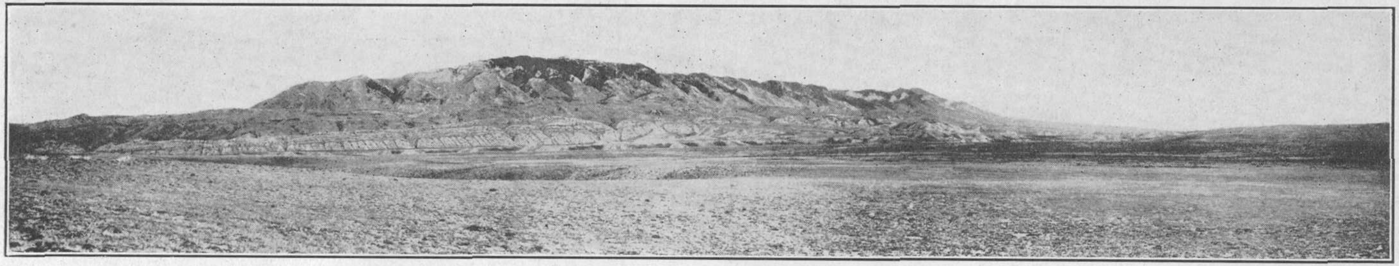
A. SAND DUNES IN SEC. 36, T. 26 N., R. 87 W.



B. LARGE EXPOSURE OF BEDROCK SHALE IN THE SAND-COVERED REGION.

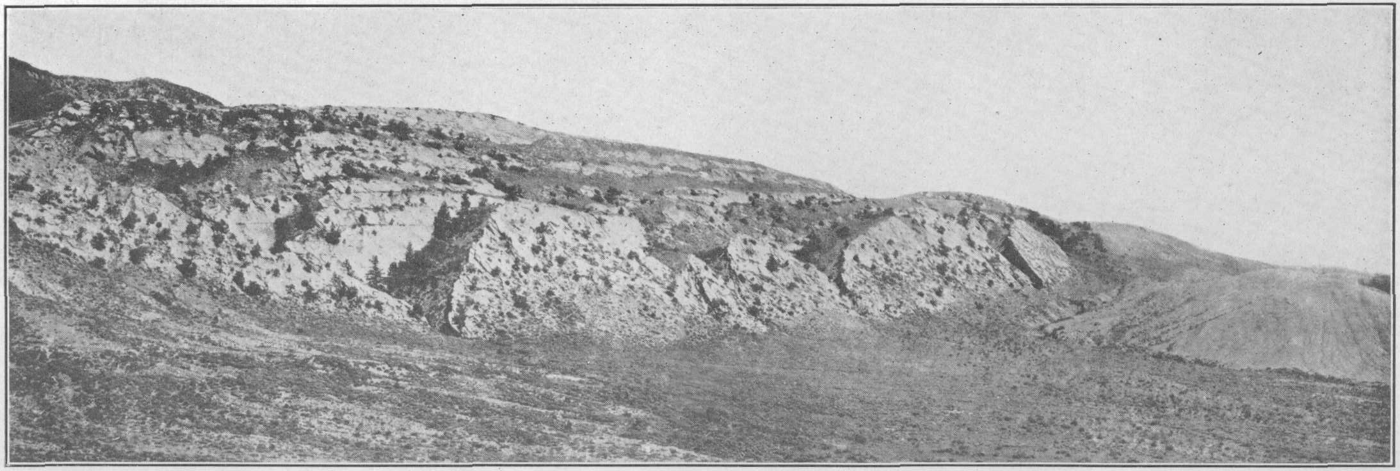


C. WHISKY GAP, CUT THROUGH TENSLEEP SANDSTONE.
Granite Mountains in the distance.

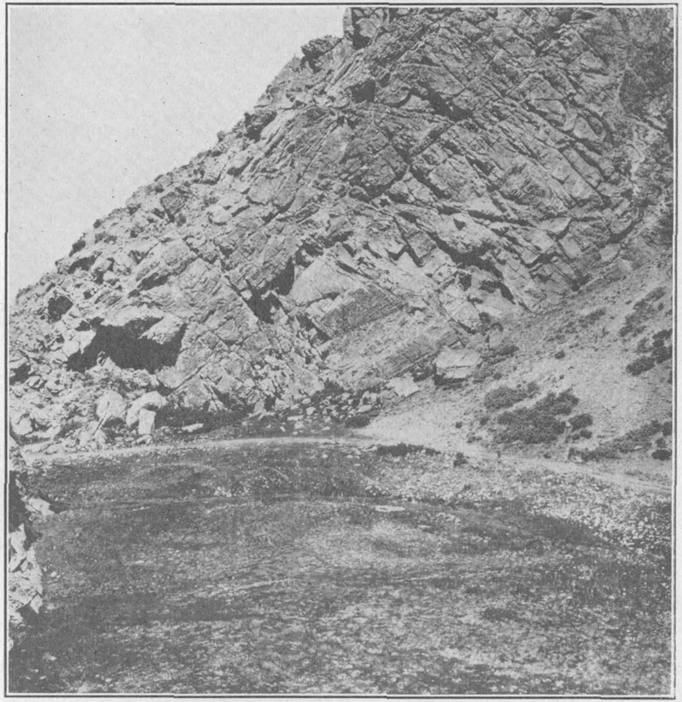


A. FERRIS MOUNTAINS.

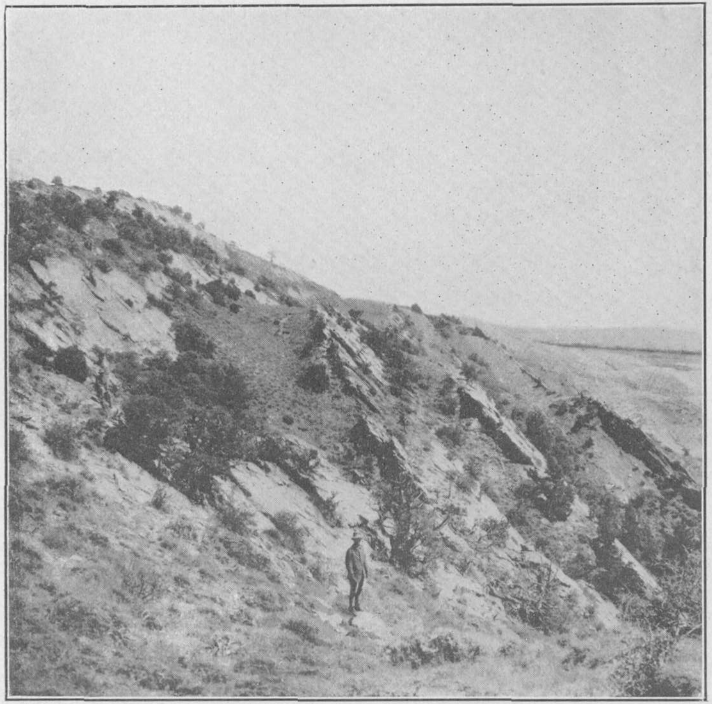
The prominent walls in the left middle distance are formed by the steeply dipping sandstone beds at the top of the Frontier formation.



B. WALLS OF STEEPLY DIPPING FRONTIER SANDSTONES ON SOUTH SIDE OF FERRIS MOUNTAINS.



A. TENSLEEP SANDSTONE FORMING THE WEST SIDE OF WHISKY GAP.



B. LONGITUDINAL VIEW OF STEEPLY DIPPING FRONTIER SANDSTONES ON SOUTH SIDE OF FERRIS MOUNTAINS.

In densely settled regions containing manufacturing industries, such as the Appalachian region, natural gas is at a premium because of the nearness of its market, and as a result an average gas field in such a region may be more valuable to its owners than an average oil field, but in the thinly settled State of Wyoming the opposite is usually true.

In the Lost Soldier-Ferris district it was profitable to build storage tanks for the oil and to lay a pipe line to conduct it to the railroad at Fort Steele, from which it could be transported by tank cars to existing refineries, but until the winter of 1921–22 no such procedure was possible for the gas, and as a result a gas well was a liability instead of an asset except as the gas was used in drilling wells and for heating and lighting the camps.

The town of Rawlins, with its railroad shops, was the first market suggested for the gas from the Lost Soldier-Ferris district, but the quantity that could be marketed there was reported to be too small to pay a return on the investment required for the necessary pipe line. Larger towns, such as Laramie and Cheyenne, were even more distant in relation to the size of the market which they could furnish, and hence pipe lines to reach these cities were not to be considered. Not until the fall of 1921 was there any movement toward the creating of a large and reliable market for the gas. At that time two of the larger companies operating in the district combined their interests and laid a pipe line to Casper, where the gas is supplied to several large refineries.

As the gas from the Wertz and Ferris fields contains the heavier vapors, which condense into gasoline, the erection of gasoline-extraction plants should be a profitable enterprise, and now that the pipe line mentioned above is completed a large supply is available for gasoline extraction without waste.

STRATIGRAPHY.

GENERALIZED SECTION.

The rocks exposed within the oil and gas fields of the Lost Soldier-Ferris district represent the Cretaceous and Quaternary only, but the stratigraphic column including the areas that immediately border these fields contains formations that range from the Carboniferous to late Upper Cretaceous and also pre-Cambrian crystalline rocks The entire section is well exposed, and nearly complete sections can be studied within reasonably small areas. Except in a few places the different formations are rather uniformly developed throughout the district. The principal characteristics of these formations are given in Table 1. More detailed descriptions of the formations, including several measured sections, are given in the pages following the table.

The relation of the stratigraphic section and producing strata of the Lost Soldier-Ferris district to those which have been described for other parts of Wyoming is given in Table 2, opposite page 12.

TABLE 1.—*Generalized stratigraphic section in the Lost Soldier-Ferris district.*

Age.	Group.	Formation.	Approximate thickness (feet).	General characteristics.
Quaternary.		Alluvium and wind-blown sand.		The alluvium consists principally of worked-over material from the surrounding formations. The wind-blown sand is probably derived from the Tertiary formations that crop out west of the district.
(?)		(?)	Not measured.	Yellowish-brown and white massive and thin-bedded sandstones interbedded with brown, gray, and black shales.
Cretaceous.	Montana.	Lewis shale.	680	Principally dark-gray, thinly laminated shale containing several beds of yellowish-brown sandstone from 1 to 20 feet thick. Marine fauna. The thickness given was measured in T. 25 N., R. 89 W.
		Mesaverde formation.	200–2,200	Generally characterized by three divisions described below. Varies greatly in thickness, from 1,700–2,200 feet where believed to be normally developed down to 200 feet or less (probably a local condition). Nonmarine and marine faunas. 1. Thick sandstone beds interbedded with equally thick series of alternating thin beds of sandstone and shale. A white sandstone about 100 feet thick (Teapot sandstone member) generally lies at or within a few hundred feet of the top. Coal-bearing locally. Forms ridges and escarpments. 2. A thick mass of dark-gray to brown shale, sandy shale, and light-gray to yellowish and reddish-brown sandstone with a few layers of brown limy sandstone. Presents in places a striking banded appearance. Forms a surface of low relief. 3. Thick sandstone beds interbedded with equally thick series of alternating thin beds of sandstone and shale. Forms ridges and escarpments. In this report the lowermost thick white sandstone is considered the base of the formation.
		Steele shale.	4,000 to 4,750	Mainly dark-colored soft shale with thin zones of sandy shale and sandstone. The upper part is relatively more sandy and is transitional into the overlying Mesaverde formation. At about 1,500 feet below the top (in some localities the formation is considered to be subnormally developed and the interval where measured is but 960 feet) is a 50-foot sandstone bed that appears to be persistent throughout a large area. Marine fauna, with some brackish-water forms in upper part.
	Colorado.	Niobrara shale. Carlile shale.	1,425–1,600	Top marked by a series of very thin beds of hard, comparatively resistant yellow limestone which shows a wavy lamination on weathered surfaces, interbedded with soft argillaceous sandstone and shale. The main body of the mass is composed of dark-gray thin-bedded shale. Marine fauna.

TABLE 1.—*Generalized stratigraphic section in the Lost Soldier-Ferris district*—Continued.

Age.	Group.	Formation.	Approximate thickness (feet).	General characteristics.
Cretaceous.	Colorado.	Frontier formation	263–705	Uniformly characterized at its top by two to five beds of comparatively resistant light-colored sandstone and interbedded shale, below which is several hundred feet of soft shale. The sandstones dip steeply and form striking walls a few hundred feet high.
		Mowry shale.	200–300	Hard fissile dark-gray shale, which weathers light colored; contains abundant fish scales. The formation is resistant in comparison with the overlying shale. Marine fauna.
		Thermopolis shale.	50–135	Soft dark-gray shale.
		Cloverly formation	75–180	Characterized by a hard resistant light-colored conglomerate or quartzitic sandstone bed, 25 to 75 feet thick, at its base. In places this is overlain by 100 to 150 feet of shale, followed by a hard quartzitic sandstone about 28 to 35 feet thick.
Cretaceous (?).		Morrison formation.	400–700	Interbedded varicolored shale, yellow to light-gray soft sandstone, and a few thin beds of fossiliferous limestone. The shale and sandstone in the upper part (chiefly Morrison) vary greatly in character and composition from place to place. Except for the limestone beds, which are not everywhere exposed, these formations, for general purposes, can be described merely as the interval between the conglomerate at the base of the Cloverly formation above and the Triassic and Permian red beds below.
Jurassic.		Sundance formation.		
Triassic and Permian.		Red beds.		Red sandstone, red sandy shale, and red shale, all rather soft, with one conspicuous thin light-gray limestone near the middle; conspicuous because of the deep-red color. At the base several thin beds of impure cherty gray limestone interbedded with deep-red shale and sandstone.
Pennsylvanian.		Tensleep sandstone.	150–175	Massive to thin-bedded and cross-bedded resistant sandstone, locally quartzitic.
		Amsden formation.	210	A series of limestone, sandstone, and shale; lower part notably red.
Mississippian.		Madison limestone.	165	Limestone; some layers sandy and in places of quartzitic character.
Cambrian.		(?)	395	Quartzite.
Pre-Cambrian.		Crystalline rocks.		

PRE-CAMBRIAN CRYSTALLINE ROCKS.

The oldest rocks of the Lost Soldier-Ferris district are found in the Seminoe Mountains, at the northeast side of the district, where the basement crystalline rocks of these mountains are brought up by faulting against the Cretaceous formations. Hares[4] considers the crystalline rocks of the Granite Mountains, 20 miles to the north of this district, to be pre-Cambrian, and it would seem that the crystalline rocks of the Seminoe Mountains are equally old. The age of these crystalline rocks is not pertinent to the present paper, except for the fact that they formed a part of the basement upon which all the sediments of the region were deposited and are therefore the oldest rocks of the district.

Indications of oil have been reported as occurring in pre-Cambrian granite on the south side of Copper Mountain, in northeastern Fremont County, Wyo.,[5] but without doubt this is an anomalous occurrence, and hence does not signify a possibility of finding oil in the pre-Cambrian crystalline rocks of the Lost Soldier-Ferris district.

CAMBRIAN QUARTZITE.

In the Ferris Mountains and the Rawlins Hills an unnamed quartzite of Cambrian age overlies the basement granite. It is pink to gray and in the vicinity of Rawlins is 395 feet thick.[6] It is conglomeratic in its lower part and at several other horizons at various intervals up to its top. The upper part contains ripple marks and worm trails.

Indications of oil in similar quartzite have been observed on the south side of Copper Mountain,[7] presumably in a locality near that where indications are reported to occur in the underlying granite. The two occurrences are possibly related in some way. It does not seem that either of these occurrences should indicate that oil may be found in similar rocks in the Lost Soldier-Ferris district.

MISSISSIPPIAN ROCKS.

MADISON LIMESTONE.

The Cambrian rocks of the Ferris Mountains and the Rawlins Hills are overlain by the Madison limestone of Mississippian age. Some of the layers of this formation are sandy and in places approach a quartzite in composition. Its thickness at one place in the Rawlins Hills is 165 feet.

[4] Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey Bull. 641, p. 250, 1916.

[5] Trumbull, L. W., Petroleum in granite: Wyoming Geol. Survey Bull. 1, pp. 1-16, 1916.

[6] This formation and the overlying Madison and Amsden were examined and measured in the Rawlins Hills by W. T. Lee, who kindly supplied the data for use in this report.

[7] Fisher, C. A., and Calvert, W. R., The oil and gas fields of Wyoming (unpublished U. S. Geol. Survey report, prepared in 1912).

TABLE 2.—*Sections showing occurrence of oil and gas in Wyoming fields.*

[Correlations approximate and sections incomplete. **o**, Good showings or small production of oil; **O**, good commercial production of oil; **g**, good showings or small production of gas; **G**, good commercial production of gas; +, oil seepage.]

Southwestern Wyoming and Southwest side of Big Horn Basin

System or series.	Group.	Spring Valley.[a]	Labarge.[b]	Baxter Basin.[c]	Shoshone.[d]	South Oregon Basin.[e]	Grass Creek.[f]	Hamilton.[g]	Golden Eagle.[h]	Warm Springs.[i]
Tertiary (Eocene).		Wasatch.	Wasatch. +	Wasatch.	Wasatch.	Wasatch.				
		Evanston.	Evanston.	"Post-Laramie."	Fort Union.	Fort Union.				
Tertiary (?) (Eocene?).		Absent.		"Laramie."	Lance.	Lance.				
Upper Cretaceous.	Montana.	Absent.	Absent.	Lewis.	Meeteetse.	Meeteetse.	Meeteetse.			
				Mesaverde.	Mesacerde.	Mesaverde.	Mesaverde.	Mesaverde.	G	
		[Adaville ?].	Adaville.	(?)						
				Blair.						
	Colorado.	Hilliard.	Hilliard.	Baxter.	Cody.	Cody.	Cody.	Cody.		
				(?) Not exposed.						
		Frontier.	Frontier.	Frontier. G o	Frontier. o	Frontier. o g	Frontier. O g	Frontier.		Frontier.
					Mowry. o	Mowry.	Mowry.	Mowry.		Mowry.
		Aspen. o	Aspen. +?	Aspen.	Thermopolis. o g	Thermopolis. G O	Thermopolis. G	Thermopolis.		Thermopolis.
		Bear River. o	Bear River.	[Dakota. G o]						
Lower Cretaceous.		Absent.		Absent.	Cloverly. g	Cloverly. G	Cloverly.	Cloverly.		Cloverly.
Cretaceous (?).		Beckwith.		Beckwith.	Morrison. g		Morrison. o[nn]	Morrison.		Morrison.
Jurassic.		Twin Creek.		Twin Creek. Nugget.	Sundance.		Sundance.	Sundance.		Sundance.
Triassic.				Ankareh. Thaynes. Woodside.	Chugwater.		Chugwater.	Chugwater. O		Chugwater.
Permian.				Phosphoria.	Embar.		Embar.	Embar. O		Embar. O
Pennsylvanian.			Carboniferous.	Weber.	Tensleep.					Tensleep.
				Older Pennsylvanian.	Amsden.					Amsden.
Mississippian.				Mississippian.	Madison.					Madison.

Northeast side of Big Horn Basin

System or series.	Hidden Dome.[j]	Torchlight.[k]	Lamb.[l]	Greybull.[m]	Sheep Mountain Anticline.[n]	Crystal Creek.[j]	Byron.[o]	Garland.[p]	Elk Basin.[q]
Tertiary (Eocene).									Wasatch.
									Fort Union.
Tertiary (?) (Eocene?).									Lance.
Upper Cretaceous.							Meeteetse.		Bearpaw.
							Gebo.	Judith River.	Judith River.
								Claggett.	Claggett.
							Cody. G	Eagle.	Eagle.
			Cody.					Niobrara.	Niobrara.
								Carlile.	Carlile.
	G	Frontier.	Frontier. o G	Frontier.			Frontier.	Frontier. o g	Frontier. O
		Mowry. O	Mowry. o g	Mowry. o g			Mowry.	Mowry.	Mowry.
		Thermopolis. g	Thermopolis.	Thermopolis. g			Thermopolis.	Thermopolis.	Thermopolis.
Lower Cretaceous.		Cloverly.	Cloverly.	Cloverly. O G			Cloverly.	Cloverly. G	G[kk] Cloverly.
Cretaceous (?).							Morrison.	Morrison. G	Morrison.
Jurassic.							Sundance.		Sundance.
Triassic.					"Red Beds."				Chugwater.
Permian.						O			Embar.
Pennsylvanian.					Pennsylvanian.				
						o			
Mississippian.					Madison. +				

Wind River Basin

System or series.	Maverick Springs.[r]	Pilot Butte.[s]	Dallas.[t]	Derby Dome.[u]	Big Sand Draw.[v]
Tertiary (Eocene).	Wind River.	Wind River.			Wind River.
	Absent.	Absent.			Absent.
Upper Cretaceous.	Mesaverde.	Mesaverde.	Mesaverde.		Mesaverde.
	Cody.	Cody: Pierre. O	Mancos.		Steele.
		Niobrara.			Niobrara.
		Unnamed shale member of Benton.			Carlile.
	Frontier.	Frontier.			Frontier. G
	Mowry.	Mowry.			
	Thermopolis.	Thermopolis.			
		Dakota.	Dakota.		
Lower Cretaceous.	Cloverly.	Fuson. Lakota.	Lower Cretaceous.		
Cretaceous (?).	Morrison.	Morrison.	Morrison.		
Jurassic.	Sundance.	Sundance.	Sundance.		
Triassic.	Chugwater. +	Chugwater.	Chugwater. O+	O ?	
Permian.	Embar. O	Embar.	Embar. O	O	
Pennsylvanian.	Tensleep.	Tensleep.	Tensleep. o[oo]		
	Amsden.	Amsden.	Amsden.		
Mississippian.	Madison.	Madison.	Madison.		

South-central Wyoming

System or series.	Lost Soldier.[w]	Ferris Dome.[w]	G. P. Dome.[w]	Rock Creek.[x]
Tertiary (Eocene).				
				Hanna.
Tertiary (?) (Eocene?).				Absent.
Upper Cretaceous.	Lewis.			Lewis.
	Mesaverde.	Mesaverde.	Mesaverde.	Mesaverde.
	Steele.	Steele.	Steele.	Steele.
			------ O ? ------	
	Niobrara.	Niobrara.	Niobrara.	Niobrara.
	Carlile.	Carlile.	Carlile.	Benton. O
	Frontier. O g	Frontier.	Frontier.	
	Mowry. o	Mowry. O	Mowry.	Benton. Mowry.
	Thermopolis.	Thermopolis.	Thermopolis.	Benton. o (First Muddy)
				(?)
Lower Cretaceous.	Cloverly. Muddy. O Shale. Conglomerate.	Cloverly. Muddy. G Shale. Conglomerate.	Cloverly. Muddy. Shale. Conglomerate.	Cloverly. O (Second Muddy) O (Third Muddy)
Cretaceous (?).	Morrison.	Morrison.		Morrison.
Jurassic.	Sundance.	Sundance.		Sundance.
Triassic.	Triassic and Permian red beds.	Triassic and Permian red beds.		Chugwater.
Permian.				Forelle. Satanka.
Pennsylvanian.	Tensleep.	Tensleep.		Casper.
	Amsden.	Amsden.		
Mississippian.	Madison.	Madison.		

East-central Wyoming

System or series.	Bolton Creek.[y]	Poison Spider.[p]	Powder River.[z]	Tisdale.[aa]	Salt Creek.[bb]	Teapot.[bb]	Big Muddy.[cc]
Tertiary (Eocene).					Wasatch.	Wasatch.	
		Fort Union.			Fort Union.	Fort Union.	
Tertiary (?) (Eocene?).		Lance.	Lance.		Lance.	Lance.	Lance.
Upper Cretaceous.			Lewis.	Lewis.	Lewis.	Lewis.	Fox Hills.
		Mesaverde.	Mesaverde.	Mesaverde.	Mesaverde.	Mesaverde.	Pierre. O
		Steele.	Steele. G	Steele.	Steele. +O	Steele. +o	
		Niobrara.		Niobrara.	Niobrara. +O	Niobrara.	
		Carlile.		Carlile.	Benton. g O	Benton. O	Benton. O
		Frontier.		Frontier.		O G	
		Mowry.	Mowry.	Mowry. +	Benton. Mowry.	Benton. Mowry.	
		Thermopolis.	Thermopolis.	Thermopolis.	(?)	(?)	(?)
	Dakota (?).	Dakota. o			O[ll]		
Lower Cretaceous.	Lower Cretaceous. Shale. Conglomerate.	[?] Lower Cretaceous conglomerate. O	Dakota (?).	Dakota (?). +	Cloverly.	Cloverly.	Cloverly.
Cretaceous (?).	Morrison.	Morrison. o	Morrison.	Morrison. +	Morrison.	Morrison.	Morrison.
Jurassic.	Sundance. O	Sundance.	Sundance.	Sundance. +	Sundance.	Sundance.	Sundance.
Triassic.	Chugwater.	Chugwater.	Chugwater.	Chugwater.	Chugwater.		
Permian.	Embar. O?	Embar.	Embar.	(?)			
Pennsylvanian.	Tensleep.	Tensleep. O	Tensleep.	Tensleep.			
	Amsden.	(?)		(?)			
Mississippian.	Madison.			Madison.			

Northeastern Wyoming

System or series.	Lance Creek.[dd]	Old Woman.[ee]	Mule Creek.[ff]	Osage.[gg]	Upton-Thornton.[hh]	Moorcroft.[ii]	Rocky Ford.[jj]
Tertiary (?) (Eocene?).	Lance.			Lance.			
Upper Cretaceous.	Fox Hills.			Fox Hills.		Fox Hills.	
	Pierre.	Pierre.		Pierre.	Pierre.	Pierre.	
	Niobrara.	Niobrara.	Niobrara.	Niobrara.	Niobrara.	Niobrara.	
	Carlile. +g	Carlile.	Carlile.	Carlile. o	Carlile. O	Carlile.	
	Greenhorn.	Greenhorn.	Greenhorn.	Greenhorn. o	Greenhorn.	Greenhorn.	
	Graneros. Shale. Mowry. Shale. Newcastle[mm] Shale.	Graneros.	Graneros. Mowry. Newcastle.	Graneros. Belle Fourche +o Mowry. o Nefsy. Newcastle. O Skull Creek. o	Graneros. Shale. Mowry. Shale. Sandstone. Shale.	Graneros. Shale. Mowry. o Sandstone. + o Shale.	
	Dakota. G O	Dakota.	Dakota.	Dakota. o g	Dakota.	Dakota. o	
Lower Cretaceous.	Fuson.	Fuson.	Fuson.	Fuson.	Fuson.	Fuson. +	
	Lakota. O ?	Lakota.	Lakota. O	Lakota.	Lakota.	Lakota.	
Cretaceous (?).	Morrison.	Morrison.	Morrison.	Morrison.	Morrison.	Morrison.	
Jurassic.	Sundance.	Sundance.	Sundance.	Sundance.	Sundance.	Sundance.	
Triassic.		"Red Beds."	Spearfish.	Spearfish.	Spearfish.	Spearfish.	
Permian.		Minnekahta.	Minnekahta.	Minnekahta.	Minnekahta.	Minnekahta.	
		Opeche.	Opeche.	Opeche.	Opeche.	Opeche.	
Pennsylvanian.		Minnelusa. o	Minnelusa.	Minnelusa.	Minnelusa.	Minnelusa.	+ o
Mississippian.		Pahasapa.	Pahasapa.	Pahasapa.	Pahasapa.		

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[e] Idem, p. 185.
[f] Idem, pp. 153–156; Heald, K. C., personal communication.
[g] Collier, A. J., Oil in the Warm Springs and Hamilton domes, near Thermopolis, Wyo.: U. S. Geol. Survey Bull. 711, pp. 61–73, 1919. Emery, W. B., Unpublished report on Wyoming oil and gas fields. Hewett, D. F., personal communication.
[h] Collier, A. J., personal communication.
[i] Collier, A. J., Oil in the Warm Springs and Hamilton domes, near Thermopolis, Wyo.: U. S. Geol. Survey Bull. 711, pp. 61–73, 1919.
[j] Lupton, C. T., personal communication.
[k] Hewett, D. F., and Lupton, C. T., op. cit., pp. 75–77.
[l] Idem, p. 72.
[m] Idem, p. 61.
[n] Washburne, C. W., Gas fields of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 340, p. 361, 1908.
[o] Ziegler, Victor, The Byron oil and gas field, Wyo.: Wyoming Geol. Survey Bull. 14, pp. 200, 201, 1917.
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[t] Woodruff, E. G., The Lander oil field, Wyo.: U. S. Geol. Survey Bull. 452, p. 27, 1911; Heald, K. C., personal communication.
[u] Trade journal reports.
[v] Collier, A. J., Gas in the Big Sand Draw anticline, Fremont County, Wyo.: U. S. Geol. Survey Bull. 711, pp. 75–83, 1919.
[w] This report.
[x] Hancock, E. T., unpublished report. Lee, W. T., personal communication.
[y] Heald, K. C., The oil-bearing horizons of Wyoming: Am. Assoc. Petroleum Geologists Bull. 5, No. 2, p. 191, 1921; and personal communication.
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[aa] Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, pp. 56–75, 1912. Emery, W. B., unpublished report on Wyoming oil and gas fields. Heald, K. C., personal communication.
[bb] Wegemann, C. H., The Salt Creek oil field, Wyo.: U. S. Geol. Survey Bull. 670, pp. 27–39, 1918.
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[ii] Barnett, V. H., The Moorcroft oil field, Crook County, Wyo.: U. S. Geol. Survey Bull. 581, pp. 83–104, 1914; Heald, K. C., personal communication.
[jj] Collier, A. J., personal communication.
[kk] Press reports.
[ll] Wegemann, C. H., Personal communication.
[mm] Hancock reported the main production of oil and gas to come from the Newcastle sand, but more recent information indicates it to come from the Dakota and possibly Lakota. This later information is based on personal communications from C. J. Hares, C. T. Lupton, and Carroll H. Wegemann.
[nn] Well completed in 1920. Personal communication from D. F. Hewett.
[oo] Estabrook, E. L., personal communication.

The Madison limestone has been reported to contain oil in Sheep Mountain Canyon, in the Big Horn Basin (see Table 2), and in 1921 it was found to be oil-bearing in the Soap Creek field, in southern Montana.[8] This discovery makes it necessary to consider the possibility that this formation is oil-bearing in the Lost Soldier-Ferris district. The Madison lies within reach of the drill in the Lost Soldier and Ferris domes and perhaps also in the Mahoney dome, where it probably lies at depths ranging from about 4,400 to 5,000 feet. (See Table 3, p. 29.) It should certainly be tested in at least one of these localities.

PENNSYLVANIAN ROCKS.

AMSDEN FORMATION.

Above the Madison limestone and below the Tensleep sandstone is a mass of limestone, sandstone, and shale that measures about 200 feet in thickness and represents the Amsden formation, which in this area is largely if not wholly of Pennsylvanian age. Its lower portion is notably red.

Section of lower part of Amsden formation measured in the Rawlins Hills, about 8 miles north of Rawlins.

	Feet.
Limestone, covered in part	42
Covered interval	70
Limestone, gray	12
Limestone, gray to pink, containing considerable red chert. The lower 10 feet is chiefly red chert	46
Sandstone, red, and interbedded red shale. In some places the lower sandstone is quartzitic	40

The Amsden is not known to be oil-bearing at any place in Wyoming, but in the Soap Creek field, in southern Montana, it is the formation from which several of the wells obtain their oil. It has been thought by those who have worked in that field that the oil found in the Amsden formation is fed to it through upward migration along faults from the underlying Madison limestone.[8] A test of the Madison limestone in the Lost Soldier-Ferris district will also be a test of the Amsden.

TENSLEEP SANDSTONE.

The Amsden is overlain by the distinct and massive Tensleep sandstone. This sandstone is well exposed at Whisky Gap, in sec. 13, T. 27 N., R. 89 W., a few miles north of the district represented on Plate I, where it forms the narrowest part of the gap. It is also

[8] Thom, W. T., jr., personal communication.

well exposed near Bell Springs, to the south, where it outcrops west of the Rawlins road in the south half of T. 23 N., R. 88 W.

At Whisky Gap (Pls. II, *A*; IV, *A*) its thickness is between 150 and 175 feet and it consists of thin to thick bedded resistant rock composed of medium-sized grains of fairly pure quartz. It is also cross-bedded and slightly quartzitic, and as it is rather porous, it should be an excellent reservoir rock for either gas, oil, or water. In color it is white, with yellow and tan shades on the weathered surfaces.

The Tensleep sandstone contains oil and gas at several places in Wyoming, although its capacity for commercial production has thus far not been very marked. Its uniform development throughout large areas and its general porous texture make it an excellent reservoir, and hence in spite of its great depth its oil-bearing possibilities should be tested in the structurally favorable localities in the Lost Soldier-Ferris district. This sandstone lies within reach of the drill in the Lost Soldier, Mahoney, and Ferris domes, where it should be found at depths of about 4,050, 4,535, and 4,100 feet, respectively, as indicated in Table 3 (p. 29). Estimates of its depth in the Sherrard dome and Separation Flats anticline must await further testing of these folds to determine the location of their crests.

PERMIAN AND TRIASSIC RED BEDS.

The conspicuous red rocks of the Lost Soldier field are commonly considered to be equivalent to the Chugwater formation of central and northern Wyoming. The upper 1,375 to 1,400 feet consists of interbedded thin-bedded argillaceous sandstone and clay shale with intergradations of sandy shale and shaly sandstone. The deep-red color, which is an outstanding feature in this district, and the interbedding of sandstone and shale are shown through this entire thickness except in a gray, thinly and ripply laminated limestone, 5 to 7 feet thick, near the middle of the formation, a 2-foot bed of light-gray rather pure quartzose sandstone about 150 feet below the limestone, and interbedded gray layers in the upper part that appear to indicate transitional phases into the overlying Sundance formation. Apparently there is an unconformity between the Sundance and the red beds, but in this locality it is not very marked.

The apparent complete absence of carbonaceous material in this upper 1,400 feet of the red beds commonly correlated with the Chugwater has generally been considered adverse to the possibility that these beds may contain oil, but beds in the Lander region, in the Hamilton dome near Thermopolis, near Maverick Springs, on the Red Spring anticline, and along the east flank of Rattlesnake Mountain, which have been correlated with the Chugwater, have either yielded oil in commercial amounts or given evidence of its presence by seepages. There can therefore be no doubt that the Chugwater, or beds of the same general character, can at least act as an oil reservoir, and whether they contain oil in the Lost Soldier-Ferris district can be determined by the drill. On the crest of the Lost Soldier and Ferris domes the top of the red beds should be reached at depths of about 2,250 to 2,300 feet, on the Mahoney dome at abut 2,750 feet, and on the Wertz dome at 4,300 feet. Estimates of the depth to the red beds on the Sherrard and Separation Flats folds are not made, for the reasons given in connection with the deeper formations.

The basal red beds in the Lost Soldier-Ferris district are by many considered to belong to the Embar formation, largely because they include numerous beds of limestone. There is no marked stratigraphic break between the basal limy beds and the overlying more sandy beds.

Below the uppermost cherty limestone in the red beds there is from 205 feet (Bell Springs) to 403 feet (Whisky Gap) of limestone interbedded with sandstone and red shale. A section measured at Whisky Gap furnishes a good idea of the character and relations of these beds, which rest conformably on the underlying Tensleep sandstone.

Section of limestone-bearing portion of red beds exposed in sec. 2, T. 27 N., R. 89 W., near Whisky Gap.

	Feet.
Limestone, impure, cherty, light gray; probably nonfossiliferous	45
Limestone, light gray, impure, interbedded with about equal proportions of red sandy shale in beds about 5 feet thick	40
Rocks poorly exposed but apparently consisting of interbedded red shaly soft sandstone and red shale	175
Limestone, impure, light gray	3
Covered, probably red sandy beds	60±
Rocks poorly exposed, consisting probably of interbedded red sandy shale and light-gray impure limestone	[illegible]0
Tensleep sandstone.	

The Embar is the oil-producing formation in several fields in Wyoming, as shown in Table 2. In most of these fields the oil is contained in sandstone, but the fact that no sandstone or indications of oil were observed on the outcrops of the basal red beds in the Lost Soldier-Ferris district is no evidence that they would be found barren if penetrated by wells in favorable localities. If they contain oil or gas in this district, it would seem reasonable to expect that the cherty limestone would be the reservoir rock. As indicated in Table 3 (p. 29), these beds probably lie within reach of the drill in the Lost Soldier, Mahoney, and Ferris domes, where they should be found, respectively, at depths of about 3,650, 4,135, and 3,700 feet. They probably lie within reach of the drill also on the Sherrard and Separation Flats folds, but in view of the lack of information concerning the crests of these folds accurate estimates of their depth there can not be made.

JURASSIC AND CRETACEOUS (?) ROCKS.

SUNDANCE AND MORRISON FORMATIONS.

The rocks lying above the red beds and below the conglomerate of the Cloverly belong in the lower part to the Sundance formation and in the upper part to beds that vary greatly in both color and lithology and are believed to be of Morrison age. The dividing line between the two formations in the Lost Soldier-Ferris district is not clear, and hence in this report they will be treated together. The formations as exposed about 1½ miles west of Whisky Gap are as follows:

Section of Morrison and Sundance formations in secs. 2 and 11, T. 27 N., R. 89 W.

	Feet.
Conglomerate of the Cloverly formation.	
Morrison and Sundance formations:	
Rocks poorly exposed, but consist principally of red shale	100
Rocks covered, probably mostly shale	100
Sandstone, light gray to brownish; upper part thin bedded	20+
Rocks poorly exposed, but probably consist principally of shale	180
Limestone, sandy, and limy sandstone, not completely exposed; weather yellowish brown; thin bedded, ripple marked, and abundantly fossiliferous. The fossils consist principally of *Camptonectes* sp	8
Rocks poorly exposed, but probably consist almost altogether of shale	222
Sandstone, thin to thick bedded, yellowish gray, fairly fine grained	60
Triassic red beds.	

The limestone bed contains many remains of *Camptonectes*, which are characteristic of the Sundance; hence the limestone and lower beds in the above section belong to the Sundance formation. The base of the Sundance is here placed at the bottom of a series of beds which are distinctly not red and whose lower part generally though not invariably consists of a thick and more or less massively bedded sandstone. The beds above the limestone vary greatly from place to place in thickness, color, and lithology. The changes in color and lithology may take place within short distances—for instance, thin-bedded yellowish sandstone changes through red shale to gray shale within less than a mile. In secs. 32 and 33, T. 28 N., R. 89 W., beyond the area shown on Plate I, the beds above the limestone include a very massively bedded, highly porous light-yellowish sandstone more than 100 feet thick. Variations in the beds below the limestone also occur but are not so marked as those in the upper beds. As a result of these changes the Sundance and Morrison formations of this district can be described, in general terms, merely as a mass of varying shale and sandstone 400 to 700 feet thick lying between the Triassic red beds and the conglomerate of the Cloverly formation and containing near the middle a thin persistent fossiliferous gray limestone.

The great variation in material, especially in the beds above the limestone, which are followed by the uniformly developed and persistent basal conglomerate bed of the Cloverly, indicates a decided unconformity between the Cloverly and the underlying formations. A remarkable feature of this unconformity is its parallelism to the general bedding in the Sundance and Morrison, which persists throughout an extensive area in the Rocky Mountain region.

The sandstones of the Sundance and Morrison formations should furnish good reservoirs for oil and gas. Prior to 1921, however, only small seepages of oil have been obtained from the Sundance, and commercial quantities of oil are known to have been obtained from the Morrison at only one locality, the Grass Creek field.[10]

In the Lost Soldier-Ferris district the Sundance and Morrison formations have been partly tested by the discovery well on the Mahoney dome, which penetrated these beds to a horizon 60 feet below the limestone. No showings of either oil or gas are noted in the well log. It is possible that the Producers & Refiners Corporation's well No. 2, in sec. 36, T. 26 N., R. 87 W., drilled to a depth of 2,815 feet, or 1,635 feet below the contact between the Niobrara and Frontier, reached the upper part of the Morrison, but it is impossible to correlate the lower part of this log with the exposed stratigraphic section. Even if this well reached the upper part of the Morrison, its position on the flanks of the Ferris dome is not a favorable locality to test the oil or gas bearing possibilities of these beds.

As the upper part of the Morrison and Sundance formations has been tested in one favorable place with discouraging results, there is little incentive to drill wells to test only these beds in other structurally favorable places. The beds will nevertheless be tested by wells that will eventually be drilled to the deeper formations.

CRETACEOUS ROCKS.

CLOVERLY FORMATION.

Along the south side of the Ferris Mountains the Morrison is overlain by a persistent conglomerate 25 to 30 feet thick, followed by a shale 125 to 150 feet thick, and this in turn by a slightly quartzitic sandstone 28 to 35 + feet thick. Hares [11] considers the conglomerate and shale to be of Lower Cretaceous age and the sandstone to be the Dakota. It is believed by the writers that these same beds consti-

[10] Hewett, D. F., personal communication. Heald, K. C., The oil-bearing horizons of Wyoming: Am. Assoc. Petroleum Geologists Bull., vol. 5, No. 2, p. 195, 1921.

[11] Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey Bull. 641, pp. 244-245, 1916.

tute the Cloverly formation in the Hanna Basin, a few miles to the east, as described by Bowen.[12]

There is considerable confusion in the Wyoming literature concerning this part of the stratigraphic section in the different regions, and the present investigation adds nothing to its clarification, except the above statement, which indicates the probable equivalency of the Dakota and Lower Cretaceous of central Wyoming and the Cloverly formation of the Hanna Basin.

During the summer of 1921 Willis T. Lee, of the United States Geological Survey, made stratigraphic studies in southeastern Wyoming, and one of the results of his studies is the correlation of the Muddy sand of east-central Wyoming with the upper sandstone of the Cloverly of this report, and because of this correlation the upper sandstone of the Cloverly will here be spoken of as the Muddy sand. It is thought that the Muddy sand of this area occupies approximately the same stratigraphic position as the Muddy sand of the Big Horn Basin, and if it does, some of the underlying shale included in the Cloverly by Bowen would correspond with the lower part of the Thermopolis shale of the Big Horn Basin.

At some places on the south side of the Ferris Mountains the pebbles in the conglomerate are so small that the bed can be classed as a quartzitic sandstone. In the Bell Springs area, to the south, the conglomerate grades upward into quartzitic sandstone at the top, and at one place was found to be 75 feet thick. At another place in this vicinity Lee found the conglomerate to be 61 feet thick and to be overlain by 10 feet or more of shale in a poorly exposed interval, which in turn was followed by quartzose sandstone about 15 feet thick. In this same locality the shale that overlies the quartzose sandstone and separates it from the Muddy sand is 135 feet thick.

The upper sandstone (Muddy sand) of the Cloverly is present in the Bell Springs area only as a shaly sandstone and measures 20 to 25 feet in thickness. In some places it may be represented only by a sandy zone in the shale, and in such places the top of the Cloverly might be difficult to discern.

The Cloverly is of particular interest because of the oil and gas content of the Muddy sand, which is the reservoir rock in the Lost Soldier dome at a depth of 1,375 feet. The Muddy is also the gas-bearing member in the Mahoney dome, at a depth of 2,160 feet in the discovery well in the southwest corner of the NE. ¼ sec. 34, T. 26 N., R. 88 W. The gas wells on the Ferris dome obtain their supply from the Cloverly formation, and the well logs indicate that

[12] Bowen, C. F., Stratigraphy of the Hanna Basin, Wyo.: U. S. Geol. Survey Prof. Paper 108, pp. 227-241, 1918.

the sand is the Muddy. In well No. 4, in sec. 25, T. 26 N., R. 87 W., it is found at a depth of 1,795 feet. The gas sand in the Wertz dome, reached at a depth of 3,400 feet in the discovery well, is also the Muddy. If the writers have correctly interpreted the field evidence and the logs of wells on the Sherrard dome the Cloverly should be found at depths of 3,100 feet or less in the vicinity of the wells in secs. 2 and 11, T. 25 N., R. 89 W. It should lie at shallower depths at places structurally higher on the dome.

THERMOPOLIS SHALE.

The interval between the Cloverly formation and the Mowry shale which measures between 50 and 135 feet, consists in general of finely laminated dark-gray soft shale, which is considered to represent the Thermopolis shale as described by Bowen in his report on the Hanna Basin.[13] As pointed out in the discussion of the Cloverly, however, it seems likely that the Thermopolis shale as here described includes only the equivalent of the upper part of the Thermopolis of the type locality in the Big Horn Basin,[14] the lower part being here included in the Cloverly.

Owing to its softness the Thermopolis is very poorly exposed. Where the upper sandstone of the Cloverly (Muddy sand) is hard and resistant, the boundary line between the Cloverly and the Thermopolis is readily determined, but where this sandstone is shaly or absent the line separating the Thermopolis from the Cloverly is indistinct. Except for this variation in the Muddy sand, a feature which may be purely depositional, the Thermopolis appears to lie conformably with the formations both below and above.

In sec. 11, T. 27 N., R. 89 W., north of the area mapped on Plate I and southwest of Whisky Gap, the Thermopolis shale is about 115 feet thick and near its base contains some coaly or very carbonaceous material. In the vicinity of Bell Springs, where the upper sandstone of the Cloverly is shaly, the Thermopolis and Mowry together occupy an interval of only 135 feet and were not separately measured.

Although the Thermopolis shale has been penetrated by wells in five of the domes in the Lost Soldier-Ferris district, no indications of oil or gas have been reported from it. So far as observed at the surface it contains no distinct sandy zones, and therefore it should probably not be classed among the oil or gas bearing beds, although its content of carbonaceous or coaly material, mentioned above, would seem to indicate that it carries material from which oil and gas could possibly be derived.

On the west side of Big Horn River [15] and in other parts of Wyoming the Thermopolis is reported to contain an oil or gas bearing

[13] Bowen, C. F., Stratigraphy of the Hanna Basin, Wyo.: U. S. Geol. Survey Prof. Paper 108, p. 229, 1918.

[14] Lupton, C. T., Oil and gas near Basin, Big Horn County, Wyo.: U. S. Geol. Survey Bull. 641, p. 168, 1916.

[15] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 656, pp. 19-20, 1917.

sand which is known as the Muddy sand among the oil operators of that region. In central Wyoming the term Muddy is applied by drillers to the upper sandstone member of the Cloverly, which in some of the geologic literature is called the Dakota sandstone. This double use of the term is confusing, but the writers believe that there is some reason for thinking that the drillers' Muddy sand is one and the same in all these localities, and that the geologists' classification in the different regions needs revising.

The present writers have no information to help clarify this situation, and further detailed stratigraphic work in the area between the Big Horn Basin and central Wyoming is needed.

MOWRY SHALE.

In this district, as in many other localities in the Rocky Mountain States, the Mowry shale is dark gray, but weathers whitish and is readily distinguished by its content of fish remains, principally scales, and by its fissile character and greater hardness than most other shales. Along the south flank of the Ferris Mountains it is 200 feet thick, but to the south, in the Bell Springs area, the Mowry and the underlying Thermopolis together measure only 135 feet.

The Mowry shale is well exposed southwest of Whisky Gap, where the entire formation consists of fairly pure shale. There is no indication here that the Mowry contains porous beds which could serve as reservoir rocks, yet in the Lost Soldier and Ferris fields oil is obtained from it. The wells that obtain oil from the Mowry do not penetrate this formation to a common horizon, but instead appear to obtain their oil at different horizons. The absence of sandstones in the Mowry at its outcrop seems to call for some explanation to account for the presence of oil in it underground. To the writers a possible explanation seems to lie in the rather hard and brittle character of the shale, which permits the presence of small open crevices, either joints or minor faults. Observations of other shales in the Lost Soldier field seem to indicate that only the Mowry has the ability to sustain openings of any appreciable size after they are once formed, and the minor faults in the Lost Soldier and Mahoney domes suggest that all the harder formations, where folded, have been subjected to fissuring and minor faulting on an extensive scale. Similar conditions appear to exist in the Wertz dome, where the discovery well encountered oil in the Mowry shale at depths of 3,140 to 3,175 feet under so great a pressure that a small production is being obtained from between the casings of the well, which is primarily a gas well obtaining gas from the Muddy sand, at the top of the Cloverly, at a depth of 3,400 feet.

The following fossil forms, identified by T. W. Stanton, were obtained from the Mowry:

Leucichthyops vagans Cockerell.
Erythrinolepis mowriensis Cockerell.
Holcolepis sp.
Fish bones.

FRONTIER FORMATION.

The prominent characteristic feature of the Frontier formation is the presence in its upper part of two to four resistant sandstones, which in places where the formation lies in a highly inclined position form prominent dip slopes, walls, or cliffs. The interval between these sandstones and the underlying Mowry is occupied by soft shale which in this report is considered as belonging to the Frontier formation. The sandstones of the Frontier are probably the richest oil-bearing rocks in Wyoming.

Section of Frontier formation as exposed in sec. 32, T. 27 N., R. 88 W.

	Feet.
Carlile shale.	
Frontier formation:	
Sandstone, medium to fine grained, cross-bedded and mostly thin bedded; fossiliferous. This sandstone forms a very prominent and strikingly picturesque sloping wall (see Pls. III, *B*; IV, *B*) on the mountainward side of the soft Carlile, Niobrara, and Steele shale belt. Known as the Wall Creek sand	30½
Shale, gray. At 5 to 8 feet from the top is a hard limy layer about 1 foot thick which seems to be in part of concretionary origin. From this layer and from the base of the still higher sandstone ledge were collected *Ostrea sannionis* White, *Inoceramus erectus* Meek, *Cardium pauperculum* Meek, *Lunatia* sp., *Nautilus* sp., *Baculites gracilis* Shumard?, *Exogyra* sp., *Volutoderma* sp., and *Scaphites ventricosus* Meek and Hayden	70
Sandstone, medium to fine grained, cross-bedded and mostly thin bedded. No fossils were found. Ledge forming	15
Shale, poorly exposed	15
Sandstone, medium to fine grained, cross-bedded and mostly thin bedded. No fossils were found. Ledge forming	23
Shale, poorly exposed	63
Sandstone, medium to fine grained, thin bedded except for upper 10 to 15 feet, which is fairly massive. The lower part grades into the underlying shale. Ledge forming	120
Shale, poorly exposed	355
Sandstone, thin bedded, upper 9 feet light gray, lower 5 feet highly ferruginous and dull brown. Ledge forming. Appears to be of local development only	14
Shale to top of Mowry shale, interval unmeasured; probably about 300 feet.	
Mowry shale.	

The prominent sandstones at the top of this section, of which the uppermost is the Wall Creek sand of the drillers, decrease in number westward, and in sec. 3, T. 27 N., R. 89 W., where Muddy Creek cuts through them in turning north toward Sweetwater River (outside of the area mapped on Pl. I) only two sandstone beds are present. Similarly, in the southern part of the district east of Bell Springs three sandstone beds are present. From this it is obvious that the number of Frontier sands differs in the different fields. These Frontier sandstone beds are the shallow pay sands of the Lost Soldier dome, found at a depth of 239 to 584 feet on the apex of the dome. In the log of well No. 22 of this field (see Pl. VIII) three distinct sands, of which the upper one is the Wall Creek, are shown to be present in the Frontier formation. Still another sand in the lower part of the formation is also recorded, and this may represent the sand about 300 feet above the Mowry in the section just given.

The Wall Creek and other sands at the top of the Frontier were found at depths of 2,145 to 2,530 feet in the discovery well in the Wertz "dome," in the northeast corner of the SW. ¼ sec. 7, T. 26 N., R. 89 W., and at depths of 890 to 1,215 feet in the discovery well in the Mahoney dome, in the southwest corner of the NE. ¼ sec. 34, T. 26 N., R. 88 W. In the Ferris dome these sands are found at depths of 290 to 510 feet in well No. 2, which is probably a short distance away from the highest point of the dome, and in the Sherrard dome the Wall Creek sand was encountered at a depth of about 1,850 feet in a well in the southwest corner of the SE. ¼ sec. 2, T. 25 N., R. 89 W. It seems probable that the Frontier sands have been penetrated in the Separation Flats anticline at depths of 975 to 1,350 feet in the New York Oil Co.'s well, in the SE. ¼ sec. 31, T. 24 N., R. 88 W., and at depths of 2,180 to 2,570 feet in the Midwest Refining Co.'s well in sec. 16 of the same township. In the logs of these two wells that were accessible to the writers no indications of either oil or gas are recorded. In the well drilled in sec. 2, T. 24 N., R. 26 W. in the O'Brien Springs anticline the Wall Creek sand was encountered at 3,120 feet and gave a good showing of gas. A deeper sand of the Frontier formation at a depth of 3,630 feet yielded gas amounting to several million cubic feet daily.

Although the Frontier sands have been penetrated in seven of the domes and anticlines in this district, they contain commercial quantities of oil in only one, the Lost Soldier dome. Gas with an estimated flow of 7,000,000 cubic feet a day was encountered in the discovery well in the Mahoney dome, at a depth of 1,130 to 1,140 feet, which is 240 feet below the top of the Wall Creek sand. This gas was cased off for deeper drilling. The flows of gas in the test well on the O'Brien Springs fold were estimated at 1,000,000 to 3,000,000 cubic feet a day. Showings of oil were encountered in the Wertz and Sherrard domes, and of gas and oil in the Ferris dome. The oil in the Frontier sands in the Lost Soldier dome, according to E. W. Krampert,[16] is due to leakage along fault planes from the underlying Muddy sand. The reasons for this conclusion are given in the detailed description of the structure of that field (pp. 33–34).

CARLILE AND NIOBRARA SHALES.

In the Hanna Basin [17] and in central Wyoming [18] the strata overlying the Frontier formation consist of a few hundred feet of Carlile shale followed by two to four times as much Niobrara shale. In the Lost Soldier-Ferris district no lithologic or paleontologic evidence was observed for differentiating these shales above the Frontier into the two formations, and hence, for the purpose of this report they are considered together.

The Carlile and Niobrara unit in the Lost Soldier-Ferris district consists almost wholly of soft dark-gray, thinly laminated shale, with a few thin white streaks of bentonite. Its differentiation from the Frontier formation below is marked by the upper surface of Frontier sandstone. Its upper limit is not so readily determined. The Steele shale, more than 4,000 feet thick, overlies the Niobrara, and the only horizon marker near the contact of these two formations consists of three to five 1-foot beds of yellowish-brown laminated limy argillaceous sandstone, which are distributed through an interval of 150 to 250 feet. Associated with these thin yellowish-brown beds, but more particularly above them, there is some thin-bedded soft argillaceous sandstone. The beds that overlie the yellowish beds occupy an interval of probably not more than 40 feet. The yellowish and associated sandstones should probably be considered transition beds between the Niobrara and Steele. The thin yellowish-brown layers are the distinctive features of these transition beds, and the uppermost of these, which is more generally exposed, is regarded in this report as marking the upper boundary of the Niobrara shale. No Montana fossils were found below this horizon, and no Niobrara forms were found above it; hence for practical purposes this horizon does very well as a formational boundary. The Carlile and Niobrara unit, including the series of thin yellowish-brown sandy layers which mark its top, is well exposed in secs. 4 and 5, T. 26 N., R. 88 W., where it has a total thickness of 1,425 feet. The thin yellowish-brown beds are well shown in the first rock exposures north of the creek at the north side of the Lost Soldier field and in the hill about half a mile southeast of

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[16] Personal communication.

[17] Bowen, C. F., Stratigraphy of the Hanna Basin, Wyo.: U. S. Geol. Survey Prof. Paper 108, pp. 227 241, 1917.

[18] Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey Bull. 641, pp. 233-279, 1916.

this field. They are also exposed in secs. 2, 3, 4, and 5, T. 25 N., R. 88 W., at the southeast, south, and southwest sides of the Mahoney field, also in the Ferris field and at a few other localities, as indicated on Plate I.

The fauna of the Niobrara consists principally of *Uintacrinus socialis* Grinnell, which is diagnostic, and *Ostrea congesta* Conrad, which is characteristic in the Rocky Mountain region. In addition to these two forms there are present many fragments of a thick-shelled *Inoceramus,* upon which the *Ostrea congesta* colonized, and forms identified by T. W. Stanton as *Baculites asper* Morton and scales of *Hypsodon* and other fishes. No distinctive Carlile species were found in the lower part of the shale.

The sandstone at the upper boundary of the Niobrara may be the reservoir rock in the G. P. dome, found at a depth of 3,020 feet in the discovery well.

STEELE SHALE.

The Steele shale crops out in most of the district within the encircling ring of the Mesaverde formation, but it is in most places concealed either by recent alluvium or dune sand. For study it is best exposed on the north side of the Camp Creek syncline. The base of the Steele shale is not clearly defined, but as noted above under the Carlile and Niobrara shales, for the purpose of this report it is considered to be at the top of the uppermost of a series of thinly laminated beds of limy, argillaceous sandstone, each about 1 foot thick, which weather yellowish brown. A Montana species, *Inoceramus barabini* Morton, was found within 20 feet above this sandstone, and it is possible that the Steele shale should be considered as extending below this sandstone series, but the facts that this peculiar series of yellowish-brown sandstone beds is the only key horizon that can be generally recognized as lying near the contact between the Niobrara and the Steele shales and that no Montana fossils were found below it seems sufficient reason for considering it to mark an approximate boundary line between these two formations. The upper boundary of the Steele shale is considered to lie below the lowermost thick white sandstone of the Mesaverde. In some places there are lenticular sandstones lying below this white sandstone, but they are regarded as transition beds and are included here in the Steele.

The Steele is essentially a soft gray shale formation, which usually forms depressions in the surface. Distributed here and there within the main body of the shale are zones of sandy shale and argillaceous sandstone, and the upper part of the formation contains well-defined sandstone beds.

In the lower part of the formation are some beds of argillaceous sandstone, one of which, about 40 feet thick in the Lost Soldier field, is at the base, immediately overlying the thin yellowish-brown beds of the Niobrara. This sandstone is of interest in connection with the oil of the G. P. "dome," which comes from a "sand" that the writers consider to be one of these argillaceous sandstones of the Steele or a sand in the upper part of the underlying Niobrara. The uncertainty in the correlation of the G. P. sand is discussed in the description of the G. P. "dome."

A persistent sandstone zone, possibly a continuous sandstone bed, which measures 30 to 60 feet in thickness on the outcrop, is present about 1,400 to 1,500 feet below the top of the formation. It is well exposed across the north sides of secs. 15 and 16, T. 26 N., R. 89 W., and is present in intermittent exposures to the west and south of the Table Hills and along the west and north sides of the Haystack Hills.

Above this persistent sandstone zone other sandstones are present, but these are generally thin and represent principally transition beds into the overlying Mesaverde formation.

The Steele shale varies somewhat in thickness in this district, thinning noticeably toward the northwest. In secs. 5 and 6, T. 26 N., R. 88 W., a detailed measurement gave it a thickness of 4,745 feet. There is some reason for thinking that this is a normal thickness for the eastern and southern parts of the region. The thinning toward the northwest appears to take place principally in that part of the formation lying above the persistent thick sandstone bed, and it is possible that on the west side of the Lost Soldier dome the thickness may be less than 4,000 feet. This thinning toward the northwest corresponds with a similar but much greater thinning in the overlying Mesaverde formation, described below.

Numerous fossil collections were made from the Steele shale, some of which have considerable stratigraphic interest.

Lot 165, in the Table Hills south of the G. P. field, about 300 feet below the top of the formation:

Ostrea sp.
Pteria nebrascana (Evans and Shumard).
Inoceramus barabini Morton.
Baculites anceps var. obtusus Meek.

Lot 139, 3,930 feet above the base, in the SW. ¼ sec. 1, T. 26 N., R. 89 W.

Pteria nebrascana (Evans and Shumard).
Cryptodon? n. sp.
Lunatia sp.
Aporrhais? sp.
Scaphites n. sp.
Scaphites? sp.
Baculites ovatus Say.

Lot 136, 2,087 feet above the base, in sec. 6, T. 26 N., R. 88 W.:

Nautilus sp.
Helicoceras? sp.
Scaphites hippocrepis Dekay.

Lot 134, from NW. ¼ sec. 12, T. 26 N., R. 90 W. (same horizon as lot 136):
- Ostrea sp.
- Inoceramus barabini Morton.
- Lucina sp. cf. L. subundata Hall and Meek.
- Gyrodes? sp.
- Baculites ovatus Say.
- Helioceras? sp.
- Scaphites hippocrepis Dekay.
- Fish scale.

Lot 137, 1,537 feet above the base, in sec. 6, T. 26 N., R. 88 W.:
- Pteria linguaeformis (Evans and Shumard)?
- Baculites ovatus Say.

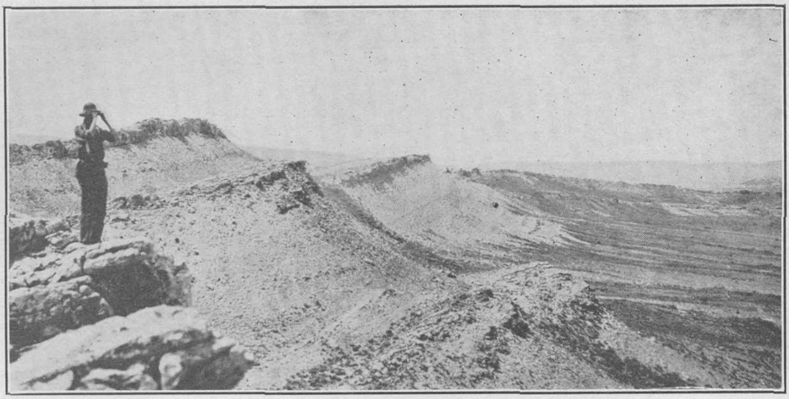
Lot 146, 1,100 feet above the base, in sec. 5, T. 26 N., R. 88 W.:
- Portheus sp., a vertebra.
- Lamna cf. L. appendiculata, a tooth.
- Scapanorhyncus sp., two teeth.
- Plesiosauridae, genus and species unrecognizable, a vertebra.

The most interesting feature in fossil lots 134 and 136, according to T. W. Stanton, who identified them, is the presence of *Scaphites hippocrepis* Dekay, which in eastern and northeastern Wyoming is distinctive for the Eagle sandstone, in the basal part of the Montana group. This form was found in the Lost Soldier-Ferris district at two widely separated places, but apparently they represent one and the same horizon, which, as given, is 2,087 feet above the base of the formation. In this locality no sandstone is associated with the beds at this horizon other than a thin and slightly sandy zone in the shale.

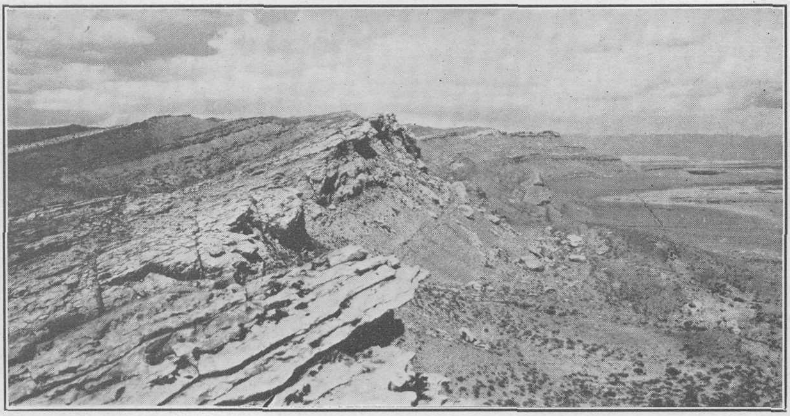
MESAVERDE FORMATION.

The Mesaverde, a brackish and shallow water formation, and the marine Steele and Lewis shales form the Montana group of the Cretaceous system in this district. In some parts of the Rocky Mountain region the Montana group is composed entirely of marine shale, but where the Mesaverde is present this formation is interpreted as consisting of the more localized shallow and brackish water sediments of late Montana time which were deposited near the land. The Mesaverde is differentiated from the underlying and overlying marine shale sediments principally on lithologic grounds and the presence of a brackish water rather than a purely marine fauna. It is coal bearing also. The sandy brackish-water deposits are considered contemporaneous with marine deposits elsewhere, and through the variation in extent of its different sandstone beds the Mesaverde in places interfingers or lies more or less interbedded with marine deposits.

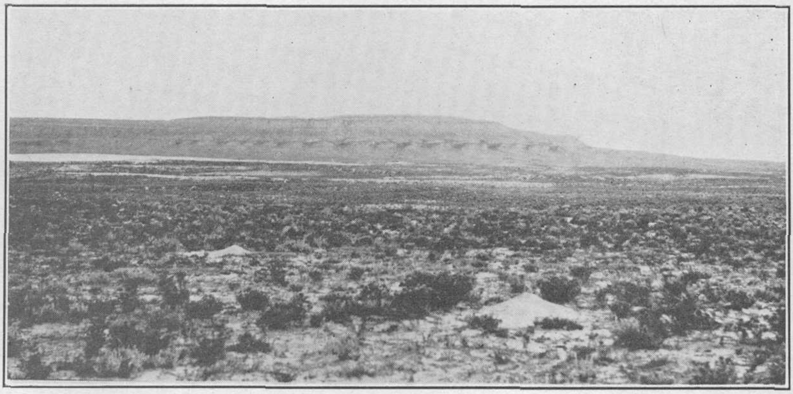
The Mesaverde in this district is normally characterized by three divisions—a sandstone division at the base, another at the top, and a shale division in the middle. The sandstone divisions consist of thick beds of sandstone interbedded with alternating thin beds of shale and thin sandstone. The shale division consists of interbedded



A. MESAVERDE ESCARPMENT ON SOUTH SIDE OF LOST SOLDIER DOME.

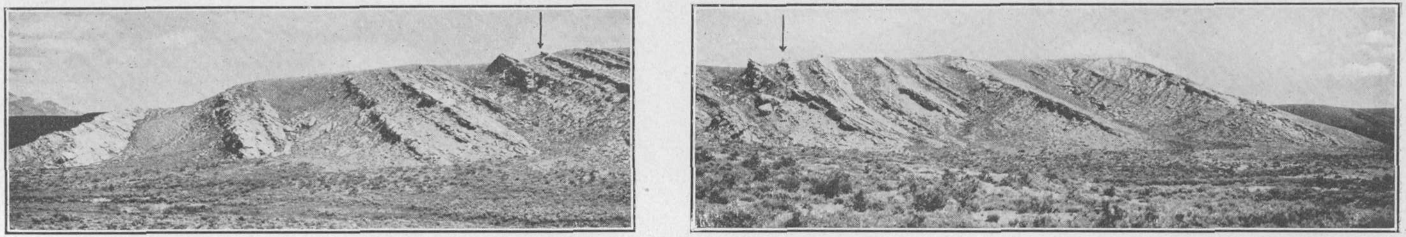


B. MESAVERDE ESCARPMENT IN NORTHEASTERN PART OF T. 24 N., R. 89 W.



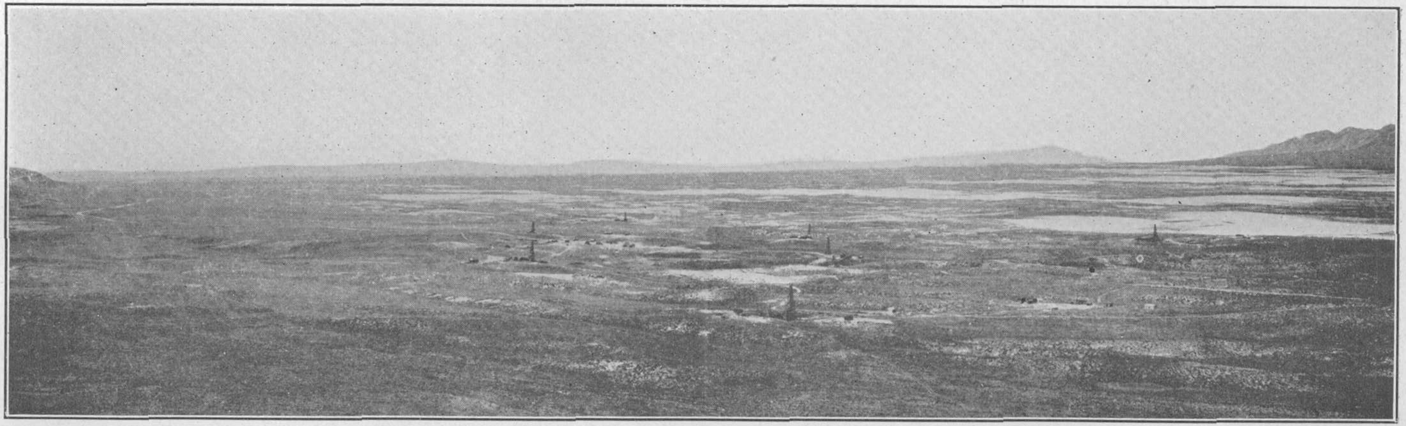
C. TABLE HILLS FROM THE NORTHWEST.

The uppermost ledge is the base of the Mesaverde formation.



A. ADJACENT PORTIONS OF A COMPLETE SECTION OF THE MESAVERDE FORMATION IN SEC. 33, T. 27 N., R. 89 W.

The arrows point to a ledge which is the same in both photographs. The middle shale division is absent in this locality.



B. VIEW ACROSS THE G. P. OIL FIELD LOOKING WEST.

thin dark-gray to brown shale, sandy shale, and light-gray to yellowish and reddish-brown sandstone with a few layers of brown limy sandstone. This middle shale division where exposed presents a striking banded appearance, which is well shown in the range of hills crossing Tps. 23 and 24 N., R. 89 W. So far as observed in this district, the middle division contains no coal, but thin beds of coal occur in both sandstone divisions.

In view of the conclusion that the Mesaverde is composed of the sandy and brackish-water deposits lying above the marine Steele shale as mentioned above and that its lower sandstone beds are interbedded with the uppermost portions of this shale, no definite line of demarkation between the two formations can be drawn. For the general purposes of this report, however, the lowest thick white sandstone in the Lost Soldier-Ferris district will be considered the basal bed of the Mesaverde (see Pl. V, *C*), though still lower lenticular sandstones are present in some localities.

In a somewhat similar way the upper boundary is also difficult to define. For general purposes the uppermost thick white sandstone (Teapot member) can usually be considered the top of the formation, but in secs. 17 and 18, T. 25 N., R. 89 W., where higher beds are exposed, it was found that coaly material and thin sandy beds continue for 410 feet above the Teapot sandstone member, and that at the top of this series are two oyster beds, which are indicative of brackish-water instead of marine conditions, as should be postulated for the overlying Lewis shale. Whether similar coaly and brackish-water material is present above the uppermost thick white sandstone in other parts of the district was not determined during this investigation.

The Mesaverde formation is very well exposed in the escarpments and hogback ridges that border the Lost Soldier-Ferris district on all sides except south and northeast. (See Pl. V, *A*, *B*.) In these exposures the thickness of the formation varies greatly. Where it appears to be most normally developed—that is, in the Haystack and Table hills and in Tps. 23 and 24 N., R. 89 W.—it measures 1,700 to 1,900 feet, but northward from T. 25 N., R. 89 W., to the southwest side of the Lost Soldier dome it thins rapidly, and in sec. 22, T. 26 N., R. 90 W., it probably measures less than 200 feet. This thinning appears to take place principally by the complete elimination of the middle thick shale and a general thinning of the other divisions. This thinning could be explained by assuming a local deformation centering somewhere to the west which shallowed the sea or perhaps even caused a slight elevation above the water level during Mesaverde time.

On the north side of the Lost Soldier dome and in the Camp Creek syncline the formation thickens again, but at no place in the northern part of the district is it known to reach its normal thickness or to exhibit its normal threefold lithologic division. Where the road to Whisky Gap crosses the west flank of the Camp Creek syncline, the Mesaverde is well exposed (see Pl. V, *A*), but its middle shale division is lacking and its thickness is but 785 feet.

The following fossils were obtained from the Mesaverde formation:

Lot 129, in the NW. ¼ sec. 17, T. 25 N., R. 89 W., 410 feet above the uppermost thick white sandstone, near the top of the Mesaverde formation:
- Ostrea glabra Meek and Hayden.

Lot 157, 10 feet above the base of the formation, in sec. 23, T. 25 N., R. 87 W.:
- Ostrea sp.
- Pteria nebrascana (Evans and Shumard).
- Lunatia sp.
- Fusus (Lerrifusus?) sp.
- Baculites anceps var. obtusus Meek.
- Baculites ovatus Say.

Lot 167, in the Table Hills south of the G. P. field, about 370 feet above the base of the formation:
- Ostrea glabra Meek and Hayden.
- Corbula subtrigonalis Meek and Hayden.

The uppermost thick white sandstone of the Mesaverde, the Teapot sandstone member, is oil bearing on the east flank of the Rattlesnake Mountains,[19] but no evidence of oil in this sandstone was observed in the Lost Soldier-Ferris district. Even if it were oil-bearing it is not buried in any of the domes or anticlines in this district and therefore could not serve as an oil reservoir.

LEWIS SHALE.

The Lewis shale is a soft nonresistant formation which as a general rule is poorly exposed and usually forms depressions in the surface. The best exposure of the Lewis in this district is in the Camp Creek syncline east of the road leading to Whisky Gap, where it consists of dark-gray, thinly laminated shale together with several beds of soft yellowish-brown sandstone, the thickest of which measure about 20 feet. The following fossils, identified by T. W. Stanton, were obtained from the Lewis:

Lot 143. Near the base of the shale, in the NW. ¼ sec. 3, T. 26 N., R. 89 W.:
- Ostrea sp.
- Glycimeris wyomingensis (Meek).
- Lucina sp.
- Cardium speciosum Meek and Hayden.

Lot 155. About 700 feet northeast of the bench mark in sec. 15, T. 24 N., R. 90 W.:
- Ostrea glabra Meek and Hayden.
- Gryphaea? sp. May be abnormal specimens of preceding species but simulate Comanche forms of Gryphaea.
- Glycimeris wyomingensis Meek.

DISTRIBUTION OF OIL AND GAS.

The stratigraphic distribution of oil and gas in the folds of the district is set forth in Table 3, which is based on developments up to November 1, 1920.

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[19] Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey Bull. 641, pp. 246–247, 1917.

TABLE 3.—*Stratigraphic distribution of oil and gas and approximate minimum depth*[a] *of "sands" in the domes and anticlines of the Lost Soldier-Ferris district.*

[Figures in parentheses indicate depth in feet.]

Formation.	Lost Soldier dome.	Wertz "dome."	Bunker Hill dome.	Mahoney dome.	Ferris dome.	G. P. "dome."	O'Brien Springs anticline.	Sherrard dome.	Separation Flats anticline.
Mesaverde formation			Surface.						
Steele shale		Surface	Only upper 300 feet tested.			Surface	Surface	Surface (?)	
Niobrara and Carlile shale.	Surface	Barren	Untested	Surface	Surface	Oil with gas showings (3,200).	Barren	Barren	Surface.
Frontier formation	Oil (240)	Barren (2,145)	Untested (6,700±).	Showings of oil and gas (860).	Showings of oil and gas (235).	Untested (?)	Good showing of gas (3,120).	Slight showing of oil where tested (1,850±).	Barren where tested (975±).
Mowry shale	Showing of oil (1,150).	Showing of oil (3,140).	Untested	Showing of gas.	Oil with gas showings (1,200–1,300).	Untested	Untested	Untested	Barren where tested.
Thermopolis shale	Barren	Barren	do	Barren	Barren (?)	do	do	do	Do.
Cloverly formation	Oil (1,375)	Gas (3,410)	do	Gas (2,160)	Gas (1,425)	do	Untested (4,300±).	Untested (3,100±) (?).	Barren where tested (2,165±).
Morrison and Sundance formations.	Untested (1,750–2,250).	Untested (3,800–4,300).	do	Barren (?) (2,250–2,750.)	Untested (1,825–2,325).	do	Untested	Untested	Untested.
Triassic and Permian red beds.	Untested (2,250–3,650).	Untested (4,300–5,675)	do	Untested (2,750–4,135).	Untested (2,300–3,700).	do	do	do	Do.
	Untested (3,650±).	Untested (5,675±).	do	Untested (4,135±).	Untested (3,700±).	do	do	do	Do.
Tensleep sandstone	Untested (4,050±).	Untested (6,075±).	do	Untested (4,535±).	Untested (4,100±).	do	do	do	Do.
Amsden formation	Untested	Untested	do	Untested	Untested	do	do	do	Do.
Madison limestone	Untested (4,450±).	Untested (6,475±).	do	Untested (4,950±).	Untested (4,500±).	do	do	do	Do.
Cambrian quartzite	Untested	Untested	do	Untested	Untested	do	do	do	Do.
Pre-Cambrian granite.	Untested (5,000±).	Untested (7,000±).	do	Untested (5,500±).	Untested (5,000±).	do	do	do	Do.

[a] These estimates may vary by several hundred feet because of varying thickness in stratigraphic intervals.

STRUCTURE.

REGIONAL FEATURES.

The Lost Soldier-Ferris district lies at the north end of the Rawlins uplift, one of the major upfolds of the Rocky Mountains in Wyoming. The Rawlins uplift is not large in area in comparison with other major upfolds, but the fact that it is elevated so high that pre-Cambrian crystalline rocks are exposed along its axis is sufficient reason to class it with them. Its alinement is northerly and it is therefore a part of that series of Rocky Mountain flexures which are characterized by northerly lines of folding and faulting. The Rawlins uplift is one of a group of major upfolds that form the northernmost of a northward-alined series, north of which the direction of the normal Rocky Mountain folds abruptly changes to east. The northerly trend is resumed in the Wind River Mountains. The Rawlins uplift measures about 50 miles in length and 20 miles in average width. It extends some distance beyond the boundary line marking the top of the Steele shale. From the general horizontal position of the Wasatch beds, of Tertiary age, on the west side of the uplift, it seems that the development of this uplift was complete or almost complete by the beginning of Wasatch time. The central core of the uplift is marked by an area of pre-Cambrian granite northwest of the town of Rawlins, from which the sedimentary rocks dip at steep angles on the west and at more gentle angles on the east. The west flank of the anticline immediately adjacent to the central granite core is modified by a zone of faults, and farther north this fault zone turns northeastward and cuts across the axis of the fold. The portion of the uplift lying north of this fault is the down-dropped side, and it is this lower north end of the uplift which is occupied by the Lost Soldier-Ferris district.

The district contains several lines of minor folds, the upfolds of which are accentuated by local high portions or domes, which are the controlling features for the accumulation of the oil and gas found in this district. These domes and the accompanying oil accumulations are described in detail on later pages. The alinement of these folds in relation to the major upfolds of the region is shown on Plate I. The noteworthy feature of the alinement of the folds is that in general they lie transverse to the major axis of the Rawlins uplift. This transverse arrangement would appear to indicate that the forces which formed them were not the same as those which caused the Rawlins uplift. The significance of the transverse position has been discussed at some length by the senior author.[20] The argument followed in that paper is that (*a*) the folds do not, as would ordinarily be expected, lie parallel to the longitudinal axis of the Rawlins uplift,

[20] Fath, A. E., The age of the domes and anticlines in the Lost Soldier-Ferris district: Jour. Geology, vol. 30, No. 4, pp. 303–310, 1922.

but instead lie parallel with the Ferris-Seminoe line of deformation; (*b*) this parallelism indicates that the folds and the mountains are probably due to the same forces; (*c*) the Ferris and Seminoe mountains are considerably younger (at least post-Wasatch) than the Rawlins uplift (pre-Wasatch), and the minor rock folds are therefore also younger than this uplift.

The significance of this argument in relation to oil and gas is that any oil or gas which had been formed prior to the minor folding of the Lost Soldier-Ferris district and was located or had migrated a short distance beyond the catchment areas of the present fields must have migrated toward the crest of the uplift and there been lost through the eroded edges of the formations that contained it. The oil and gas of the present fields and possibly an additional quantity in fields not yet proved must represent that formed by the dynamo-chemical action of the later deformational forces which produced these minor flexures, and in addition that of earlier distillation which was already present within their catchment areas. This quantity, however, must represent but a fraction of that which was formed within the area embraced by the Rawlins uplift. The oil and gas that is present in this district to-day for the use of man must therefore be merely a remnant of all the oil derived from the mother material which the rocks of this region originally contained.

This hypothesis is not accepted by a number of geologists who have worked in the Wyoming fields, nor by geologists who do not believe that oil can migrate long distances. K. C. Heald [21] believes that, even though oil may once have accumulated in the Rawlins uplift, most of it would probably have followed the retreating water table down the flanks of the uplift as erosion neared the oil-containing beds, and that therefore only the portion which would not drain by gravity from the containing rocks would be lost. He also maintains that as soon as surface water had begun to enter the oil sand the tendency of the water would be to push the oil basinward and force it into flexures on the flanks of the main uplift.

METHODS USED IN REPRESENTING STRUCTURE.

The top of the Wall Creek sand was considered to be the best horizon for showing the geologic structure of the Lost Soldier-Ferris district. The attitude of this surface was determined (1) by mapping the location, determining the dip and strike, and obtaining the altitude of the exposed key beds, and by locating and obtaining the altitude of wells in the logs of which key beds have been recognized and recorded; (2) by determining the thickness of the strata between the several key beds in the stratigraphic section; (3) by computing

[21] Personal communication.

from the altitudes obtained, the altitude of the top of the Wall Creek sand; and (4) by drawing contours showing the configuration of the Wall Creek sand, by using not only the computed altitude of its top but also the dip and strike of the key beds. The result is represented by structure contours on Plate I.

Throughout a large part of the district the rocks are covered with alluvium and dune sand, and the contours drawn for these areas are wholly inferred, as there is no available information on which they can be based. To make such contours clearly distinct from those for which there is some evidence, they are shown in green.

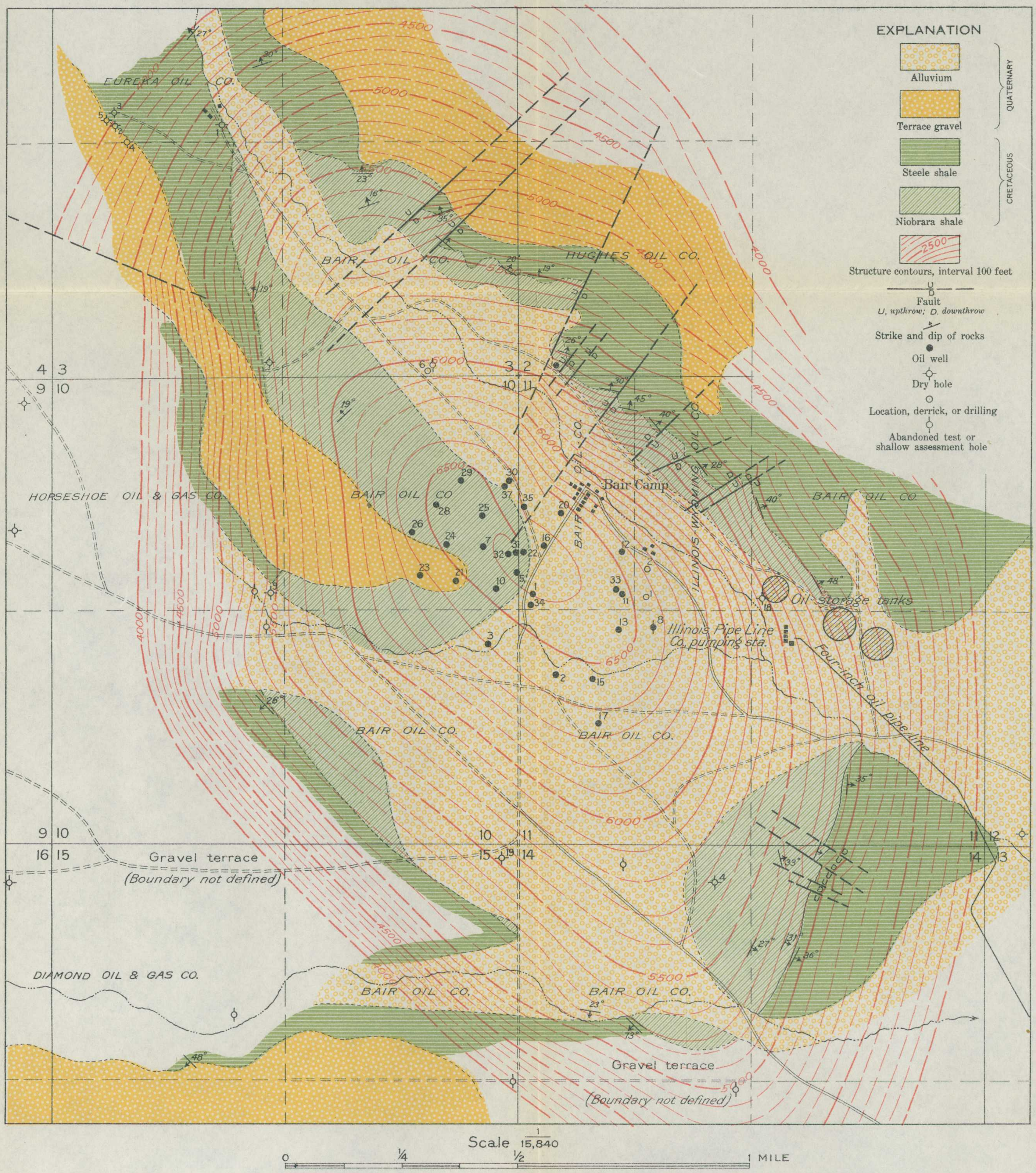
Within the 6,000-foot interval of shale (Carlile, Niobrara, and Steele) that forms the outcropping rock in the great central area of the district, where not concealed by alluvium and dune sand, only one key horizon has been recognized that is common to two or more localities. This horizon, or rather zone, consists of the transition beds at the top of the Niobrara shale. The lack of definite structure contours in so much of the area occupied by these thick formations can therefore be readily understood.

EFFECTS OF STEEP DIPS.

The altitude of the Wall Creek sand can not be calculated from the altitudes determined for the key beds mapped at the surface by merely subtracting the thickness of the intervening strata, except where the beds lie horizontal. The dip of the beds must be taken into consideration, because the vertical distance through a dipping formation is greater than the stratigraphic thickness, the difference depending on the rate of dip. The vertical distance from the surface to the Wall Creek sand was obtained by the formula $t = T \sec a$, in which t = vertical distance, T = stratigraphic interval, and a = angle of dip. This formula is applicable to all similar problems, and results for certain angles are given in the second column of Table 4. The formula must be used with some caution in areas close to rapid changes in dip, as near a synclinal or anticlinal axis, for in most oil fields such folds are of the similar rather than the parallel type.

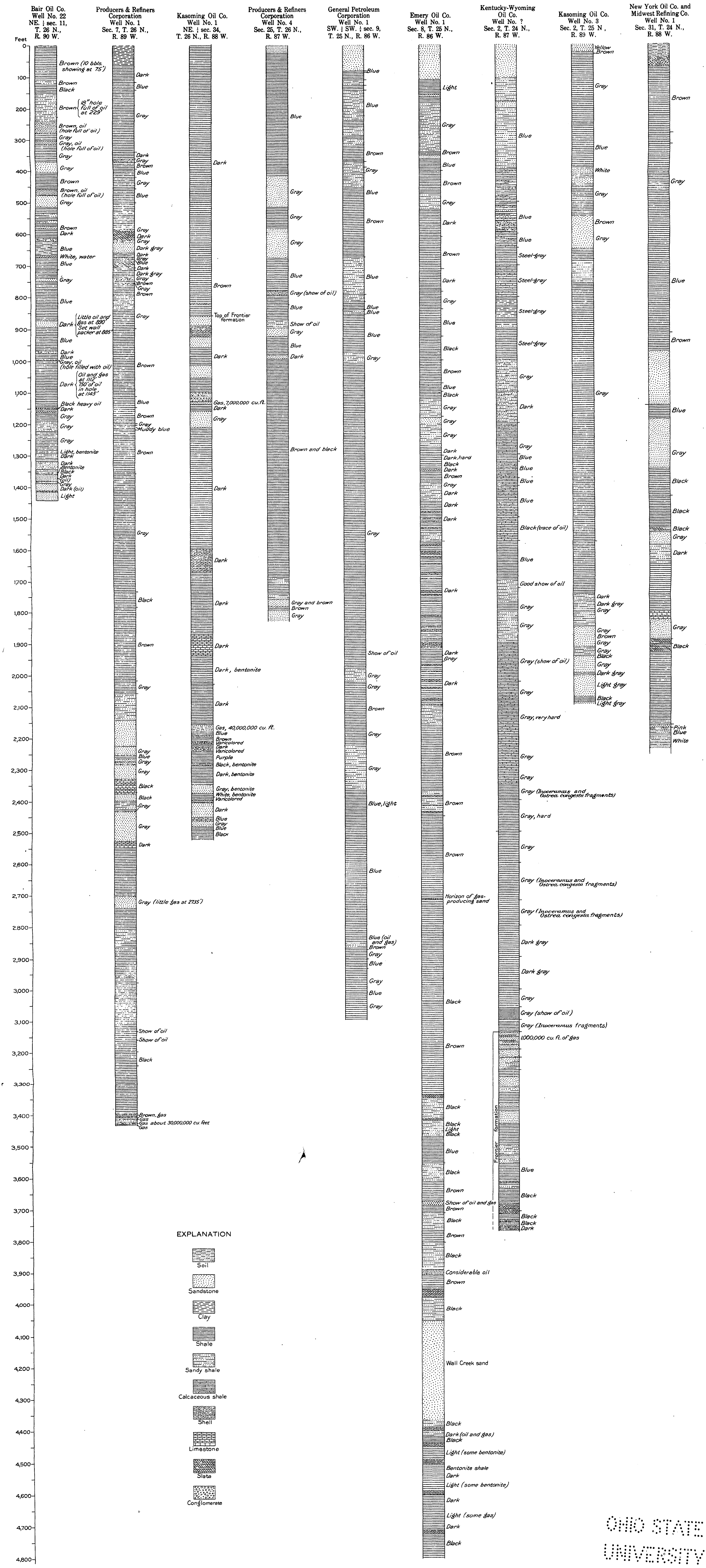
If the rate of dip only is known, it is possible also to determine the horizontal distance between contours for any given contour interval by the formula $d = I \cot a$, in which d = distance between contours, I = contour interval, and a = angle of dip. Table 4, in the third and fourth columns, gives the results obtained from the use of this formula for contour intervals of 100 and 500 feet.

The producing area of a dome or anticline in which the beds have steep dips is very small, because oil and gas do not extend through large vertical intervals in any sand, and the horizontal distance from points high on such a rock fold to points below the level at which oil and gas are present is short. Steep dips also cause difficulties in



MAP OF THE LOST SOLDIER DOME, WYOMING

Showing areal geology and structure of the Wall Creek sand



GRAPHIC LOGS OF WELLS IN THE LOST SOLDIER-FERRIS DISTRICT, WYOMING well-log correlation unless they are taken into consideration. Some operators, even where the dip was known, have apparently failed to realize this effect of steep dips. The amount of this effect—that is, the increase in depth due to the dip for any horizontal distance—is expressed by the formula $e = d \tan a$, in which e = increased depth, d = horizontal distance, and a = angle of dip. Results obtained from the use of this formula are given in the fifth and sixth columns of Table 4.

TABLE 4.—*Effects of dips at certain angles on vertical thickness, distance between contours, and depth to a bed.*

Angle of dip (a).	Vertical thickness (t) of a bed 100 feet thick (T=100 feet; t=100 sec a).	Distance between contours (d=I cot a).		Increase in depth to a bed (e=d tan a).	
		I=100 feet.	I=500 feet.	d=100 feet.	d=1 mile.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1°	100.01	5,729	28,645	1.75	92.4
5°	100.38	1,143	5,715	8.75	462.1
10°	101.54	567	2,835	17.63	930.9
15°	103.58	373	1,865	26.75	1,412.4
20°	106.42	274	1,370	36.40	1,921.9
25°	110.34	214	1,070	46.63	2,462.0
30°	115.47	173	865	57.73	3,048.1
35°	122.08	143	715	70.02	3,679.0
40°	130.54	119	585	83.91	4,430.4
45°	141.42	100	500	100.00	5,280.0
50°	155.57	84	420	119.18	6,292.7
55°	174.34	70	350	142.81	7,540.4
60°	200.00	57	285	173.2	9,145.0

OIL AND GAS FIELDS.

LOST SOLDIER DOME.

SURFACE GEOLOGY AND STRUCTURE.

The Lost Soldier dome, the first structural feature to be proved oil-bearing in this district, is in the northeastern part of T. 26 N., R. 90 W. It is elongated in a N. 30° W. direction and is fairly symmetrical. Its presence is well indicated by the partly surrounding hogback escarpment of the Mesaverde sandstones, which is well developed to the southwest, south, and southeast and also to the north and northwest. (See Pl. V, *A*, *B*.) This hogback rim is the only prominent indication of the presence of a dome. The soft sandstone and thin limy sandstone that occur in transitional beds at the top of the Niobrara formation also crop out in a circular belt within the Mesaverde rim, but their presence would not be noted except by the trained observer. The boundary line between the Niobrara and the Steele marked by these sandstones is well indicated in a few places, especially in the hill near the north quarter corner of section 14 and in the low ridge and hills north of and parallel to the creek at the north side of the oil field. (See Pl. VII.) The highest part of the dome, which lies within this inner belt of sandstone, is composed of Niobrara shale, and its flanks, out to the Mesaverde rim, of the Steele shale.

The apex of the dome lies immediately north of the west quarter corner of sec. 11, T. 26 N., R. 90 W., where the Wall Creek sand, the top sandstone of the Frontier formation, was found at a depth of 239 feet, and oil in the Muddy sand, the upper sandstone of the Cloverly, was reached at 1,375 feet.

The dome is modified on the east and north by numerous small radiating faults whose presence was determined where they cut the sandstone beds at the top of the Niobrara shale. They may be much longer than is shown on the map, but their length could not be ascertained in the field. Similar faults may occur on the west and southwest sides of the dome, but as no rocks are exposed in these localities their presence could not be determined. The Mesaverde rim is cut by at least one fault on the northwest side of the dome. All these faults have probably had considerable influence on the stratigraphic distribution of the oil by permitting its migration into open fissures in the Mowry shale and into the porous Frontier sands.

DRILLING OPERATIONS.

By the end of 1921 the Lost Soldier field had 32 producing wells, of which 20 obtained their oil from the Wall Creek sand only (first Frontier sandstone), 3 from the first and second sands, 3 from deeper sands in the Frontier formation, 3 from the Mowry shale, and 3 from the Muddy sand. The first well to reach the Muddy sand encountered oil in three distinct sands of the Frontier formation, as indicated in the graphic log of this deeper test well given on Plate VIII.

When completed several of the earlier wells drilled to the Wall Creek sand were reported to have yielded more than 500 barrels daily, but in the summer of 1920 the average daily production was about 50 to 70 barrels. At that time many of the shallow wells in the Wall Creek sand were producing considerable quantities of water, which was decreasing their output of oil. These wells could undoubtedly be profitably deepened so as to obtain oil from the lower sands of the Frontier.

The three wells obtaining their oil from the Mowry shale are the Hughes Oil Co.'s well, in the southwest corner of sec. 2; the Illinois-Wyoming Co.'s well No. 2, in the E. ½ NW. ¼ sec. 11; and the Bair Oil Co.'s well No. 33, an offset to the Illinois-Wyoming well. The Bair Co.'s well flowed at a rate of about 500 barrels a day when first drilled in.

The first well to reach the Muddy sand was the Bair Oil Co.'s well No. 22, which is on the apex of the dome. Its initial flow was estimated to be about 1,500 barrels a day. The Muddy sand had been penetrated by two other wells (Nos. 29 and 34) prior to 1922, but these two wells are not so located as to indicate the probable extent of its productive area. It would seem reasonable to expect that this area would be as large as that of the Wall Creek sand, if not larger.

Mr. E. W. Krampert, geologist for the Kasoming and Bair companies, informed the writers of a peculiar condition in the oil reservoir on this dome that was brought to light by a curtailment of production during the fall of 1921. Prior to this time the shallow wells in the Frontier sands were producing considerable quantities of water, and at an increasing rate. One of these wells was pumping as much as 80 per cent of water. When the production of the field was curtailed by the shutting in of the Muddy sand wells, an immediate improvement was noted in the production from the Frontier sand, which increased about 300 barrels daily, and this increase was accompanied by a marked dropping off in the quantity of water obtained. In the well that had been producing 80 per cent of water the water was reduced to less than 10 per cent. The intercommunicating character of the Muddy and Frontier sands, as above described, indicates that the small faults that cut the dome provide open passages through which the pressure in the Muddy sand is transmitted to the higher sands. When this pressure is removed from the Frontier sands by the flowing of the Muddy sand wells the edge water in the Frontier sands is enabled to crowd into the wells.

UNTESTED DEEP SANDS.

It is possible that oil in commercial quantity may also be found in sands below the Muddy. The conglomerate at the base of the Cloverly, which is about 150 feet stratigraphically below the Muddy sand, is probably more porous and even better suited as a reservoir for oil. At depths of 200 to 700 feet below the Cloverly in the Whisky Gap region there are two sandstones, which occur in the Sundance. Although neither of them is known to be oil or gas bearing in other parts of Wyoming, it is possible that oil and gas may have accumulated in them here.

The Triassic and Permian red beds, whose sandstones could well act as oil and gas reservoirs, underlie the Sundance, and the equivalents of the Embar, which produces oil in several Wyoming localities, would probably be reached at a depth of 3,650 feet on the apex of the dome. The Tensleep sandstone would probably be encountered at about 4,050 feet, and the Madison at about 4,450 feet.

CHARACTER OF OIL.

The oil from the Wall Creek sand has a paraffin base and a specific gravity when fresh of about 0.8675 (31.4° Baumé). According to the analyses on page 54, it contains about 19.3 per cent of naphtha and gasoline (the fraction distilled below 200° C.), 18.1 per cent of kerosene (the fraction distilled between 200° and 275° C.), 18.65 per cent of gas oil (vacuum-distillation fraction below 225° C.), 23.5 per cent of lubricating oils (vacuum-distillation fraction between 225° and 300° C.), and about 18 per cent of residue. Its viscosity increases so greatly in cold weather that it could not be piped to the Fort Steele loading station through the 4-inch pipe line during the period from November, 1919, to April, 1920.

No samples were obtained of the oil from the Muddy sand, but in view of the intercommunicating character of these two reservoirs it is probably very nearly the same as that from the Wall Creek sand.

PRODUCTION.

The distance of the Lost Soldier field from transportation routes did not warrant active development and production immediately after oil was discovered. Prior to the completion of the pipe line, in April, 1919, the product was held by two steel storage tanks. Until August, 1920, when the first well reached the Muddy sand, the oil marketed was derived entirely from the Frontier sands.

TABLE 5.—*Petroleum produced and sold in the Lost Soldier field, 1916–1921, in barrels.*

Year.	Number of wells producing at end of year.	Barrels.	Year.	Number of wells producing at end of year.	Barrels.
1916	3	871	1919	20	174,431
1917	4	2,683	1920	25	206,903
1918	14	100,188	1921	28	380,811
					865,887

WERTZ "DOME."

SURFACE GEOLOGY AND STRUCTURE.

East of the Lost Soldier dome the valley of Lost Soldier Creek is flanked by Mesaverde escarpments, somewhat obscure on the south but prominently developed on the north, in which the beds of rock dip away on either side. The dips in these escarpments indicate an anticlinal fold with its middle in the valley, but the configuration of the crest can not be ascertained, as the entire valley is filled with alluvium and dune sand. Near the south side of T. 26 N., R. 89 W., the south escarpment swings abruptly southward and the eastward extension of the anticlinal fold is very obscure.

The northwest end of this fold, in secs. 1 and 12, T. 26 N., R. 90 W., and sec. 6 and parts of secs. 5, 7, and 8, T. 26 N., R. 89 W., is indicated by the dip and strike of bedding planes in the Steele shale. In addition the Steele shale contains a thin bed of limy argillaceous yellowish-brown sandstone, which though indistinct, can be traced across parts of secs. 1 and 12, T. 26 N., R. 90 W. This bed was of material aid in determining the probable structure. The crest line of the fold is fairly well defined in the northwestern part of sec. 7 by the change in direction of the dips determined on the shale bedding planes. The position of the crest line and the configuration of the fold toward the southeast are not determinable, because in that direction the rocks are concealed under a cover of alluvium and dune sand.

The evidence described above was used by the Producers & Refiners Corporation for locating a test well in the northeast corner of the SW. ¼ sec. 7, T. 26 N., R. 89 W., at the edge of the shale outcrops and near the crest line. The success of this well in encountering a little oil and large quantities of gas has demonstrated the reliability of the geologic evidence afforded by the exposed rocks.

Whether or not the accumulation of oil and gas here is caused by a local high point or dome on the anticlinal fold can not be ascertained by an examination of the exposed rocks. Notwithstanding this uncertainty, the indeterminate structural feature in the vicinity of the well is known as a "dome" among the local oil fraternity and bears the appellation "Wertz dome."

The position of the inferred contours on the map (Pl. I) gives the Wertz "dome" some prominence for a short distance southeast of the discovery well. The inference that closed contours may be drawn on this southeastern extension of the "dome" is based entirely on the slight change of strike in the northern Mesaverde escarpment, in sec. 9, T. 26 N., R. 89 W.

DRILLING OPERATIONS.

The gas well of the Producers & Refiners Corporation in the northeast corner of the SW. ¼ sec. 7, T. 26 N., R. 89 W., was the only one drilled on the Wertz "dome" before the end of 1920. The Wall Creek sand and the other sands at the top of the Frontier formation were found at depths of 2,145 to 2,530 feet, and a small showing of gas was encountered in the lowermost of them. (See log B on Pl. VIII.) In the Mowry shale at a depth of 3,140 to 3,175 feet a very good showing of oil with a gravity of 36° Baumé, according to a rough field test, was encountered, and at times the gas pressure was sufficient to force the oil to the surface. Enough oil was obtained for a time to supply the fuel for the deeper drilling, and after the well was completed to the gas sand it produced between 400 and 500 barrels of oil monthly from the Mowry. The Muddy sand, at the top of the Cloverly, was reached at 3,410 feet. It gave a showing of gas, and when it had been penetrated 35 feet the pressure became so great that the tools were blown out of the well. An open-flow volume of 30,000,000 cubic feet and a few hundred gallons of casing-head gasoline daily were reported in trade journals as the productive capacity of the well.

Why the Muddy sand should yield oil on the Lost Soldier dome, only a few miles distant, and nothing but gas here may be explained by the possible absence in the Wertz "dome" of open passages like those in the Lost Soldier dome, which would permit oil to be fed upward into the sand.

Trade journals reported the completion of a second gas well during the summer of 1921. Until the fall of 1921 the gas of this field, like that of other fields in the district, had no market aside from its use as fuel in the field itself. Since the completion of the gas pipe line to Casper, late in 1921 the wells of this field, according to press reports, have supplied a large part of the gas transported by that line.

Further prospecting on this "dome" will seek to determine whether oil underlies the gas in the Muddy sand on the flanks of the uplift, whether any deeper sands contain oil or gas, and in how large an area the Muddy sand is productive.

It is altogether possible that oil exists in the Muddy sand beneath the gas, and according to press reports the gas apparently contains some of the heavier constituents that evaporate from oil. Whether or not oil is present in the Muddy sand on the flanks of the "dome" can be determined only by test wells drilled there. As the structure is indefinite along the axis of the fold to the southeast, it would seem advisable to drill either to the northeast or to the southwest of the discovery well. A few wells so spaced as to find the Muddy sand approximately 200 feet lower at successive points would soon determine whether or not it is oil-bearing.

Wells will probably be drilled to the lower sands to determine whether the basal conglomerate of the Cloverly and perhaps the sands of the Morrison and Sundance formations contain oil or gas. The basal conglomerate of the Cloverly should be encountered at about 3,560 feet in the discovery well, and the sandstones belonging to the Morrison and Sundance at 3,800 and 4,300 feet. The Embar horizon would be found at about 5,675 feet and the Tensleep about 400 feet lower.

In determining the extent of the area in which the Muddy sand is productive, the first endeavor should be to sink test wells on the axis and in this way to determine whether or not there is a distinct dome in this vicinity. Should an eastward pitch be discovered, it would not require a great deal of additional drilling to ascertain the breadth of the productive area.

EASTWARD EXTENSION OF WERTZ "DOME."

Whether or not the anticlinal fold extends eastward from the Wertz "dome" can not be determined by surface examination, but because the Mesaverde escarpment on the north continues eastward with its persistent northward dip, it seems reasonable to suppose that the anticlinal fold also continues southeastward and joins the Mahoney dome. Four wells have been drilled in the direction of this possible eastward extension of the anticline, but because the configuration of the crest of the fold is not determinable, the locations of the wells were chosen without close structural control, and the results obtained have been very discouraging. One of thse wells, drilled by the Lost Soldier Oil Co., is within three-quarters of a mile from the northern Mesaverde escarpment and about 3 miles from the southern escarpment—a location, it would seem, far down on the north flank and certainly not near the crest of the fold. The three other wells, drilled by the United States Petroleum Corporation, although not located with any immediate control, nevertheless tested the middle region lying between the Mesaverde escarpments. The well in sec. 16, T. 26 N., R. 89 W., reached the Wall Creek sand, which carried some gas, at a depth of 3,348 feet. Drilling continued to a depth of 3,530 feet without finding additional showings. The gas in the Wall Creek was reported to amount to several million cubic feet daily and to have been used in the further drilling of this well and the other wells of the company. The well in sec. 22, T. 26 N., R. 89 W., encountered the Wall Creek sand at 3,472 feet. The sand was recorded in the log as containing a showing of oil but no gas. The drilling continued in the Wall Creek to a depth of 3,600 feet, at which the well was abandoned. The company's third well, in sec. 26 of the same township, was drilled to a depth of about 1,600 feet and then abandoned before reaching the Wall Creek sand. From neither the surface geology nor the findings of the first two of these wells is it possible to determine whether any of them were located on the crest of the fold, or in which direction from any of them the crest may be. Further search for oil and gas along this anticlinal fold must proceed rather blindly. By drilling transversely on the fold in the neighborhood of the wells in secs. 16 and 22 it should be possible to locate the anticlinal crest with considerable accuracy.

BUNKER HILL DOME.

The Bunker Hill dome, in the southwestern part of T. 27 N., R. 89 E., northeast of the Wertz "dome," is the most clearly defined structural feature in the district. The outline of the dome is very definitely shown by the outcrops of several Mesaverde sandstones, which lack very little of completely encircling it. The fold is oval, and its major axis trends northwest. Its apex lies at a point about 800 feet east of the southwest corner of sec. 29, T. 27 N., R. 89 W. From this point the rocks dip rather gently in all directions but at somewhat larger angles to the north, northwest, and west than to the south and east. As mapped on Plate I its apex in the Frontier formation lies about 800 feet above the syncline to the southwest that separates it from the Wertz "dome" and about 600 feet above the Sand Creek syncline, to the northeast.

The dome has been eroded down so that a thin-bedded sandstone of considerable thickness is exposed, which is overlain by about 50 feet of soft shale, and the resulting topographic form of the crest is a very slightly modified reproduction of the structural form.

Only one test well had been drilled on the Bunker Hill dome at the time of this investigation. This well was drilled by the Kasoming Oil Co. in the northeast corner of the NW. ¼ sec. 32, T. 27 N., R. 89 W., near the apex of the dome. It was reported to have been abandoned at the very slight depth of 827 feet without encountering any showings of oil or gas. As its mouth is about 500 feet above the base of the Mesaverde formation, which here has a thickness of about 785 feet, it passed through the lower sandstones of the Mesaverde and entered the Steele shale only in its last 300 to 400 feet. As the drill ascertained the oil and gas possibilities of only the Mesaverde sandstones it is obvious that the sands which are productive in the neighboring fields were not tested. The great depth of about 6,700 feet to the Wall Creek sand, at the top of the Frontier, prevented the drilling of the well to this and lower sands.

As shown in the consideration of the G. P. field (pp. 46–47), it seems very probable that the producing sand there is considerably higher in the stratigraphic section than the Wall Creek and belongs to the lower part of the Steele shale or the upper part of the Niobrara. If this correlation is correct, the G. P. sand should be found within reach of the drill on the apex of the Bunker Hill dome at a depth of about 5,300 feet.

MAHONEY DOMES.

SURFACE GEOLOGY AND STRUCTURE.

Attempts by prospectors to find other domes in the basin between the Rawlins Hills on the south and the Ferris and Seminoe mountains on the north soon led to the discovery of a local area of Niobrara shale in secs. 33, 34, and 35, T. 26 N., R. 88 W. and secs. 3 and 4, T. 25 N., R. 88 W. This area of Niobrara shale is bordered on the east, south, and west by an inconspicuous rim of the thin beds of limy argillaceous yellowish sandstone that mark its top and on the north by dune sand. The beds of yellowish sandstone dip away from the central shale area at gentle angles, and in a few places the overlying Steele shale is exposed beyond the rim. These features, in conjunction with the northward dip of the Mesaverde 2 miles to the north, clearly indicate the presence of a dome, the west one of the two Mahoney domes.

The configuration of the top of this west dome has been well established on the east, south, and west, where the dip of the beds is gentle (about 5°), but the cover of dune sand has made the contouring of the north flank very uncertain. As the Mesaverde is so near on the north, in secs. 21 and 22, T. 26 N., R. 89 W., it would appear that the dip in this direction must be rather steep. The surrounding rim of yellowish beds marking the top of the Niobrara is broken by numerous small radiating faults similar to those in the Lost Soldier dome. The extent of these faults within and beyond the obscure rim of yellowish beds is not known, because of the absence of exposed rocks in which dislocations can be discerned.

DRILLING OPERATIONS.

The discovery well on the west Mahoney dome was drilled in the southwest corner of the NE. ¼ sec. 34, T. 26 N., R. 88 W., by the Kasoming Oil Co. (See log C, Pl. VIII.) It passed through the Wall Creek sand and the other sands of the upper part of the Frontier formation at depths between 865 and 1,215 feet and encountered gas in sand at a depth of 1,130 to 1,140 feet. The yield of this gas was estimated at about 7,000,000 cubic feet a day. Early in the fall of 1919, at a depth of 2,160 feet, the drill entered the Muddy sand and struck gas which was reported to be of the "dry" variety and was estimated to have amounted to a daily open-flow yield of 30,000,000 to 50,000,000 cubic feet. The means for controlling this large gas flow were inadequate, and the well blew wild. Early in the morning of October 1, 1919, lightning ignited the gas, and it burned for 27 days before being put out. The means used to extinguish the fire are interesting. Water was ponded about the well to cool the ground and iron, and steam from eight field boilers was directed at the mouth of the well. This alone had no effect in extinguishing the fire, so a 25-pound charge of dynamite was rigged up to explode close to the well mouth. The concussion of the explosion was strong enough to stop or slow down the flow of gas momentarily, so that the steam could snuff out the flames.[22]

A new derrick was then erected over the well, and the gas sand was cased off for a deeper test. The hole was drilled to 2,525 feet. The log of this deeper hole does not conform closely to the section as exposed 6 miles to the north. There the basal conglomerate of the Cloverly lies 125 feet below the Muddy sand, but the log of the

[22] Reported in personal communication from E. W. Krampert.

Kasoming well records only 30 feet of shale between the Muddy and a 10-foot bed of varicolored conglomerate. It is possible that a small inclined fault similar to those mapped in sections 3 and 4, to the south, cuts the beds immediately below the Muddy sand and that the well encountered the conglomerate displaced in an upthrown block at a point where the conglomerate itself was in a wedge form and presented a vertical thickness of only 10 feet. This supposition is slightly supported by the log of the deeper part of the well, which includes first 6 feet of "dark shale" followed by "16 feet of varicolored shale with some pebbles." The pebbles might very probably be loosened pebbles from the conglomerate ground into the underlying shale adjacent to the plane of dislocation. A little gas was encountered in the shale that contains pebbles. The rocks below this bed to a depth of 2,455 feet correspond to the Morrison, and below this formation a 10-foot "lime" was encountered, which very probably is a limestone bed of the Sundance formation. Drilling continued to a depth of 60 feet below this "lime." After the casing that shut off the Muddy sand had been withdrawn considerable trouble was experienced in closing the well, and it blew wild for several months before being brought under control on August 28, 1920.

In the summer of 1921 the Kasoming Oil Co. completed its second well in the southeast corner of sec. 28, T. 26 N., R. 88 W., where the pay sand was found at a level 200 feet lower than in the discovery well. This well was drilled in an attempt to find oil in the Muddy sand at a lower level on the dome, but, like the discovery well, it encountered only gas. The open flow was estimated at 35,000,000 cubic feet a day.

In sec. 4, T. 25 N., R. 88 W., on the southwest flank of the dome, the Midwest Refining Co. drilled a well which had to be abandoned because of drilling troubles during the summer of 1920 before reaching the Muddy sand. A new well was then started, but it was abandoned at a depth of about 2,690 feet in August, 1922.

Believing that the dome tested by the Kasoming Co.'s well was but a local "high" on a fold which parallels the Sand Creek syncline and that it extended eastward, the Ohio Oil Co. drilled a well in the southwest corner of the NW. ¼ sec. 36, T. 26 N., R. 88 W., hoping, it is reported, to find the Muddy sand at such a level that oil rather than gas would be struck. The sand was reached in the early part of July, 1920, at a level 318 feet lower than that in the discovery well, and, contrary to expectations, gas was encountered with an open flow of 30,000,000 cubic feet daily and a closed rock pressure of 1,040 pounds to the square inch. A second well was drilled by the same company about a mile farther east, in the southeast corner of the NE. ¼ of the same section. This well reached the sand at a level 55 feet below that in the first well and likewise obtained only gas, with an open flow of 30,000,000 cubic feet a day and a closed rock pressure of 1,000 pounds to the square inch.

The area around these two gas wells is devoid of rock outcrops, but the underground information supplied by these wells and by the log of the Wyanna Oil Co.'s test well in the southwest corner of the SE. ¼ sec. 25, T. 26 N., R. 88 W., appears to indicate that there is a second dome on the east-west anticlinal fold, east of the one indicated by the Niobrara shale area, and that the two domes are separated by a very shallow syncline. Because of the ill-defined nature of the upfold in this vicinity, no special name will be given to this second dome in this report, but it will be referred to simply as the east Mahoney dome

The deeper drilling of the discovery well appears not to have found the basal conglomerate of the Cloverly in its normal state, and hence the writers believe that this conglomerate has not received a conclusive test. It should normally be found about 125 to 150 feet below the Muddy sand.

There is still some possibility that drilling on the east Mahoney dome to depths greater than that reached by the discovery well may find oil. The lower sandstones of the Sundance and the underlying red beds extend to a depth of about 4,550 feet. The top beds equivalent to the Embar should be found on the apex of the dome at a depth of about 4,150 feet, the Tensleep should follow at a depth of about 4,550 feet, and the Madison at 4,950 feet.

FERRIS DOME.

SURFACE GEOLOGY AND STRUCTURE.

Centering in sec. 25, T. 26 N., R. 87 W., is the crest of the Ferris dome, an elongated fold whose axis extends in nearly a straight northwesterly direction from a point near the southwest corner of sec. 31, T. 26 N., R. 86 W., into sec. 23, T. 26 N., R. 87 W. (See fig. 2.) The rock exposures of this vicinity are very few in number, but with the assistance of information supplied by well logs it has been possible to outline the general configuration of the fold.

The Niobrara shale, carrying characteristic fossils and dipping in opposite directions on either side of the anticlinal axis, is exposed at several places near the center of the E. ½ sec. 25, T. 26 N., R. 87 W. The transition beds at the top of the Niobrara are probably represented in the exposures near the middle of the north line of the NE. ¼ sec. 25, T. 26 N., R. 87 W. This is the only point where the contact between the Niobrara and Steele shales is exposed, but it is thought that beneath the concealing dune sand the Niobrara shale occupies approximately the area within the 6,000-foot contour line as given on Plate I.

To the northeast the adjacent syncline is fairly well indicated by dips and strikes determined on bedding planes in scattered outcrops of shale in sec. 24, T. 26 N., R. 87 W., and sec. 19, T. 26 N., R. 86 W., and farther south by shale exposures and the comparatively extensive outcrops of a few thin beds of hard limy argillaceous sandstone, of which one could be mapped across secs. 27, 28, and 29, T. 26 N., R. 86 W. This one mappable bed is considered to be in the Steele shale about 2,590 feet above its base. It seems reasonable to suppose that this syncline northeast of the Ferris dome is a continuation of the Camp Creek syncline, to the west, and that toward the southeast

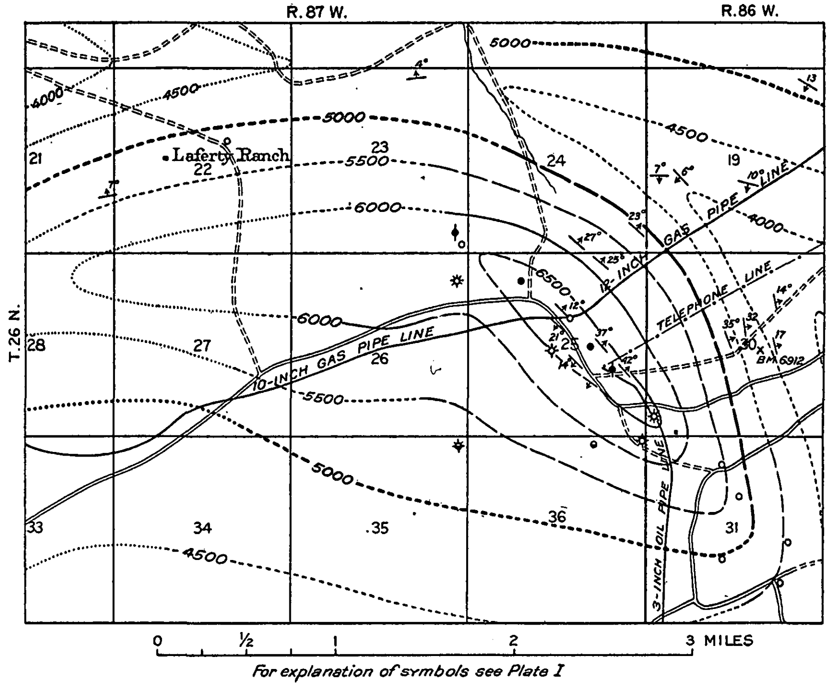


FIGURE 2.—Map of the Ferris dome.

it joins with the syncline indicated by the outcrops of the Mesaverde formation in secs. 2, 3, and 4, T. 25 N., R. 86 W.

The southeast end of the elongated Ferris dome is fairly well outlined by the information obtained from the logs of the wells in secs. 30 and 31, T. 26 N., R. 86 W., and sec. 36, T. 26 N., R. 87 W. The configuration of the northwest end of the dome, however, is very uncertain. There is no information available to indicate the direction of its crest across sec. 23, T. 26 N., R. 87 W. It is believed, however, as indicated on the map, that the axis turns westward along the south margin of sec. 23 and that farther west it bends slightly toward the southwest and joins the east-west axis of the Mahoney dome.

DRILLING OPERATIONS.

The Wall Creek sand comes within less than 300 feet of the surface at the apex of the Ferris dome, which is near the center of the E. ½ sec. 25, T. 26 N., R. 87 W. This and the other Frontier sands, which together here occupy an interval of about 290 feet, contain but small showings of oil and gas, and commercial quantities are found only at greater depth. (See log D, Pl. VIII.) The oil obtained in the first three wells in sec. 25 was encountered in the Mowry shale (probably in crevices), but the gas in the three wells drilled near the center of sec. 25, near the center of sec. 26, and in the northeast corner of sec. 36 comes from the Muddy sand, at the top of the Cloverly formation.

Thus far no test well has reached the basal conglomerate member of the Cloverly, unless it is the Producers & Refiners Corporation's well No. 2, in sec. 36, T. 26 N., R. 87 W., which was drilled to a depth of 2,815 feet, or 1,635 feet below the top of the Wall Creek sand. It is impossible to correlate the lower part of the log of this well with the exposed stratigraphic section, and hence the uncertainty as to what beds were reached. Minor faults such as affect the Lost Soldier and Mahoney domes are probably present also in the Ferris field, and may cause the apparent irregularity in well logs. The information to which the writers had access does not indicate that the oil or gas bearing possibilities of the beds below the Muddy have been tested. The conglomerate of the Cloverly formation should be found at depths ranging from 125 to 150 feet below the Muddy sand. The sands of the Sundance and Morrison formation lie at depths of 1,825 to 2,325 feet below the surface on the apex of the dome, and the Embar, Tensleep, and Madison at depths of about 3,700 4,100 and 4,500 feet, respectively.

PRODUCTIVITY OF WELLS AND QUALITY OF THE OIL AND GAS.

The three oil wells of the Ferris field are small pumpers and have an estimated combined daily production of 65 barrels. Because they had no access to a market they were not in active operation until the winter of 1920–21, when the pipe line reached this field.

Petroleum produced in the Ferris field, 1919-1921.

	Barrels.
1919	2, 390
1920	10, 088
1921 (Jan. 1 to Nov. 30)	16, 740
	29, 218

The initial daily open-flow capacity of the well in the northeast corner of sec. 26, T. 26 N., R. 87 W., was reported to have been 5,000,000 cubic feet; that of well No. 4, in sec. 25, 13,000,000 cubic feet; and that of the well in the northeast corner of sec. 36, 23,000,000 cubic feet. The capacity of the well in the center of sec. 26 was reported to be rather small. The closed rock pressures of these wells were not ascertained by the writers but are said to be comparable to those on the Mahoney domes.

The oil obtained here from the Mowry has a specific gravity of about 0.827 (39.3° Baumé) and is thus of considerably higher grade than that from the Wall Creek sand in the Lost Soldier field. From the analyses given on page 54 the gasoline and naphtha content amounts to 33.1 per cent (fraction distilled below 200° C.); kerosene, 13.6 per cent (fraction distilled between 200° and 275° C.); gas oil, 13.6 per cent (vacuum-distillation fraction below 225° C.); lubricating oil, 18.7 per cent (vacuum-distillation fraction between 225° and 300° C.); residue, about 20 per cent.

As the gas from the Muddy sand is known to contain constituents that are condensable to gasoline, it is the opinion of some operators that there is a possibility of finding oil in the Muddy sand on the flanks of the dome below the gas level. Press reports during the winter of 1921–22 indicated that some of the gas wells were yielding sufficient oil along with the gas to hamper in some degree the transportation of the gas.

G. P. "DOME."

SURFACE GEOLOGY.

A pitching anticlinal fold crossing secs. 15 and 16, T. 25 N., R. 86 W., is indicated by the dip and strike of the rocks in a nearly semicircular rim of Mesaverde sandstone which crosses secs. 4, 10, 15, 16, 21, and 20 of the same township. The area within this encircling rim is entirely covered by dune sand, hence the configuration of the northwestward extension of this upfold can not be definitely ascertained. With the hope that the pitching fold indicated by the Mesaverde rim represents the southeastward extension of an elongated dome that might contain oil, the General Petroleum Corporation drilled a well in the northwest corner of sec. 16 and, at a depth of 3,020 feet, obtained oil that amounted to 300 barrels daily for a period of 14 days. The structural fold controlling this oil pool is called the G. P. "dome" by the local oil fraternity, after the initials of the corporation mentioned. Whether accumulation of oil here is caused by a dome, an anticlinal nose, a faulted and sealed sand, or a lenticular sand can not be ascertained from the present available information. A view across the field is shown in Plate VI, *B*.

STRATIGRAPHIC POSITION OF G. P. PAY SAND.

Because the Wall Creek sand was the shallowest known producing sand in the district it was at first thought that this was the pay sand in the discovery well, but extrapolation of the dips in the Mesaverde rim makes it appear more probable that the G. P. sand lies between 1,200 and 2,000 feet above the Frontier formation. It is possible, however, that the dips increase rapidly within the escarpment rim and that the pay sand is considerably lower in the stratigraphic section, but it does not seem possible that the sand can belong to the Frontier formation, for that would necessitate an increase in the angle of dip within the escarpment rim from 9° to more than 45°. If the dip of the rocks within the Mesaverde rim remains nearly the same as that of the rim itself, then the pay sand should be considered to lie between 1,200 and 2,000 feet above the Frontier formation, which would place it in the upper part of the Niobrara formation or in the lower part of the Steele shale. Only soft argillaceous sandstone and sandy shale zones are known to be present within this interval, and the best developed of these are the soft sandstones lying above and associated with the key beds that mark the top of the Niobrara, about 1,500 feet above the Wall Creek sand. This conclusion is further substantiated by the evidence derived from the somewhat uncertain correlation of well logs, discussed below. The correlation, however, is not clear, and hence the stratigraphic position of the G. P. sand can not be definitely known until more wells are drilled in the area between the G. P. and Ferris fields so that the sands can be correlated across this area with more certainty.

POSSIBLE FORMS OF STRUCTURE.

Because the configuration of the upfold can not be determined, on account of the absence of rock outcrops, several possibilities may be considered in an attempt to interpret the structure. Various forms of domes have been supposed for this area by different geologists. Some have considered the fold to be an east-west anticline parallel to the Table Hills syncline. The site of the well in sec. 13, T. 25 N., R. 87 W., seems to have been chosen on this supposition. Others have thought that it trends toward the Mahoney dome, and the wells in secs. 1, 2, 3, and 11, T. 25 N., R. 87 W., seem to have been so located as to test out this theory. The writers, however, believe that as the G. P. "dome" lies on the first upfold west of the syncline that crosses secs. 32 and 33, T. 26 N., R. 86 W., and secs. 4, 3, and 2, T. 25 N., R. 86 W., it should be considered the southeastward continuation of the structural fold on which the Ferris dome is situated. The difference of opinion over this point, however, can not well be settled until more wells are drilled to increase knowledge of the underground conditions.

In the vicinity of the discovery well several others have been drilled. The General Petroleum Corporation in its second well in this field, near the center of the SW. ¼ SW. ¼ sec. 9, about 1,000 feet north of the discovery well, encountered an oil-bearing black sandy shale at a depth of 2,863 feet (log E, Pl. VIII), or at an altitude about 167 feet above that of the oil sand in the discovery well. The Sand Hills well No. 1, in the southwestern corner of the SE. ¼ sec. 9, encountered the G. P. sand at a depth of 3,168 feet, or 95 feet lower than in the discovery well. In this well a small quantity of oil was encountered, during the summer of 1920, and it was reported that on drilling deeper in 1921 other showings were found at 3,252 feet and 3,818 feet.

Half a mile west of the discovery well, in the northwest corner of the NE. ¼ sec. 17, the General Petroleum Corporation drilled a well that went to a depth of 4,920 feet before being abandoned as dry. In the log of this well the driller recorded one thin sand and several "limestones" in the interval between 2,785 and 3,245 feet, and sand as forming most of the 90-foot interval between 4,445 and 4,535 feet. It is possible that this deep sand is the Wall Creek, and if so the uppermost of the "limestones" may be interpreted as the equivalent of the G. P. sand, if it is assumed that the dip in the rocks at this locality remains the same as in the Mesaverde rim to the south. It is possible, of course, that a radical change takes place in the local dip and strike of the rocks, which would require another interpretation of the deep sandstone and the "limestone" noted in the log.

In the SW. ¼ sec. 8 the No. 1 well of the Emery Oil Co. was drilled to a depth of 4,810 feet. (See log F, Pl. VIII.) Between 4,060 and 4,375 feet the drillers recorded sand, and possibly this "sand" represents the Wall Creek and other sandstones at the top of the Frontier formation. The reasonableness of such an interpretation is enhanced because it seems that this sand should be correlated with the deep sand of the dry hole in sec.17, noted in the preceding paragraph. If the sand found between 4,060 and 4,375 feet in the Emery well is the Wall Creek, then it is probable that the "brown shale and hard shells" recorded at 2,370 to 2,450 feet represent the G. P. sand.

Still farther west, in the northeastern corner of sec. 13, T. 25 N., R. 87 W., the Ohio Oil Co. drilled to a depth of 3,300 feet and encountered at 2,860 feet a sand which, if the dip of the rocks in this vicinity remains nearly the same as in the Mesaverde escarpment to the south, could well be the equivalent of the G. P. sand. If this and the previous correlations are correct the area within a distance of 1 mile from the Mesaverde rim shows no marked change in structure from the rim itself. Different correlations between the logs of these wells, however, would necessitate radical changes in the conception of the local structure.

The writers have considerable confidence in the well-log correlations given above and believe that the G. P. sand is one of the sands in the basal part of the Steele shale or the top of the Niobrara, which lie about 1,500 feet above the Wall Creek sand. The structure here is therefore shown on the map (Pl. I) as that of an anticlinal nose. The positions of the 3,000 and 3,500 foot contours in this vicinity are altogether inferred. If the well-log correlations are incorrect, or if the G. P. sand lies at some other horizon, then the structure of the G. P. "dome" must be quite different. From the uncertainties attached to the local conditions, it is obvious that the configuration of the G. P. "dome" can not be fully determined until more underground information is available through the drilling of additional wells.

It is likewise obvious that the controlling factor in the accumulation of the oil in this field is uncertain. It is not usual in regions so closely folded as Wyoming for oil to accumulate on anticlinal noses. The 3,000 and 3,500 foot contours, however, may have a local closure, and the oil found in secs. 9 and 16 may be that which would accumulate on the pitching end of a dome whose apex may be in sec. 9. The accumulation also may have been caused by a transverse fault cutting the sand northwest of the wells, with the result that the sand was sealed and this sealing prevented the oil from migrating farther up the rise. It is also possible that the sand is a local lens. In view of these uncertainties it is quite impossible to predict the extent of the productive area.

PRODUCTION.

The discovery well of the General Petroleum Corporation was rated a 300-barrel initial producer. The same company's second well, in sec. 16, its well in sec. 9, and the Sand Hills well were also good producers. A market for the oil was obtained late in the fall of 1920, when a pipe line to Fort Steele was completed. The gross production of the General Petroleum Corporation's wells is given below.

Petroleum produced in G. P. field, 1919–1921.

Year.	Number of wells producing at end of year.	Barrels.
1919	1	4,465
1920	1	13,898
1921	3	74,199

The oil of the G. P. field is similar to that of the Ferris field and differs considerably from that of the Lost Soldier field. The detailed analysis given at the end of the report shows that it yields gasoline and naphtha (fractions distilled below 200° C.), about 29 per cent; kerosene (fractions distilled between 200° and 275° C.), about 15 per cent; gas, lubricating and fuel oils, about 66 per cent.

O'BRIEN SPRINGS ANTICLINE.

Along the south border of the Table Hills the basal Mesaverde rocks and the sandstone bed about 1,500 feet below the top of the Steele shale dip to the north at angles that average about 40°. This northward dip represents the north flank of an upfold, the O'Brien Springs anticline, whose south flank is to be found in the same beds dipping southward in the northern part of T. 24 N., R. 86 W. The intervening area is completely covered by dune sand, hence the extent of the fold and the configuration of its crest line are uncertain. The dip of the rocks on the south flank changes abruptly to a southeasterly and easterly direction in the northwestern part of T. 24 N., R. 86 W. In the northern part of T. 24 N., R. 87 W., the bedrock is concealed by dune sand, and the nature of the westward extension of the anticlinal fold into this area is therefore very obscure. Whether or not the anticline rises toward the west and flattens out or whether it becomes more closely folded and carries a local "high" or dome is obviously uncertain. The configuration of the anticline as represented by contours on the map is based entirely on the extrapolation of dips.

To the writers it seems that the change in the strike and dip of the rocks along the margin of the Haystack Hills suggests a flattening of the fold in its westward course, and that in T. 24 N., R. 87 W., it probably merges with the general eastward dip along this flank of the Separation Flats anticline, which is on the main axis of the Rawlins uplift. It is recognized, however, that the information afforded by the rim rocks is altogether too meager and that they are too distant from the apparent crest of the fold to indicate its configuration. For this reason the contours for this locality on the map are based on inference only. It is altogether possible, however, that a local dome that would be favorable for the accumulation of oil and gas may occur somewhere in this sand-covered area. The search for a possible trapped body of oil or gas in this area must be made blindly, inasmuch as its location along the general axis of the fold can not be predicted. For this reason whatever information can be obtained from every well drilled in this vicinity should be recorded.

In the hope that somewhere along the concealed crest in Rs. 86 and 87 W. it might be found that the eastward pitch is arrested or a local "high" developed, the Kentucky-Wyoming Oil Co. drilled a well in sec. 2, T. 24 N., R. 87 W., to reach the G. P. sand. This well, started in the fall of 1920, was drilled to a depth of 3,390 feet. (See log G, Pl. VIII.) The horizon of the G. P. sand was probably reached at about 1,675 feet, but no showings of oil or gas were encountered until the Wall Creek was reached at 3,140 feet. The showing here was gas, estimated at more than 1,000,000 cubic feet daily. Early in 1922 oil was encountered at 3,620 feet, in quantity considered large enough to supply fuel for further drilling in this locality. The gas was cased off, and the company planned to drill deeper and test the Muddy sand.

The Shell Co. of California completed an assessment hole in the SE. ¼ sec. 1, T. 24 N., R. 87 W., during the winter of 1921–22.

A well was started in sec. 5, T. 24 N., R. 87 W., by the Wyomass Oil Co. Drilling troubles were encountered at shallow depths, and the well was abandoned. A second effort was then made in sec. 6, and a hole with 15-inch casing carried to 508 feet to fulfill validating requirements. It is reported that the company expects to drill this well deeper as soon as economic conditions become favorable.

A location has been made in sec. 4, T. 24 N., R. 86 W., by the Matador Petroleum Co., and another in sec. 5 of the same township by the Washoming Oil Co. To the writers these two locations seem to be more favorably situated than any of those to the west.

SHERRARD DOME.

Beginning in sec. 33, T. 26 N., R. 89 W., the Mesaverde formation, dipping about 40° W., swings in a broad arc southward across the west half of T. 25 N., R. 89 W., and then southeastward as far as sec. 11, T. 24 N., R. 89 W. This arc of the Mesaverde marks the west flank of a broad fold known as the Sherrard dome, for which the available field evidence is extremely meager. Its southeast flank is indicated by a series of dip readings, averaging about 5°, on bedding planes in the Steele shale, which crops out in a narrow belt across secs. 21, 27, and 34, T. 25 N., R. 88 W. The northeast flank is roughly marked by the extension of the synclinal axis indicated by the change in strike of the Steele shale in sec. 21, T. 25 N., R. 88 W. The southward extent of the dome is presumably marked by the sharply westward-pitching fold indicated by the Steele and Mesaverde outcrops in secs. 10, 11, and 12, T. 24 N., R. 89 W., and its north end is in like manner indicated by the sharp bend in the Mesaverde outcrop in secs. 35 and 36, T. 26 N., R. 89 W. The great area, about 40 square miles, thus outlined as being occupied by the Sherrard dome is practically all covered by alluvial wash and wind-blown sand, except for a few square miles at the north end, and it is therefore impossible to determine the configuration of the dome or even the location of its axis. Some geologists consider the evidence so meager that they doubt the very presence of a fold of any consequence. The contours on the map (Pl. I) drawn for this area are almost all inferred, but they show the dome elongated in a N. 35° W. direction. From these contours it would seem probable that the Wall Creek and other Frontier sands should lie within 2,000 feet of the surface throughout a large area.

The Kasoming Oil Co. drilled three unsuccessful holes on the Sherrard dome. The first was in the southwest corner of the NE. ¼ sec. 11, T. 25 N., R. 89 W., and reached the Wall Creek sand at 1,790 feet. No information was obtained as to its findings. The second, in the southwest corner of the SE. ¼ sec. 2, T. 25 N., R. 89 W., was abandoned at a shallow depth because the hole became crooked and the tools were lost. The rig was skidded a short distance, and the third hole started. A slight showing of oil was encountered at 1,806 feet, and the thick sandstones of the Frontier, without showings of either oil or gas, were found at 1,850 feet. (See log H, Pl. VIII.) Drilling, according to the log, was continued almost exclusively in these sands to 2,097 feet and, at that depth, the hole filled with water. The hole was abandoned in the summer of 1921.

The writers do not believe that the Sherrard dome has been adequately tested by the wells drilled. At the same time it is obvious, from the lack of structural information, that more favorable locations for further testing can not be suggested, and that additional prospecting must proceed blindly and be based on the subsurface structural information obtained in drilling. By carefully determining the relative altitude of key beds, such as the Wall Creek sand of the Frontier formation, as encountered in different holes, it should be possible after drilling a few holes to locate the crest of the dome rather accurately. This determined, the possible productivity of the dome could be soon ascertained. The basal conglomerate of the Cloverly and at least the deeper Sundance sands should be tested before the dome is condemned.

SEPARATION FLATS ANTICLINE.

Early in the search for geologically favorable places for drilling test wells the area north of the Bell Springs fault, on Separation Flats, was found to possess some of the essential features. The Mesaverde escarpment to the west, with its rocks dipping strongly westward, contained all the essentials for the west flank of an anticline. No complementary feature to the east is to be found nearer than the Table and Haystack hills, in which the eastward dip of the rocks is gentle. The strong dips on the west and gentle dips on the east would appear to indicate that the crest of the fold, which is the less highly developed north end of the major Rawlins uplift, is nearer the west side.

As the rocks in secs. 35 and 36, T. 24 N., R. 88 W., southeast of the northeast end of the Bell Springs fault, dip eastward, it would seem very probable that the rocks northwest of the fault dip in the same direction, although more gently. From this it would also seem probable that the crest of the fold lies somewhere between T. 24 N., R. 87 W., and the Mesaverde escarpment to the west. Its probable general position is indicated by an exposure of Niobrara shale in and around sec. 19, T. 23 N., R. 88 W., but its direction across T. 24 N., R. 88 W., over which alluvium and dune sand form a thick mantle, is impossible to determine from an examination of the surface. The transverse downfold indicated in the rocks in secs. 11 and 12, T. 24 N., R. 89 W., would appear to indicate that a shallow syncline crosses the northern part of T. 24 N., R. 88 W., and marks the extent of the Separation Flats anticline in this direction and separates it from the Sherrard dome.

In an effort to find oil in this fold four wells have been drilled, none of which encountered encouraging evidence. The Texas Co.'s well in the southwest corner of sec. 8, T. 23 N., R. 88 W., found the Wall Creek sand at a depth of 1,265 feet and the Muddy sand at 2,371 feet. The well was abandoned in February, 1920, at a depth of 2,445 feet, before reaching the conglomerate of the Cloverly.

The well 2 miles to the north, in the SE. ¼ sec. 31, T. 24 N., R. 88 W., started by the New York Oil Co. and completed by the Midwest Refining Co., encountered the Wall Creek sand at 975 feet and the Muddy at 2,165 feet. No encouraging showings of oil or gas were found, and the well was abandoned at a depth of 2,240 feet. (See log I, Pl. VIII.) From the depth of the Muddy sand it is clear that beneath the alluvium of this vicinity the Niobrara shale is the outcropping formation.

About 3 miles to the northeast, in the SW. ¼ sec. 16, T. 24 N., R. 88 W., the Midwest Refining Co. drilled another hole to a depth of 3,055 feet and then abandoned it. The log of the hole, to which the writers had access, indicated that the Wall Creek sand was reached at about 2,180 feet but gave no encouraging showings. A little gas was found in shale at 1,040 feet.

The same company also drilled a well 2 miles farther north in the NE. ¼ sec. 9, T. 24 N., R. 88 W., in which a little gas was encountered in shale at 1,370 feet. The log was very indefinite, and the writers made no attempt to hazard an interpretation. The drill went to a depth of 2,530 feet before the hole was abandoned, and it was reported that shale only was penetrated.

These rather widely scattered test wells have discouraged additional drilling, but it must be realized that the linear distribution of these wells was not the most helpful in locating the crest of the fold. Without surface rock exposures to indicate the configuration of the fold it is impossible to suggest more favorable places at which to drill. In view of the possibility that there may be in the area points structurally higher than those where wells have been drilled, the writers believe that the anticline has not been adequately tested.

PETROLEUM ANALYSES.

The following analyses were made in the Bureau of Mines:

Analyses of petroleum from the Lost Soldier-Ferris district, Wyo.

[Distillation in Bureau of Mines Hempel flask.]

Lost Soldier field.

Temperature (°C.).	Laboratory No. 0378. Specific gravity at 15° C., 0.867 (31.5° Baumé). Amount distilled, 200 cubic centimeters. First drop, 51° C. Sulphur, 0.15 per cent.						Laboratory No. 0375. Specific gravity at 15° C., 0.868 (31.3° Baumé). Amount distilled, 300 cubic centimeters. First drop, 51° C. Sulphur, 0.34 per cent.					
	Air distillation, with fractionating column (barometer 754 mm.).			Vacuum distillation, without column (pressure 40 mm.).			Air distillation, with fractionating column (barometer 758 mm.).			Vacuum distillation, without column (pressure 40 mm.).		
	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.
50 to 75	0.7	0.7	0.740	......	......	......	1.0	1.0	0.731	......	......	......
75 to 100	2.5	3.2		......	......	......	2.7	3.7		......	......	......
100 to 125	3.8	7.0	.772	......	......	......	4.7	8.4	.779	......	......	......
125 to 150	3.9	10.9	.798	......	......	......	4.0	12.4	.802	......	......	......
150 to 175	4.0	14.9	.815	1.4	36.7	0.859	4.2	16.6	.820	1.8	41.4	0.861
175 to 200	3.2	18.1	.828	7.0	43.7	.859	3.9	20.5	.830	7.2	48.6	.860
200 to 225	4.7	22.8	.842	9.1	52.8	.858	5.0	25.5	.842	10.8	59.4	.858
225 to 250	5.9	28.7	.851	9.2	62.0	.867	5.8	31.3	.852	8.8	68.2	.872
250 to 275	6.6	35.3	.856	8.2	70.2	.877	8.3	39.6	.857	7.8	76.0	.882
275 to 300	......	......	......	7.7	77.9	.881	......	......	......	5.3	81.3	.893

Ferris field.

Temperature (°C.).	Laboratory No. 0382. Specific gravity at 15° C., 0.826 (39.5° Baumé). Amount distilled, 200 cubic centimeters. First drop, 51° C. Sulphur, 0.12 per cent.						Laboratory No. 0376. Specific gravity at 15° C., 0.828 (39.3° Baumé). Amount distilled, 300 cubic centimeters. First drop, 24° C. Sulphur, 0.20 per cent.					
	Air distillation, with fractionating column (barometer 765 mm.).			Vacuum distillation, without column (pressure 40 mm.).			Air distillation, with fractionating column (barometer 758 mm.).			Vacuum distillation, without column (pressure 40 mm.).		
	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.	Fractions (per cent by volume).	Total per cent (by volume).	Specific gravity.
Up to 50	2.1	2.1	0.668	......	......	......	3.8	3.8	0.631	......	......	......
50 to 75	2.9	5.0	.678	......	......	......	3.1	6.9	.671	......	......	......
75 to 100	7.0	12.0	.719	......	......	......	5.6	12.5	.713	......	......	......
100 to 125	7.2	19.2	.742	......	......	......	6.6	19.1	.741	......	......	......
125 to 150	6.0	25.2	.760	......	......	......	5.1	24.2	.760	......	......	......
150 to 175	4.9	30.1	.779	2.0	49.0	0.836	4.4	28.6	.778	1.5	48.1	0.842
175 to 200	3.5	33.6	.795	3.1	52.1	.844	4.1	32.7	.793	5.5	53.6	.841
200 to 225	3.7	37.3	.810	6.5	58.6	.848	3.9	36.6	.808	5.5	59.1	.847
225 to 250	4.7	42.0	.820	7.4	66.0	.863	4.7	41.3	.818	6.6	65.7	.859
250 to 275	5.0	47.0	.829	5.3	71.3	.875	5.3	46.6	.828	6.4	72.1	.873
275 to 300	......	......	......	5.8	77.1	.883	......	......	......	5.9	78.0	.885

The following analysis was made in the Vernon Refinery laboratories of the General Petroleum Corporation:

Analysis of crude oil from well No. 1, sec. 16, T. 25 N., R. 86 W.

[Gravity at 60° F., 38.3° Baumé. M. and B. S., trace. Cold test, below −2° F. (flowed slowly at this temperature). Saybolt viscosities at 80° F., 45 seconds; at 60° F., 68 seconds; at 40° F., 515 seconds; at 20° F., 7,500 seconds.[a] 1000 cubic centimeters distilled in a 2000 cubic centimeter flask with modified Hempel tube. Each fraction 2 per cent.]

Fraction.	Temperature (° F.).	Gravity at 60° F.	Fraction.	Temperature (° F.).	Gravity at 60° F.
1	96	93.4	14	375	47.8
2	126	92.6	15	400	46.3
3	168	79.5	16	420	44.9
4	194	69.4	17	445	43.3
5	218	64.0	18	460	42.5
6	232	61.0	19	475	41.7
7	248	59.1	20	492	40.8
8	273	57.2	21	514	39.9
9	283	55.7	22	532	39.1
10	300	54.3	23	552	38.7
11	316	52.9	24	562	38.0
12	338	51.3	25	574	37.5
13	356	49.6			

[a] This is probably higher than the true viscosity of the oil owing to the formation of paraffin crystals which clogged the viscosimeter.

DETERMINATIONS OF POROSITY.

The porosity of a number of sand samples from the Lost Soldier district has been determined by A. F. Melcher. The method employed [23] determines the volume of the voids in the sample but does not show what percentage of these voids would be filled by oil or gas. The close relation between porosity and productivity makes it appear probable that in a sand that occurs in an oil field most of these voids are actually filled by oil. The determinations are as follows:

	Porosity (per cent).
Wall Creek sand (top member of Frontier):	
Bair well No. 32, sec 10, T. 26 N., R. 90 W	20.1
Outcrop, sec. 23, T. 27 N., R. 89 W	19.9
Muddy sand:	
Outcrop, sec. 12, T. 27 N., R. 89 W	17.9
Outcrop, sec. 33, T. 27 N., R. 88 W	12.5
Well on Wertz dome, sec. 7, T. 26 N., R. 89 W	11.4

[23] Melcher, A. F., Determination of pore space of oil and gas sands: Am. Inst. Min. and Met. Eng. Trans., vol. 65, pp. 469–497, 1921.

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