THE GEOLOGICAL SURVEY OF WYOMING
HORACE D. THOMAS, STATE GEOLOGIST

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Geology and Petroleum Resources of Wyoming

By HORACE D. THOMAS, State Geologist[1]

Wyoming is one of the oldest oil-producing states, yet the last few years have brought about renewed exploration and development on a scale never witnessed before. The first producing oil wells were drilled in Wyoming in the 1880's. Although the famous Salt Creek field was discovered in 1908, the state did not become an important oil producer until 1913, in which year about 2,300,000 bbl. of oil were produced from 4 main fields. In 1947, about 43,000,000 bbl. were produced from about 4200 wells in about 80 fields, the state ranking seventh among the oil-producing states. There were 7 fields whose individual production in 1947 each exceeded that of the entire state in 1913.

Twenty-five new fields, discovered in the past 5 years, contributed over 8,000,000 bbl. of oil to the 1947 production, and deeper pays discovered since 1942 in old fields helped raise Wyoming's production from 33,000,000 bbl. in 1942 to 43,000,000 in 1947. The 1948 production will exceed the banner year of 1923, when over 44,000,000 bbl. of oil were produced. New fields and new pays continue to be found.

From many vantage points in Wyoming, rocks representative of the five major eras of geologic time may be observed. The state has a remarkably complete rock sequence, and sediments representing all but one of the periods of post-Proterozoic time are exposed at the surface. These sediments, of Paleozoic and later age, rest upon an ancient basement complex composed of various sorts of igneous and metamorphic rocks of Archeozoic and Proterozoic (pre-Cambrian) age. The ancient crystalline rocks, although not oil-bearing, are of interest in petroleum exploration because their nature, attitude, and nearness to the surface must be considered in geophysical exploration. Furthermore, there are suggestions that the structure of the younger oil-producing rocks may be related to, or controlled by, features of the basement complex.

The eras and periods of post-Proterozoic geologic time are shown in Fig. 1. The ancient Archeozoic and Proterozoic eras are omitted. Each era is divided into periods. On the chart, the Silurian period, which intervenes between the Ordovician and the Devonian, has been omitted since the Silurian is not represented in Wyoming. Eras and periods are world-wide time units.

Locally, rocks deposited during the different periods are divisible into units called formations, the formations being discriminated on the basis of their physical features and fossil content. The formations shown in Fig. 1 represent a compiled sequence made up of the best known formations, although the sequence given is essentially characteristic of many parts of the state.

In Fig. 2 can be seen the distribution of Paleozoic rocks in Wyoming.

Geological structure. Structurally, Wyoming is made up of major anticlinal folds that are the present

[1]The kindness of Miss Ernestine Adams, Managing Editor of the *Petroleum Engineer*, in granting permission for the reprinting of this article is deeply appreciated.

ERA	PERIOD	FORMATION	OIL-PRODUCING SAND
CENOZOIC	QUARTERNARY	GLACIAL DEPOSITS	
	PLIOCENE	NORTH PARK	
	MIOCENE		
	OLIGOCENE	WHITE RIVER	
	EOCENE	WASATCH	WASATCH SANDS
	PALEOCENE	FORT UNION	
MESOZOIC	CRETACEOUS	LANCE	
		MONTANA GROUP	SHANNON SAND
		NIOBRARA	
		FRONTIER	FRONTIER SANDS
		MOWRY	
		MUDDY	MUDDY SAND
		THERMOPOLIS	
		CLOVERLY	DAKOTA & LAKOTA SANDS
	JURASSIC	MORRISON	
		SUNDANCE	SUNDANCE SAND
	TRIASSIC	CHUGWATER	
		DINWOODY	
PALEOZOIC	PERMIAN	PHOSPHORIA	PHOSPHORIA LIME (EMBAR)
	PENNSYLVANIAN	TENSLEEP	TENSLEEP SAND
		AMSDEN	DARWIN SAND
	MISSISSIPPIAN	MADISON	MADISON LIME
	DEVONIAN	DARBY	
	ORDOVICIAN	BIG HORN	
	CAMBRIAN	GALLATIN	
		GROS VENTRE	
		FLATHEAD	FLATHEAD SAND

FIG. 1. Table showing standard geological time, representative formations in Wyoming, and oil-producing sands.

mountain uplifts, and intervening synclinal depressions that are the present intermontane basins. The major structural framework was outlined by the Laramide folding, with slight modification and uplift of a regional nature during Cenozoic time.

The mountain uplifts are asymmetric anticlines with one gently dipping flank and one steeply dipping flank, which may be overturned or thrust faulted. The direction of overturning and thrust faulting varies in the different ranges. The mountains of westernmost Wyoming differ from those to the east in that they are fundamentally a series of low-angle thrust blocks in which the pre-Cambrian

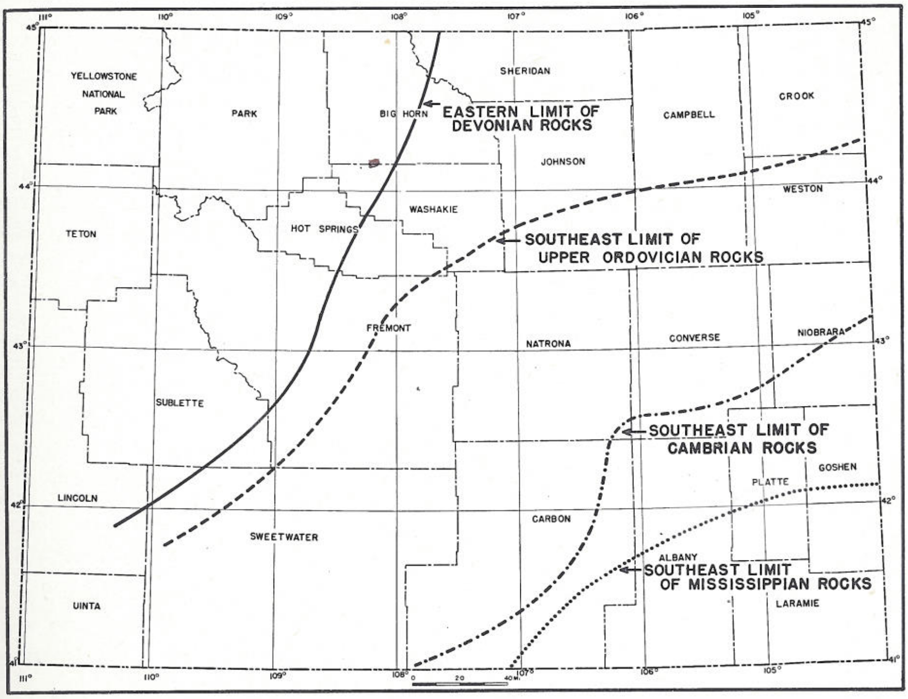

FIG. 2. Map showing distribution of Paleozoic rocks in Wyoming. Silurian rocks are absent; Pennsylvanian and Permian rocks are present throughout state.

rocks are not exposed, as they are in other mountains. The intermontane basins are large downwarped areas that in themselves are made up of minor anticlines and synclines. They, too, are generally asymmetric and the deepest structural part of most basins lies fairly close to one of the bounding mountain uplifts.

The minor structures lying within the basins are anticlinal and synclinal folds that may be concentrically arranged around a basin, as in the Big Horn Basin, or may parallel a mountain front, as along the west margin of the Laramie Basin, or may trend at an angle to the axis of a mountain range and plunge off into the basin obliquely, as in the Wind River Basin. The minor anticlines are usually asymmetric, with one flank of moderately low dip and the other of steeper dip. On the steep flank of strongly asymmetric anticlines, beds may stand vertically or be overturned. This type of structure is commonly characterized by a high-angle thrust fault on the steep flank. Some anticlines may be fairly broad, or open, whereas others may be very narrow and tightly compressed. Some are essentially unfaulted, but others are characterized by numerous radial normal faults. Others show normal faults transverse to the anticlinal axis, dividing the structure into a number of individual units. The normal faults commonly die out with depth so that deeper horizons are unfaulted. The Elk Basin anticline is marked by dozens of normal faults that displace the Frontier sands and control accumulation in them, but none is known to extend deep enough to displace the Tensleep, some 3000 ft. deeper. Conversely, thrust faults seem to have their greatest displacement at depth and to die out upward. Wells drilled on some anticlines that appear unfaulted at the surface have passed through thrust faults at depth.

In earlier years there was considerable conjecture regarding the nature of the central parts of the basins, since the central parts are masked by relatively undeformed Cenozoic sediments. The marginal folds, exposed where Cenozoic rocks have been stripped back from the mountain fronts, were very apparent but there was little evidence to indicate whether the central parts of the basins were simple downwarps or whether they were characterized by minor anticlines as are the marginal parts. Seismic exploration indicates that the central parts of the basins have been folded to such an extent that anticlines present are adequate for the trapping of commercial oil pools.

Oil producing horizons. A peculiar philosophy has existed in Wyoming in respect to possible oil-producing horizons. It held that there was little use in drilling wells deeper than certain formations. Although some of the first oil produced in the state came from the Tensleep and Phosphoria, those formations were not looked upon with favor because the crude was low-gravity black oil. Oil found in the Cretaceous sands in the early days was high gravity green oil, and the Cretaceous sands were consequently extensively developed. In a general way, then, the Cretaceous sands came to be looked upon as constituting the "deepest commercial production." Fields were drilled no deeper than the producing Cretaceous horizons, and wildcats were abandoned after testing the Cretaceous sands.

Although Sundance oil had been known for 10 years, it was not until 1935 that the Sundance came into its own as a producer with the completion of a 3000-bbl. well in the

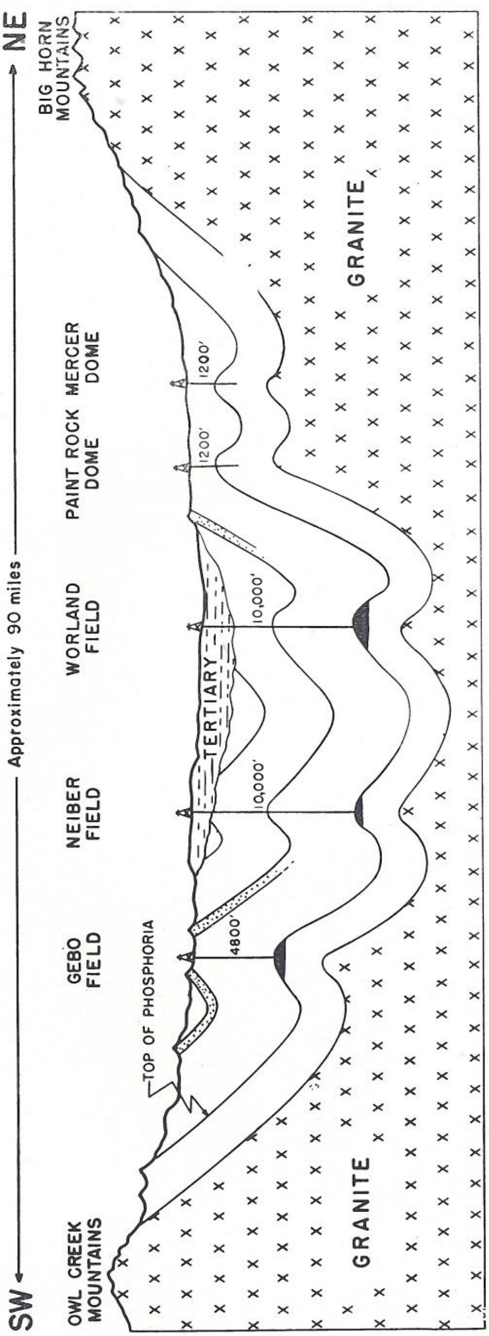

FIG. 3. Diagrammatic cross-section through the southern part of the Big Horn Basin, Wyoming. The structure is simplified, with marginal folds on the flank of the Owl Creek Mountains eliminated.

basal Sundance sand in the Lance Creek field. This resulted in a flurry of deeper drilling to the Sundance in old fields and of the redrilling of unproved anticlines to test the Sundance, giving rise to many new deeper discoveries in southeastern Wyoming and to Sundance discoveries in anticlines that had proved barren in the Cretaceous sands.

Phosphoria-Tensleep production was widely distributed over the northwestern part of the State, mostly in shallow fields, but in general the oil was too heavy and sulphurous to be of great value. Many fields were discovered and shut in. Circle Ridge, for instance, was discovered in 1923 but not developed until 1941. In January, 1943, however, a well drilled to the Tensleep at Elk Basin flowed 2400 bbl. of 30° gravity oil, and this seemed to be the necessary stimulus to start a campaign of deepening old fields all over the state to the Tensleep and of redrilling previously barren anticlines in which the Tensleep had not been tested. This resulted in the discovery of many deeper pays in old fields and in the discovery of new fields, with the surprising disclosure that not all Phosphoria-Tensleep crude is low gravity. Phosphoria crude at Worland proved to be 40° gravity; Tensleep crude at Medicine Bow proved to be 61° gravity. High gravity Phosphoria and Tensleep crudes have been found in many other fields.

Since 1942, the tendency has been to test units below the Tensleep, with encouraging results. The Darwin sand, at the base of the Amsden, has proved to be a new pay in several fields. The Madison lime, which long was given little attention, now produces in a dozen or more fields. Even the Cambrian rocks, at the base of the section, which were once thought to offer no possibilities, have been proved for commercial oil production.

Whereas in earlier days, there were regionally "deepest possible producing horizons," it appears today that no anticline can be considered completely tested until a well has been carried to the pre-Cambrian rocks, and that the total potentialites of a field can not be determined until a well has been drilled to the basement complex.

Cenozoic rocks.— The Cenozoic rocks over much of Wyoming have not been looked upon with favor as oil producers because of their nonmarine origin. Some small uncommercial wells produced some oil from the Oligocene rocks near Douglas and near Shawnee in central Wyoming, but the oil and gas certainly originated in other rocks and migrated into the Oligocene rocks. Main production from Cenozoic rocks lies along the Wyoming-Colorado border, south of Rock Springs, Wyoming, where oil and gas are produced from the Wasatch formation in the Hiawatha and Powder Wash fields. Oil also is produced from the Wasatch in the Labarge field in westermost Wyoming. Some gas is found in Eocene rocks in the Green River and Great Divide basins, and this part of the state, at the moment, appears to offer the best possibilities for the discovery of new petroleum or gas reservoirs in the Eocene rocks.

Mesozoic rocks.— Sandstones in the thick Cretaceous section have been the state's best producers of high-gravity paraffin base oil. Although some gas has been produced from the Mesaverde formation, the highest producing sand of Cretaceous age is the Shannon sandstone. Oil was produced from the Shannon sand in the old Shannon pool, on the north plunge of the Salt Creek anticline, down dip from the outcrop, in 1894. The Shannon sand, however, has not been an important producer and there is but one field of any size, Cole Creek, which produces from this sand. The sandstones in the Frontier formation, commonly known as the Wall Creek sands, produce over wide areas in central and northern Wyoming, the main production in the Salt Creek field being from the Wall Creek sands. Many old important fields produce from these sands and new Frontier discoveries have been made in recent years. The Muddy, Dakota, and Lakota sands, at the base of the Cretaceous section, have produced oil and gas for many years. These sands are productive in all parts of Wyoming.

The Jurassic rocks are oil producers in southeastern Wyoming. Some oil is produced from sands in the Morrison formation, but Sundance sands are important producers in many fields lying in a northeast-southwest trending belt parallel with the old Sundance shoreline. The Nugget sand produces oil in the Steamboat Butte field, outside of the belt of ordinary Sundance production, but it seems that the oil is not indigenous to the Nugget and is migratory from older formations.

Triassic rocks are not important oil producers in Wyoming. Some heavy black oil has been produced from the Chugwater in some of the old fields in the Lander area and in the Thermopolis area.

Paleozoic rocks.—The Phosphoria formation produces much oil in the Wind River and Big Horn basins from dolomites in the marine facies. To the eastward, in the area where the Phosphoria is replaced by redbeds, equivalent rocks are barren. The shallowest Phosphoria production is at Circle Ridge, in the Wind River Basin, where the formation produces from a depth of around 600 ft. (plus 6500 ft., sea level). The deepest Phosphoria production is at Worland, in the Bighorn Basin, from a depth of 10,000 ft. (minus 6000 ft., sea level).

The Tensleep sandstone is a prolific oil producer in the Big Horn and Wind River Basins, in the Lost Soldier district, and in the Casper area. The Tensleep (Casper) produces in the Laramie Basin, and the equivalent Minnelusa is productive in the eastern part of the Powder River Basin. Some oil has been known from the Amsden in the Big Horn Basin for over 20 years, but during 1948 production was established in the Darwin sand at the base of the Amsden in the Lost Soldier and Wertz fields. Many fields in the general region have not been tested below the Tensleep and the Amsden offers possibilities for production in adjacent fields.

The first Madison production was developed in the Frannie field, on the Wyoming-Montana border, in 1929. Madison oil was also found in the nearby Garland field in 1930. It was not until 13 years later, however, that commercial Madison production was found in another Big Horn Basin field; at Oregon Basin in 1943. In 1946, the Madison lime was found productive in the famous Elk Basin field and the first Madison oil was found in the Wind River Basin in the Circle Ridge field. In 1947 and 1948, Madison production was developed in the Lost Soldier and Wertz fields in the Rawlins area. The important point is that this formation, which 5 years ago was known to be an oil producer over only a very limited area, has now been proved productive almost across the state from north to south.

No oil is at present produced from Devonian or from Ordovician rocks. These beds have been penetrated by a number of wells and the results so far have been negative.

Cambrian oil was discovered in the summer of 1948 when a well in the Lost Soldier field flowed 720 bbl. of 34.5° gravity oil from the basal Cambrian sandstone, only a few feet above the basement complex. Shows of oil had been obtained in Cambrian rocks at two other localities, but since so few wells have penetrated these beds, their ultimate productive area and possibilities remain uncertain.

Mode of accumulation. Essentially all of Wyoming's oil production comes from the conventional anticlinal trap. Closed structures may or may not produce oil. Some structures with a large amount of closure have, so far, proved barren. Other structures with a relatively small amount of closure have proved to be prolific producers. In many anticlines, only one sand may be productive whereas in others essentially every pervious bed will produce. In the Lost Soldier field, for instance, there are 14 producing horizons.

In general, none of the anticlines is completely filled with oil and the water table lies part way down the flanks of structures. In addition, the size of the area over which different sands produce in a multiple-zone field is extremely variable. In the Salt Creek field, for instance, productive acreages are as follows: First Wall Creek, 2500 acres; Second Wall Creek, 20,500 acres; Lakota, 2100 acres; Sundance, 920 acres; and Tensleep, 1000 acres. In the Elk Basin field, the Second Wall Creek sand produced from 500 acres; the Tensleep produces from 5000 acres.

Fault traps have not been important producers, except where individual fault blocks have acted as units along anticlinal axes, in which case accumulation is actually primarily controlled by anticlinal structure, with faulting being a subsidiary factor. Some new fields seem to have been dependent fundamentally on faulting as a control of accumulation, however. Little attention has been paid to fault trap possibilities but, because of the prevalence of faulting in Wyoming, it seems likely that fault traps will prove more common when greater attention is focused on their possibilities.

The only fields that are fundamentally of the stratigraphic type trap are those along the west flank of the Black Hills, such as the Osage and Mush Creek fields, and small fields in the southwestern corner of the state, such as Spring Valley. In the Osage and Mush Creek fields, accumulation is related to lenticularity and loss of permeability in the Newcastle (Muddy) sandstone. The original discovery was based on surface seeps, followed by random drilling along the trend of outcrop. The chances for the discovery of other stratigraphically trapped pools seem rather good. There are many sandstones that are productive in certain areas that thin out and are absent in others, and lensing sands are known to be present in parts of the sedimentary section. Accumulation in the Madison seems to be related in part to permeability, although the known Madison oil has been found on structure. Exploratory thinking is turning to the possibility of stratigraph type pools, but actual drilling will probably await the time when more subsurface and surface stratigraphic information is available.

Distribution of Wyoming oil fields. Of the 23 counties in the state, 18 have commercial oil or gas production. It is possible that all counties will prove productive. The ruled areas on the map of Wyoming on (Fig. 4) are the pre-Cambrian cores of the mountain masses, and may be eliminated as possible productive territory. The crosshatched area in the northwest is occupied by volcanic rocks that had their source in Yellowstone Park. This area offers no chance for oil production. Over most of the remaining area, there are chances for the development of new fields.

Essentially all the producing fields are located around the margins of the basins. These fields represent anticlines that are observable and mappable at the surface. Many of them are so beautifully exposed as to be recognizable by most anyone with even an elementary understanding of geology—the so-called "Sheepherder anticline," since even a sheepherder could recognize its presence. Most of the fields are on anticlines that have been known for many years and many have produced oil or gas for long periods. Some have become oil fields only in the past few years simply because deep drilling has come into practice only recently. Productive depths in these marginal fields ordinarily range from several thousand feet to five or six thousand feet.

It has been in the past two years only that oil and gas fields have been found in the central parts of the basins. The Church Buttes field lies in the exact center of the Green River Basin. Four fields have been found well out toward the axial part of the Big Horn Basin; Worland, South Fork, Nieber, and Sand Creek. Production or promising shows in wells now drilling have been found well out in the Powder River and Wind River Basins. The large areas in the central parts of the basins will probably yield more new fields.

New discoveries. The present oil activity in Wyoming dates back to about 1942 and between that time and the present many important discoveries have been made. These may be classed as (1) the discovery of entirely new fields and (2) the discovery of new producing horizons in old oil or gas fields. In this six-year period, 1942-1947, 41 new fields were discovered in 15 counties widely scattered over the state (Fig. 4). The importance of these fields varies; some have developed or will develop into large important producers, others will make only small fields. Nine new fields were discovered during the first seven months of 1948.

From 1942 through 1947, new producing horizons were developed in 23 old fields in 8 counties. Some old fields that formerly had not been important became heavy producers through the discovery of new pays, such as Elk Basin. Old gas fields were proved for important deep oil production, such as Big Sand Draw and Little Buffalo Basin. New deep pays found in many old oil fields added greatly to the reserves and will serve to prolong the lives of those fields. In early 1948, three new deep pays were added to the known 11 producing horizons in the Lost Soldier field. During the first 7 months of 1948, 12 new pays were found in 8 old fields.

Application of new exploratory concepts and techniques. This record of new discoveries has resulted from the application of new geological concepts and of new techniques in exploration and drilling. This situation may be illustrated by a diagrammatic cross-section through the southern part of the Big Horn Basin (Fig. 3). In the early days, only those anticlines that had surface expression could be discovered by the discovery tool then used—regional geological mapping. Gebo dome, on the left of the cross-section is such a structure. Although the dome had been known for many years and had been drilled as early as 1916 to a depth of 2700 ft., it was not until 1943 that a well was drilled to over 5000 ft. to discover good quality oil in the Phosphoria.

The central part of the basin, however, is occupied by a mantle of Eocene rocks that blankets and obscures the structure of the older folded rocks. Anticlines buried by this mantle, such as the Nieber and Worland anticlines shown on the cross-section, cannot be observed at the surface but can be located through seismic exploration. Numerous other buried anticlines have been discovered by seismograph. Since great areas in Wyoming are covered by Cenozoic rocks that obscure older structures, the fact that the seismic method can be used to discriminate anticlines is indeed important in the state's future as an oil producer.

Not many years ago it was believed by many geologists that at depths of 7000 or 8000 ft. the well known oil-producing sands in Wyoming would lack porosity and hence be incapable of containing oil. This belief has been proved to be completely unfounded. Only a few years ago a 4000-ft. well was considered deep. Then wells were drilled to 5000, 6000, and 7000 ft. and finally, in 1931 oil was discovered below 8000 ft. in the Badger Basin field, which for many years was the state's deepest producing field. The first well drilled below 10,000 ft. was completed in 1939 and a second 10,000 ft. well was drilled in 1940 (Fig. 4). Both were failures. In 1944 another 10,000-ft. well was drilled and it, too, was a failure. In 1946, the first production below 10,000 ft. was discovered in the Church Buttes field in the Green River Basin. Oil and gas were found in an anticline located by seismograph at a total depth of 12,887 ft. The second deep field to be discovered in 1946 was the Worland field, in the Big Horn Basin, with production from below 10,000 ft. In 1947, two fields, Nieber and South Fork, both in the Big Horn Basin, were discovered at depths in excess of 10,000 ft. In 1947, 10 wells were completed below 10,000 ft.; 6 were oil wells and 4 were dry holes. In 1948, a discovery well was completed at West Poison Spider at a total depth of 14,307 ft. It flowed 900 bbl. of 43° gravity crude. Deep drilling, therefore, appears to be an important technique in the discovery of new Wyoming oil fields.

In summary, the following observations can be made: (1) Rocks as young as Eocene and as old as Cambrian are commercial oil producers in Wyoming, (2) most fields are of the anticlinal type trap; possible fault traps and stratigraphic traps have not been fully explored, (3) buried anticlines that can be located by geophysical methods are present in the central parts of the basins and have proved to be productive, opening up large untested areas, (4) high gravity crude oils have been found in deep basinward structures in Paleozoic rocks that formerly produced only heavy sulphur-bearing crude oils in shallow structures on the basin margins, (5) rocks lying as deep as 14,300 ft. are still pervious and are suitable oil and gas reservoirs, and (6) production from deep wells is apparently large enough to justify drilling costs and to yield a profit. It appears, therefore, that the future of Wyoming as an oil-producing state is indeed bright.

PETROLEUM MAP OF WYOMING

The Petroleum Engineer--November, 1948

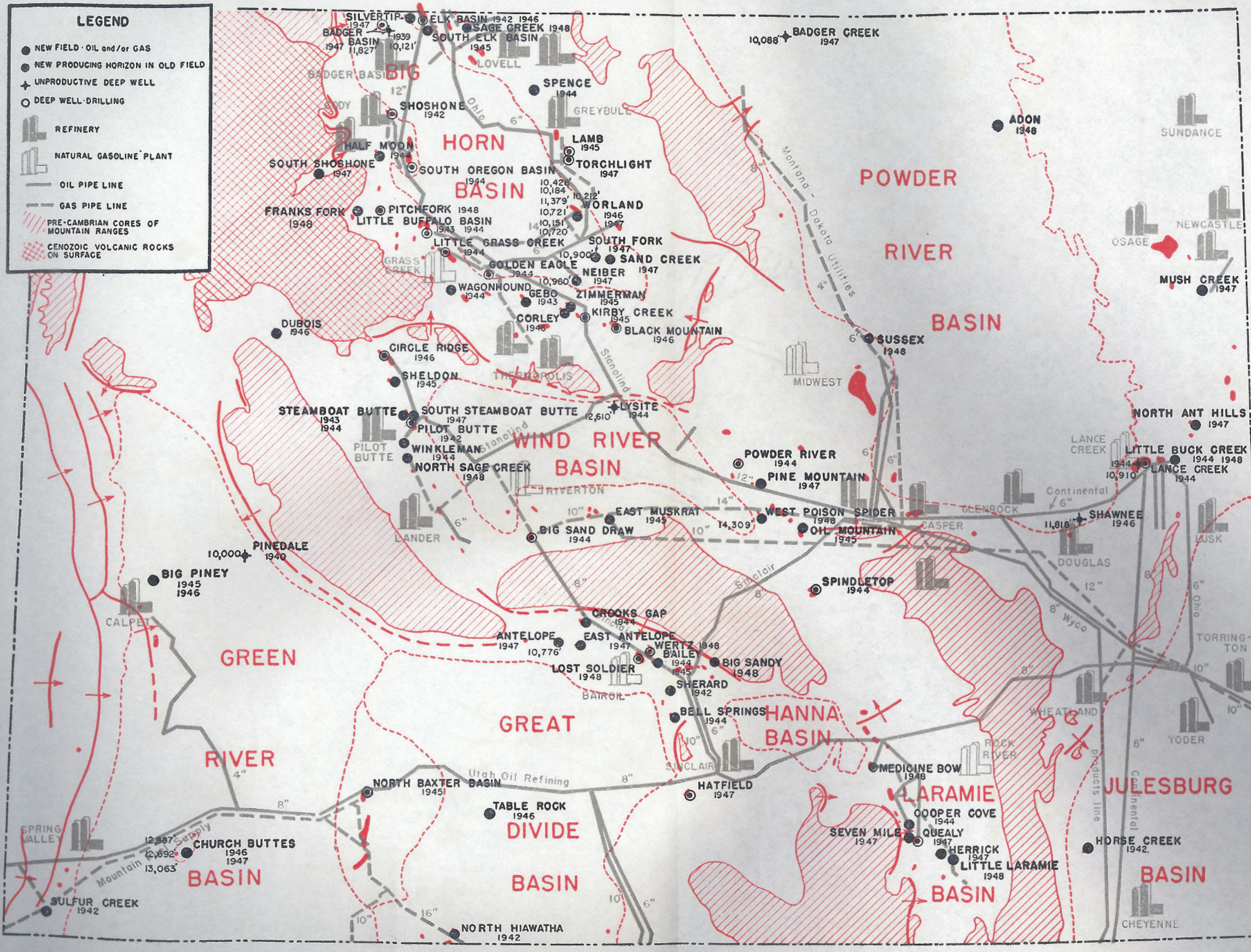

Figure 4—Established oil and gas fields of Wyoming, pre-Cambrian and Cenozoic rocks, and major faults are illustrated by the red background on the map. Oil and gas field activity between 1942 and June, 1948, and wells drilled below 10,000 ft. are shown in black. Pipe lines, refineries, and natural gasoline plants are given in gray.