THE GEOLOGICAL SURVEY OF WYOMING

HORACE D. THOMAS, STATE GEOLOGIST

BULLETIN NO. 42

THE GEOLOGICAL HISTORY AND GEOLOGICAL STRUCTURE OF WYOMING

BY

Horace D. Thomas

UNIVERSITY OF WYOMING

Laramie, Wyoming

October, 1949

GEOLOGICAL TIME-ROCK TABLE

ERAS	PERIODS	EPOCHS	SERIES	REPRESENTATIVE WYOMING ROCK UNITS
CENOZOIC	Quaternary	Recent		
		Pleistocene		Glacial deposits
	Tertiary	Pliocene Miocene		North Park fm.
		Oligocene		White River group
		Eocene		Wasatch, Wind River fms.
		Paleocene		Fort Union, Hanna fms.
MESOZOIC	Cretaceous	Gulfian	Upper	Many formations
		Comanchean	Lower	Cloverly fm.
	Jurassic		Upper Middle	Morrison fm. Sundance fm.
			Lower	Nugget ss.
	Triassic		Upper	Popo Agie, Jelm fms.
			Middle	
			Lower	Dinwoody, Chugwater fms.
PALEOZOIC	Permian	Ochoan	Upper	
		Guadelupian Leonardian	Middle	Phosphoria fm.
		Wolfcampian	Lower	Upper Casper fm.
	Pennsylvanian	Virgilian Missourian	Upper	
		Desmoinesian Atokan	Middle	Tensleep ss. ?
		Morrowan Springeran	Lower	Amsden fm. ?
	Mississippian	Chesterian Meramecian	Upper	Brazer ls.
		Osagian Kinderhookian	Lower	Madison ls.
	Devonian	Chautauquan Senecan	Upper	Darby fm.
		Erian	Middle	
		Ulsterian	Lower	
	Silurian	Cayugan	Upper	
		Niagaran	Middle	
		Medinan	Lower	
	Ordovician	Cincinnatian	Upper	Bighorn dol.
		Mohawkian Chazyan	Middle	Whitewood shale
		Beekmantownian	Lower	
	Cambrian	Croixan	Upper	Gallatin, Deadwood fms.
		Albertan	Middle	Flathead-Gros Ventre fms.
		Waucoban	Lower	
PROTEROZOIC ARCHEOZOIC	Pre-Cambrian time			Complex igneous and metamorphic rocks

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Lecture sponsored by the Distinguished Lecture Committee
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

presented before

The Department of Geology of the University of Wisconsin, the Department of Geology of the University of Illinois and the Illinois Geological Survey, the Indiana-Kentucky Geological Society, the Mississippi Geological Society, the Tulsa Geological Society, the Kansas Geological Society, the Dallas Geological Society, the Fort Worth Geological Society, the North Texas Geological Society, the Houston Geological Society, the South Texas Geological Society, the East Texas Geological Society, the West Texas Geological Society, the Panhandle Geological Society, the Rocky Mountain Association of Geologists, the New Mexico Geological Society and the Wyoming Geological Association.

April, 1949

UNIVERSITY OF WYOMING
Laramie, Wyoming
October, 1949

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ILLUSTRATIONS

THE GEOLOGICAL HISTORY AND GEOLOGICAL STRUCTURE OF WYOMING[1]

by

Horace D. Thomas[2]

INTRODUCTION

It is my very pleasant commission to describe the geological history and geological structure of Wyoming in such a fashion as to give a generalized picture to those not familiar with Wyoming geology. Consideration will be given to the occurrence of petroleum in the State and to its relation to the stratigraphic and structural history. In generalizing, I do not wish to give the impression that Wyoming geology is cut and dried. Indeed, there are many controversial points. The details of the stratigraphy of any one of the geological systems represented have hardly been touched. The Silurian is the only system not presenting problems, simply because it is the only one lacking in Wyoming. Obviously such a paper as this brings together the work of innumerable geologists and it would be impossible to give credit to all who have contributed.[3] Suffice it to say, I have drawn freely on everything any one has ever done on the geology of Wyoming.

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[1]Lecture presented under the sponsorship of the Distinguished Lecture Committee of the American Association of Petroleum Geologists, April, 1949.

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[2]Professor of Geology and State Geologist of Wyoming, University of Wyoming, Laramie.

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[3]The kind help of colleagues at the University of Wyoming can not be dismissed without mention. Dr. J. D. Love, of the U. S. Geological Survey and Professors S. H. Knight, D. L. Blackstone, Jr., and P. O. McGrew freely gave advice and criticism. Wallace Bell, graduate student in geology, assisted in the preparation of the illustrations.

PHYSIOGRAPHY

By way of introduction, a word should be said about the physical features of the State. Wyoming is characterized by major mountain ranges which are separated by intermontane basins (Fig. 1). The basins are generally flat-floored and lie at elevations ranging from 4,000 to 7,000 feet above sea level. Mountains rise abruptly from the plains and reach a maximum elevation of 13,785 feet at Gannett Peak in the Wind River Range. There are, of course, marked climatic variations, but the region in general is semi-arid. Because of this fact, and because there is no mantle of glacial material, rock exposures are excellent.

OCCURRENCE OF PETROLEUM

Wyoming is now receiving great attention in petroleum exploration and it seems appropriate, therefore, to remark upon the occurrence of petroleum in the State before passing to the geological history and structure. Wyoming now ranks seventh in the oil-producing states and the 1948 production was approximately 55 million barrels—a record production.

Mode of accumulation.—Essentially all oil produced comes from the conventional anticlinal trap. Closed structures may or may not produce oil. Some structures with large closure have, so far, proved barren. Other structures with relatively small closure have been good producers. In some 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.

Anticlines are rarely completely filled with oil and usually only the structurally highest part of the total area within the lowest closing contour is productive. In addition, the size of the areas over which different sands produce in a multiple-zone field is extremely variable. The productive area in one sand may be 10 to 20 times as large as the productive area of a higher or lower sand.

Fault traps have not been important producers, except where individual fault blocks have acted as units along anticlinal axes, in which case accumulation is controlled primarily by the anticline, with faulting a subsidiary feature. Some new fields, however, seem to be fundamentally dependent on faulting as a control of accumulation. As yet little attention has been given to fault trap possibilities but, because of the prevalence of faulting, it seems possible that fault traps may prove to be more common when greater attention is focused on their possibilities.

The only important fields which are fundamentally of the stratigraphic type are those located along the west flank of the Black Hills, such as the Osage and Mush Creek fields. In these fields, accumulation is related to lenticularity and to permeability changes in a Cretaceous sand. The original discovery was based on surface seeps, followed later by random drilling. The chances for the discovery of other pools of the stratigraphic type seem rather good. There are many sandstones which are productive in certain areas but which thin out and are absent in others. Lensing sands are also known to be present in parts of the sedimentary section. Exploratory thinking is turning to the possibility of stratigraphic type traps, but actual drilling will probably

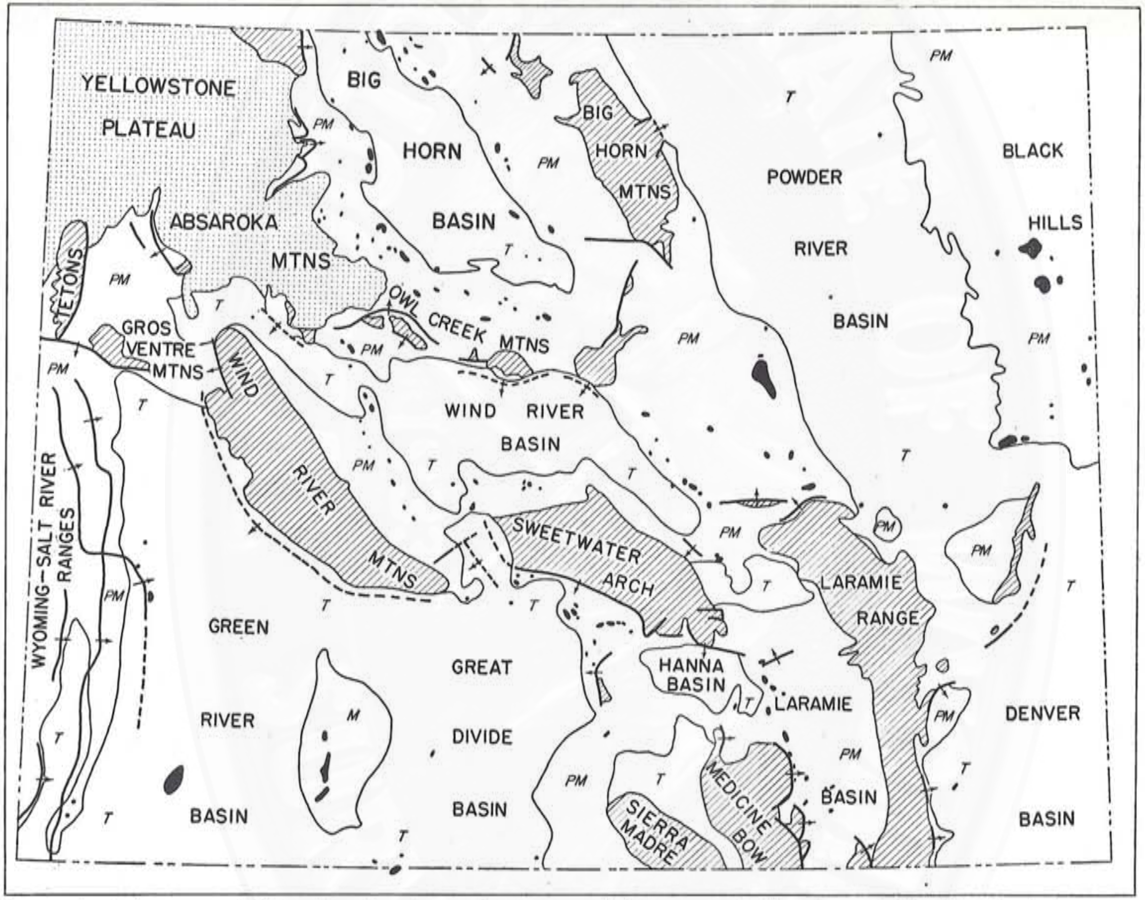

FIGURE 1. Index map of Wyoming showing major structural features and oil and gas fields. Pre-Cambrian areas are cross hatched. Paleozoic and Mesozoic areas are indicated by the symbol PM. Tertiary areas are indicated by the symbol T. Tertiary volcanics are shown by coarse stipple. Faults are shown as heavy lines with arrows showing direction of movement of hanging wall of thrust faults.

await the time when more surface and subsurface stratigraphic information is available.

Distribution of oil and gas fields.—Of the 23 counties in Wyoming, 18 have commercial oil or gas production. It is possible that all counties will prove productive. The ruled areas on the index map (Fig. 1) are the pre-Cambrian cores of the mountain masses, and may be eliminated as possible productive areas. The dotted area in the northwest is occupied by volcanic rocks and this region offers little hope for oil production. Over most of the remaining area, however, there are chances for the development of new fields.

Essentially all the producing fields are located around the margins of the basins and represent anticlines in Paleozoic and Mesozoic rocks which are observable and mappable at the surface. Many of them are so beautifully exposed as to be recognizable by almost anyone with even an elementary understanding of geology (Fig. 2). Most of the fields are on anticlines which have been known for many years and which have produced oil

FIGURE 2. Aerial photograph of the Circle Ridge anticline, Fremont County, Wyoming. (Photograph courtesy Soil Conservation Service.)

FIGURE 3. Map showing new oil and gas fields, and new pay zones in old fields, discovered in Wyoming between 1942 and 1948.

or gas for long periods. Some anticlines found long ago have become fields only in the past few years because deep drilling has come into practice only recently. Productive depths in these marginal fields ordinarily range from 1,000 to 6,000 feet.

It has been in the past two years only that oil and gas fields have been found out in the basins in areas where the surface is occupied by Tertiary beds which rest unconformably on folded older beds. The Church Buttes field lies in the center of the Green River Basin. Other fields have been found well out in the Wind River, Big Horn and Powder River basins.

New discoveries.—The present oil activity in Wyoming dates back to about 1942, and between that time and the present many important new 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. Discoveries are widely scattered over the State (Fig. 3). In the seven-year period, 1942-1948, 56 new fields were found. Some of these have proved, or will prove, to be important fields; others will be small or even noncommercial. In the same period new pay zones were developed in 40 old oil or gas fields.

This record of discoveries is attributable to an intensive geological and geophysical exploratory program and to deep drilling. Many of the basin discoveries have been made through seismic exploration. The first 10,000-foot well drilled in Wyoming was in 1939. The first discovery made below 10,000 feet was in 1946. Six fields now produce from depths in excess of 10,000 feet and the deepest production is from 14,300 feet in the West Poison Spider field. It is of interest to note that the sand which produces at that depth is exposed at the surface only five miles away.

GEOLOGICAL HISTORY AND GEOLOGICAL STRUCTURE

INTRODUCTION

The geological history and the structure of Wyoming constitute my main topic. To cover the long and complicated geological story, readable in the rocks of the State, within a reasonably short time necessitates speed and generalization. To treat the 1,800,000,000 years of Wyoming earth history in the available time, I shall have to proceed at the rate of 60,000,000 years per minute of discussion. If the discussion is restricted to Cambrian and later history, the rate will have to be 17,000,000 years per minute of discussion. It is necessary, therefore, hurriedly to whisk back to pre-Cambrian time.

PRE-CAMBRIAN TIME AND ROCKS

The pre-Cambrian rocks of Wyoming are exposed in the cores of most of the mountain ranges. The 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 this 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 the region 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. 4, Fig. 5). 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 northwestern third of the State. Continued expansion took place during Upper Cambrian (Croixan) time and all but the southeastern part of the State was submerged. The sediments deposited in the Upper 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 considerably older than the upper beds of the Deadwood. Latest Cambrian rocks may have been removed by pre-Ordovician erosion in the Wind River Mountains. Wyoming then was completely emergent at the end of Cambrian time.

Ordovician.—The early Ordovician, or Beekmantownian, sea covered southeastern Idaho and adjacent Utah, and 1,200 feet of early 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 they have been penetrated by wells drilled north of the Hills.

Wyoming was then emergent until late in Ordovician time, when the northern and western parts of the State were submerged and, during Richmond time, the Big Horn dolomite was deposited. The Bighorn is a dense, massive, pure dolomite which in the Wind River Mountains has a basal sandstone 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.—In summary, sediments of Middle and Upper Cambrian age are widespread through Wyoming, the Upper Cambrian rocks having the widest distribution. Ordovician rocks are mainly dolomites and are

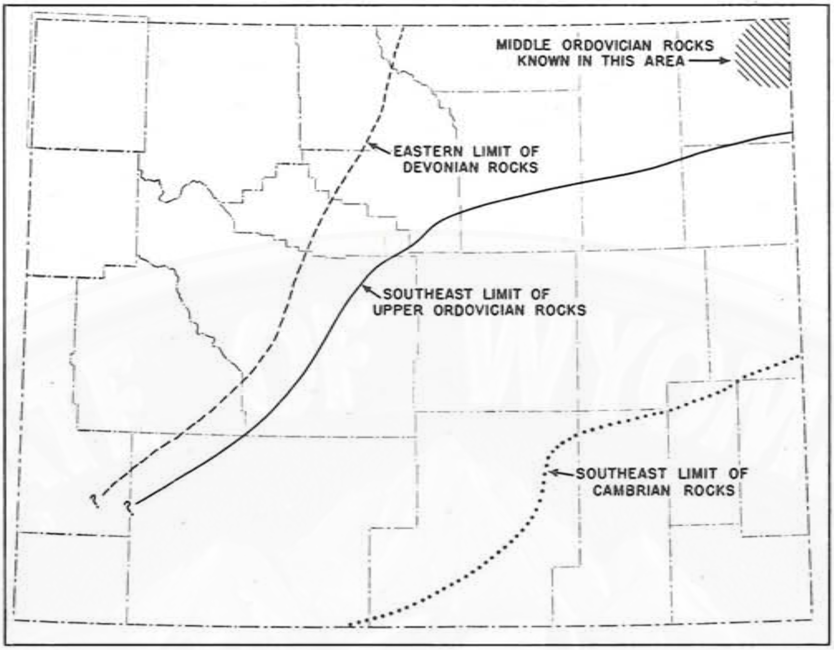

FIGURE 4. Map showing the distribution of Cambrian, Ordovician and Devonian rocks in Wyoming.

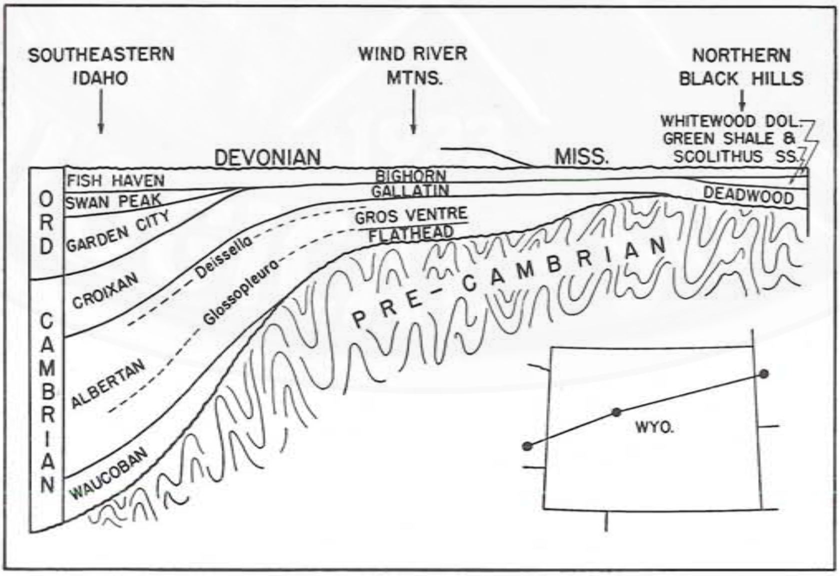

FIGURE 5. Stratigraphic diagram showing the relations of Cambrian and Ordovician rocks between southeastern Idaho and the northern Black Hills.

more restricted in extent 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. No oil is produced from Ordovician rocks.

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. 6).

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

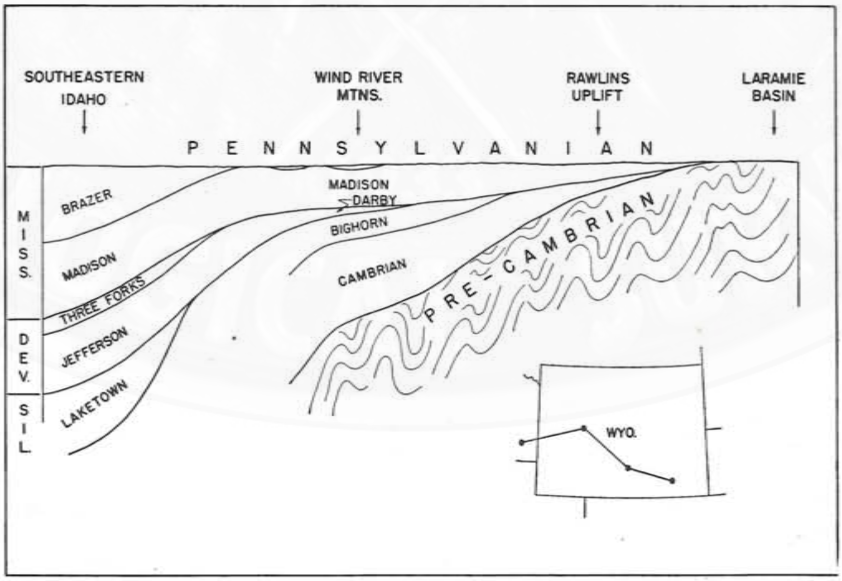

FIGURE 6. Stratigraphic diagram showing the relations of the Silurian, Devonian and Mississippian rocks between southeastern Idaho and the Laramie Basin.

submerged. During early 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. 7). At the wedge-edge the Madison rests on pre-Cambrian granites and 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, late Mississippian rocks, representing the Meramec and Chester series, are known as the Brazer limetsone 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.

The Madison produces oil in a number of fields in the Big Horn Basin, in the Wind River Basin and in the Lost Soldier district.

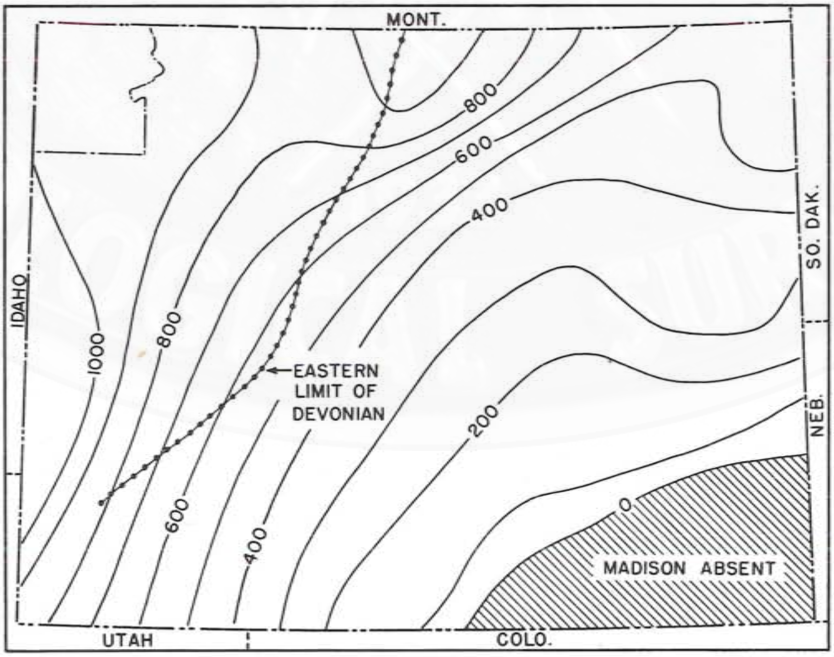

FIGURE 7. Map showing thickness of the Madison limestone.

Summary.—The positive nature of Wyoming is again emphasized by the distribution and thickness of the Silurian, Devonian 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.

Pennsylvanian.—The Pennsylvanian strata of Wyoming present more problems, and are apparently more complex, than 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 striking changes in time-scope from place to place, and by disconcerting and unexpected problems which pop up 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. 8). 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. 9). 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. 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 field. 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. A sandstone at the base of the Amsden, the Darwin sandstone member, has recently been proved for oil production in the Lost Soldier district.

Each of the different formations has a somewhat different time-scope. In southeastern Wyoming, the Casper and Hartville formations represent almost the whole of Pennsylvanian time, and actually extend on into early Permian time. In contrast, the Amsden and Tensleep represent only earlier Pennsylvanian time. Although many of the details remain to be worked

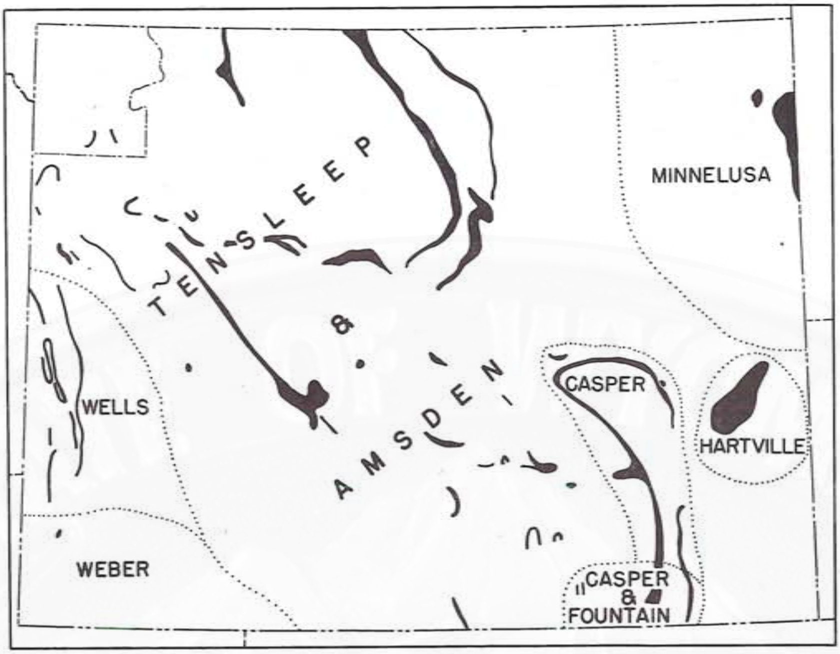

FIGURE 8. Map showing the outcrops and the terminology of the Pennsylvanian formations of Wyoming.

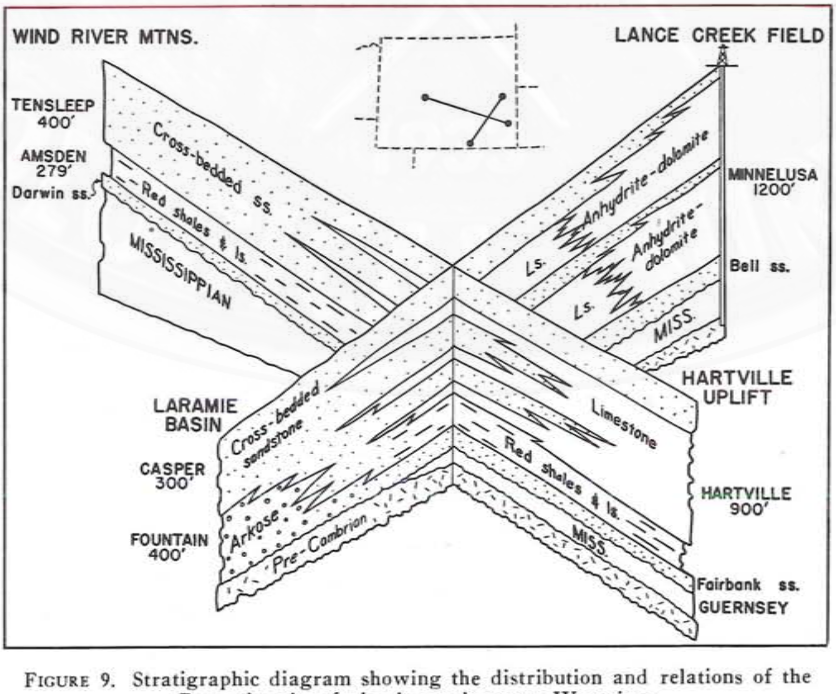

FIGURE 9. Stratigraphic diagram showing the distribution and relations of the Pennsylvanian facies in southeastern Wyoming.

out, it appears that the Pennsylvanian rocks of central and eastern Wyoming represent a sequence in which the facies cross time-lines. It is suggested that the sea attained a maximum extent fairly early in Pennsylvanian time (Des Moines) and retreated eastward through later Pennsylvanian time, restricting the younger beds to eastern Wyoming. Central Wyoming, then, was emergent through later Pennsylvanian time and the State was completely emergent early in Permian time.

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. 10). 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 exceeding large for a sediment. 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 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.

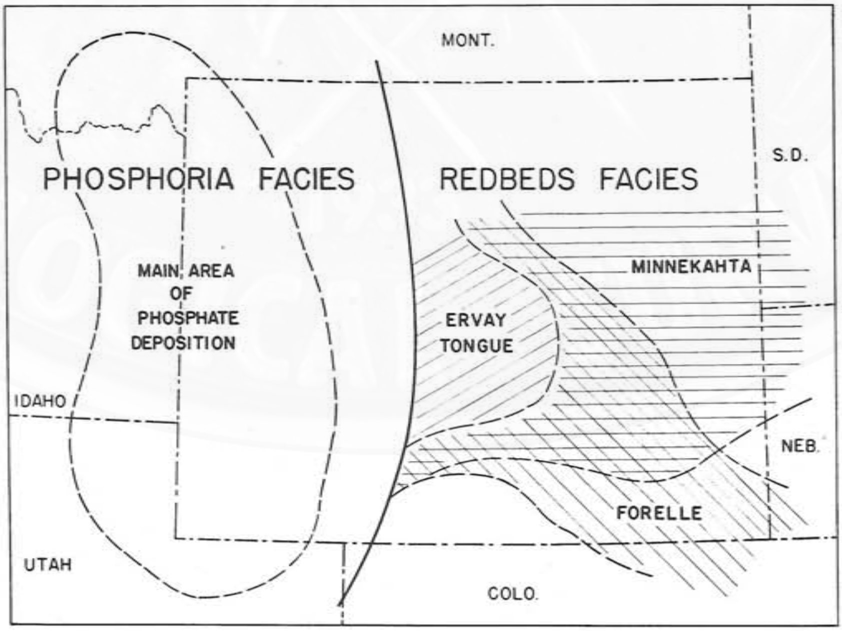

FIGURE 10. Map showing the distribution of the Permian facies and of limestone tongues of the Phosphoria formation.

On the eastern margin of the Phosphoria sea there was an interfingering of the marine Phosphoria facies with a redbeds facies (Fig. 11). 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 redbeds 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 redbeds 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.

Summary.—In summary, the late Paleozoic rocks show complex facies changes, 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 different paleogeographic conditions.

The Pennsylvanian and Permian rocks of Wyoming are important oil producers. Pennsylvanian formations produce in the Big Horn Basin, the Wind River Basin, the Rawlins and Casper districts and the Powder River and Laramie basins. The Phosphoria produces in the Big Horn and Wind River basins.

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

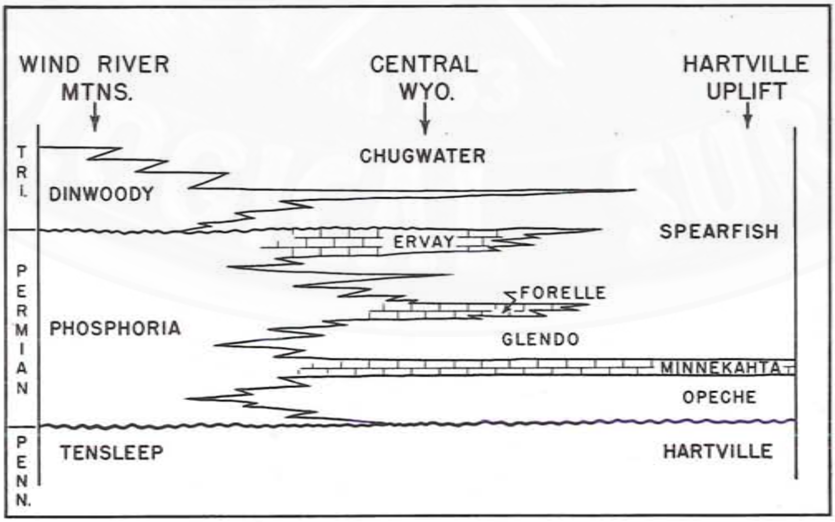

FIGURE 11. Stratigraphic diagram showing the relations of the Permian rocks between the Wind River Mountains and the Hartville uplift.

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. 12, Fig. 13). 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, redbeds 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 redbeds environment was pushed to the eastward and deposition of 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 Upper 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. 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 the Triassic rocks.

Jurassic.—The most complete Jurassic sections, and the thickest ones, are found in westernmost Wyoming (Fig. 14, Fig. 15). 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 wide-spread *Belemnites densus* 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.

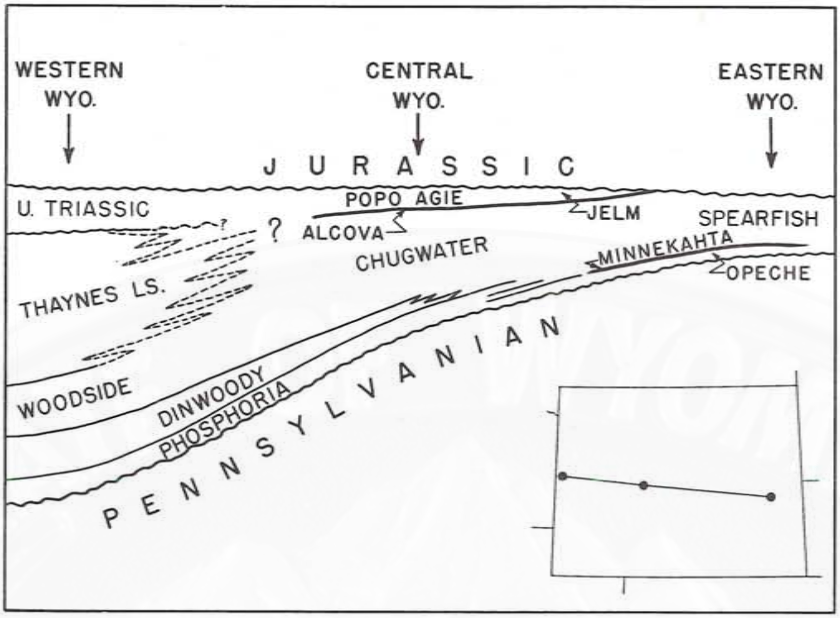

FIGURE 12. Stratigraphic diagram showing relations of Triassic rocks between western and eastern Wyoming.

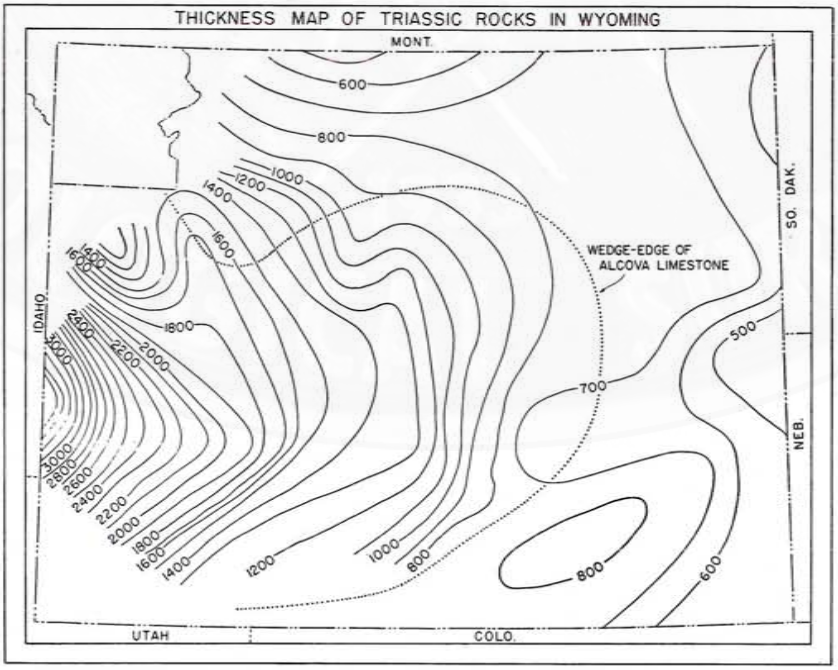

FIGURE 13. Map showing thickness of the Triassic rocks of Wyoming.

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 *Belemnites* 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 foreland nature of eastern Wyoming. The *Belemnites* fauna lies at least 25,000 feet above pre-Cambrian rocks in southeastern Idaho. In southeastern Wyoming, the *Belemnites* fauna lies less than 2,000 feet above pre-Cambrian rocks.

In the southern part of the Laramie Basin, marine Sundance rocks are absent, and the only representative is a pink cross-bedded sandstone which represents a part of the lower Sundance of areas to the north.

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. Indeed, 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, at the end

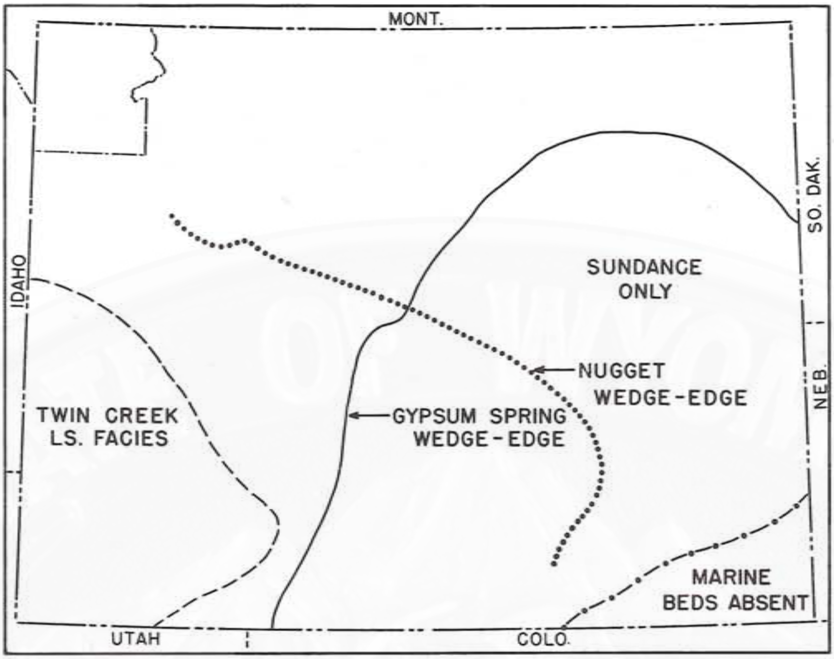

FIGURE 14. Map showing distribution of the Jurassic formations in Wyoming.

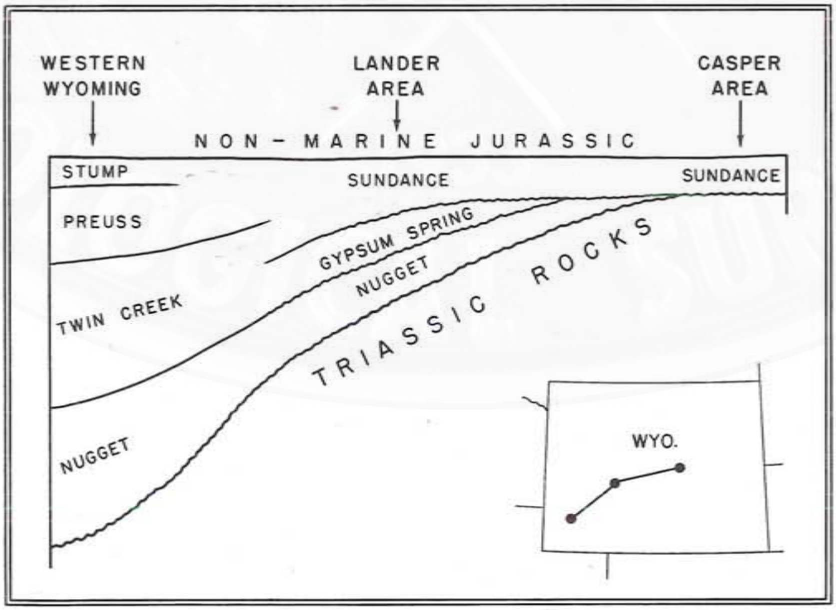

FIGURE 15. Stratigraphic diagram showing relations of Jurassic formations between western and eastern Wyoming.

of 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 marine deposition far to the west of what had earlier been the shore.

The source of the Cretaceous strata was located to the west of Wyoming, since units become thicker and more coarsely clastic in that direction (Fig. 16, Fig. 17). Over most of Wyoming, Lower Cretaceous strata are only a few hundred feet thick but locally, in the southwestern corner of the State, they attain a thickness of several thousand feet. That the southwestern corner of Wyoming was the locus of maximum deposition during early Upper Cretaceous time is evidenced by the fact that the pre-Niobrara rocks retain a fairly uniform thickness of from 1,000 to 2,000 feet over most of the State, but thicken to about 8,000 feet in the southwest corner. During Niobrara time, 500 feet of strata, mainly calcareous, were deposited in eastern Wyoming while 2,000 feet of strata, mainly shale, were deposited in central Wyoming, and 12,000 feet of strata, mainly sandstone, were deposited in western Wyoming. During Eagle and Telegraph Creek time, maximum accumulation again centered in the southwestern corner of the State, where 3,000 feet of strata were deposited. In contrast, there are no rocks of Eagle or Telegraph Creek age in the southeastern part of the State. At the end of Eagle time, a new site of thick deposition became evident in southcentral Wyoming, in what is now the Hanna Basin region. As much as 8,000 feet of Pierre equivalents were deposited in this 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 Fox Hills and Lance strata accumulated. Beds of those ages thin in all directions away from the Hanna trough, and are much thinner, or are absent, on the margins of the State.

The two areas of maximum deposition are brought out on the thickness map modified from that of J. B. Reeside, Jr. If Lower Cretaceous strata were included, the only modification of the map would be in an increased overall thickness in southwestern Wyoming to aggregate about 22,000 feet of beds. The excessive thickness there is attributable to great thickness of Niobrara and older beds, as shown on the cross-section. The abnormal thickness in the Hanna Basin area is attributable to an unusually thick section of rocks younger than Niobrara.

Oil is produced from Cretaceous rocks over all parts of the State, with the Cloverly sandstones and the Frontier sandstones being the most important producers. In 1948 commercial oil was found in the Mesaverde formation, high in the Cretaceous section, in the West Poison Spider field.

Summary.—In 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.

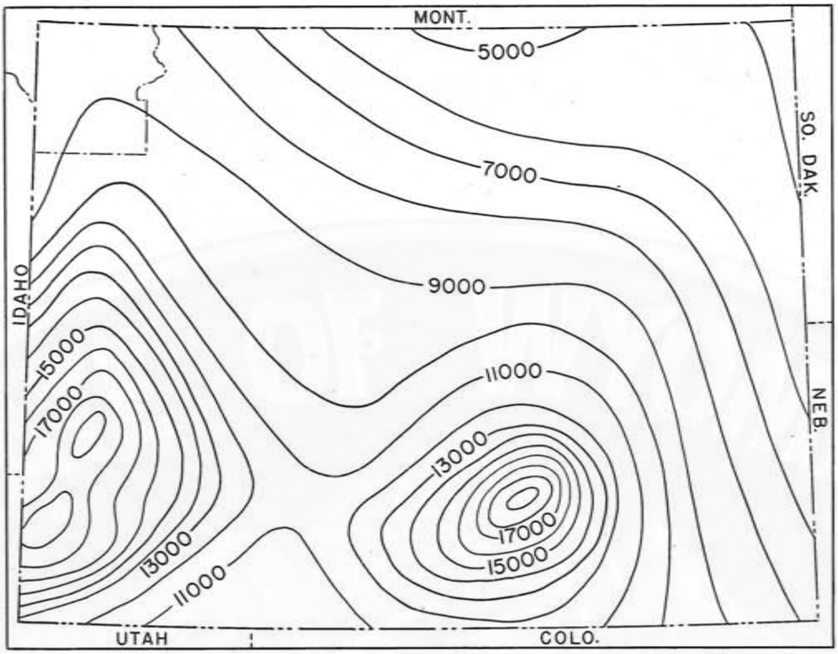

FIGURE 16. Map showing thickness of the Upper Cretaceous rocks of Wyoming (After J. B. Reeside, Jr.)

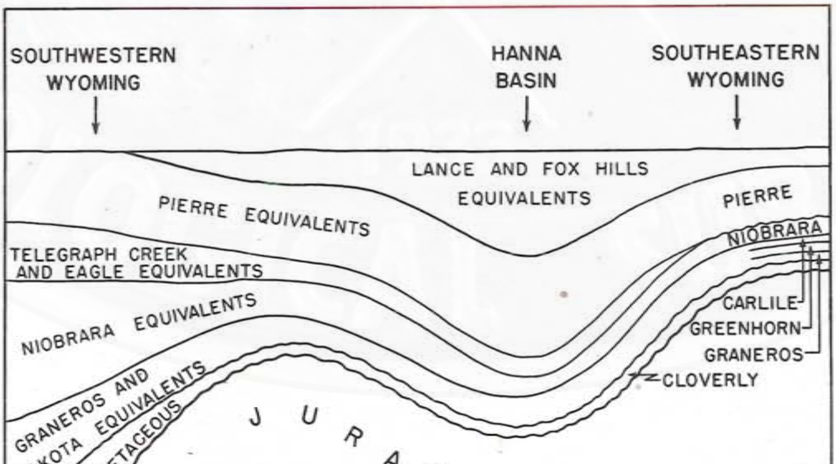

FIGURE 17. Stratigraphic diagram showing relations of Cretaceous time units in Wyoming.

LARAMIDE REVOLUTION

The period of intense folding and faulting which outlined the major structural features of Wyoming, the Laramide Revolution, 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 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 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 asymmetric and on the steep flank of strongly asymmetric ones beds may stand vertically or be overturned (Fig. 2). 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 axes, dividing the structures into a number of individual units. Normal faults commonly die out at depth so that 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. The only commercial oil and gas production from Tertiary rocks is found in a few fields in the Green River Basin, the production being from sands in the Wasatch.

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 in the Platte Valley of southeastern Wyoming, where they attain a thickness as great as 1,600 feet, and east of the Laramie Range.

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.

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

STATE OF WYOMING

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GEOLOGICAL SURVEY