GEOLOGIC HISTORY OF WIND RIVER BASIN, CENTRAL WYOMING[1]

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ABSTRACT

The Wind River basin was part of the stable shelf that lay east of the Cordilleran geosyncline during Paleozoic and much of Mesozoic time. Sediments representing all systems except possibly the Silurian were deposited across the area during repeated transgressions by the epicontinental seas. Most formations are thicker and the stratigraphic sequences more complete in the western part of the basin than in the eastern part; some units disappear eastward because of truncation or non-deposition. Depositional environments, generally marine, commonly were influenced locally by slight fluctuations in sea-level or by tectonic movements. The latter were limited to broad upwarps and downwarps along trends which, with a few exceptions, show little direct relation to structural trends developed later during Laramide deformation.

Near the close of the Jurassic, highlands began to form in the geosynclinal area west of Wyoming, and the major sites of deposition were shifted eastward. During late Cretaceous time the seaways were in eastern Wyoming, and a thick sequence of alternating transgressive, regressive, and non-marine deposits accumulated across the Wind River basin area. The latest Cretaceous marine invasion (represented by the Lewis Shale) covered only the eastern part of the basin.

Laramide deformation began in latest Cretaceous time with downwarping of the basin trough and broad doming of parts of the peripheral areas. The intensity of movement increased through the Paleocene, and culminated in earliest Eocene time in high mountains that were uplifted along reverse faults. A complete record of orogenic events is preserved in the more than 20,000 feet of fluviatile, paludal, and lacustrine strata that accumulated in the areas of greatest subsidence.

Basin subsidence and mountain uplift had virtually ceased by the end of early Eocene time. Clastic debris eroded from the mountains, augmented by volcanic debris, continued to fill the basin during the later stages of Tertiary time. Near the close of the Tertiary the entire region was elevated several thousand feet above its previous level, and the present cycle of erosion was initiated. Normal faulting, perhaps concomitant with regional uplift, locally modified the older structural features.

Introduction

The Wind River basin in central Wyoming is a prime example of the large sedimentary and structural basins that formed in the Rocky Mountain region during Laramide deformation. This extensive structural depression is completely surrounded by broad belts of folded and faulted Paleozoic and Mesozoic rocks: the Granite Mountains on the south; the Wind River Mountains on the west; the Washakie, Owl Creek, and southern Big Horn Mountains on the north; the Casper arch on the east; and the Laramie Mountains on the southeast (Fig. 1). The central part of the basin is covered by nearly flat-lying lower Eocene rocks that overlap all older strata near the basin margins. The structural basin includes about 8,500 square miles.

The first commercial oil well in Wyoming was drilled on Dallas dome, along the western edge of the Wind River basin, in 1884; this region has since become one of the most important oil- and gas-producing areas in the State. At present there are nearly 50 fields in the basin, producing from rocks ranging in age from Mississippian to early Eocene. Production is chiefly from structural traps that are mappable in exposures along the basin margins, or that have been delineated by seismic exploration in the structurally deeper parts of the basin. The discovery of oil and gas in the predominantly non-marine uppermost Cretaceous and lower Tertiary sequence (Lance, Fort Union, and Wind River Formations; Fig. 1) has spurred exploratory drilling in the central part of the basin during the past 5-10 years.

The geology of the Wind River basin and adjacent regions has been studied extensively since the time of the earliest territorial surveys in the 1870s. As a result, much basic information regarding regional structure, stratigraphy, and geologic history is now available. These data, many of which were obtained by the U.S. Geological Survey during a program of detailed geologic mapping in the basin, begun in the early 1940s, are summarized briefly in this paper.[3] Pertinent publications are not cited in the main body of the text, but are included in a selected bibliography at the end.

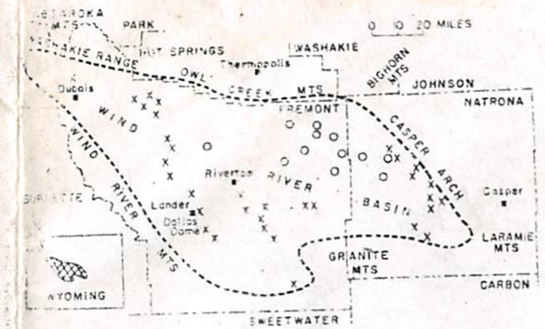

FIG. 1.—Major structural and physiographic features in central Wyoming. Approximate outline of Wind River structural basin shown by dashed line. X, oil and gas field productive in pre-Lance rocks; O, oil and gas field productive in Lance, Fort Union, or Wind River Formations.

Precambrian

The sedimentary history of the Wind River basin area began long before the Cambrian, as indicated by thick successions of metasedimentary rocks that are now exposed in the cores of some of the surrounding mountain ranges. Little is known about these rocks, except that they probably were deposited in early Precambrian time, were later intruded by igneous rocks, mostly granite, and subsequently deformed many times. Prior to Cambrian time, extensive erosion reduced the region to a broad, nearly level plain.

Paleozoic

From the beginning of the Paleozoic Era until Late Cretaceous time, central Wyoming was part of the vast foreland or stable shelf which lay along the eastern side of the main Cordilleran geosyncline. Sediments representing all systems except possibly the Silurian were deposited during repeated transgressions of the Paleozoic and Mesozoic seas, but the stratigraphic sequence is thin and discontinuous compared with the thick geosynclinal accumulations farther west in Idaho. Also, most rock systems are thicker and more complete in the western part of the Wind River basin than in the eastern part. Deposition took place mainly in shallow seas, with the result that slight changes in base level, caused by fluctuations in sea-level or by tectonic movements of low amplitude, commonly resulted in widespread unconformities and changes in the patterns of sedimentation.

Cambrian.—The first advance of the Paleozoic seas was in Middle Cambrian time. The Cambrian rocks form a well-defined transgressive sequence, containing a basal quartzitic sandstone (Flathead Sandstone), a middle shale (Gros Ventre Formation), and an upper limestone (Gallatin Limestone) (Fig. 2). The sedimentary pattern is one of continuous transgression, reaching a maximum eastward advance in Late Cambrian time, but the strata show that the major cycle was interrupted many times by minor regressions. The contacts between the three formations are gradational, and the formation boundaries become younger eastward across the basin area.

The sea retreated in latest Cambrian time, and a period of erosion followed.

Ordovician.—The Middle and Upper Ordovician Bighorn Dolomite is very resistant, forming massive cliffs along the western and northern

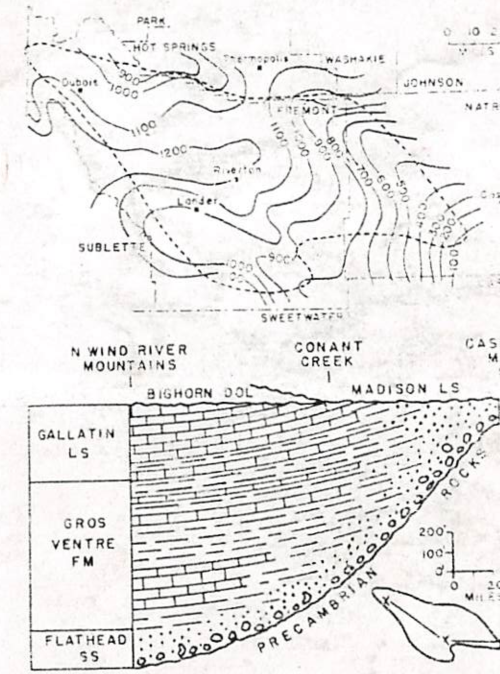

FIG. 2.—Stratigraphic diagram and thickness map of Cambrian rocks in Wind River basin.

[1] Read before the Rocky Mountain Section of the Association at Durango, Colorado, October 1, 1964. Manuscript received, May 7, 1965. Publication authorized by the director of the United States Geological Survey.

[2] Geologist, United States Geological Survey.

[3] Many individuals have contributed valuable information and ideas to this basin-wide study. The work of J. D. Love, J. F. Murphy, H. A. Tourtelot, R. M. Thompson, J. A. Van Lieu, M. L. Troyer, C. N. Pipiringos, and V. L. White is especially acknowledged.

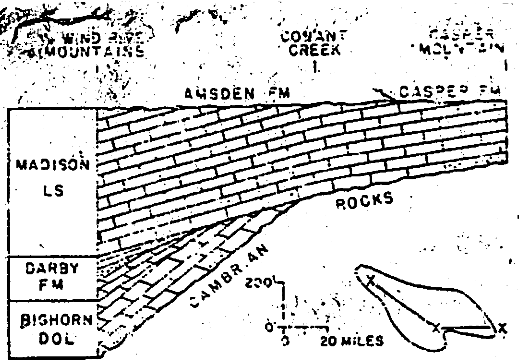

FIG. 3.—Stratigraphic diagram of Mississippian (Madison), Devonian (Darby), and Ordovician (Bighorn) rocks in Wind River basin.

sides of the Wind River basin. At the base, in places, is a thin lenticular sandstone (the Lander Sandstone Member), but the main mass of carbonate rock is remarkably free of clastic material (Fig. 3). The eastward thinning to a wedge-edge across the central part of the basin (Fig. 4) probably resulted from both non-deposition and beveling by erosion. However, the original limits of the Ordovician rocks toward the east and southeast are not known; the absence of clastic material suggests that the carbonate rocks near the present zero edge were still deposited a considerable distance west (seaward) of the shoreline.

Silurian.—At the close of the Ordovician the sea withdrew. The period of erosion that followed possibly represents all of Silurian time as well as part of the Devonian. There is no positive evidence that Silurian rocks ever were deposited in the region, but the presence of such rocks in the northern part of the Powder River basin, as well as in isolated patches in southeastern Wyoming, suggests that Silurian seas [illegible] central Wyoming.

Devonian.—The region was emergent [illegible] most of Early and Middle Devonian time [illegible] paleontological evidence indicates that [illegible] the channel-like deposits at the base of the D[illegible] Formation in the northwestern Wind River Mountains are Early Devonian. [illegible] Devonian time the sea again advanced eastward and southward into central Wyoming, initially filling only narrow channelways, but later covering all the land surface at least [illegible] the zero line shown on Figure 5. Carbonate rocks were deposited first and clastic rocks later [illegible] Darby Formation is more clastic near the zero edge, and this, as well as the presence of wind-blown sand grains in the dolomites along the western edge of the basin, suggests that the Darby was deposited fairly close to shore. It is therefore inferred that a broad landmass extended across the eastern half of the Wind River basin during the deposition of the main mass of the Darby.

The latest Devonian and earliest Mississippian history presents some very complex problems. Stratigraphic relations show that the sea withdrew before the end of the Devonian, and a short but intense period of erosion ensued. Then, in latest Devonian time, a thin but widespread unit of dark-colored marine shale and siltstone was laid down (Fig. 3). This unit truncates Upper Devonian rocks in western Wyoming, and rocks as old as Precambrian in eastern Wyoming. The unit is well developed in the Wind River Mountains along the western edge of the Wind River basin, where it rests unconformably on the lower part of the Darby, but data are too meager to de[illegible] [illegible] eastward and [illegible] [illegible] part of the Madison [illegible] was actually removed [illegible] before the Madison was deposited. In [illegible] in the Wind River Mountains, however, [illegible] apparently was continuous from [illegible] into Mississippian time, and an unconformity probably does not exist at the base of the Madison in that region.

Mississippian.—Figure 6 shows the distribution of formations exposed across central Wyoming at the beginning of Madison deposition. The unconformity at the base of the Madison Limestone, at least east of the zero edge of the Darby Formation, is one of the most pronounced within the Paleozoic sequence. However, much of the beveling may have taken place during latest Devonian time, rather than at the close of the Devonian. Apparently a broad positive area extended across the region near the beginning of the Mississippian, and rocks as old as Cambrian were eroded in the southeastern part of the Wind River basin.

Normal marine sedimentation took place across the entire basin area in Early Mississippian time, and extensive carbonate deposits were laid down in seas that advanced from the north and northwest (Fig. 3). The Madison shows considerable variations in thickness (Fig. 7), facies, and textures from place to place, which probably reflect minor tectonic movements, and the consequent lowering or raising of sea-level across the shelf area. In the southeastern part of the basin, clastic debris from the underlying rocks was incorporated in the basal strata of the Madison, but apparently the coarse material was spread only a short distance into the main depositional area on the west.

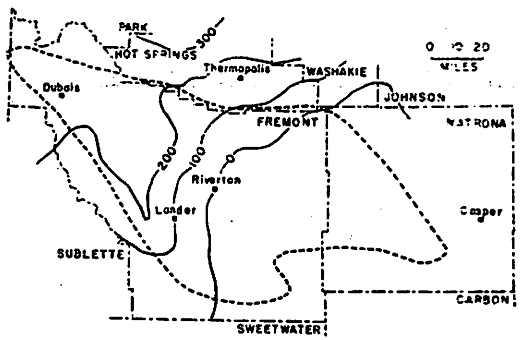

FIG. 4.—Thickness map of Bighorn Dolomite in Wind River basin.

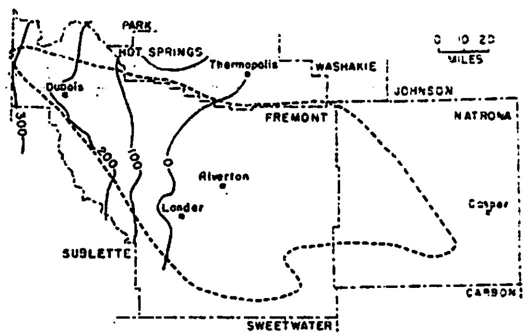

FIG. 5.—Thickness map of Darby Formation in Wind River basin.

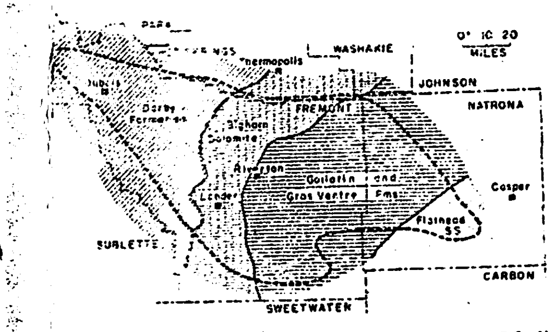

FIG. 6.—Formations exposed at beginning of Madison deposition across central Wyoming.

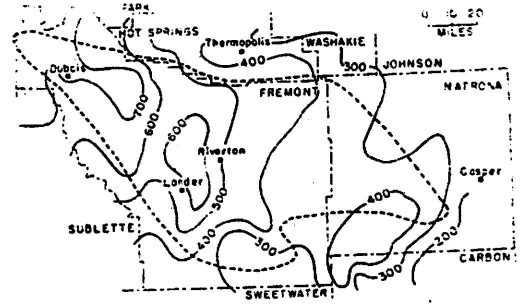

FIG. 7.—Thickness map of Madison Limestone in Wind River basin.

Carbonate deposition continued during Late Mississippian time in at least the western part of the Wind River basin, but equivalent rocks, if once deposited in the central and eastern parts, were eroded before Pennsylvanian time. Evaporites occur in the Upper Mississippian rocks of western and northern Wyoming, but these deposits do not extend into the Wind River basin. Prominent brecciated and cavernous zones in the upper part of the Madison in the western part of the basin, however, may be former evaporitic zones that were leached either during or after Mississippian time.

Pennsylvanian.—At the end of Madison deposition all of central Wyoming emerged, and an irregular surface was formed on the exposed carbonate rocks. In the central and eastern parts of the Wind River basin erosion cut down into Lower Mississippian rocks. A broad positive area occupied southeastern Wyoming and extended as far northwest as the southeastern corner of the basin. In places the Precambrian core of this uplift was breached.

In Early Pennsylvanian time a shallow sea spread across much of the Wind River basin area, probably from the west and northwest, and an extensive deposit of sand (Darwin Sandstone Member of the Amsden Formation) was laid down (Fig. 8). Some geologists believe that the major sources of sand were south and east of the present State boundaries, whereas others have argued that the source was toward the northeast. Precambrian crystalline rocks exposed in southeastern Wyoming at this time may have provided a partial source. The evidence is likewise obscure regarding the source for the overlying red ferruginous shale and siltstone. Much of this

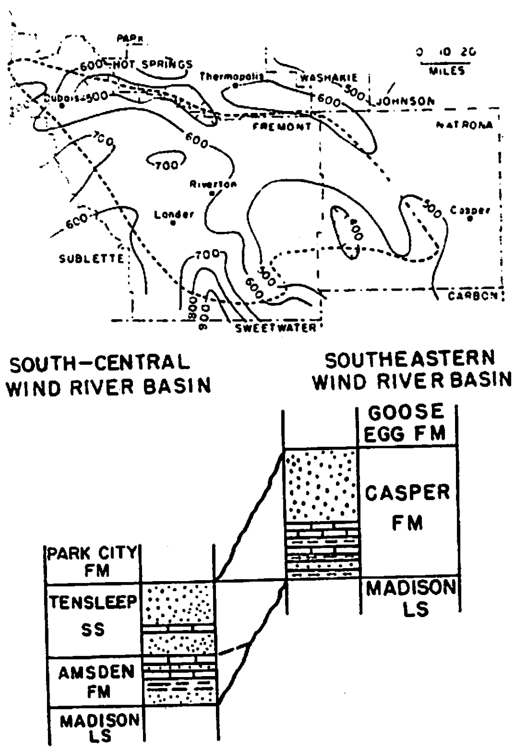

FIG. 8.—Stratigraphic diagram and thickness map of Amsden and Tensleep Formations (Lower and Middle Pennsylvanian), and Casper Formation (Upper Pennsylvanian and Lower Permian) in Wind River basin.

material, however, may have come from weathered Precambrian rocks in southeastern Wyoming.

During the remainder of Amsden time, an alternating succession of limestone, shale, and sandstone was deposited under marine conditions.

After deposition of the Amsden Formation a shallow sea remained in much of the Wind River basin area. In Middle Pennsylvanian time (Des Moines) a vast amount of quartz detritus was shed into the basin of deposition. The source of this sand may have been on the southeast, south, or west because equivalent rocks in eastern and northeastern Wyoming are chiefly carbonates.

Although sedimentation took place over much of the basin in Early to Middle Pennsylvanian time, the southeastern corner remained emergent. However, in Late Pennsylvanian time the situation was reversed; much of the basin area that had been flooded previously was raised above sea-level and the seas migrated eastward into eastern Wyoming and westward toward the major geosynclinal area in southeastern Idaho. Sand eroded from the exposed Tensleep Sandstone was redeposited in the shallow basins that flanked the uplift. Thus, much of the Casper Formation (Late Pennsylvanian and Early Permian) in the southeastern part of the basin closely resembles the older Tensleep Sandstone farther west.

Marine sedimentation continued along the southeastern edge of the Wind River basin throughout Late Pennsylvanian time, and also in areas on the west until near the close of the period.

Permian.—Rocks of Permian age form one of the most complex systems within the Paleozoic sequence of central Wyoming. Because of oil, gas, and phosphate, this system has also been one of the most widely studied. Figure 9 shows the distribution of the major facies across the region: red siltstone and shale and gypsum on the east; carbonate rocks in the center; mudstone, chert, and phosphorite along the western edge; and sandstone at the northwestern corner.

At the beginning of Permian time a broad, north-trending highland occupied all of the Wind River basin area. Rocks of Middle Pennsylvanian age were exposed in the central and western parts of the basin, and rocks of Late Pennsylvanian age in the eastern part. Seas lay both east and west of the highland, and in earliest Permian time began to encroach from both sides; by Late Permian the entire region was flooded (Fig. 10). Toward the east the sea remained shallow, and redbeds and evaporites accumulated. Toward the west carbonate rocks were deposited in deeper waters. Periodically the sea expanded or deep-

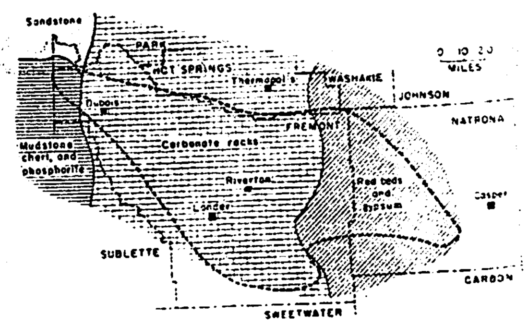

FIG. 9.—Distribution of major facies in Permian rocks in central Wyoming. After McKelvey and others (1959).

-ed eastward, and thin but very widespread tongues of limestone and dolomite were deposited over the westward-projecting tongues of redbeds. Triassic rocks apparently rest on Permian rocks with little or no unconformity. Deposition may even have been continuous from the Paleozoic into the Mesozoic Era, although there is no positive record that sedimentation occurred in the basin area during latest Permian (Ochoa) time.

Summary.—One of the most striking features of Paleozoic history in central Wyoming was the remarkable crustal stability throughout the era. Angular discordances between rock systems can be detected only on a regional scale. The isopachous maps show that tectonic movements were limited to broad upwarping and downwarping along trends which, with a few exceptions, are essentially unrelated to structural trends developed later during Laramide deformation. One notable exception is along the southeastern margin of the basin, where an area coinciding roughly with the northern Laramie Mountains was relatively positive during much of Paleozoic time. In some places the reverse was true, the Paleozoic highs and lows corresponding with Laramide lows and highs, respectively.

At the end of the Permian the westward dip of the Precambrian surface was about 15 feet per mile across central Wyoming.

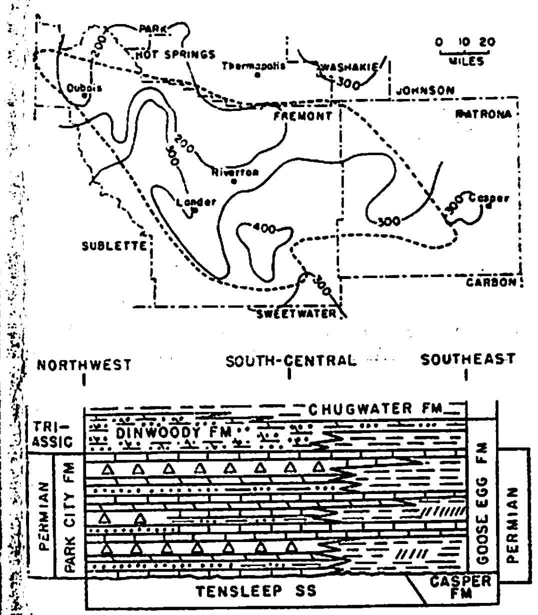

FIG. 10.—Stratigraphic diagram and thickness map of Permian rocks in Wind River basin. In part after Thomas (1934).

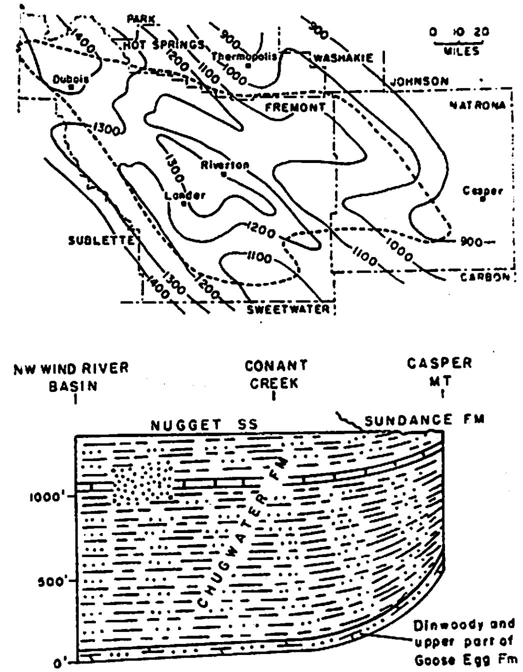

FIG. 11.—Stratigraphic diagram and thickness map of Triassic rocks in Wind River basin. Thicknesses from Love, Johnson, Nace, and others (1945).

MESOZOIC

Triassic.—In earliest Triassic time siltstones and carbonates of the marine Dinwoody Formation were deposited in the central and western parts of the Wind River basin (Fig. 11). At the same time, redbed and evaporite deposition continued along the east edge. Later, there was a westward shift in the environment for redbed deposition, and, by the end of the Early Triassic, nearly a thousand feet of red shale, siltstone, and sandstone had accumulated across the entire region. This sequence is non-fossiliferous, but sedimentary features suggest that deposition took place on broad alluvial, deltaic, and littoral plains and mud flats. The bedding, texture, and lithologic character are uniform over very wide areas, so there is little evidence of tectonic activity in or near the Wind River basin during Early Triassic time.

The sea readvanced eastward in middle or early Late Triassic time, and the thin persistent

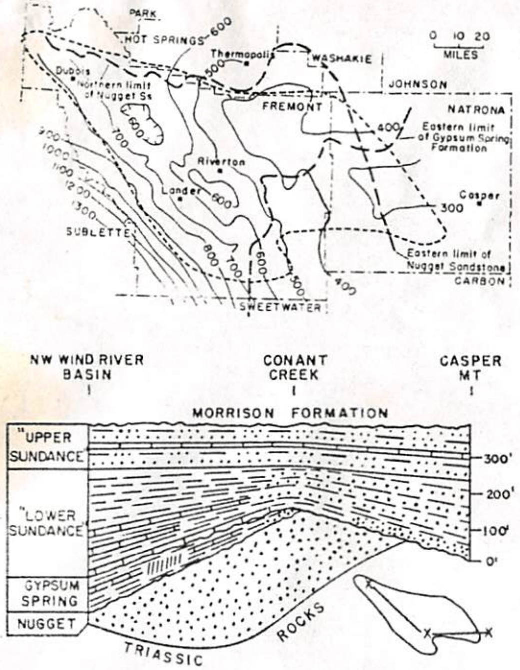

FIG. 12.—Stratigraphic diagram and thickness map of Nugget, Gypsum Spring, and Sundance Formations (Jurassic) in Wind River basin. Thicknesses from Love, Tourtelot, Johnson, and others (1945).

Alcova Limestone Member of the Chugwater Formation was laid down; in places, the limestone contains marine reptiles, pelecypods, and gastropods. As this sea withdrew, redbed deposition was renewed in many parts of the region. However, the strata in the Chugwater above the Alcova do not show the same uniformity of texture and lithologic character as those below, and this disparity probably reflects tectonic unrest in some of the adjacent areas, particularly on the south and west.

Jurassic.—The Jurassic of central Wyoming is a complex system, showing diverse types of sediments and widespread unconformities (Fig. 12). Early Jurassic time (represented by the Nugget Sandstone) was characterized by continental conditions, with the deposition of a thick cross-bedded sandstone that is mostly eolian in origin. In Middle Jurassic time shallow seas invaded from the north, and carbonates, evaporites, and red siltstone were deposited. Locally the Gypsum Spring Formation contains beds of gypsum and anhydrite more than 100 feet thick. With a freshening and deepening of waters across the shelf area in Late Jurassic time, more normal marine conditions returned to the basin area.

The pattern of unconformities within the Jurassic sequence indicates considerable tectonic unrest in some parts of central Wyoming (Fig. 12). At the end of Nugget deposition, uplift along the northern and eastern edges of the Wind River basin caused extensive beveling, although the thinning of the Nugget in these directions may also have been partly the result of non-deposition. Uplift also took place in the eastern part of the basin at the close of the Middle Jurassic. As a result, the Upper Jurassic marine Sundance Formation was deposited across the truncated edges of both the Gypsum Spring and Nugget Formations.

Source material for these Jurassic rocks apparently was derived both from the west and from the southeast, where highlands existed at this time.

Non-marine Upper Jurassic and Lower Cretaceous rocks.—Before the end of the Jurassic the sea withdrew, and several hundred feet of sandstone and variegated shale of the Morrison and Cloverly Formations accumulated in fluviatile and lacustrine environments (Fig. 13). The Morrison is well known for its abundant dinosaur remains, especially in southeastern Wyoming. Because of lithologic similarity of uppermost Jurassic and lowermost Cretaceous rocks, the position of the Jurassic-Cretaceous boundary is uncertain in many places; locally a series of lenticular conglomerates near the middle of the sequence may mark the systemic boundary. These conglomerates were derived partly from the west, after uplift and erosion of regions that lay beyond the present Idaho-Wyoming State line, and perhaps also from sources south and east of Wyoming.

Toward the end of Cloverly deposition the region was again flooded, and thin-bedded siltstone and sandstone were deposited in shallow marine and brackish waters.

Marine Lower Cretaceous rocks.—Shallow seas remained in central Wyoming during the remainder of Early Cretaceous time; black marine shale dominates both the Thermopolis and the Mowry (Fig. 14). The well-known oil-producing Muddy Sandstone Member, which is a persistent, though locally lenticular, sandstone near the top of the Thermopolis, shows characteristics of both ma-

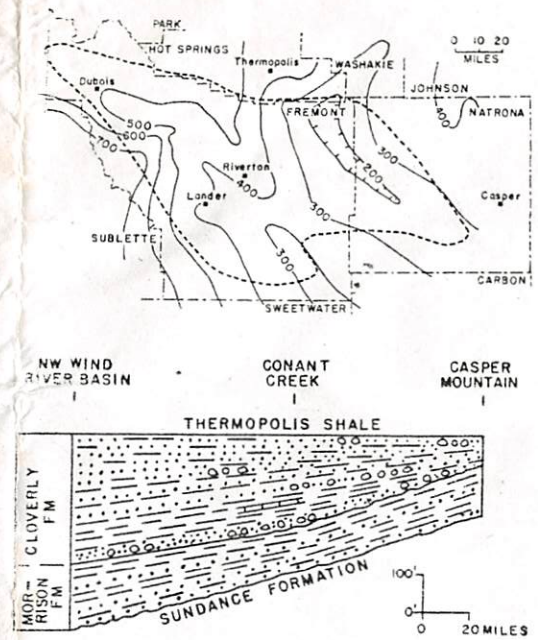

FIG. 13.—Stratigraphic diagram and thickness map of non-marine Upper Jurassic (Morrison Formation) and Lower Cretaceous (Cloverly Formation) rocks in Wind River basin. Thicknesses from Love, Thompson, Johnson, and others (1945).

rine and non-marine origin. Low islands, with fresh-water streams and abundant vegetation, apparently projected above the level of the sea during this particular interval. Widespread bentonite beds in the Mowry reflect the volcanism that was taking place in unknown areas west and northwest of Wyoming.

Late Cretaceous.—Upper Cretaceous rocks in the Wind River basin, as in most other basins of the Rocky Mountain region, show a complex history of transgression and regression (Fig. 15). Uplift in areas west of the present Wyoming-Idaho boundary in Late Jurassic and Early Cretaceous time had caused the axes of the major sedimentary troughs to be relocated eastward in Wyoming. Vast amounts of clastic debris were shed into this region from these highlands, and the main seaways were mostly in eastern Wyoming.

As the seas shifted eastward in early Late Cretaceous time, an extensive regressive sandstone, which now forms the base of the Frontier Formation, was laid down across the black marine shale of the Mowry. The sea withdrew into east-

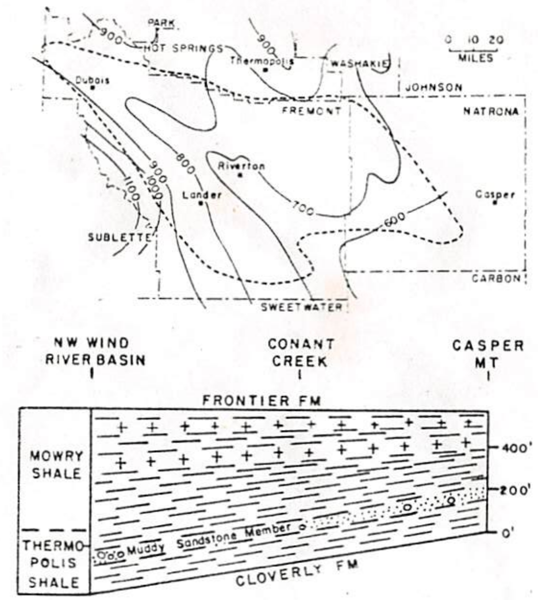

FIG. 14.—Stratigraphic diagram and thickness map of marine Lower Cretaceous rocks (Mowry and Thermopolis shales) in Wind River basin. Thicknesses from Thompson, Love, and Tourtelot (1949).

ern Wyoming, and a rather prolonged period of continental sedimentation in the Wind River basin area ensued, although minor readvances are recorded by the interfingering of marine and non-marine sediments in the middle part of the Frontier in some places. Swamps, lagoons, and marine embayments dominated the landscape, as slight changes in sea-level, or in the rates of sedimentation or subsidence, brought about significant migrations of the shoreline (Fig. 16).

Toward the end of Frontier deposition there was a major advance of the sea that extended westward across all of central and western

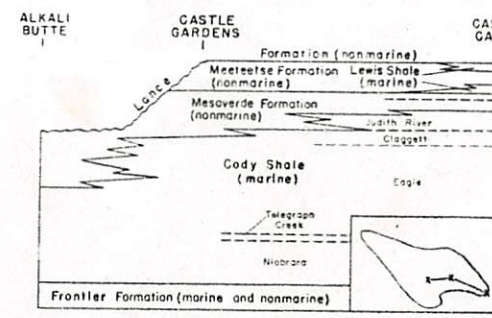

FIG. 15.—Diagram of Upper Cretaceous rocks, southern Wind River basin. Approximate boundaries of time zones shown by dashed lines.

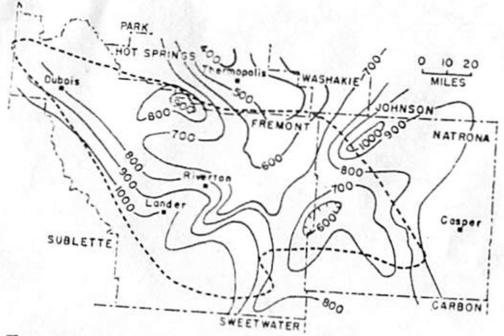

FIG. 16.—Thickness map of Frontier Formation in the Wind River basin. In part after Goodell (1962), and Thompson, Love, and Tourtelot (1949).

Wyoming. The initial deposit therefrom, which now forms the top unit of the Frontier, is a conspicuous, highly fossiliferous sandstone. As transgression proceeded, the supply of sand from the west diminished, and black muds of the Cody Shale began to accumulate in the eastern part of the region and eventually spread westward across the entire basin. This shale corresponds generally to deposits of early Niobrara age elsewhere.

During the transgression of the Cody sea more than 2,000 feet of marine shale was deposited across central Wyoming. Maximum transgression was reached in middle Niobrara time; then began a long period of regression. Through late Niobrara, Telegraph Creek, and Eagle times (the Telegraph Creek and Eagle are formations in the Montana Group in areas on the north) another 2,000 feet of marine sediments accumulated, mostly very fine-grained shaly sandstone. The final regressive deposit is the basal sandstone of the Mesaverde Formation.

Much intertonguing takes place between the Cody and the Mesaverde, and the contact becomes younger eastward. In the western part of the basin the transition from shallow offshore sedimentation to near-shore and brackish-water sedimentation took place in Eagle time; in the eastern part of the basin the change took place considerably later, in Claggett and Judith River times. As shown on Figure 15, the preserved part of the Mesaverde in the south-central part of the basin is almost entirely older than the Mesaverde in the southeastern part.

During the deposition of the Mesaverde Formation and the next younger Meeteetse Formation, which have a combined thickness of 2,000-3,000 feet, the present site of the Wind River basin was an emergent surface of low relief, characterized by broad flood-plains, coastal swamps, deltas, and lagoons. The Late Cretaceous sea invaded the eastern part of the basin twice during Meeteetse deposition (Figs. 15, 17) and marine shale and sandstone of the Lewis Shale intertongue with the non-marine, highly carbonaceous strata of the Meeteetse.

The landscape of the Wind River Basin area, as it may have been at the time of maximum westward advance of the Lewis sea, is shown in Figure 18. The land surface sloped gently eastward, and existing highlands in eastern Idaho continued to furnish large amounts of clastic debris to the eastward-flowing rivers. Volcanic ash from the centers north and northwest of Wyoming was also deposited across the region.

Little tectonic activity apparently occurred in the Wind River basin during the time of Meeteetse and Lewis deposition, although thickness variations in places indicate ancestral folding of some anticlines and synclines. Commencing with the deposition of the latest Cretaceous Lance Formation, however, the history is much different; tectonic movements of the Laramide began in several places within and around the basin, and these movements had a significant influence on the pattern of sedimentation throughout latest Cretaceous, Paleocene, and early Eocene times.

For purposes of Laramide structural interpretation, the upper surface of the Meeteetse and Lewis may be considered as a plane of "zero" deformation. At this time, the Precambrian surface lay about 10,000 feet below sea-level in the eastern part of the basin, and 15,000 feet in the western part; the westward dip was about 40 feet per mile. This surface forms a convenient refer-

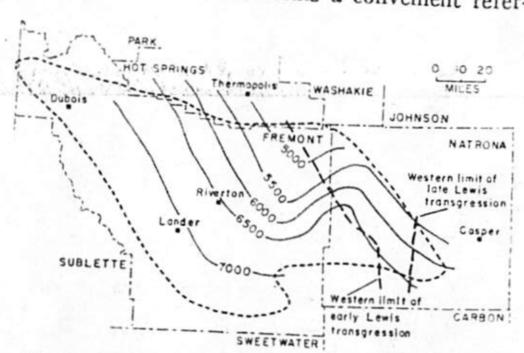

FIG. 17.—Thickness map of Cody, Mesaverde, Lewis, and Meeteetse Formations in Wind River basin.

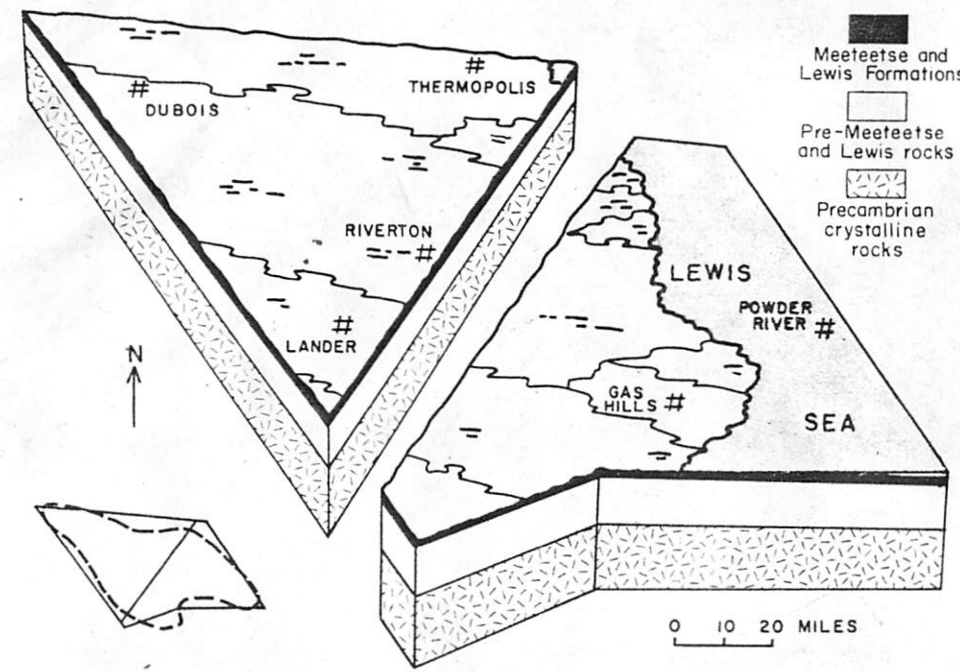

FIG. 18.—Wind River basin at time of maximum advance of Lewis sea. In part after Murphy and Love (1958), and Love (1954a).

ence for calculating the magnitude of basin sinking and mountain uplift during successive stages of the oncoming orogeny.

At the beginning of Lance deposition broad upwarps began to form in the areas now occupied by the Granite Mountains along the southern edge of the basin, and by the Washakie Range at the northwestern corner (Fig. 1). By the end of the Cretaceous these upwarps had become fairly well defined (Fig. 19), and in some places erosion cut into the Lower Cretaceous rocks. Downwarping of the major basin trough was pronounced during this period, and 5,000-6,000 feet of fine-grained clastic sediment was deposited in the areas of greatest subsidence (Fig. 20). Major drainage was eastward out of the basin area, although the southwestern part may have been drained by streams flowing south and southeast; lakes may have formed locally.

CENOZOIC

Paleocene.—The Wind River Mountains began to rise along the western side of the Wind River basin probably at the beginning of Paleocene time. Broad, low, west-northwest-trending folds also formed at that time along the present site of the Owl Creek Mountains along the northern side of the basin. The Granite Mountains and Washakie Range continued to rise, and anticlinal folding took place in some of the marginal areas of the basin proper. By middle to late Paleocene time (Fig. 21) the Precambrian crystalline cores of the Wind River and Granite Mountains had been breached locally, but in the Washakie and Owl Creek Ranges erosion probably had not yet reached the Paleozoic rocks in most places.

The basin trough continued to subside during all of Paleocene time, and in the latter part of the epoch the central part was flooded by a large body of water known as Waltman lake. During its maximum stage of development, this lake covered more than a thousand square miles of the present basin area, and apparently extended still farther eastward (Fig. 21).

Though locally derived material accumulated along the mountain slopes, deposition in the basin during the Paleocene was confined largely to the central downwarped part (Fig. 22). In late Paleocene time 2,000-3,000 feet of black organic shale and siltstone known as the Waltman Shale Member of the Fort Union was deposited in Waltman lake. Certain features of these sediments—espe-

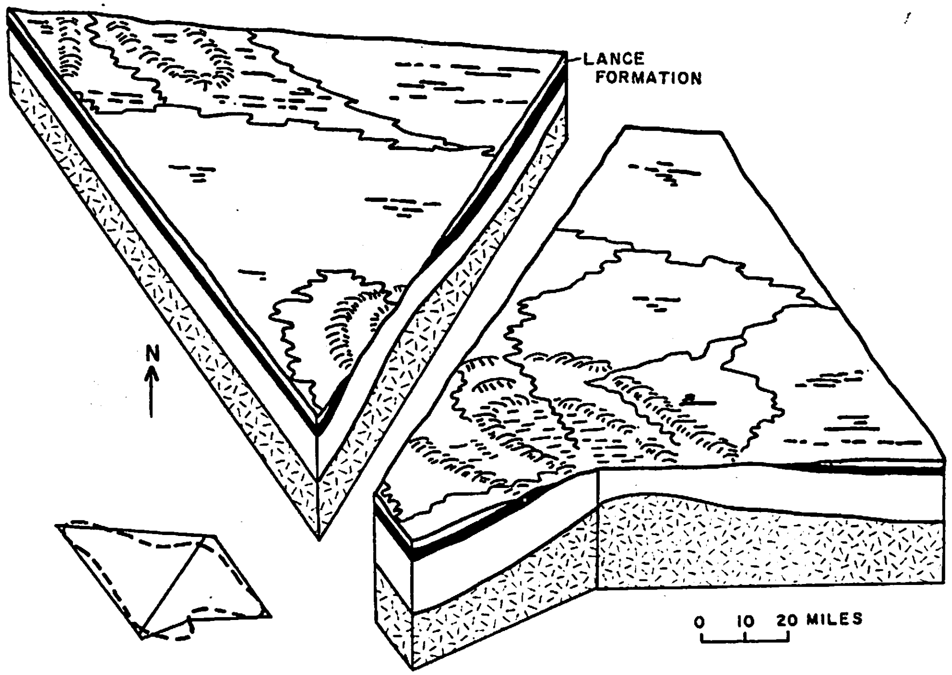

FIG. 19.—Wind River basin near close of Cretaceous (Lance) time. In part after Murphy and Love (1958), and Love (1954a).

cially the abundance and variety of marine-type fossil sharks that have been collected from a few localities—suggest that there was a close association with marine waters. The Cannonball sea lay east of Wyoming during Paleocene time, but no open-sea connection with central Wyoming during late Paleocene time has been demonstrated. The best interpretation seems to be that Waltman lake was an isolated body of water that had been linked eastward with the open sea by rivers or narrow estuaries across the southern part of the Powder River basin. The Casper arch had not yet begun to rise along the eastern side of the Wind River basin, so there was no barrier to the movement of water in that direction as there was on the other three sides of the basin (Fig. 21).

The black organic shale yields petroleum during distillation tests, and is possibly the source rock for much of the oil and gas that has been found in the lower Tertiary rocks in the northeastern quarter of the Wind River basin.

Early Eocene.—In earliest Eocene time, folding and uplift of the various mountain masses were accelerated, and large-scale reverse faulting took place in the northwestern part of the basin. Very coarse clastic debris of the Indian Meadows Formation accumulated in extensive alluvial fans in front of the rising highlands, while thick deposits of fine-grained material continued to be shed into the central downwarp.

After deposition of the Indian Meadows, the central and eastern parts of the Owl Creek Mountains, the southern Big Horn Mountains

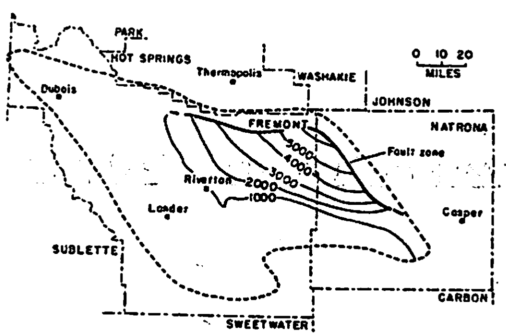

FIG. 20.—Thickness map of Lance Formation in Wind River basin. (Thickness lines on this map and on Figures 22 and 25 have been terminated along a major Laramide fault zone; north of fault these rocks have been stripped from uplifted mountain blocks. Same is true for some older formations, but, in general, information concerning them is sufficiently detailed to restore thicknesses across eroded areas.)

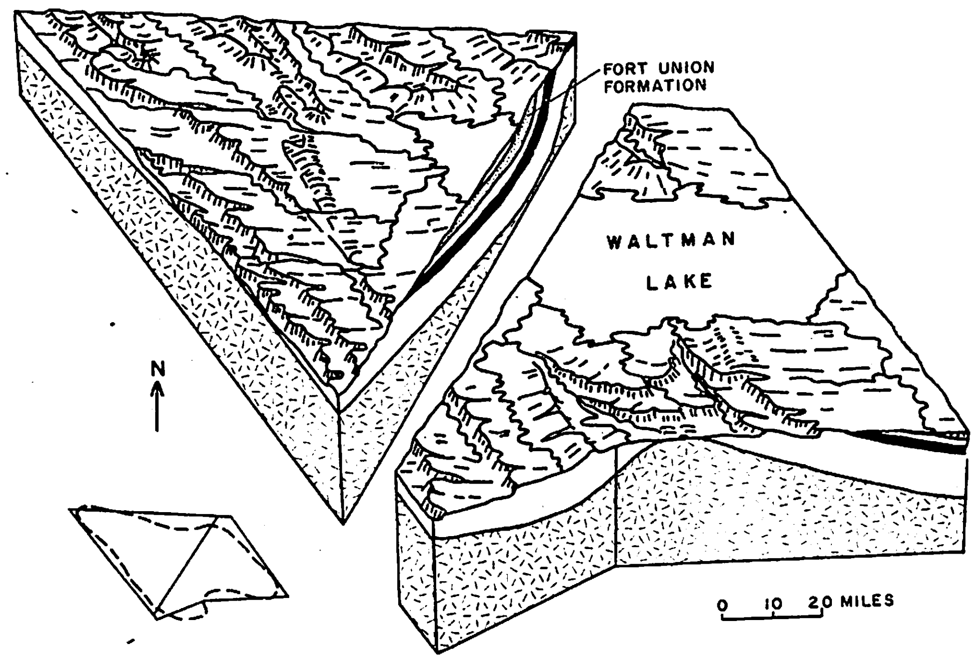

FIG. 21.—Wind River basin in late Paleocene time. In part after Murphy and Love (1958), and Love (1954a).

and the Casper arch also were uplifted along extensive reverse faults. Large areas of Precambrian rocks in both the Wind River and Granite Mountains, as well as smaller areas of the Washakie, Owl Creek, and Big Horn Mountains, were exposed to erosion, and the smaller folds along the basin margins were deeply dissected (Fig. 23). All streams which formerly had flowed out of the basin probably were blocked, and for a brief time there may have been interior drainage. A vestige of Waltman lake probably remained in the center of the basin.

Extensive erosion of the highlands surrounding the Wind River basin continued throughout the remainder of early Eocene time. The debris was spread basinward on all sides, and toward the latter part of this time interval fine-grained volcanic material was supplied from the Absaroka-Yellowstone region. By the end of the early Eocene, the basin fill lapped high onto the mountain flanks, and probably buried the Casper arch and some parts of the Owl Creek and Washakie Ranges (Fig. 24). Exterior drainage toward the east was re-established.

The major trough areas continued to sink, and up to 8,000 feet of lower Eocene sediment was deposited (Fig. 25). At this stage, the structural displacement between basin and mountain provinces had reached a maximum of about 35,000 feet along the southern edge of the Owl Creek Mountains. Nearly half of this displacement can be attributed to active subsidence of the basin floor.

Post-early Eocene.—Basin subsidence and the mountain-building movements of the Laramide had virtually ended by the close of early Eocene time. Renewed folding and faulting of existing structural features, such as the Casper arch, took

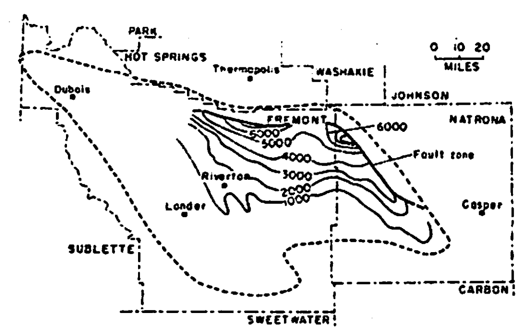

FIG. 22.—Thickness map of Fort Union Formation in Wind River basin.

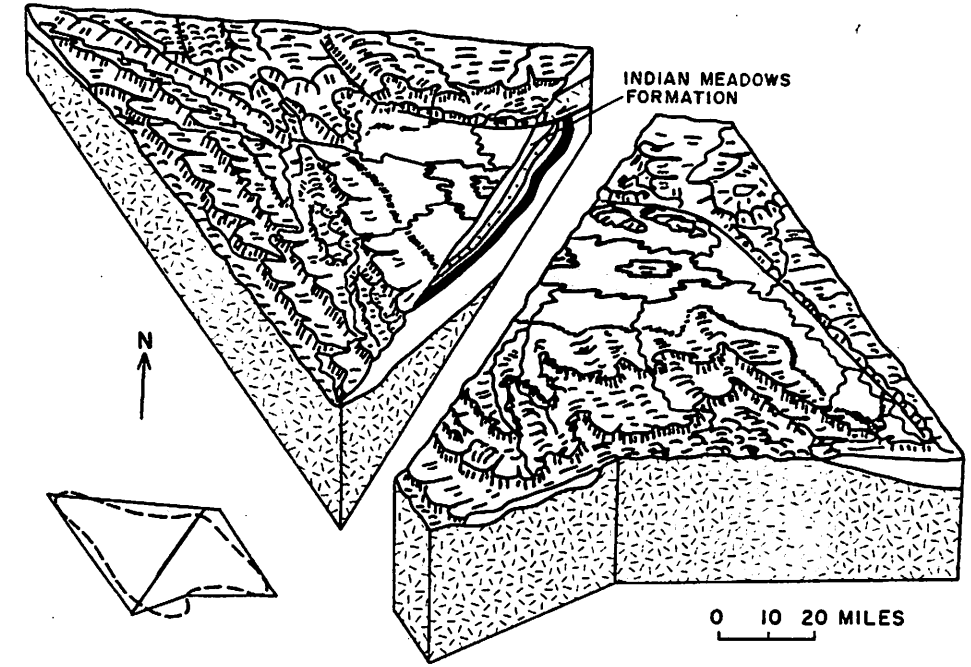

Fig. 23.—Wind River basin in earliest Eocene time (end of Indian Meadows deposition). In part after Murphy and Love (1958), and Love (1954a).

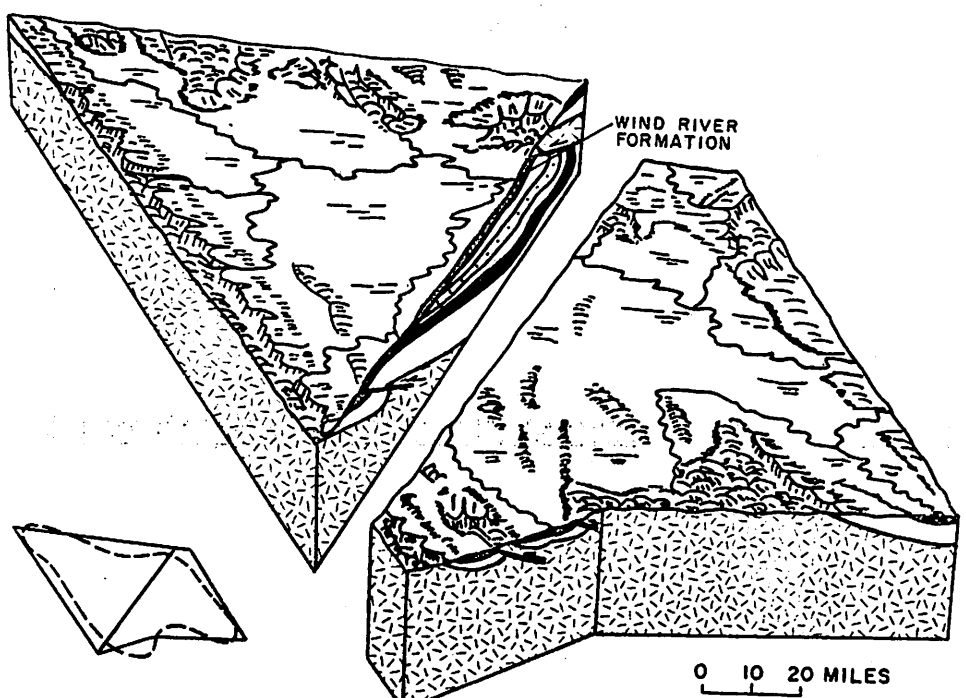

Fig. 24.—Wind River basin at close of early Eocene time. In part after Murphy and Love (1958), and Love (1954a).

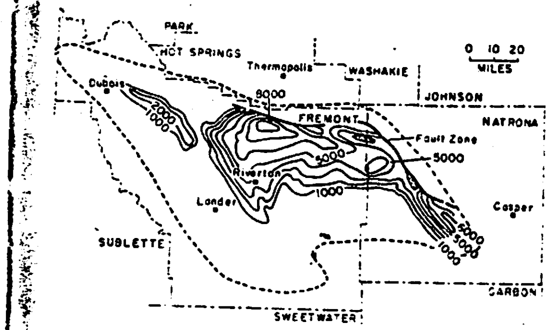

Fig. 25.—Thickness map of Wind River and Indian Meadows Formations in Wind River basin.

place after deposition of the Wind River Formation. With few exceptions, however, these movements were of minor consequence and did not greatly modify the structural patterns that had been established earlier. Large-scale normal faulting, probably closely related to regional epeirogenic uplift, also occurred in late Tertiary time. In many places this faulting resulted in the collapse of major Laramide uplifts along former reverse-fault zones.

The sedimentary history of the Wind River basin in middle and late Tertiary times is one of nearly continuous aggradation. The Oligocene, Miocene, and Pliocene rocks are predominantly volcanic, which is in sharp contrast to the predominantly non-volcanic, locally derived clastic material of the lower Eocene and older parts of the basin fill. By late Tertiary time apparently only the highest mountain ridges projected above the sedimentary plain. Then, perhaps in middle or late Pliocene time, the entire region, mountains and basins alike, was uplifted 3,000-4,000 feet, the cycle was reversed, and a long period of degradation began which still continues. Re-excavation of the basin at the present time has progressed to the point where only the lower Eocene and older rocks remain. Drainage patterns have changed considerably—master drainage is now northward out of the basin—but in many other respects the structural and physiographic features that may be seen in the basin today are not too different from those of early Eocene time.

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