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Geologic History and Structure of Wyoming

By

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GEOLOGIC HISTORY AND STRUCTURE OF WYOMING

by

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The following discussion is condensed and modified somewhat from a lecture presented in 1949 under the sponsorship of the Distinguished Lecture Committee of the American Association of Petroleum Geologists. The lecture later was published as Bulletin 42 of the Geological Survey of Wyoming. It was pointed out that the geological literature had been drawn upon freely in the preparation of the lecture, although no references were given, and that the discussion was based on the publications of scores of workers on Rocky Mountain geology.

In the original lecture, considerable time was devoted to the occurrence of petroleum in Wyoming, its mode of accumulation, the distribution of fields, and the new discoveries. An optimistic view was taken of the petroleum possibilities of Wyoming. These topics are not considered in the present paper, but mention is made of the stratigraphic occurrence of oil and gas.

PRE-CAMBRIAN TIME AND ROCKS

The pre-Cambrian rocks of Wyoming are exposed in the cores of most of the mountain ranges. (Fig. 1). The

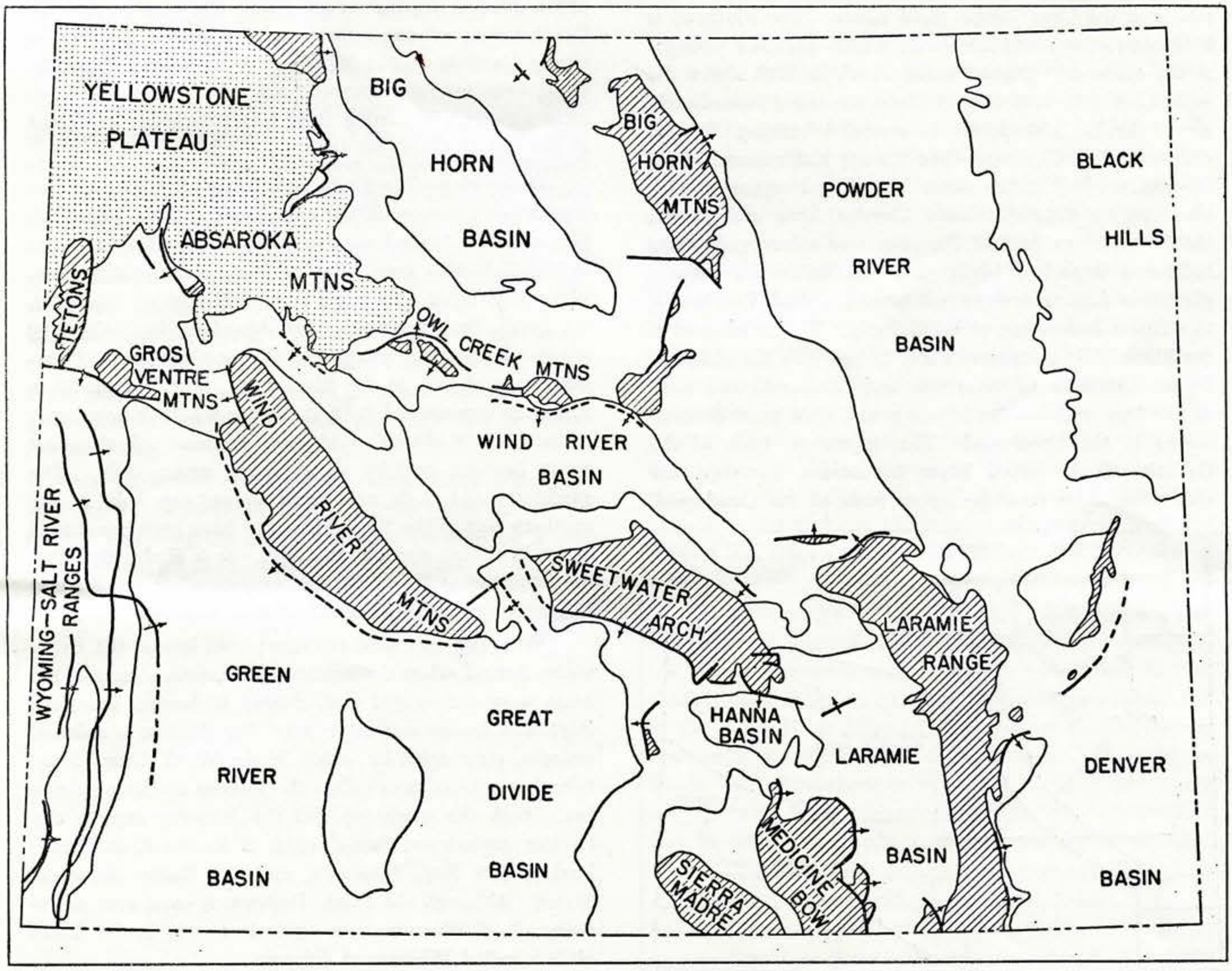


Fig. 1. Index map of Wyoming showing major structural features. Pre-Cambrian areas are cross-hatched. Tertiary volcanics are shown by coarse stipple. Faults are shown as heavy lines with arrows showing direction of movement of hanging wall of thrust fault.

oldest rocks comprise great thicknesses of sediments which were deposited on an unknown crust. After folding and metamorphism, these rocks were invaded by batholiths which were largely granitic, although many other igneous rock types were developed. After an incredibly long pre-Cambrian history of deposition of sediments, of folding and regional metamorphism, and of igneous intrusion, the region was subjected to erosion, the old mountains were worn away, and by Cambrian time was reduced to a peneplane.

PALEOZOIC TIME AND ROCKS

Cambrian.—The Early Cambrian sea was restricted to the Cordilleran trough to the west of Wyoming. This sea expanded eastward and reached the western border of Wyoming fairly early in Middle Cambrian (Albertan) time and continued its eastward spread throughout that epoch (fig. 2, Fig. 3). The Middle Cambrian rocks of Wyoming are represented by the Flathead sandstone below, and the Gros Ventre shale above. The Flathead is a transgressive sandstone facies which becomes younger to the eastward. Faunal zones which lie high above the basal Cambrian sandstone in Idaho are found immediately above the basal sandstone in central Wyoming. By the end of Middle Cambrian time the sea had covered about the western half of the state. Continued expansion took place during Late Cambrian (Croxian) time and all but the southeastern part of the state was submerged. The sediments deposited in the Late Cambrian sea show a gradation from nearshore sandstones, called Deadwood, to offshore limestones, called Gallatin. The Deadwood of the Black Hills compares closely in age with the standard Upper Cambrian of Wisconsin and Minnesota and most of the Upper Cambrian faunal zones have been discriminated in the Deadwood The uppermost beds of the Gallatin of the Wind River Mountains, however, are somewhat older than the upper beds of the Deadwood.

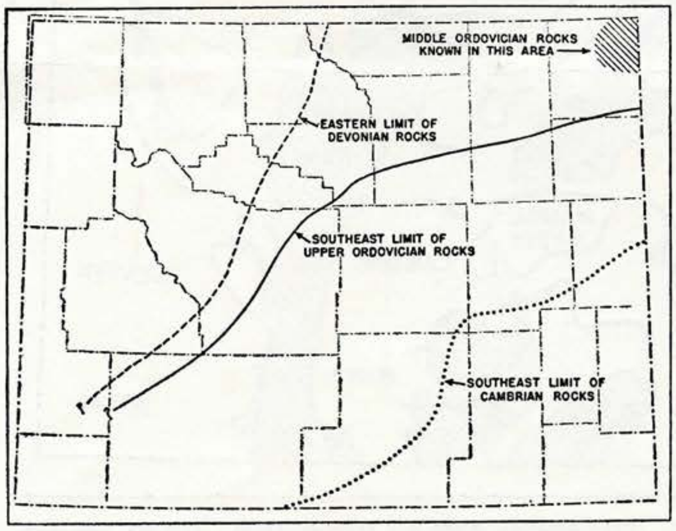


Fig. 2. Map showing the distribution of Cambrian, Ordovician and Devonian rocks in Wyoming.

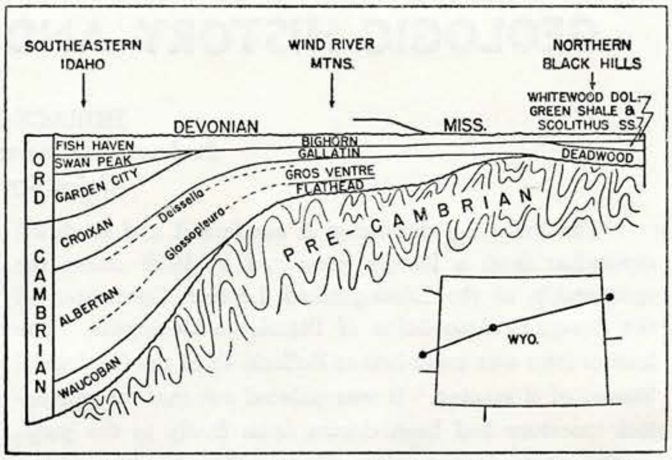


Fig. 3. Stratigraphic diagram showing the relations of Cambrian and Ordovician rocks between southeastern Idaho and the northern Black Hills.

Latest Cambrian rocks have been removed by pre-Ordovician erosion in the Wind River Mountains. In the Rawlins area, erosion was of such magnitude that all the Upper Cambrian rocks, which must have been deposited there, were entirely removed, and only Middle Cambrian rocks remain. Wyoming then was completely emergent at the end of Cambrian time.

Ordovician.—The Early Ordovician, or Canadian, sea covered southeastern Idaho and adjacent Utah, and 1,200 feet of Lower Ordovician limestone, the Garden City, was deposited in that area. During Middle Ordovician time, Idaho was again submerged and 500 feet of sandstone, the Swan Peak quartzite, was deposited, but Wyoming remained emergent except for the northeasternmost corner of the state. In the Black Hills, Middle Ordovician rocks are represented by a sandstone which is commonly called the "**Scolithus** sandstone," because of abundant worm borings, and by an overlying green shale. The sandstone and shale are found in outcrop only in the northern part of the Black Hills, but have been penetrated by wells drilled north of the Hills. It is likely, also, that the fish-bearing "basal Bighorn sandstone" of the Bighorn Mountains represents these Middle Ordovician rocks.

Wyoming was then emergent until late in the Ordovician Period, when the northern and western parts of the State were submerged and, during Richmond time, the Bighorn dolomite was deposited. The Bighorn is a dense, massive, pure dolomite which in the Wind River Mountains has a basal unit called the Lander sandstone member. Both the sandstone and the dolomite carry a distinctive cephalopod fauna which is known from Greenland, Baffin Bay, Manitoba, and the Rocky Mountain States. Although the name, Bighorn, is used over essentially all of Wyoming, an equivalent unit in the Black Hills is called Whitewood dolomite.

Summary.—Sediments of Middle and Late Cambrian age are widespread through Wyoming, the Upper Cambrian rocks having the widest distribution. Ordovician rocks are mainly dolomites and are less widespread than the Upper Cambrian rocks. The positive nature of Wyoming is brought out by the eastward thinning of the sediments. Cambrian and Ordovician rocks in Idaho comprise about 7,500 feet of strata, which thin to about 1,500 feet in the Wind River Mountains and which thin out and are absent in southeastern Wyoming.

In 1948 commercial oil production was found in the basal Cambrian sandstone, just above granite, in the Lost Soldier and Wertz fields in the Rawlins area of south-central Wyoming. The first oil to be discovered in Ordovician rocks in Wyoming was found in the Bighorn dolomite in the old Hamilton field, in the southern Bighorn Basin, in 1953. There is no other Ordovician production.

Silurian.—Wyoming was completely emergent at the end of Ordovician time, and remained above the sea through Silurian and much of Devonian time. Although no Silurian rocks are present in the state, some 1,500 feet of Laketown dolomite was deposited in adjacent southeastern Idaho during Silurian time (Fig. 4).

Devonian.—Not until late in Devonian time was Wyoming again submergent. This Late Devonian sea was of limited areal extent and covered only northwestern and western Wyoming. In the Wind River Mountains the Devonian rocks comprise about 200 feet of brown granular dolomites, red shale, and some sandstone, and are known as the Darby formation. The Darby thins eastward and southward and is lacking over all of eastern and southern Wyoming. Correlative rocks in northwestern Wyoming are known as Jefferson dolomite and Three Forks shale. A much thicker Devonian section, aggregating over 1,000 feet of beds, was deposited in southeastern Idaho.

Mississippian. — Widespread submergence characterized Early Mississippian time. Indeed, it is likely that for the first time the entire state was covered by a sea.

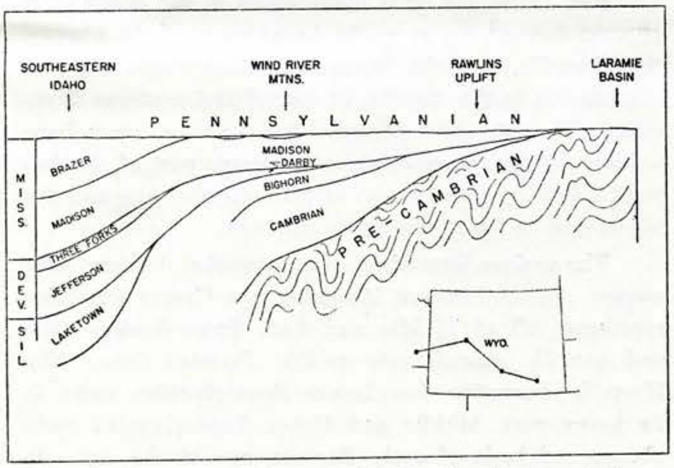
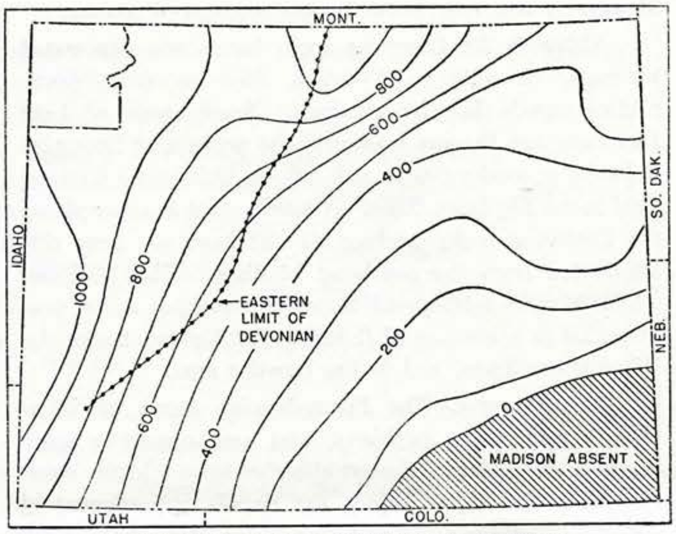


Fig. 4. Stratigraphic diagram showing the relations of the Silurian, Devonian and Mississippian rocks between southeastern Idaho and the Laramie Basin.



THICKNESS MAP OF MADISON IN WYOMING

Fig. 5. Map showing thickness of the Madison limestone.

During earlier Mississippian (Kinderhook and Osage) time there was widespread carbonate deposition, and the resulting limestones are known over most of the Rocky Mountain region as Madison limestone. Uplift at the end of Osage time resulted in the restriction of the Mississippian sea to the geosynclinal area to the west, and most of Wyoming was subjected to subaerial erosion. As a result, the Madison thins southeastward from nearly 1,000 feet in northern Wyoming to a vanishing edge in southeastern Wyoming (Fig. 5). At the wedge-edge the Madison rests on pre-Cambrian crystalline rocks. Its earlier more widespread nature is indicated by large chert masses, crowded with Madison fossils, which came to rest without lateral transport on pre-Cambrian granite 50 miles south of the present Madison wedge-edge. Furthermore, the fact that the Madison is just as pure a limestone near the wedge-edge as it is in thick sections, indicates that the rocks in the present wedge-edge were deposited far from land and away from the influence of clastic material.

In southeastern Idaho, later Mississippian rocks, representing the Meramec and Chester Series, are known as the Brazer limestone and aggregate over 1,000 feet of strata. It is believed by some that a Mississippian unit in the Wind River Mountains, known as the Sacajawea, represents a remnant, or a wedge-edge, of rocks of Brazer age. Elsewhere in Wyoming, rocks of Brazer age are known in the northwesternmost part of the state, and may be present at certain localities in the Big Horn Basin.

Summary.—The positive nature of Wyoming is again emphasized by the distribution and thickness of the Silurian, Devoniain and Mississippian sediments. Rocks representing these three systems reach a thickness of 5,000 feet in southeastern Idaho. Devonian and Mississippian strata are less than 1,000 feet thick in the Wind River

Mountains and are absent in southeastern Wyoming.

Although the Devonian rocks have been penetrated by numerous wells in Wyoming, their petroleum possibilities remain largely unknown. Brachiopods of Late Devonian age (**Atrypa missouriensis**) prove that Devonian dolomite is productive in at least one well in the Garland field in the Big Horn Basin. It may be that in other places the Devonian rocks produce oil but have not been discriminated from the overlying Madison. The Madison, which is more widespread than the Devonian rocks, produces oil in a number of fields in the Bighorn Basin, the Wind River Basin, and in the Rawlins area.

Pennsylvanian.—The Pennsylvanian strata of Wyoming present more problems, and are apparently more complex, than those of most other systems. Much work remains to be done before the details are adequately known. The Pennsylvanian rocks are characterized by marked facies changes over relatively short distances, by facies crossing time lines, by striking changes in time-scope from place to place, and by disconcerting and unexpected problems which appear from time to time.

The Pennsylvanian is the oldest system to be represented in all parts of the state. Outcrops are shown on the map (Fig. 6). All succeeding systems have a similar widespread distribution. The Pennsylvanian rocks, in a simple way, may be thought of as comprising four distinctive facies (Fig. 7). A continental arkose grit facies in the southeastern part of the state is known as the Fountain formation. It rests directly on pre-Cambrian rocks. To the northward it interfingers with marine strata and loses its identity. A limestone facies is best developed in southeastern Wyoming, in the Hartville uplift and along the Laramie Mountains. Limestone tongues extend westward and southward but thin out in those directions.

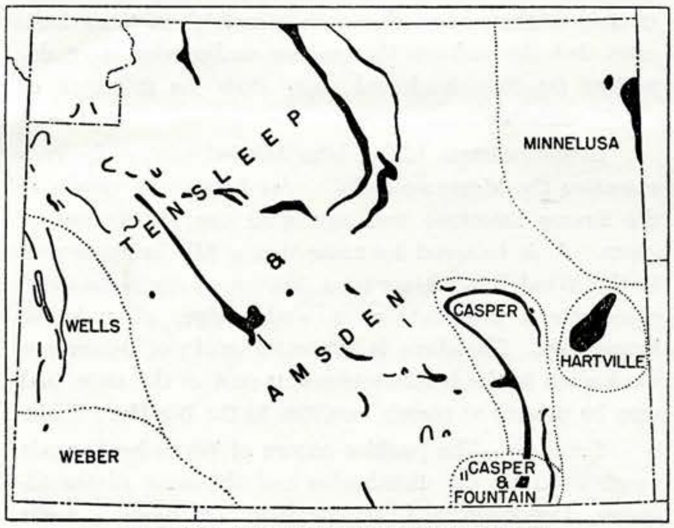


Fig. 6. Map showing the outcrops and the terminology of the Pennsylvanian formations of Wyoming.

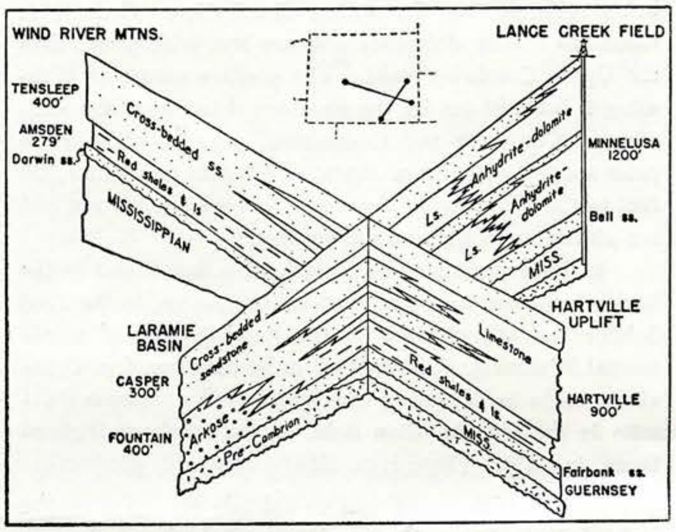


Fig. 7. Stratigraphic diagram showing the distribution and relations of the Pennsylvanian facies in southeastern Wyoming.

A cross-laminated sandstone facies is most conspicuous in the west and in the south. At different places, rocks of different facies predominate, thus the Casper of the Laramie Basin represents intertonguing of the arkose grit, limestone and cross-bedded sandstone facies; the Casper of the northern Laramie Mountains represents intertonguing of the limestone and sandstone facies; the Hartville of eastern Wyoming represents the limestone facies, mainly, with thin tongues of the sandstone facies; and the Tensleep of central Wyoming represents the cross-bedded sandstone facies alone. The fourth major facies is found in the evaporite sequence of the Minnelusa of the Lance Creek area. Other facies there are minimized at the expense of an anhydrite-dolomite facies. These major rock types represent responses to particular physical environments. With paleogeographic changes, there were shifts in the environments, with resultant lateral displacements of the major facies.

Red shales are quite conspicuous in the lower parts of most formations, as in the lower parts of the Casper, the Hartville, and the Minnelusa. Red shales are also conspicuous in the Amsden of central and northern Wyoming. The age of the Amsden has for many years been a controversial question, since the lower part of the formation has appeared to be of Mississippian age and the upper part to be of Pennsylvanian age.

The various formations have somewhat different time scopes. In southeastern Wyoming, the Casper formation represents all of Middle and Late Pennsylvanian time and actually extends into earliest Permian time. The Hartville formation has Lower Pennsylvanian rocks in its lower part, Middle and Upper Pennsylvanian rocks above, and beds of early Permian age at the top. In contrast, the Amsden and Tensleep represent only earlier Pennsylvanian time. Although many details remain to be worked out, it appears that the sea attained a maximum extent in early Middle Pennsylvanian time (Desmoinesian) and retreated both eastward and westward through later Pennsylvanian time, restricting the younger beds to the eastern and southwestern parts of the state.

Paradoxically, the Casper Mountain area remained emergent during the greater part of the Pennsylvanian Period and was not the site of deposition until late in Pennsylvanian time. The Casper formation there is of latest Pennsylvanian and earliest Permian age. Central Wyoming was emergent through the last half of the Pennsylvanian Period and the entire state was emergent early in Permian time.

The Pennsylvanian rocks of Wyoming are among its most important oil producers. The Tensleep is productive in a host of fields, most of which are in the Bighorn and Wind River basins, and the Darwin sandstone, at the base of the Amsden, is locally productive in the same area. Sandstones in the Minnelusa produce in a number of fields in eastern Wyoming, the best known being the Lance Creek field. The Casper sandstone yields oil in Laramie Basin fields.

Permian.—In the Middle Permian, an arctic sea encroached from the north over Wyoming, and in it was deposited the well-known Phosphoria formation (Fig. 8). In western Wyoming this formation has a basal black phosphatic shale unit and an upper cherty limestone unit, aggregating about 300 feet of beds. Commercial beds of phosphate rock are found in the basal shale member. The environment of deposition through the phosphate rock area must have been unique. In addition to beds of high-grade phosphate rock, a siltstone carries vanadium in an amount exceedingly high for a sedimentary rock. The vanadium is believed to have been a primary precipitate on the sea floor. It has been pointed out that the vanadium pentoxide contained below one square meter

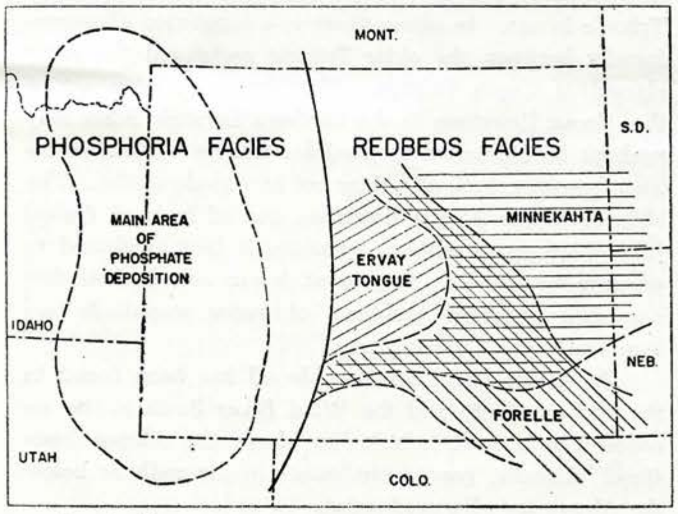


Fig. 8. Map showing the distribution of the Permian facies and of limestone tongues of the Phosphoria formation.

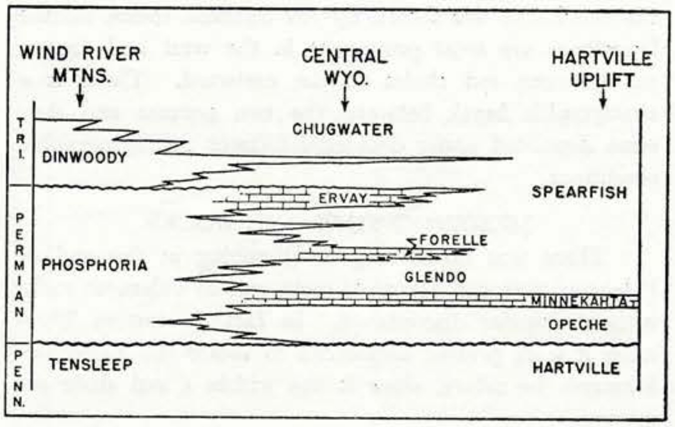


Fig. 9. Stratigraphic diagram showing the relations of the Permian rocks between the Wind River Mountains and the Hartville uplift.

of surface of the vanadiferous siltstone is equivalent to that contained in a column of modern sea water one meter square and 32,000,000 meters high. In addition to phosphorus and vanadium, over 30 other elements, many rare ones, are known to occur in appreciable amounts in the shale member. The peculiar environment which fostered the deposition of phosphate rock and other rocks of peculiar composition was restricted to the area where Wyoming, Utah, Idaho and Montana adjoin.

On the eastern margin of the Phosphoria sea there was an interfingering of the marine Phosphoria facies with a redbed facies (Fig. 9). Red shale, the Opeche, was deposited to the east while basal Phosphoria beds were accumulating to the west. A spread of the sea resulted in the deposition of the Minnekahta limestone. A recession resulted in the westward shift of the redbed facies, followed by an advance during which the Forelle limestone was deposited. The outline of the Forelle sea was quite different from that of the Minnekahta sea. A second recession resulted in a time of more widespread redbed deposition. Toward the end of Phosphoria time a minor submergence resulted in the deposition of a limestone tongue, called the Ervay, which carries a fauna characteristic of the upper Phosphoria. The Phosphoria sea completely withdrew from Wyoming in late Permian time.

Dolomites in the Phosphoria formation are important oil producers in the Bighorn Basin and the western part of the Wind River Basin. The eastern productive limit is locally controlled by a change from pervious dolomite to dense anhydritic dolomite as the redbed facies is approached, and some oil pools appear to have been trapped down-dip from this permeability barrier.

Summary.—The late Paleozoic rocks show complex facies changes, in which respect they are quite unlike the earlier Paleozoic rocks. Pennsylvanian marine limestones are most conspicuous in eastern Wyoming and tongue out between sandstones to the westward. Opposite conditions are shown by the Permian rocks; marine limestones are most prominent in the west and tongue out between red shales to the eastward. There is a stratigraphic break between the two systems and they were deposited under decidedly diffrent paleogeographic conditions.

MESOZOIC TIME AND ROCKS

There was no folding in Wyoming at the end of Paleozoic time and Mesozoic rocks rest on Paleozoic rocks without angular discordance. In fact, in eastern Wyoming it is at present impossible to locate the Paleozoic-Mesozoic boundary, since it lies within a red shale sequence.

Rocks of Triassic, Jurassic and Cretaceous age were deposited everywhere over the state. Where absent today they have been removed by post-Cretaceous erosion.

Triassic.—Early in Triassic time a sea reached southeastern Idaho and somewhat later spread eastward into Wyoming. The initial deposits in this sea constitute the Dinwoody formation (Fig. 10, Fig. 11). There is an eastward overlap of Dinwoody sediments so that only the younger part of the Dinwoody of Idaho is present in Wyoming. The tawny-colored Dinwoody siltstones and shales are replaced in eastern Wyoming by red shales which were obviously deposited under different environmental conditions. At one time, however, the sea spread with the resultant deposition of a Dinwoody tongue which can be recognized over a rather wide area in central and southeastern Wyoming. Following the deposition of the Dinwoody, redbed deposition migrated westward, so that while a part of the Chugwater red shale was being deposited in Wyoming, the Woodside red shale was being deposited in southeastern Idaho. With the return of normal marine deposition in Idaho, during which time the thick Thaynes limestone was deposited, the redbed environment was pushed to the eastward and deposition of

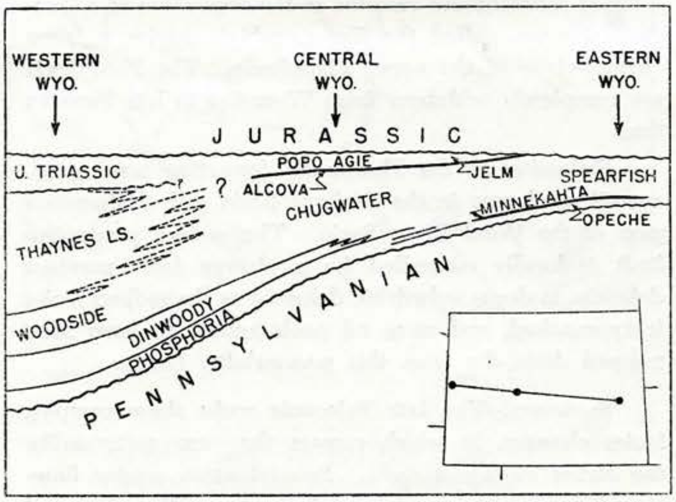


Fig. 10. Stratigraphic diagram showing relations of Triassic rocks between western and eastern Wyoming.

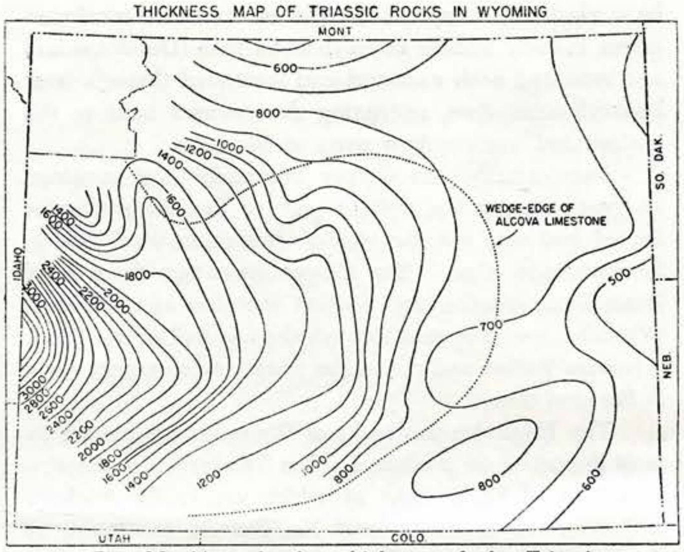


Fig. 11. Map showing thickness of the Triassic rocks of Wyoming.

Chugwater redbeds continued in central and eastern Wyoming.

At the end of Chugwater time there was a marine invasion which covered a large part of Wyoming, and the thin but conspicuous Alcova limestone was deposited. The reptiles and invertebrates found in the Alcova suggest a marine origin and it is generally regarded as a tongue of the Thaynes limestone. If this is true, then the exact part of the Thaynes represented by the Alcova remains unknown. It must be emphasized, however, that the relation of the Alcova to the Triassic rocks of the thicker geosynclinal sections is very obscure, and the Alcova may represent some unit other than the Thaynes.

The stratigraphy of the Triassic beds younger than the Alcova is not well understood. These rocks comprise varicolored clays, sandstones and conglomerates which are called Popo Agie in the Wind River Basin and Jelm in central Wyoming, and are generally classed as Late Triassic in age. In places there is a suggestion of unconformity between the older Triassic rocks and the rocks classed as Upper Triassic. The abrupt thinning out of the Alcova limestone in the northern Laramie Basin may perhaps be attributed to pre-Jelm erosion. Some geologists, however, believe it thins out by non-deposition. The absence of the Alcova limestone and of beds of typical Jelm lithology in eastern Wyoming is best attributed to pre-Jurassic erosion. At present, it can only be said that numerous unsolved problems of major magnitude are associated with Triassic rocks.

In recent years considerable oil has been found in the Bighorn Basin and the Wind River Basin in the so-called Curtis sand, which lies above the Alcova limestone. Locally, porous sandstones in the redbeds below the Alcova are also productive.

Jurassic.—The most complete Jurassic sections, and the thickest ones, are found in westernmost Wyoming

(Fig. 12, Fig. 13). A thick basal sandstone, the Nugget, is overlain by a thick marine limestone, the Twin Creek. A red siltstone unit, the Preuss, is overlain by a thin marine unit, the Stump sandstone, which carries the well-known and widespread **"Belemnites"** (**Pachyteuthis**) fauna. These units aggregate nearly 5,000 feet of strata in westernmost Wyoming. The Jurassic beds thin eastward so that in eastern Wyoming they are represented by no more than several hundred feet of strata.

In addition to eastward thinning, marked facies changes characterize the Jurassic rocks. The cross-bedded Nugget sandstone thins eastward with little change in lithology. Its wedge-edge has been accurately determined in central Wyoming, but there is some question as to whether or not a similar cross-bedded sandstone at the base of the Jurassic section in the Laramie Basin is actually the Nugget sandstone. The lower Twin Creek limestone is replaced to the eastward by redbeds and anhydrite, known as the Gypsum Spring formation. In the Big Horn Basin, where the Nugget is absent, the Gypsum Spring rests directly on Triassic rocks. The upper part of the Twin Creek, the Preuss and the Stump, are represented to the eastward by the Sundance formation. East of the wedge-edges of the Nugget and the Gypsum Spring, only Sundance is present. Lithologically the Sundance comprises a variable sequence of different sorts of sandstones and shales and the distinctive marine **Pachyteuthis** fauna occurs everywhere in its upper part. The horizon of this fauna may be further used to indicate the geosynclinal nature of western Wyoming in contrast to the shelf-like nature of eastern Wyoming. The **Pachyteuthis** fauna lies at least 25,000 feet above pre-Cambrian rocks in southeastern Idaho. In southeastern Wyoming, the **Pachyteuthis** fauna lies less than 2,000 feet above pre-Cambrian rocks.

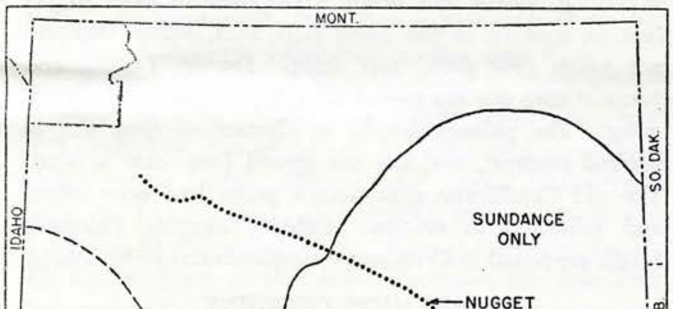


Fig. 12. Map showing distribution of the Jurassic formations in Wyoming.

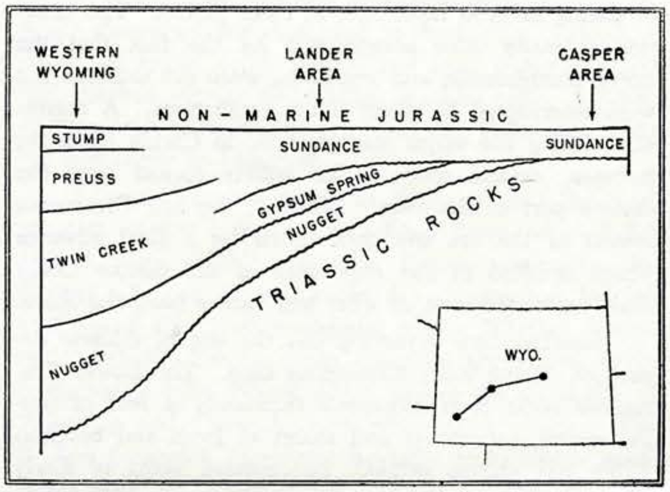


Fig. 13. Stratigraphic diagram showing relations of Jurassic formations between western and eastern Wyoming.

In the southern part of the Laramie Basin, marine Sundance rocks are absent, and the only representative is a pink cross-bedded sandstone which may be the Nugget. Some geologists, however, have correlated it with a sandstone near the middle of the Sundance of central Wyoming.

With the termination of marine conditions at the end of Sundance time, the continental variegated shales of the Morrison formation were spread completely over Wyoming. The Morrison of eastern Wyoming has yielded the remarkable dinosaurian faunas which are well known to all geologists. The Morrison is quite thin over most of Wyoming, comprising only a few hundred feet of distinctive strata. It thickens in western Wyoming, and its exact limits have not been determined, since there it is overlain by somewhat similar beds of Lower Cretaceous age. It is difficult to draw the dividing line between Jurassic and Cretaceous strata in western Wyoming and in adjacent Utah and Idaho.

Jurassic rocks produce oil in Wyoming over a zone which was marginal to the Sundance shore, and which runs in a northeast-southwest direction through the southeastern part of the state.

Cretaceous.—In a simple manner, the Cretaceous strata of Wyoming represent an example of deposits associated with a marine transgression followed by regression. Ideally, in eastern Wyoming, the transgressive cycle is represented by basal sandstones, overlying marine shales, then by calcareous sediments laid down during the time of maximum submergence. The regressive cycle is represented by marine shale, then sandstone, then continental coal-bearing strata deposited in the wake of the regressive sea. The relation is complicated, however, in that the Cretaceous rocks are made up of major lithologic facies which cross time-lines and change in age from place to place. A continental coal-bearing sequence in one place may be the time equivalent of marine sandstones, or shales, or even limestones at other places. The situation is made more complicated by the fact that the major transgression and regression were not uniform but were interrupted by many minor oscillations. A regression during the major transgression, in Carlile time, for instance, caused sands to be widely spread over the eastern part of the state. Likewise, the late Cretaceous retreat of the sea was interrupted by a final advance which resulted in the deposition of the marine Lewis shale far to the west of what had earlier been the shore.

Southwestern Wyoming was the site of thickest deposition during Early Cretaceous time. The Lower Cretaceous rocks there aggregate thousands of feet of conglomerates, sandstones and shales of fresh and brackish water and marine origin. In contrast, rocks of Early Cretaceous age in eastern Wyoming are only a few hundred feet thick. During the earlier part of the Late Cretaceous Epoch (Coloradoan), southwestern Wyoming remained subsident, and a very thick succession of clastic rocks accumulated. The Coloradoan rocks of eastern Wyoming comprise about 1,000 feet of shales and limestones. Deposition apparently terminated in western Wyoming at about the end of Coloradoan time.

A new subsident area which became a site of thick deposition then became evident in southcentral Wyoming in what is now the Hanna Basin area, and persisted through the remainder of Cretaceous time. As much as 8,000 feet of Pierre equivalents were deposited in the Hanna trough, whereas only 2,000 to 4,000 feet of strata of that age are present elsewhere in the state. During latest Cretaceous time, deposition centered in the Hanna trough, where 6,000 feet of strata of Fox Hills and Lance age accumulated. Beds of those ages thin in all directions away from the Hanna trough, and are much thinner, or absent, on the margins of the state.

The two areas of maximum deposition are brought

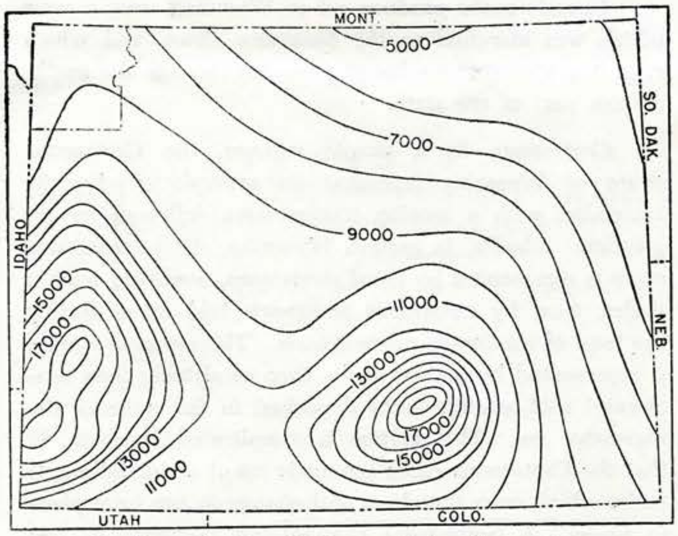


Fig. 14. Map showing thickness of the Upper Cretaceous rocks of Wyoming. (After J. B. Reeside, Jr.)

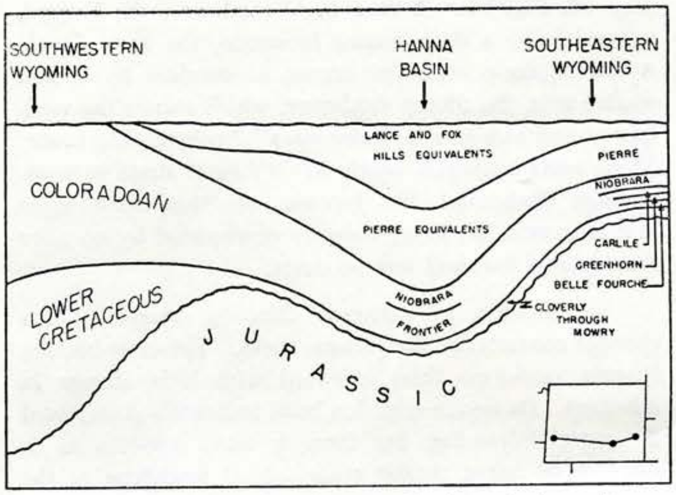


Fig. 15. Stratigraphic diagram showing relations of Cretaceous time units in Wyoming.

out on the thickness map (Fig. 14). If Lower Cretaceous strata were included, the only modification of the map would be in an increased overall thickness in southwestern Wyoming to aggregate over 25,000 feet of beds. The excessive thickness there is attributable to great thickness of Lower Cretaceous and Coloradoan rocks, as shown in the cross-section (Fig. 15). The abnormal thickness in the Hanna Basin area is attributable to an unusually thick section of rocks younger than Coloradoan.

Sandstones of Cretaceous age produce oil and gas in Wyoming from the east front of the deformed belt of western Wyoming eastward to the Nebraska line, and entirely across the state in a north-south direction. Important Lower Cretaceous sandstones are the Lakota, Dakota and Muddy (or Newcastle); important Upper Cretaceous ones are the sandstones in the Frontier, the Shannon, the Sussex, and sandstones in the Mesaverde.

Summary.—Mesozoic rocks are thickest in western Wyoming, where they attain a thickness of over 30,000 feet, in contrast to the Black Hills area, where they are not much over 6,000 feet thick. During Triassic and Jurassic time the sea spread from west to east over Wyoming. The paleogeography of Cretaceous time was in marked contrast, and the sea spread from east to west. The old Cordilleran geosynclinal prism had been raised and subjected to erosion. Pebbles carrying Paleozoic fossils are found in Cretaceous conglomerates in Wyoming.

LARAMIDE OROGENY

The period of intense folding and faulting which outlined the major structural features of Wyoming, the Laramide orogeny, extended over a considerable period of time. The late Cretaceous strata of southeastern Wyoming show evidence indicating that major folds had started to grow late in the Cretaceous. The mountain axes and the major basins were well outlined by Paleocene time. It is conceived that as soon as the uplifted areas came into being, they were subjected to erosion, with consequent deposition in the basins. In basins in which Paleocene rocks lie near the mountains there is angular unconformity between the Paleocene rocks and the Cretaceous rocks. In basins where the Paleocene rocks have been etched far back from the mountain areas, it is difficult to locate the Cretaceous-Paleocene boundary, and in places there may have been continuous deposition between Mesozoic and Cenozoic time. In certain areas, strong folding and thrust faulting followed Paleocene deposition, with further deformation of the Paleozoic and Mesozoic rocks and moderate to strong deformation of the Paleocene rocks. By the end of Paleocene time, the major structural elements of Wyoming had attained essentially their present form.

Structural trends in Wyoming are mainly north-south, although there are local deviations (Fig. 1). Most of 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 western Wyoming differ from those to the east in that they are fundamentally a series of low-angle thrust blocks in which pre-Cambrian rocks are not exposed, as they are in other mountains. The intermontane basins are large downwarped areas which in themselves are made up of minor anticlines and synclines. The basins, too, may be strongly asymmetrical and the deepest structural parts of most basins lie fairly close to one of the bounding mountain uplifts.

The minor structures lying within the basins are anticlinal and synclinal folds which may be concentrically arranged around a basin, as in the Big Horn Basin, or may trend at an angle to a mountain axis and plunge off into a basin obliquely, as in the Wind River Basin. The minor anticlines are generally asymmetrical and on the steep flank of strongly asymmetric ones beds may stand vertically or be overturned. This type 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 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 structures into a number of individual units. Normal faults commonly die out at depth so the deeper horizons are unfaulted. Conversely, thrust faults appear to have their maximum displacements at depth and to die out upward. Wells drilled on some anticlines which appear unfaulted at the surface have passed through thrust faults at depth.

CENOZOIC TIME AND ROCKS

Sedimentary rocks representing all Tertiary epochs are present in Wyoming and have yielded an amazing fossil record of mammalian evolution. They are of nonmarine origin, and comprise sediments derived from adjacent mountains and deposited in the basins. Paleocene rocks are found in all basins, and near mountains rest with marked angular discordance on older rocks. Locally conglomerates are conspicuous and the Paleocene rocks are commonly coal-bearing.

Eocene rocks are found in all basins but the most complete section is in the Green River Basin, where 5,000 feet of lower, middle and upper Eocene rocks were deposited. Lower Eocene rocks are represented by the varicolored clays and sandstones of the Wasatch formation. Middle Eocene rocks comprise the Green River formation, a lake deposit which carries the oil shales of Wyoming and Colorado now receiving attention. The Bridger formation represents fluviatile rocks which interfinger with the Green River. Upper Eocene rocks are present in the Green River Basin and in a small area in the Wind River Basin.

Oligocene rocks are best developed in central and southeastern Wyoming. These rocks contain a great amount of volcanic ash. Miocene and Pliocene rocks are found locally in a number of places but are conspicuous east of the Laramie Range and in the Platte Valley of southeastern Wyoming, where they attain a thickness as great as 1,600 feet.

There had been no igneous activity in Wyoming since pre-Cambrian time, but during Tertiary time volcanic activity centered in the Yellowstone Park area. These Tertiary volcanic rocks occupy the surface over a wide area in the northwestern part of the State.

Evidence of Tertiary deformation is shown in all parts of the State. Eocene rocks are moderately to strongly folded in places. Oligocene rocks are warped and faulted. Miocene rocks in the Platte Valley dip as much as 30 degrees and Pliocene rocks in the same area have been tilted and displaced by faults.

Some oil and gas is produced from Tertiary rocks in Wyoming but they are not nearly as important producers as are the Paleozoic and Mesozoic rocks, perhaps because of their nonmarine nature. Most Tertiary production is in the western and southwestern parts of the state, in and around the Green River Basin. Rocks of Paleocene age yield gas in the Big Piney field, the Table Rock field, the Hiawatha field and the Shell Creek field. Lower Eocene rocks are productive of oil and gas in the Hiawatha field. Oil and gas have been found in uncommercial quantities in Oligocene rocks in the Shawnee area, Converse County, but apparently had their source in underlying Cretaceous strata.

During Pleistocene time the mountains were subjected to alpine glaciation and were sculptured to their present rugged forms. Thus we come to the present time of sagebrush deserts, snow-capped mountains, and good trout fishing.