RELATIONSHIP OF LATEST CRETACEOUS AND TERTIARY DEPOSITION AND DEFORMATION TO OIL AND GAS IN WYOMING

BY

J. D. LOVE, PAUL O. McGREW, AND H. D. THOMAS

CONTRIBUTION OF THE GEOLOGICAL SURVEY OF WYOMING

Reprint No. 21

Reprinted from
THE BACKBONE OF THE AMERICAS—TECTONIC HISTORY FROM POLE TO POLE
A SYMPOSIUM, MEMOIR NO. 2

The American Association of Petroleum Geologists, 1963

RELATIONSHIP OF LATEST CRETACEOUS AND TERTIARY DEPOSITION AND DEFORMATION TO OIL AND GAS IN WYOMING

BY

J. D. LOVE, PAUL O. McGREW, AND H. D. THOMAS

CONTRIBUTION OF THE GEOLOGICAL SURVEY OF WYOMING

Reprint No. 21

Reprinted from

THE BACKBONE OF THE AMERICAS—TECTONIC HISTORY FROM POLE TO POLE

A SYMPOSIUM, MEMOIR NO. 2

The American Association of Petroleum Geologists, 1963

RELATIONSHIP OF LATEST CRETACEOUS AND TERTIARY DEPOSITION AND DEFORMATION TO OIL AND GAS IN WYOMING[1]

J. D. LOVE,[2] PAUL O. McGREW,[3] AND H. D. THOMAS[3]
Laramie, Wyoming

ABSTRACT

Oil and gas have been known in nonmarine Tertiary rocks in Wyoming since 1896. Commercial oil or gas pools have been discovered in Paleocene and Eocene rocks in the Green River, Washakie, and Wind River basins. The source of most of this oil and gas is believed to be sediments deposited under lacustrine conditions during Paleocene time and again during Eocene time. Oil and gas production from nonmarine beds of latest Cretaceous age is a recent development.

The diastrophic and depositional history from latest Cretaceous through Tertiary time has a significant bearing on essentially all Wyoming oil and gas fields. The Laramide orogeny began with gentle folding in latest Cretaceous time, reached a climax of intense folding and thrust faulting in earliest Eocene time in most parts of Wyoming, and was essentially completed by latest Eocene time. Conventional Wyoming oil and gas fields are those related to structural traps formed during this orogeny.

The Green River, Wind River, and Hanna basins were sites of deposition of more than 20,000 feet of latest Cretaceous, Paleocene, and Eocene strata. Oligocene, Miocene, and Pliocene beds were deposited across the now completely filled basins and high onto the flanks of partly buried mountains. Volcanic debris from centers within or near Wyoming comprises the bulk of these young strata. Regional uplift, large-scale normal faulting, and rapid degradation that exhumed the mountains and re-excavated the basins occurred in late Pliocene and Pleistocene time. During this episode some of the structures containing oil and gas were significantly modified.

INTRODUCTION

The history of latest Cretaceous and Tertiary deformation and deposition in Wyoming can best be summarized through the utilization of a series of maps of Wyoming showing the changing landscape. The modern scenery is characterized by major mountain ranges which are separated by intervening basins. These are indicated on an index map (Fig. 1).

LATEST CRETACEOUS AND TERTIARY OIL AND GAS FIELDS

Oil and gas have been known in the nonmarine Tertiary rocks of Wyoming for many years. As early as 1896, wells of small capacity were completed at shallow depths in the Oligocene White River Formation at Brenning Basin (Fig. 2), in central-eastern Wyoming (Biggs and Espach, 1960, p. 90). Subsequently about 80 wells were drilled, and it is estimated that about 7,000 barrels of oil was produced prior to 1937 from the White River or from the Cretaceous rocks on which it rests. In later years other noncommercial oil and gas accumulations were found in the White River in the South Douglas and the Shawnee fields. In all cases it appears that oil migrated up dip in the truncated Cretaceous rocks and into pervious units in the overlying White River. These occurrences are significant in that they represent post-Oligocene migration of oil and gas which originated in Cretaceous, or older, rocks.

The La Barge field, in western Wyoming, was the first discovery of Tertiary oil and gas in commercial amounts. In 1924 production was obtained from sandstones in the Almy Formation, of Paleocene or earliest Eocene age, and the field subsequently produced more than 15 million barrels of oil. Although the structure of

[1] Read before the Association at Denver, Colorado, April 26, 1961. Manuscript received, August 31, 1961. Published with the permission of the Director, U. S. Geological Survey.

The accompanying paleogeographic maps were prepared by first outlining the structural elements on a geological map of Wyoming, assuring correct location in respect to each other. The data were then transferred to reduced outline maps. The topography of the uplifted areas was drawn by Dr. Samuel H. Knight; without his skill with pen and ink, and his willingness to help, the maps would lack the character and texture he so ably imparts to illustrations.

[2] U. S. Geological Survey.
[3] University of Wyoming.

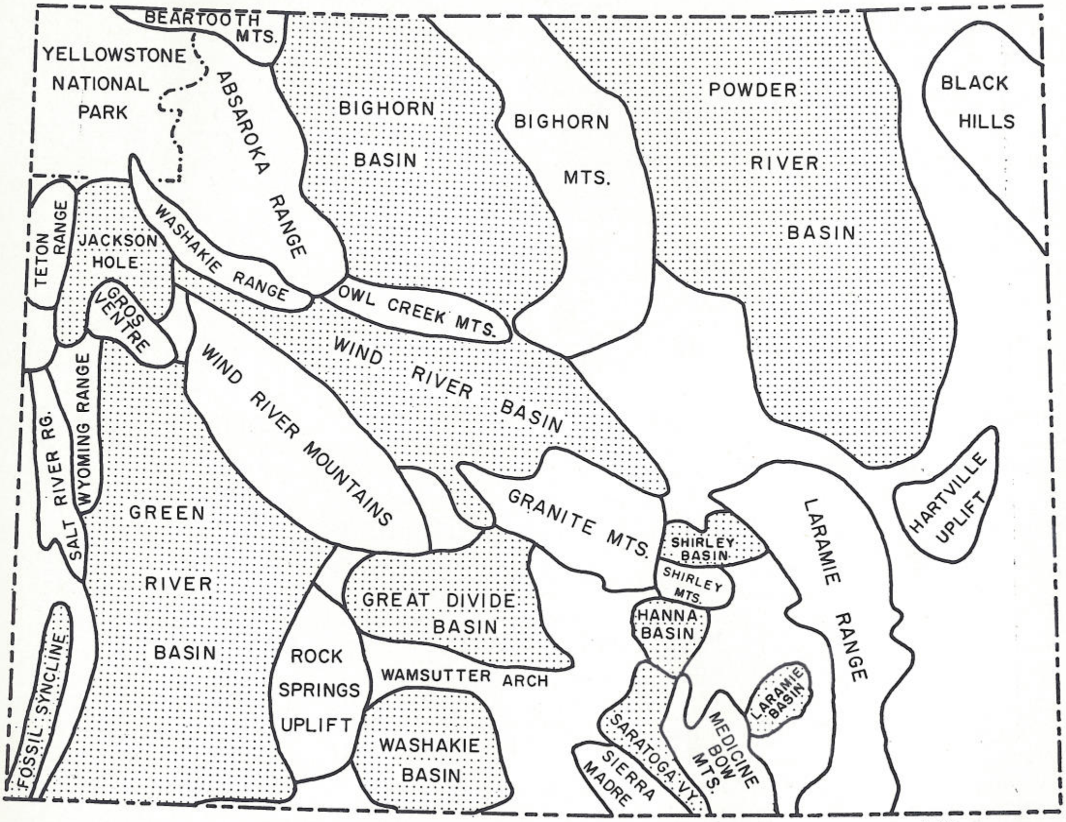


FIG. 1.—Index map of Wyoming showing mountains and basins.

the La Barge field is complicated (Murray, 1960), and it would be possible for oil originating in Cretaceous rocks to migrate into sandstones of the Almy Formation, it has been shown by Crawford and Larsen (1943, p. 1308) that La Barge oil is quite unlike Cretaceous oils and that it is almost identical in its chemical and physical characters to Tertiary crude oil from the Hiawatha field.

Natural gas was found in commercial quantities in sandstones in the nonmarine Paleocene-Eocene Hiawatha Formation in the Hiawatha anticline, along the Colorado-Wyoming border, in 1927. Although the Hiawatha Formation has been generally considered as Eocene in age, correlation with fossiliferous strata on the east flank of the Rock Spring uplift suggests that it is, in part at least, Paleocene in age. In 1952 gas was also found in deeper sandstones which are definitely in the Paleocene Fort Union Formation. Oil in commercial amounts was discovered in sandstones of the Hiawatha Formation in 1953 (Gras, 1955). The Hiawatha field has produced a large volume of gas and an appreciable amount of oil. The oil is chemically unlike Cretaceous or older crude oils in Wyoming and seems to be indigenous to the Tertiary rocks.

In 1941 noncommercial gas flows were found in Hiawatha sandstones at Canyon Creek, near the Hiawatha field, and in 1946 gas was discovered in commercial amounts in the Hiawatha Formation at Table Rock, north of the Hiawatha field.

The State Line oil and gas field was discovered in 1959 with a flow of 9 million cubic feet of gas per day from a Hiawatha sandstone. A sec-

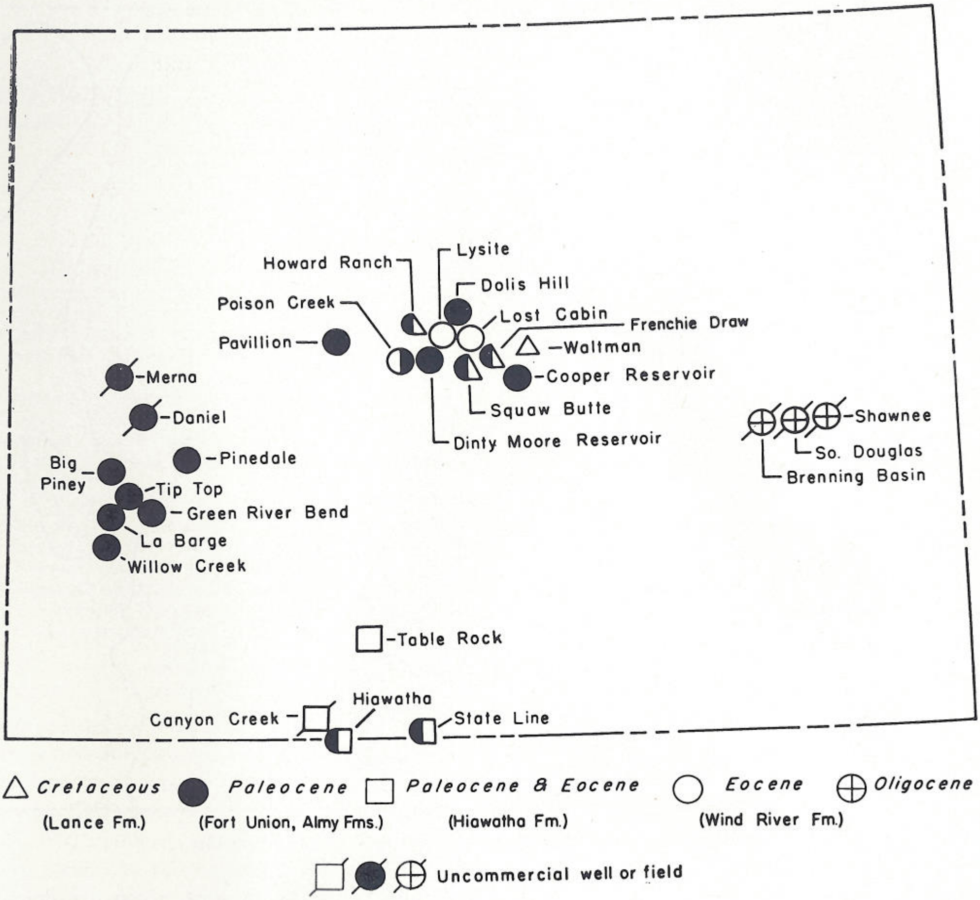


FIG. 2.—Map of Wyoming showing oil and gas fields in which production is from latest Cretaceous and Tertiary rocks.

ond well discovered gas in the deeper Paleocene Fort Union Formation, and in 1960 an oil well was completed in the Fort Union with an initial production of 450 barrels per day.

The prolific Big Piney gas field was discovered as early as 1938, but because of remoteness and lack of market was not developed until the 1950's. Gas, along with some oil, is produced from lenticular sandstones in the Almy Formation, of Paleocene or earliest Eocene age (Krueger, 1960). A number of other fields which produce gas or oil from the Almy sandstones have been discovered in the general Big Piney area.

By the late 1950's, thus, the early Tertiary rocks of western and southwestern Wyoming had become important gas and oil producers. It was not until 1958, however, that commercial oil and gas were found in these rocks elsewhere in the state. In that year, oil was found in sandstones in the Eocene Wind River Formation in the Lysite and Lost Cabin fields in the northern part of the Wind River basin. In early 1961 gas in sufficient quantities to cause blowouts was encountered in the Wind River Formation in an exploratory well at Poison Creek, but the commercial potential has not yet been proved by adequate testing. The well was completed in deeper Paleocene rocks and no confirmation wells have yet been drilled.

In the same general area, the Cooper Reservoir discovery well encountered gas in commercial quantities in the Fort Union Formation in July 1959. Other Fort Union gas discoveries were made at Dolis Hill in October 1959, and in the Pavillion field in August 1960. New gas and condensate discoveries were made in Fort Union sandstones in early 1961 by exploratory wells drilled at Dinty Moore Reservoir, Poison Creek, and Frenchie Draw. The first indicated commercial Fort Union oil discovery in this area was made in early 1961 by the Squaw Butte well.

The first discovery of oil in the nonmarine Late Cretaceous Lance Formation was made in September 1959, when the Waltman field discovery well was completed for a flow of 200 barrels of oil per day. The first Lance gas discovery was the Howard Ranch field, the discovery well flowing 2 million cubic feet of gas per day in February 1961. The Squaw Butte and Frenchie Draw wildcats also discovered commercial quantities of gas in Lance sandstones.

LATEST CRETACEOUS AND TERTIARY HISTORY

INTRODUCTION

Our specific topic deals with the diastrophic, erosional, depositional, and volcanic events which took place in Wyoming during latest Cretaceous and Tertiary time. All the structurally trapped oil in Wyoming is related to this history. Although most structural traps were created early, they were intermittently modified throughout Tertiary time.

LATEST CRETACEOUS HISTORY

The last major invasion of the Cretaceous sea was attained during the time of deposition of the Lewis Shale (Fig. 3). Thereafter, the history was one of regression, with nearly complete withdrawal of the sea by the beginning of Lance time. Deformation of what had been a region of flood plains, coastal plains, and a subsiding sea bottom, began in Late Cretaceous time, and the western, central, and southeastern parts of Wyoming were the sites of growing uplifts (Fig. 4). During Lance time, two main areas of subsidence developed. A northern trough extended from the south border of Yellowstone Park into the present site of the Wind River basin and on toward the Black Hills, and more than 6,000 feet of sediments accumulated in it. A southern trough lay south of the juvenile Granite Mountains and extended through the area now occupied by the Great Divide basin and the Hanna basin. South of this trough, the Rock Springs uplift had begun to form, as had the ancestral Uinta Mountains. Over most of Wyoming, thus, there accumulated stream, lake, and swamp deposits whose clastic components had their sources in nearby uplifts. The fact that a local uplift marginal to the Laramie basin had been dissected as deeply as the Precambrian basement is shown by Precambrian pebbles in a conglomerate of Lance age in the Laramie basin (Knight, 1937).

In some parts of Wyoming, deposition temporarily ceased at the end of Lance time, but over much of the state was apparently continuous into the Paleocene Epoch, as in the Fossil syncline, the Hanna basin, the Bighorn basin, the Powder River basin, and probably the deep part of the Wind River basin.

By the end of Cretaceous time, a number of present-day structural units had come into being in ancestral form (Fig. 5). North-south folding had developed along the western border of the state. The Beartooth, Owl Creek, Washakie, Wind River, and western Gros Ventre Mountains were present in juvenile form. The ancestral Medicine Bow Mountains, Granite Mountains, and Rock Springs uplift had been further accentuated. Structural trends in some of these, such as the western Gros Ventre Mountains and the Granite Mountains uplift, were northwest. A broad area in southeastern Wyoming had been uplifted. The Bighorn Mountains and the Black Hills had not yet risen.

Northeastward tilting and erosion of the northern half of the Green River basin caused removal of the younger beds from the western part of that area.

PALEOCENE HISTORY

The Paleocene history was a remarkable one. With the resumption of widespread deposition, a variety of sedimentary environments developed,

FIG. 4.—Map of Wyoming showing uplifts during time of deposition of the Lance Formation near the close of the Cretaceous Period.

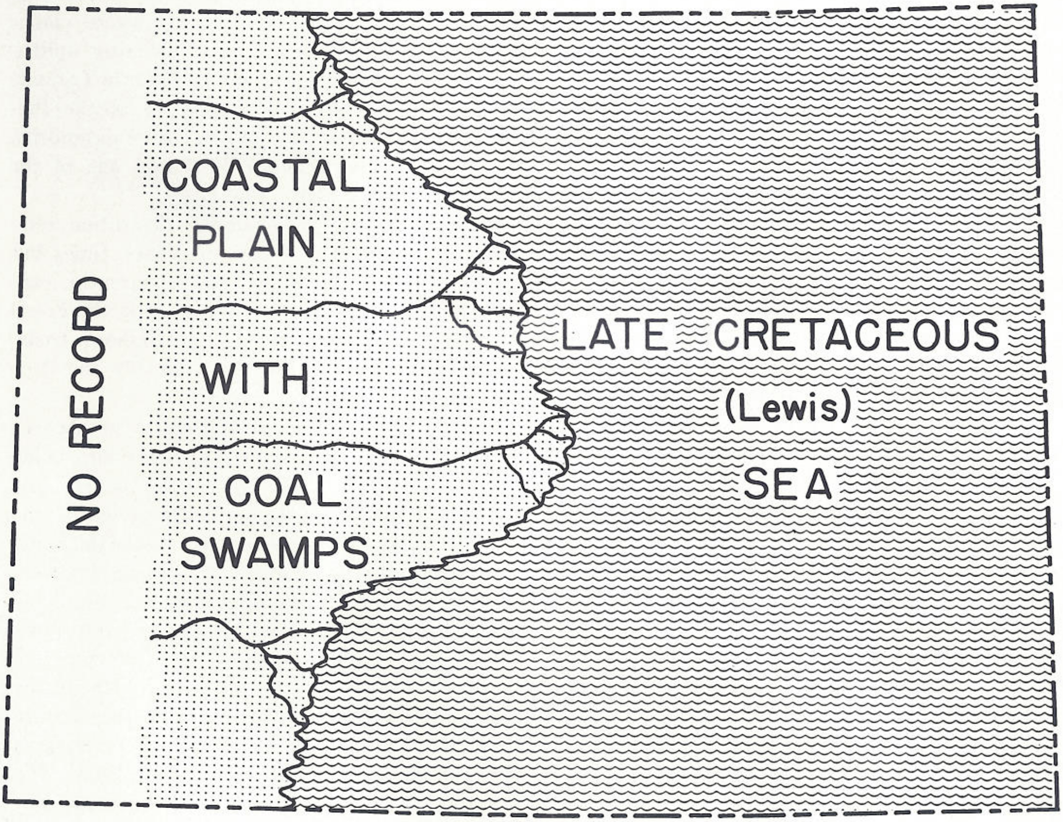
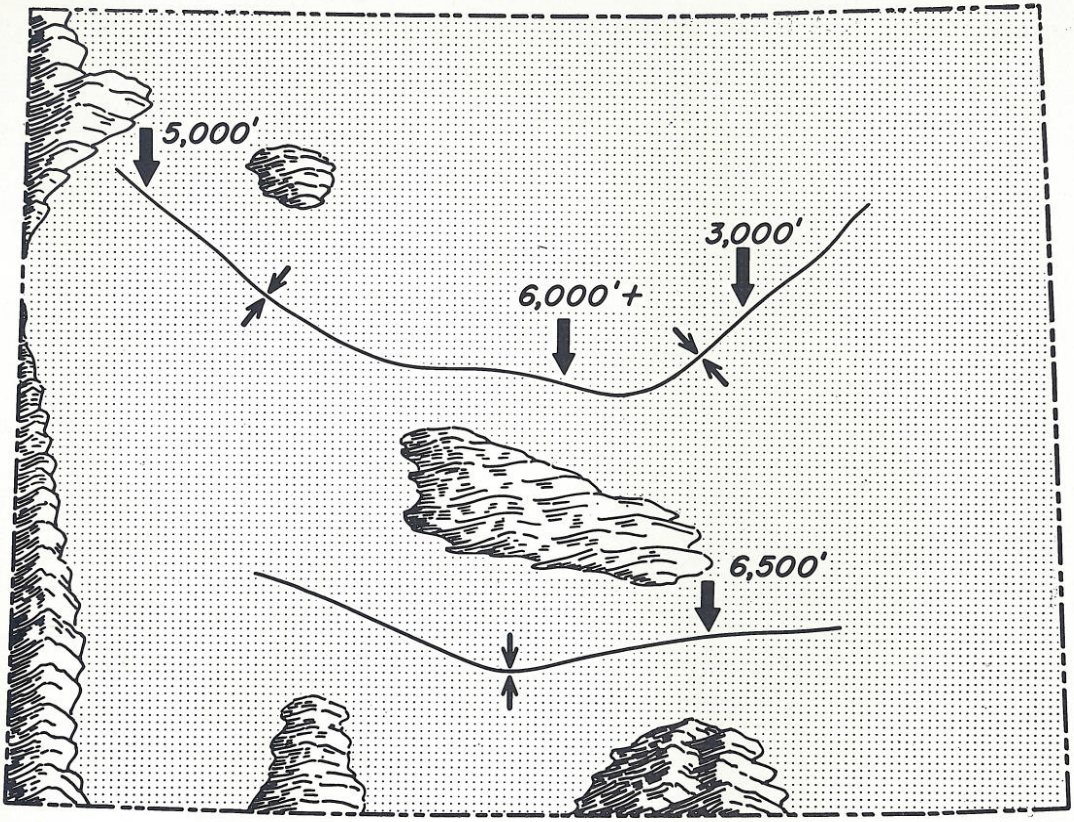
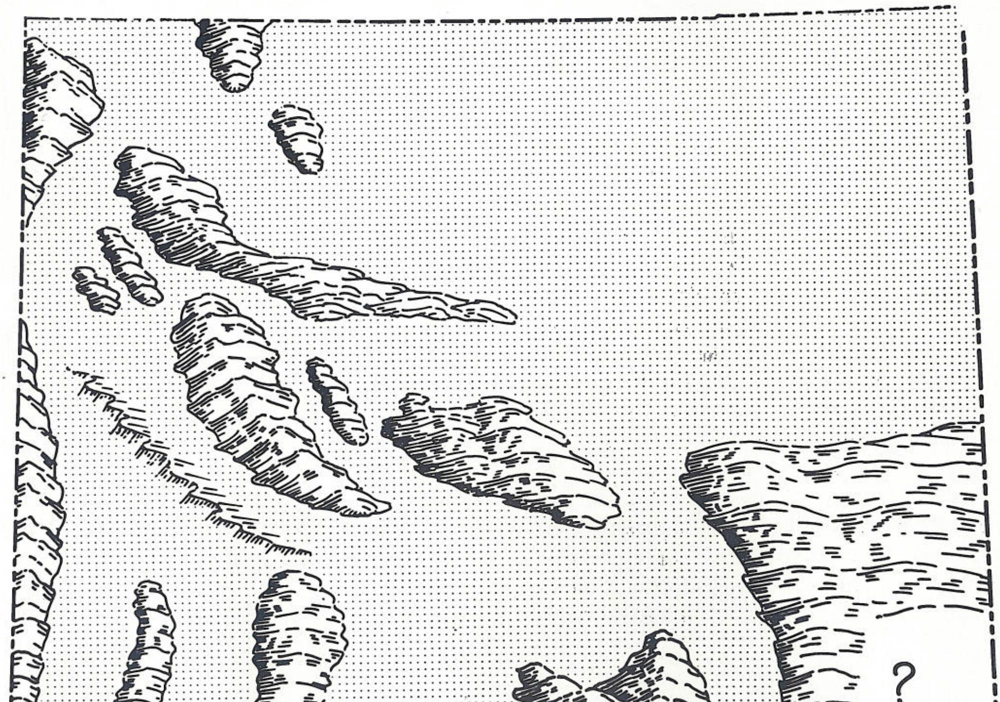


FIG. 3.—Map of Wyoming showing the area covered by the Late Cretaceous sea during time of deposition of the Lewis Shale.

FIG. 5.—Map of Wyoming showing uplifted areas at the close of the Cretaceous Period.


5,000'
3,000'
6,000'+
6,500'


?

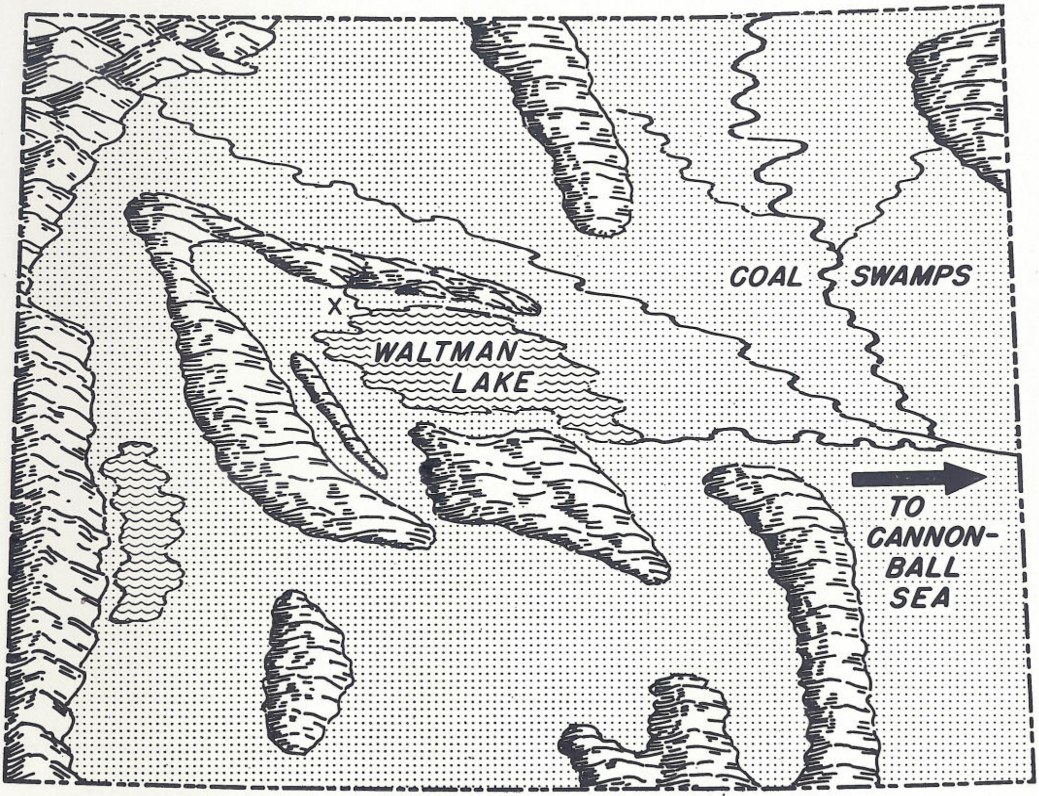


FIG. 6.—Map of Wyoming showing uplifted areas during late Paleocene time. Fluviatile, paludal, and lactustrine sediments were deposited over the remainder of the state. *X* indicates the location of a channel deposit containing many kinds of fossil mammals.

and, consequently, there was diversity in the rock types laid down. Throughout broad areas the Paleocene rocks, generally known as Fort Union Formation, were derived from soft Cretaceous shales and sandstones and, therefore, are mainly fine-grained clastics. Local conglomerates were deposited along the older, more deeply dissected uplifts, principally adjacent to the ancestral Wind River, Medicine Bow, and Granite Mountains. Conglomerates of Precambrian quartzite, whose source was in an unknown area in or west of Yellowstone Park, were deposited along an ancient river that flowed across the southern part of the Bighorn basin and the southwest part of the Powder River basin. As stream gradients decreased, extensive coal swamps formed. Some individual coal seams in the Powder River basin exceed 100 feet in thickness.

A large, foul-bottomed lake, here called Waltman lake, formed in the central part of the Wind River basin and in it were deposited as much as 2,000 feet of dark carbonaceous shales (Keefer, 1960, 1961). These lake deposits may well be the source of at least some of the Tertiary oil and gas found in the Wind River basin. In a channel deposit laid down near the northwest margin of the lake, shown by an *X* on Figure 6, W. R. Keefer, Paul O. McGrew, and others (Keefer, 1961, p. 1315) have found an amazing fauna, made up of many kinds of mammals, including a variety of primates, with which are associated abundant shark and crocodile teeth. The shark teeth need not imply a marine environment, for there are present-day instances of sharks migrating far up streams and inhabiting fresh-water lakes. The lake was probably connected by a now-obliterated stream course with the Cannonball sea, which, during Paleocene time, extended from the Gulf of Mexico into the Dakotas. The smallest mammalian teeth and jaws are perfectly preserved, but with increasing size, the jaws and teeth become progressively more fragmental. This suggests that the mammal teeth may represent the excrement of crocodiles which came onto the land, preyed on the mammals, and then returned to the water. This not only explains the uncrushed nature of the smaller mammal teeth, and the crushing of the larger teeth, but also explains the association of mammal, crocodile, and shark teeth in a single deposit.

Elongate, log-like concretions in the Fort Union Formation of the Powder River basin are invariably oriented toward the southeast, suggesting that ground water movement, and hence the drainage system, were in that direction.

There were other Paleocene lakes, but only two are shown on Figure 6. Fine-grained strata with features suggesting a lacustrine origin are found in part of the Almy Formation in the Big Piney area. These beds may have been the source of the oil and gas found in the Almy Formation.

A third Paleocene lake, not yet well delineated, probably occupied the area south and east of the Rock Springs uplift. The oil and gas found in the Hiawatha Formation in the Table Rock, State Line, and Hiawatha fields, perhaps originated in these lake deposits.

EOCENE HISTORY

By the beginning of Eocene time all the major basins, as we know them now, were well delineated (Fig. 7). Except for the western Gros Ventre, the Absaroka, and the Teton Ranges, all the mountains which characterize modern Wyoming were present.

Earliest Eocene time was marked by strong folding and faulting over most of the state. Many of the present oil-producing anticlines were folded into essentially their present form at this time. The mountain blocks rose while the basins subsided. Not until fairly recent time was there again as much relief in Wyoming as existed during the early Eocene. The typical early Eocene deposits are fluviatile, red-banded shales (Van Houten, 1948; Bradley, 1926) and associated sandstones, but along some of the actively rising mountain blocks thick, coarse conglomerates were deposited. In places, especially in the northern and central parts of the Powder River basin, coal swamps were present.

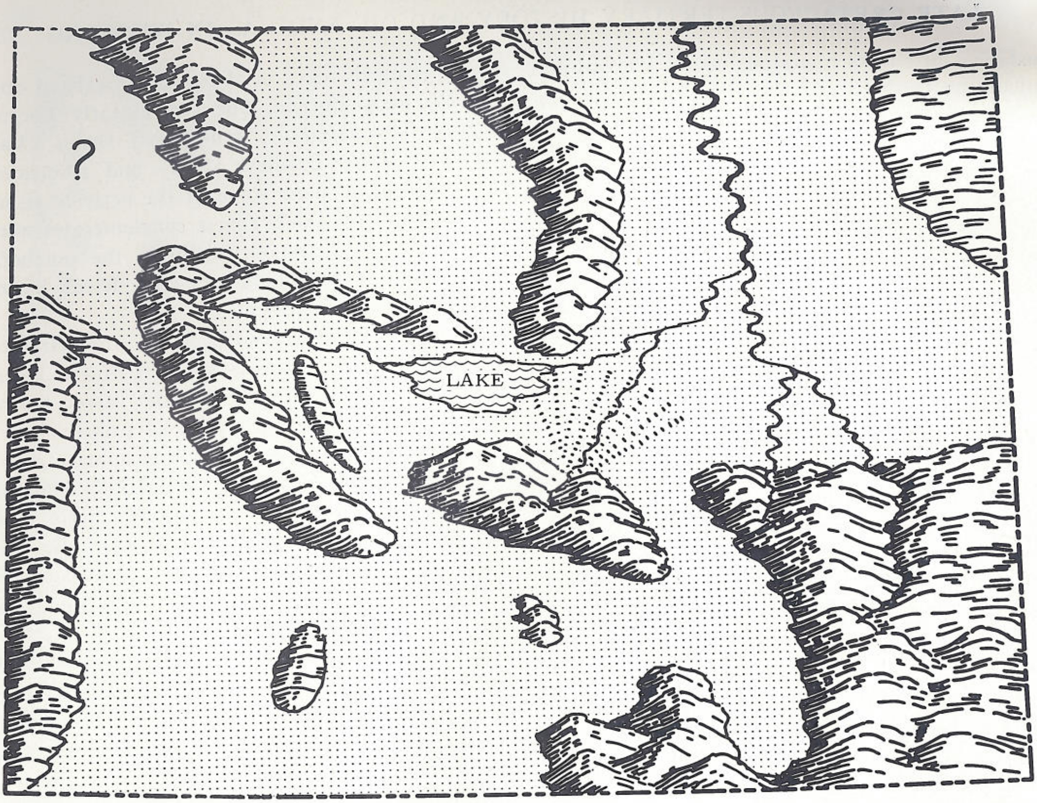
Extending northeastward from the Granite Mountains, across the eastern part of the Wind River basin, and into the Powder River basin, was a large alluvial fan composed principally of arkosic sediment derived from Precambrian granite. It is possible that this fan partially blocked the drainage from the Wind River basin and caused Waltman lake to persist into Eocene time. Very fine-grained, lacustrine-type deposits of early Eocene age are found in the northern part of the Wind River basin.

Drainage systems were considerably modified from those of Paleocene time. Instead of the major drainage being eastward across Wyoming, streams were apparently diverted northward into the Powder River basin, perhaps as the result of the rising of a broad upland in the High Plains area, where no Eocene rocks are known.

During middle Eocene time, volcanic activity was widespread (Fig. 8). Centers were located in the Yellowstone Park-Absaroka area, the Rattlesnake Hills of central Wyoming, and in the Black Hills. Westward tilting of eastern Wyoming blocked the eastward drainage and concentrated deposition in and around the lake basins of western and central Wyoming.

Gosiute lake covered a large part of southwestern Wyoming and in it accumulated the well-known Green River Formation. The history of the lake was long and complex, with numerous expansions and contractions, and with the development of unique sedimentary environments which fostered the deposition of finely laminated oil shale, bedded sodium carbonate and sodium chloride, uraniferous phosphate rock, marlstone, algal reefs, and other types of lacustrine beds. These were replaced laterally along the lake margins by paludal and fluviatile deposits.

A similar lake was present in the southern part of the Bighorn basin. In it were deposited oil


?
LAKE

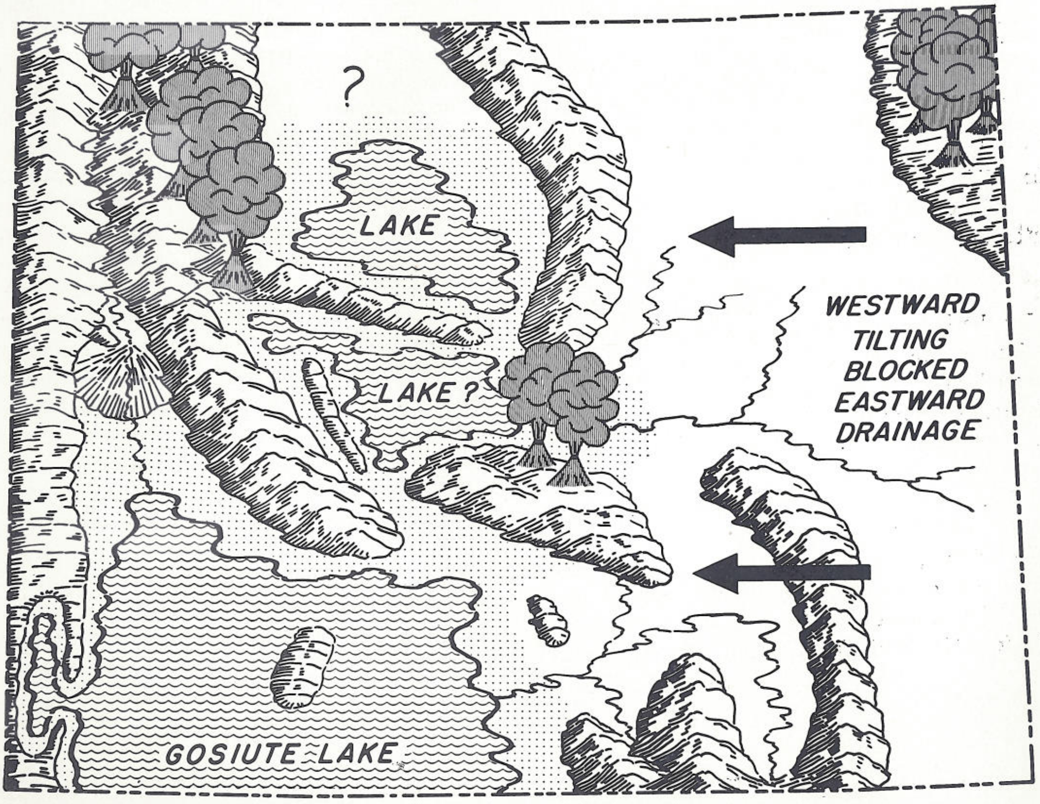

?
LAKE
LAKE ?
WESTWARD TILTING BLOCKED EASTWARD DRAINAGE
GOSIUTE LAKE

FIG. 7.—Map of Wyoming showing mountainous uplifts and depositional basins during earliest Eocene time.

shales identical with those which accumulated in Gosiute lake. Shales in the southwestern part of the Bighorn basin have yielded 12 gallons of oil per ton, and others in the southeastern part have yielded as much as 40 gallons per ton. An extremely fragmentary record suggests that another such lake may have existed in the Wind River basin at this time. These lakes probably formed somewhat later than Gosiute lake.

Toward the end of Eocene time, tuffaceous sediments, in part lacustrine, had buried the Washakie and the Owl Creek Mountains so that the Wind River and Bighorn basins were not separated. Gosuite lake no longer existed in southwestern Wyoming, but deposition of fluviatile and swamp deposits (Bridger Formation) continued in the area previously occupied by the lake.

Degradation, which possibly began with the westward tilting during middle Eocene time, continued in eastern Wyoming, with the development of a mature topography which was subsequently buried by Oligocene deposits.

OLIGOCENE HISTORY

The beginning of Oligocene deposition was the inauguration of a sedimentary cycle which continued into the Pliocene and brought about the nearly complete burial of all the Wyoming mountain ranges. The Oligocene Epoch also was a time of climatic change from the subtropical climate of Eocene and early Oligocene time—indicated by fossil breadfruits, figs, and magnolias—to a warm, temperate climate in late Oligocene time—as shown by fossil oaks, beeches, and maples (Dorf, 1959).

Volcanic activity increased, both in violence and areal extent in the Yellowstone-Absaroka region. Airborne ash was so abundant that streams became choked and were unable to erode, even in the highlands. Oligocene strata contain a surprisingly small amount of material derived from the Precambrian rocks, even in beds filling pre-Oligocene valleys cut in the mountains. By the end of Oligocene time, only the upper 1,000-4,000 feet of the crests of the major mountain ranges protruded above the aggradational plain (Love, 1960, p. 210).

MIOCENE HISTORY

The burial of the mountain ranges continued throughout Miocene time. Surprising thicknesses of sandstones and tuffaceous debris accumulated. Much of the volcanic material originated in the Yellowstone-Absaroka region and spread eastward and southeastward. The Miocene rocks comprise 7,000 feet of beds in the Jackson Hole area, 2,800 feet on the Granite Mountains, and 2,500 feet in the Platte Valley near Saratoga (Love, 1960, p. 210). Areas of mountain tops

FIG. 8.—Map of Wyoming showing the early middle Eocene landscape. Areas of fluviatile and paludal deposition are stippled. Lacustrine deposits accumulated in the lakes.

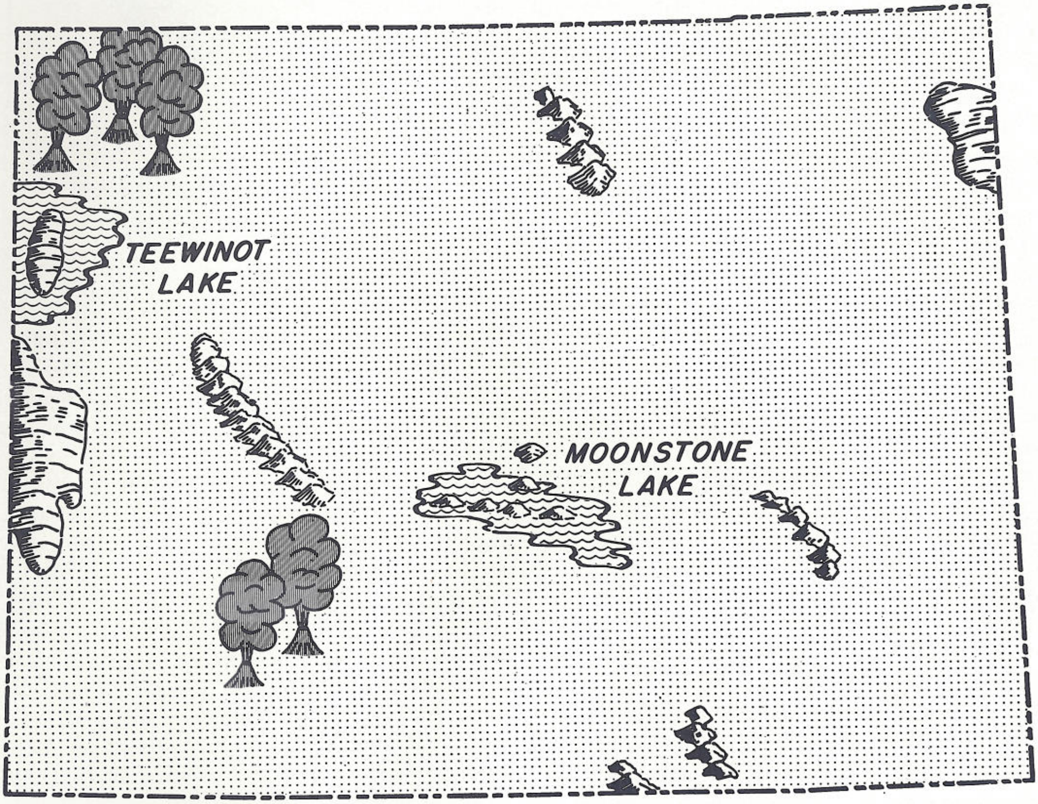


FIG. 9.—Map of Wyoming showing the almost complete burial of the mountains during late Pliocene time.

protruding above the plain of aggradation were considerably reduced from those which projected during Oligocene time. From the Wind River Mountains southward to Colorado and eastward to Nebraska, the plain was unbroken except for the tops of the highest peaks of the Granite Mountains, Laramie Range, Sierra Madre, and Medicine Bow Mountains.

PLIOCENE HISTORY

Although earlier Pliocene time, in general, was one of structural stability, the Gros Ventre Mountains were thrust to the southwest and more than 5,000 feet of strata, chiefly conglomeratic debris, accumulated in front of the rising block. Later, Teewinot lake formed in the Jackson Hole area, and in it were deposited about 5,000 feet of fine-grained sediments—pumicite, claystone, limestone and diatomite—indicating that the towering Teton Range had not come into existence, or at best was no more than a series of low hills (Fig. 9). Remnants of Pliocene rocks are found in a few other parts of the state. A thick lacustrine sequence was deposited in Moonstone lake, which formed along the downwarped and downfaulted crest of the present Granite Mountains. It is believed that the Pliocene deposits are remnants of a sheet whose upper surface was continuous with the erosion surfaces which now lie at elevations between 10,000 and 12,000 feet on the margins of many of the major mountain ranges (Love, 1960, p. 212).

Volcanic activity continued in the Yellowstone region and a vast quantity of rhyolitic debris was added to the earlier accumulations of volcanic material. A swarm of small volcanoes came into existence and formed the Leucite Hills in the Rock Springs uplift of southwestern Wyoming.

These have recently been dated as of Pliocene age (Love, 1960, p. 211).

LATE PLIOCENE AND EARLY PLEISTOCENE UPLIFT

At or near the close of Pliocene time, regional uplift of tremendous magnitude took place. Normal faults with displacements as great as 20,000 feet formed in western Wyoming. The magnificent Teton Range arose.

With uplift, streams which had been flowing on the monotonous plain of aggradation were rejuvenated. With downcutting they became superimposed across the mountains. Most of the major rivers of Wyoming cut directly across one or more mountain ranges along their courses.

During Pleistocene time the mountains were exhumed and the basins were re-excavated to bring about the present relief. The mountains were subjected to Alpine glaciation and sculptured to their present grandeur.

TERTIARY EVENTS AND OIL AND GAS ACCUMULATION

It is clear that the Tertiary history of Wyoming has greatly influenced oil and gas accumulation. In those pools found in Laramide anticlines where migration was early, many changes took place between the time of accumulation and the discovery of the pools within recent years. With deeper and deeper burial through most of Tertiary time, temperatures and pressures were increased. With increased temperature, viscosity would decrease, allowing freer movement of oil. With increased pressure, free gas would become dissolved gas, further decreasing viscosity. Outcrops of Paleozoic and Mesozoic reservoir rocks which had been intakes for surface water were sealed, terminating any hydrodynamic gradients which had existed.

With the excavation of the basins in post-Pliocene time, pools were again brought nearer to the surface with resultant decreases in reservoir temperatures and pressures. Outcrops were again opened to surface waters and new hydraulic gradients were established. Espach and Fry (1951) have shown that the oil and gas in the Tensleep reservoir in the Elk Basin field are not in equilibrium throughout the reservoir. This condition probably prevailed in other Wyoming oil fields but went unrecognized. The peculiar relations between dissolved gas and oil in the Elk Basin Tensleep reservoir may be related in some way to the various events which affected the pool during Tertiary time.

Deformation, which went on intermittently during Tertiary time, modified structural traps. Some anticlines which formed during late Cretaceous or earliest Tertiary time were accentuated by later folding. Other anticlines which have been proved barren by drilling may have been unclosed until after migration had ceased. Grenville dome, as shown by Barlow (1953), was a plunging anticline until some 400 feet of closure was developed by post-Miocene deformation. Other anticlines surely were transected by late Tertiary faulting.

The Tertiary rocks themselves constitute both source beds and reservoir rocks. The recognition of Tertiary lacustrine beds as source rocks becomes more important, and it may well be that the distribution of production from Tertiary reservoirs is largely controlled by the distribution of lacustrine deposits.

Migration of petroleum now found in Paleozoic and Mesozoic reservoirs in structural traps generally has been thought to have taken place soon after the traps were formed. Yet there are examples of late migration. Oil and gas found in the Brenning Basin and Shawnee fields must have originated in Paleozoic or Mesozoic rocks, but migrated in post-Oligocene time. Gas found in the Cretaceous Mesaverde Formation in Slater dome, along the Colorado-Wyoming border, occurs in a domal structure related to an igneous intrusion (Wells, 1956). The time of migration, Wells believes, was during Miocene or early Pliocene time.

Although the results are not easily recognized, every oil or gas field in Wyoming—structural or stratigraphic—was affected in some manner, or brought into being, by the deformation, subsidence, sedimentation, uplift, and degradation which took place over a complicated 60-million year Tertiary history.

REFERENCES

Barlow, James A., 1953, The geology of the Rawlins uplift, Carbon County, Wyoming: unpub. Ph.D.

thesis, Univ. of Wyoming.

Biggs, Paul, and Espach, Ralph, 1960, Petroleum and natural gas fields in Wyoming: U. S. Bur. Mines Bull. 582.

Bradley, W. H., 1926, Shore phases of the Green River formation in northern Sweetwater County, Wyoming: U. S. Geol. Survey Prof. Paper 140-D, p. 121-131.

——— 1948, Limnology and Eocene lakes of the Rocky Mountain region: Geol. Soc. America Bull., v. 59, no. 7, p. 635-648.

Crawford, J. G., and Larsen, R. M., 1943, Occurrence and types of crude oils in Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., v., 27, no. 10, p. 1305-1334.

Dorf, Erling, 1959, Climatic changes of the past and present: Univ. Mich. Mus. Paleontology Contr., v. 13, no. 8, p. 181-210.

Espach, Ralph, and Fry, Joseph, 1951, Variable characteristics of the oil in the Tensleep sandstone reservoir, Elk Basin field, Wyoming and Montana: U. S. Bur. Mines Rept. Inv. 4768.

Gras, V. B., 1955, Vermilion Creek Basin area, Sweetwater County, Wyoming, and Moffat County, Colorado, *in* Wyoming Geol. Assoc. Guidebook, 10th Ann. Field Conf.: p. 177-181.

Keefer, W. R., 1960, Magnitude of crustal movement and deposition during latest Cretaceous and early Tertiary time in the Wind River basin, central Wyoming (abs.): Geol. Soc. America Bull., v. 71, no. 12, p. 1901.

——— 1961, Waltman shale and Shotgun members of Fort Union Formation (Paleocene) in Wind River basin, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 8, p. 1310-1323.

Knight, S. H., 1937, Origin of late Upper Cretaceous sediments of the Laramie and Hanna basins, Wyoming (abs.): Geol. Soc. America Proc., p. 94.

Krueger, Max L., 1960, Occurrence of natural gas in the western part of Green River basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 15th Ann. Field Conf.: p. 195-209.

Love, J. D., 1960, Cenozoic sedimentation and crustal movement in Wyoming: Am. Jour. Sci., v. 258-A, p. 204-214.

Murray, Floyd E., 1960, An interpretation of the Hilliard thrust fault, Lincoln and Sublette Counties, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 15th Ann. Field Conf.: p. 181-186.

Van Houten, F. B., 1948, Origin of red-banded early Cenozoic deposits in Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., v. 32, no. 11, p. 2083-2126.

Wells, R. E., 1956, Igneous tectonics at Slater dome, Moffat County, Colorado: Rocky Mtn. Sec.. Am. Assoc. Petroleum Geologists, Geological Record, p. 49-53.