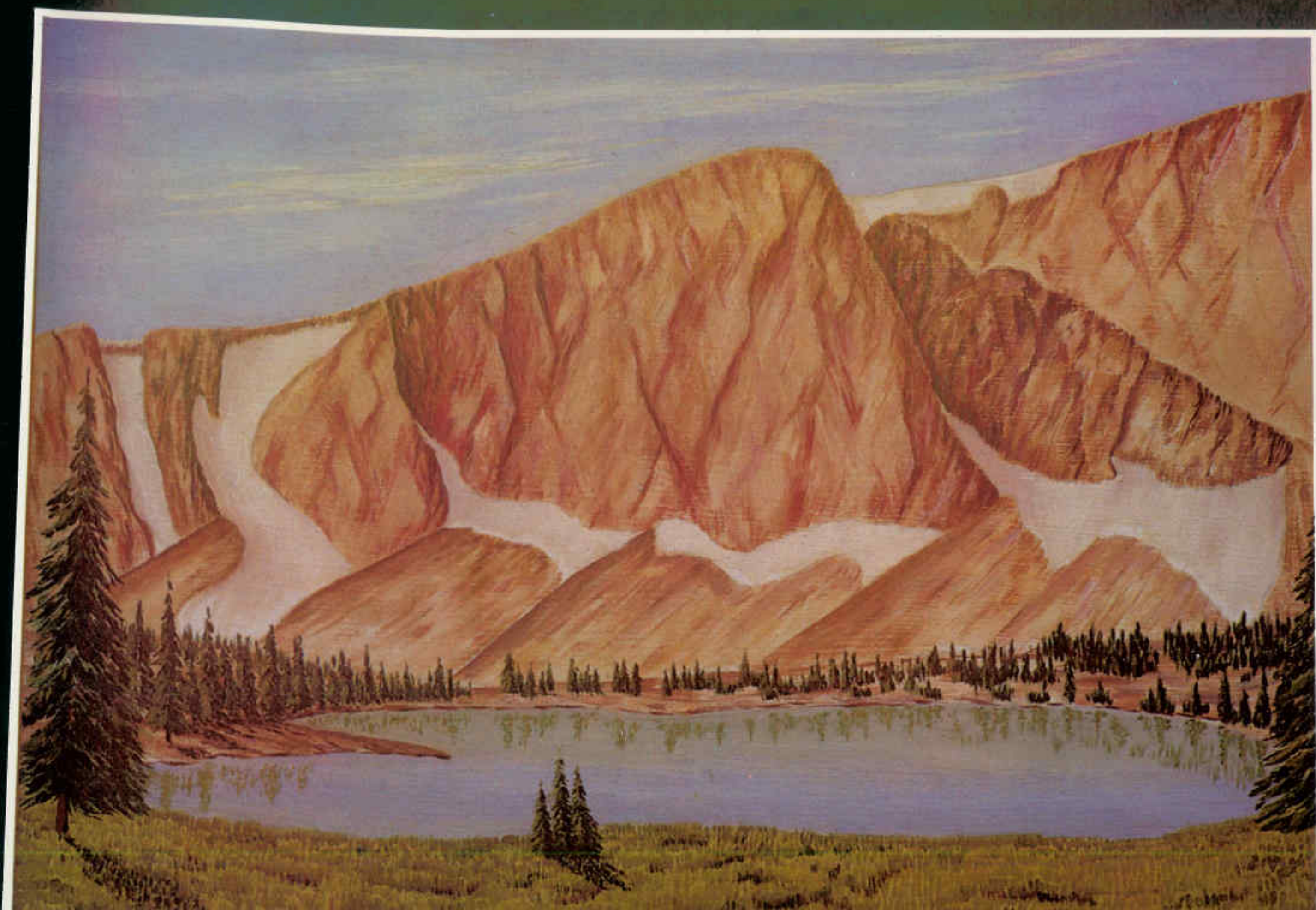
The Geological Survey of Wyoming
Gary B. Glass, State Geologist

Illustrated geologic history of the Medicine Bow Mountains and adjacent areas, Wyoming

by Samuel H. Knight



Memoir 4

Published in cooperation with the S.H. Knight Memorial Fund,
Department of Geology and Geophysics, University of Wyoming

Laramie, Wyoming
1990

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Front cover: Photograph of a painting of the Snowy Range, Medicine Bow Mountains by S.H. Knight (from the collection of Eleanor Knight Keefer).

THE GEOLOGICAL SURVEY OF WYOMING

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Memoir No. 4

ILLUSTRATED GEOLOGIC HISTORY OF THE MEDICINE BOW MOUNTAINS AND ADJACENT AREAS, WYOMING

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Preface

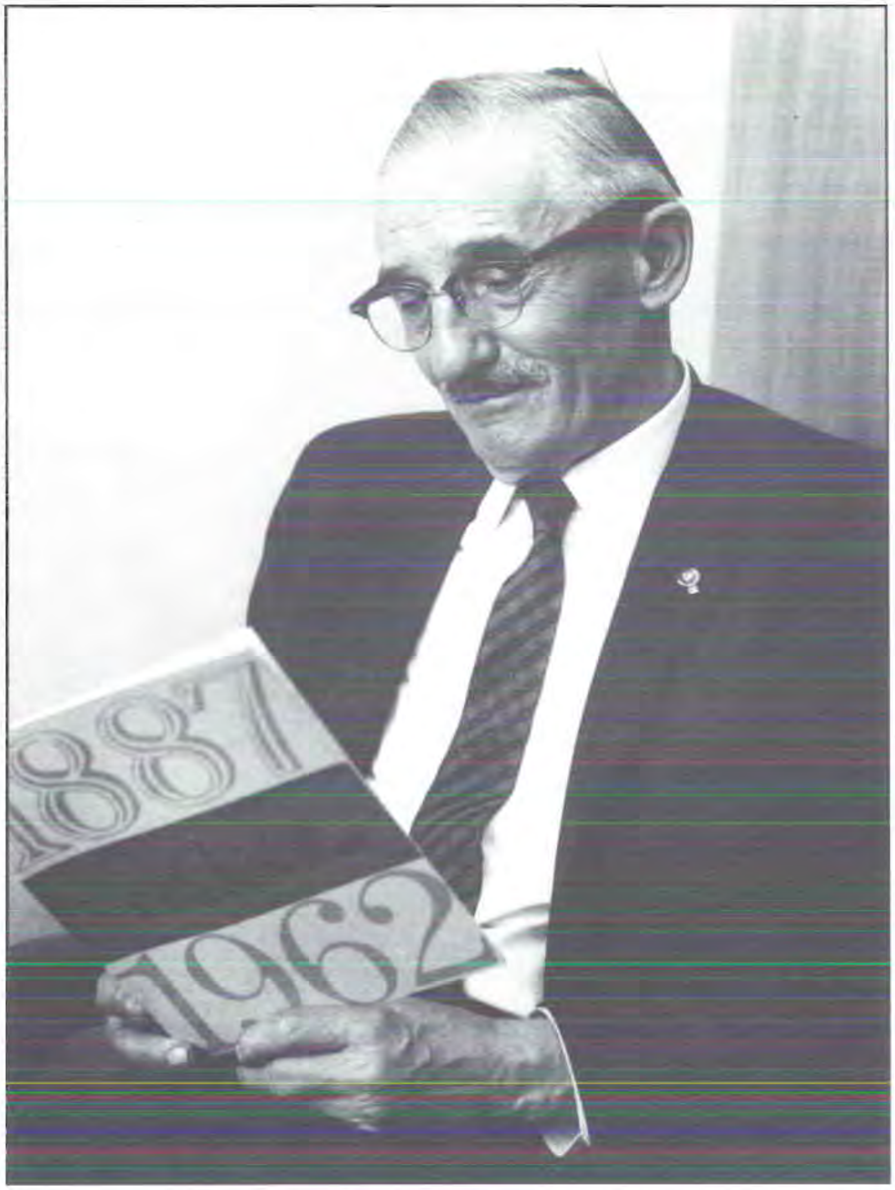
Wyoming is a geologic showplace, a panorama of windswept basin floors and imposing mountains. The acknowledged master in presenting the state's long and eventful geologic history was the late Samuel Howell Knight, "Doc" to generations of geology students. His lectures were "chalk talks", 50-minute sessions encapsulating his extensive knowledge of Wyoming's changing landscapes through the immensity of geologic time. Today some instructors scrawl small diagrams for overhead projectors and show slides and films to students dozing in darkened rooms. I doubt that such techniques can instill the three-dimensional visualization and grasp of geological principles that Doc's students absorbed as they diligently strove to emulate the master's blackboard drawings in their notebooks. With monumental block diagrams, boldly done in colored chalks, he vividly depicted and expounded on the physical evolution of Wyoming. Paleozoic and Mesozoic seas advanced and retreated across the continental platform, depositing sediments. As the Cretaceous seas withdrew, "broad-backed anticlines arose and wide synclines subsided" to initiate the Cenozoic structural framework of Wyoming mountains and basins. The rising mountains were eroded, exposing the Precambrian basement complex in their cores. Concurrently, the basins were filled with debris from the mountains, greatly supplemented by "vast clouds of volcanic ash drifting in from remote sources." Subsequent cycles of erosion, transportation, and deposition modified the late Tertiary landscape. Near the conclusion of his presentation, "ice sculpted the final scene" as Pleistocene glaciers flowing down pre-existing stream valleys in the mountains scoured great U-shaped troughs and deposited hummocky horseshoe-shaped moraines on the adjacent plains.

Although the carefully drafted diagrams presented here are in the style of Knight's professional publications, they catch the artistry of his elaborate blackboard showmanship. At the time of his death, Dr. Knight's diagrams were completed. However, his written text was a preliminary draft. Sheila Roberts, editor for the Geological Survey of Wyoming, and I have made considerable editorial corrections and minor geological updating, with the help of Dr. Robert S. Houston, Dr. D. L. Blackstone, Jr., and Dr. Jason A. Lillegraven. We have left the style of the presentation intact in order to preserve the inimitable flavor of a chalk talk by S.H. Knight.

In his original paste-up copy, Dr. Knight added supplementary sketches of the present-day scenic setting of the Medicine Bow Mountains and the animals who live or have recently lived in the area. The scenic sketches appear here as end pieces throughout the text and the animal sketches appear in the final section on modern landscapes of the region.

Brainerd Mears, Jr.
December, 1990

An alluvial cone



Dr. Samuel H. Knight in 1962. (Photograph by Herb Pownall, from the collection of Eleanor Knight Keefer.)

Samuel Howell Knight (1892-1975)

B.A., University of Wyoming 1913
Ph.D., Columbia University 1929
Dr. of Laws (honorary), University of Wyoming 1953

Professor, University of Wyoming, Department of Geology 1916-1966, Emeritus 1966-1975
Chairman, University of Wyoming, Department of Geology 1917-1963
Founder and Director, University of Wyoming Summer Science Camp 1923-1963
Curator, University of Wyoming Geology Museum 1916-1946

Wyoming State Geologist 1933-1941

A.A.P.G. Distinguished lecturer (twice)
Honorary member, American Association of Petroleum Geologists and Wyoming Geological Association

Author's prologue

The following review is an attempt to visualize, with the aid of three-dimensional diagrams (herein called Scenes), the outstanding events in the geologic history of the Medicine Bow Mountains and adjacent areas insofar as the record is preserved in the rocks of the region. The brief descriptions accompanying the ancient scenes are written, as far as possible, in nontechnical language.

I first became interested in the geology of the region while a student. In the summer of 1917, I accompanied Dr. Eliot Blackwelder into these mountains, although I took no part in Dr. Blackwelder's mapping of the Precambrian rocks in the core of the range. In 1925, I established the University of Wyoming Science Camp [the S.H. Knight Science Camp] in these mountains, and for the next forty summers conducted, with the assistance of others, classes for advanced geology students. In 1957, Dr. Robert S. Houston, Professor of Geology at the University of Wyoming, began intensive studies of the mountains with special reference to rocks of Precambrian age. The results of these studies, including a colored geological map in which is incorporated all available geologic maps, were published in 1968 as Geological Survey of Wyoming Memoir 1. Dr. Houston's knowledge of the area is such that his active collaboration was most helpful, especially in the construction of the Precambrian scenes, and I wish to express my thanks and appreciation to him for his help in the preparation of this review. I also wish to thank Professors Paul O. McGrew and Donald W. Boyd, of the staff of the Department of Geology, and Dr. J. David Love, U.S. Geological Survey geologist, for timely suggestions; and Mrs. Elaine Hertzfeldt, for typing the preliminary manuscript.

S.H. Knight
1974

Engelmann Spruce near timberline

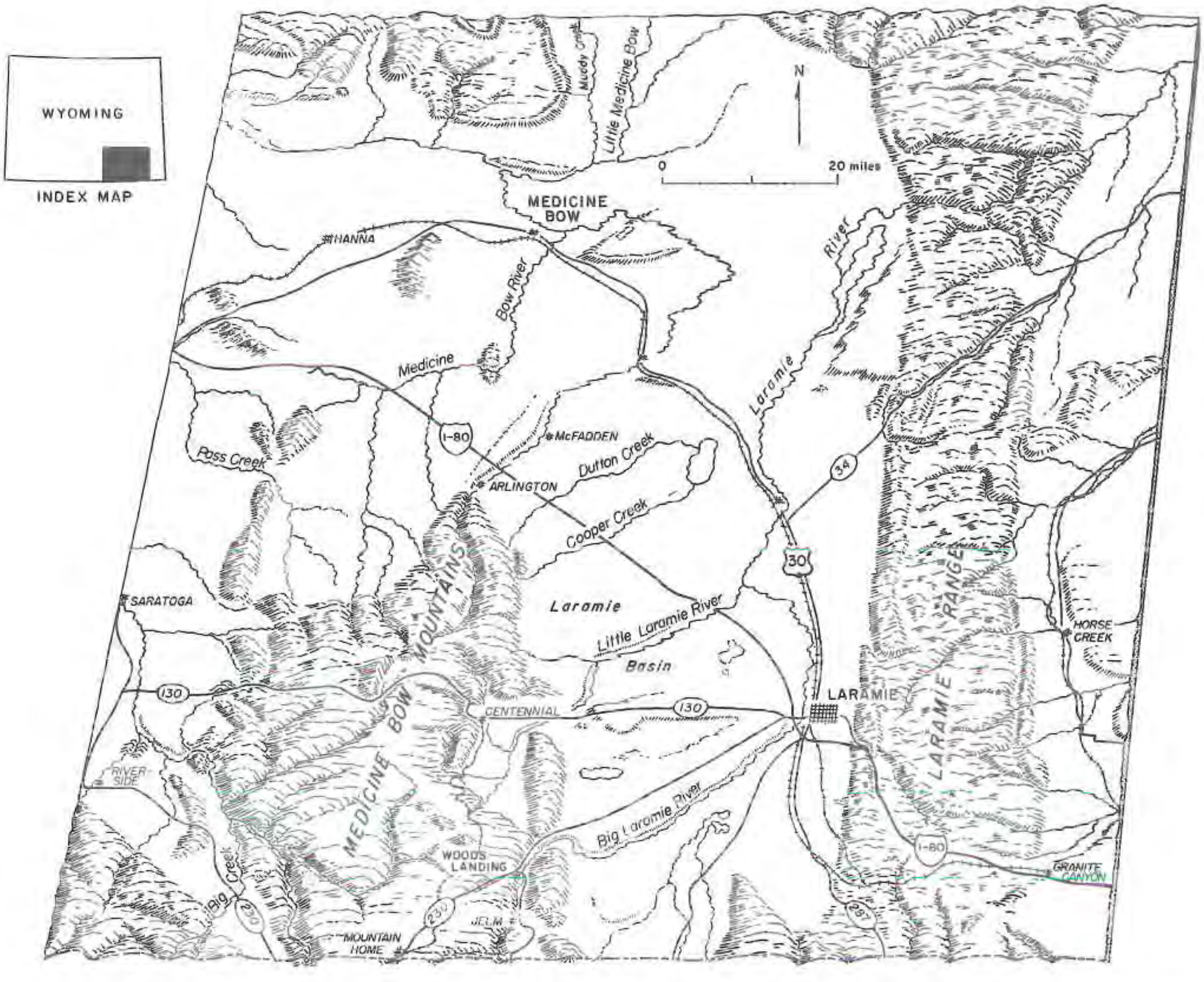


Figure 1. Physiographic map of the Medicine Bow Mountains and adjacent areas (by S.H. Knight, originally published in 1953, Wyoming Geological Association Eighth Annual Field Conference Guidebook.)

Introduction

Some climb mountains "because they are there,"
Others climb mountains their secrets to share,
For mountains hold in their massive grasp,
Profound records of the infinite past.

To appreciate the geological history and present landscapes of the Medicine Bow Mountains and adjacent areas, as pictured in the following scenes, the viewer should have some understanding of: (1) the rocks that document the record; (2) the time involved; and (3) the processes that operate both on the surface and within the outer crust of the Earth to create the changing landscapes of the planet.

Rocks

Rocks are aggregates of minerals or older rock fragments. Rocks are divided into three main classes, depending upon their origin (igneous, sedimentary, or metamorphic). The classes are in turn divided into types, depending upon composition, texture or size of grains, and structure or arrangement of grains.

The three main classes of rocks are:

1. **Igneous rocks** (from *ignis*, Latin for fire). Igneous rocks are formed by the solidification of molten rock-forming material. When this magma is extruded onto the surface, it is referred to as lava. Examples: granite, basalt, and rhyolite.

2. **Sedimentary rocks**. Sedimentary rocks are made up of broken fragments of pre-existing rocks and minerals, skeletal remains of organisms, and chemical precipitates. Examples: sandstone, limestone, and shale.

3. **Metamorphic rocks** (from *meta*, Greek, implying change; and *morphe*, Greek for form). Metamorphic rocks are pre-existing igneous or sedimentary rocks that have undergone physical and chemical changes due to heat, pressure, and chemical action, which give them features different from the parent rocks. Example: gneiss, schist, and marble.

Many types of each class of rocks are present in the Medicine Bow Mountains.

Time

All events occur relative to some chosen point in time; there is no known beginning or foreseeable end of time. In the history of the Earth, the chosen point of reference is the present, and we refer to past events as having occurred so many years before the present.

There are several ways we can tell when an event recorded in the rock record occurred with reference to preceding and subsequent events. However, we are dependent on the radioactive decay "clocks" of certain elements found in rocks to tell us approximately how many years ago the event took place. Methods of dating geologic events include:

1. **Inferences from the Law of Superposition**. In any series of objects piled one upon another, such as layers of rock, a time-space sequence is established. The layer at the bottom of the sequence is the oldest — it was the first to be laid down — while the layer at the top is the youngest. Each layer is younger than the underlying layer and older than the overlying layer (unless subsequent, usually recognizable, events have disturbed this order).

2. **Inferences from igneous intrusions**. When magma invades the outer crust it penetrates pre-existing rocks and therefore is younger than the host rocks that it invades.

3. **Evidence from organic evolution**. Life forms have changed through time and the preserved remains of organisms (fossils) record these changes in the rocks. Although the rate of measurable change of different forms has varied greatly, it is possible to correlate (in time) rocks containing the same kinds of fossils across widely spaced localities. There has been no recorded repetition of a species through time.

4. **Radiometric age determination**. Radioactive elements have the property of changing into other elements at a constant rate by the emission of radia-

tion. With the discovery of the radioactive decay "clock" and its worldwide application to rocks of various types and ages, it was possible, for the first time, to determine when, in years, certain rocks formed. Using this discovery, the age of the Earth was estimated to be 4.5 billion years or more.

The geologic time scale

Current evidence leads to the conclusion that the earth is 4.5 to 5 billion years old. The Earth's oldest dated crustal rocks are almost 4 billion years old. The oldest dated rocks exposed in the Medicine Bow Mountains are not less than 2.5 billion years old. It is possible that they may be several hundred million years older.

The history of the Earth is formally divided into major and minor time segments (**Figure 2**). The grandest divisions are eons, followed by eras, periods, and epochs (smaller divisions are not shown on **Figure 2**). During the development of the geological time scale, no attempt was made to divide the history of the earth into equal time spans (in years). The divisions are based on natural events of special significance, such as changes in the character of life or times of crustal unrest, when mountain systems came into being or when vast surface areas were depressed beneath the sea or elevated above the sea.

At no single locality is the complete record preserved. In each particular locality there are many lost intervals, during which the region was being eroded, and there is no positive record of the passing of time. Elsewhere, eroded debris was being deposited or other rock-forming processes were creating a geologic record of that time. The geological time scale evolved in response to intensive studies of the behavior of the Earth's outer crust and the changing panorama of life through the last 3.5 billion years.

Unconformities

Unconformities are surfaces of erosion or nondeposition between two rock sequences that rest one upon the other and are separated by a time interval. They play a role in our understanding of the physical changes in the environment of an area at various times in its history. An unconformity can be the only evidence in the rocks of a time interval that is otherwise lost from the record.

Unconformities are often recognized by changes in the orientation of rock bedding or local omission of beds. To understand the different kinds of unconformities common to the Medicine Bow Mountains area, the reader should know that sedimentary rocks are usually bedded. Igneous rocks in the Medicine Bow Mountains are not bedded. Metamorphic rocks may or may not be bedded depending on their origin and degree of metamorphism; they frequently exhibit compositional banding.

Bedded rocks are made up of a sequence of layers of similar or different character that are separated by bedding planes. Bedding planes are a response to cyclic changes, for example, in the energy output of the depositing force. Two contrasting types of bedding are:

Planar bedding (Figure 3A). In this type, which is the most common, the layers of a sequence are deposited parallel to one another and in a nearly horizontal position; consequently the bedding planes that separate the layers were in a nearly horizontal position at the time they formed. If the bedding planes of this type now stand at measurable angles to the horizontal, it is evident that the layered sequence has been folded or tilted since it formed.

Crossbedding (Figures 3B and 3C). In this type, laminations of material within beds are deposited at various angles to the main planes of stratification. In the varieties of crossbedding shown in **Figure 3**, the sets are separated by minor unconformities (a portion of the underlying set was removed by erosion before the overlying set was deposited) or planar beds. Crossbedding is a conspicuous feature in some of the sandstones in the mountain area. It is especially well developed and exposed in the Sand Creek region of the southern Laramie Basin (**Figure 4**).

Three different kinds of unconformities common to the Medicine Bow Mountains area are illustrated in **Figure 5**:

Regional angular unconformities (Figure 5, line A). Younger bedded rocks rest on older, tilted, bedded rocks. This kind of unconformity develops over large areas in response to the following sequence of events: (a) deposition of a sequence of parallel layers at a time when the region stood either below sea level or at some other level below the influence of erosion; (b) uplift of the region, with tilting or folding of the sequence; (c) a time interval during which erosion removed a portion of the sequence; and (d) deposition of a younger sequence on the eroded surface of the older sequence.

Minor angular unconformities in crossbedded deposits. This kind of unconformity occurs on a much smaller scale than the regional unconformity

TIME*	EON	ERA	PERIOD	EPOCH
0.01	PHANEROZOIC	CENOZOIC	Quaternary	Holocene
1.6				Pleistocene
5.3			Tertiary	Pliocene
23.7				Miocene
36.6				Oligocene
57.8				Eocene
66.4				Paleocene
		MESOZOIC	Cretaceous	Late
144				Early
			Jurassic	Late
				Middle
208				Early
			Triassic	Late
				Middle
245				Early
		PALEOZOIC	Permian	Late
286				Early
320			Carboniferous: Pennsylvanian	Late
360			Carboniferous: Mississippian	Early
			Devonian	Late
				Middle
408				Early
			Silurian	Late
438				Early
			Ordovician	Late
				Middle
505				Early
			Cambrian	Late
				Middle
570				Early
900 (PRECAMBRIAN)	PROTEROZOIC	Late		
1,600 (PRECAMBRIAN)		Middle		
2,500 (PRECAMBRIAN)		Early		
3,000 (PRECAMBRIAN)	ARCHEAN	Late		
3,400 (PRECAMBRIAN)		Middle		
4,600 (PRECAMBRIAN)		Early		

*In millions of years before the present (from Geological Society of America 1983 Geologic Time Scale). Not to scale.

Figure 2. Geologic time scale.

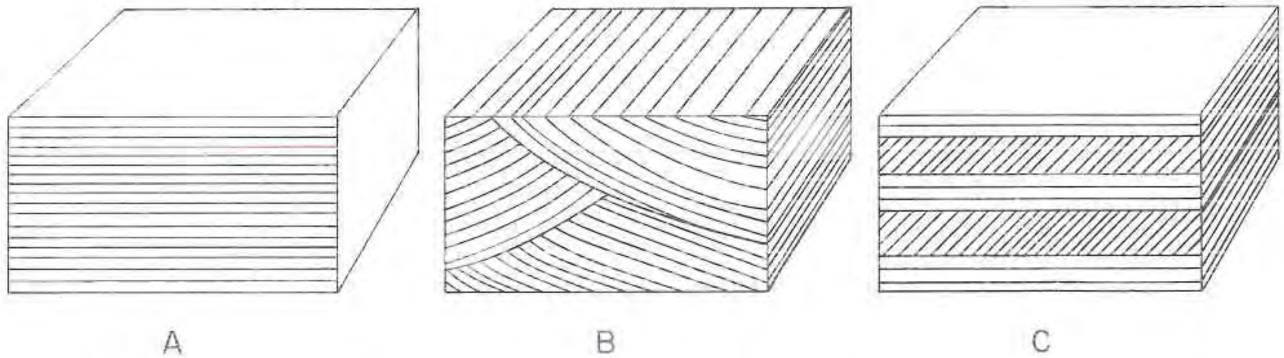
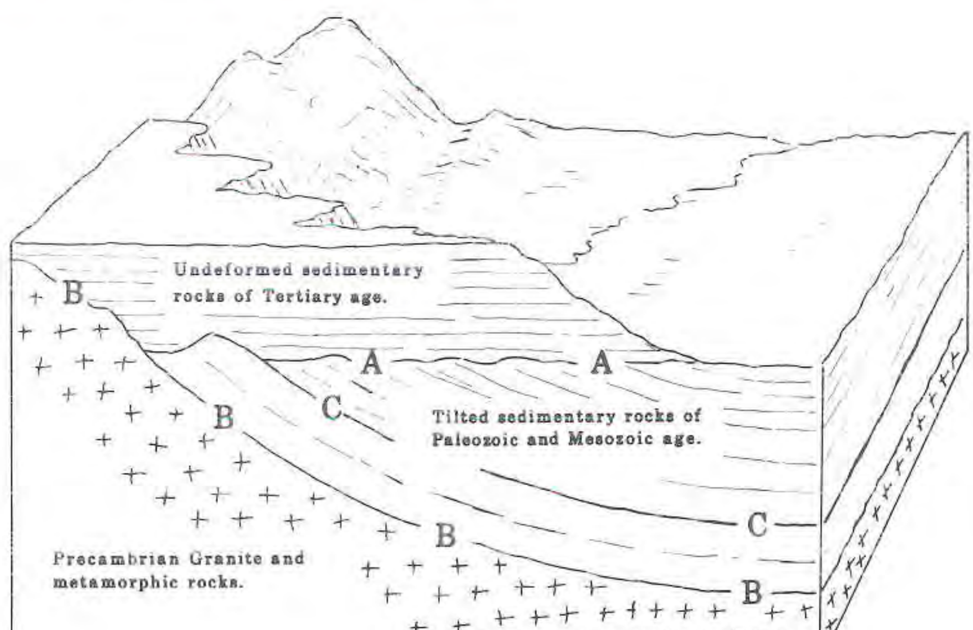


Figure 3. Diagrams of some common types of sedimentary bedding. (A) planar bedding, (B) crossbedding, and (C) crossbedding alternating with planar bedding.

Figure 4. Photograph of crossbedding in sandstone in the Sand Creek area southwest of Laramie. Erosional remnants of many sets of laminae are crossed at various angles and directions.

Figure 5. Three types of unconformities common to the Medicine Bow Mountains: (A) regional angular unconformity, (B) nonconformity, and (C) disconformity. (See text for more detailed explanation.)



described above. It comes into being in response to this sequence of events: (a) deposition of a parallel set of layers at an angle to the horizon; (b) a short time interval during which a portion of the set is removed by erosion; and (c) deposition of a younger set upon the eroded surface of the older set. Here, the angular discordance between sets is a local erosional-depositional phenomenon not related to crustal movements. In some instances, small-scale folding due to local slumping may occur as seen in **Figure 6**.

Nonconformities (Figure 5, line B). Stratified rocks rest on unstratified rocks. Intrusive igneous rocks in the Medicine Bow Mountains are not bedded; they are seamed with fracture or joint planes that intersect at various angles, but such planes are not related to bedding planes characteristic of sedimentary rocks. Coarse-grained igneous rocks form (crystallize) beneath a protective cover of pre-existing rocks. Nonconformities come into being in response to this sequence of events: (a) intrusion of magma into pre-existing rocks; (b) a time interval during which the overlying pre-existing rocks are removed by erosion; and (c) deposition of a sequence of sedimentary rocks on the eroded surface of the igneous rocks.

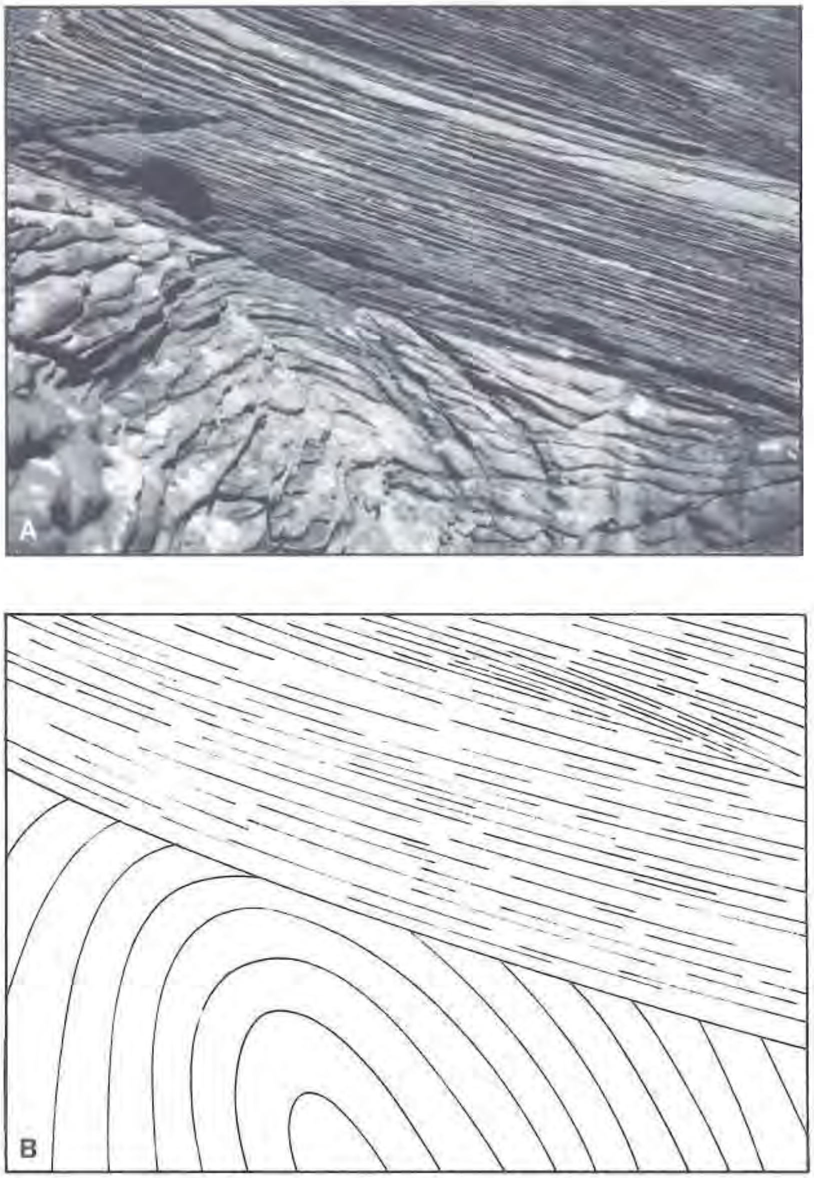


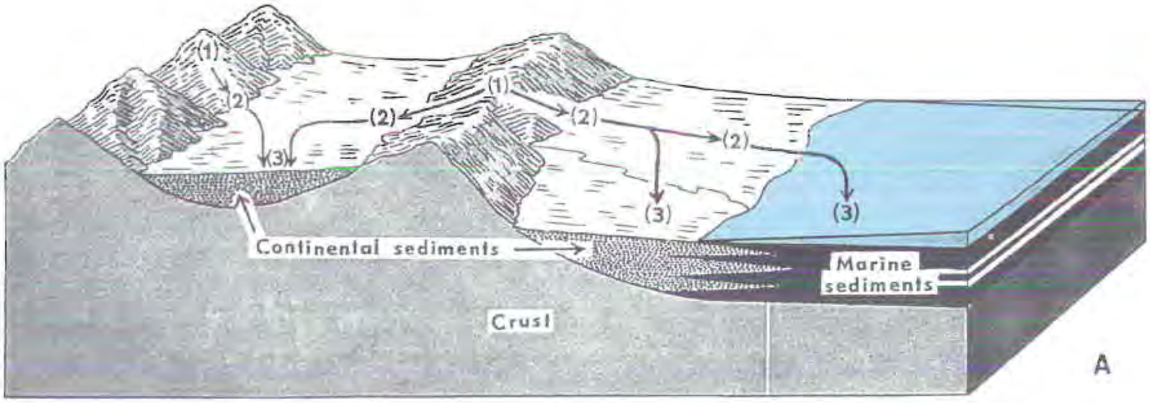
Figure 6. (A) Photograph of minor unconformity between two sets of layers in a festoon crossbedded sandstone. The underlying set was folded by local slumping and eroded before the overlying set was deposited. The total view is 10 feet long. (B) Interpretation of the above photograph. The folded bedding planes are partially obscured by fracture cleavage formed at the time of folding.

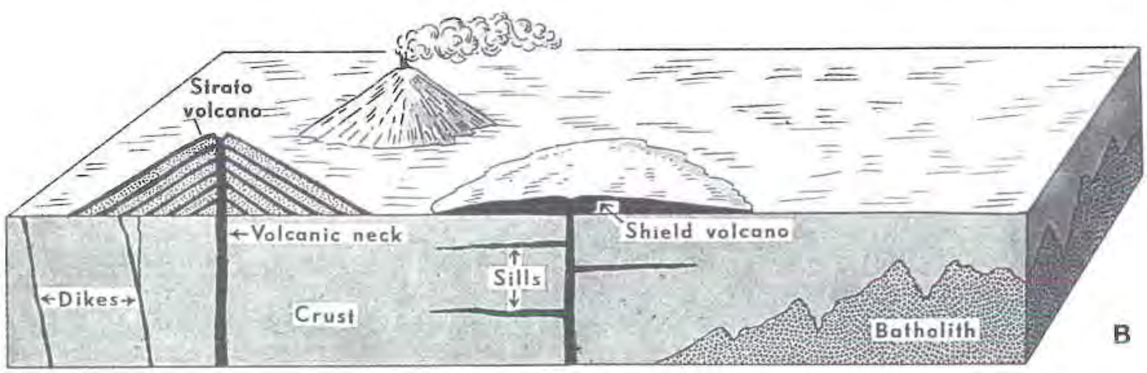
Disconformities (Figure 5, line C). Disconformities are unconformities between parallel strata. This kind of unconformity comes into being in response to the following sequence of events: (a) deposition of a sequence of parallel-bedded rocks; (b) a time interval during which the sequences is elevated without tilting or folding and a portion of the sequence is removed by erosion; and (c) deposition of a younger sequence of parallel-bedded rocks on the eroded surface of the older sequence. In disconformities, there is no angular discordance between the two sequences.

Changing landscapes

Landscapes are made up of landforms whose shapes are controlled by (1) the character and attitude of the rocks of which they are formed, (2) the processes, both physical and chemical, that operated to create the landforms, and (3) the length of time the landforms have existed. The configuration of landforms reflects these natural phenomena. For example, glaciated landscapes are made up of characteristic landforms that could only have been created by moving ice.

The portion of the outer crust of the Earth open to observation contains the age-old record of a never-ending conflict between two groups of opposing forces. One group, which operates upon the surface, triggers the processes of weathering and erosion that are destructive of highlands (**Figure 7A**). The processes operating on the surface are those inherent in running water, waves, moving ice,





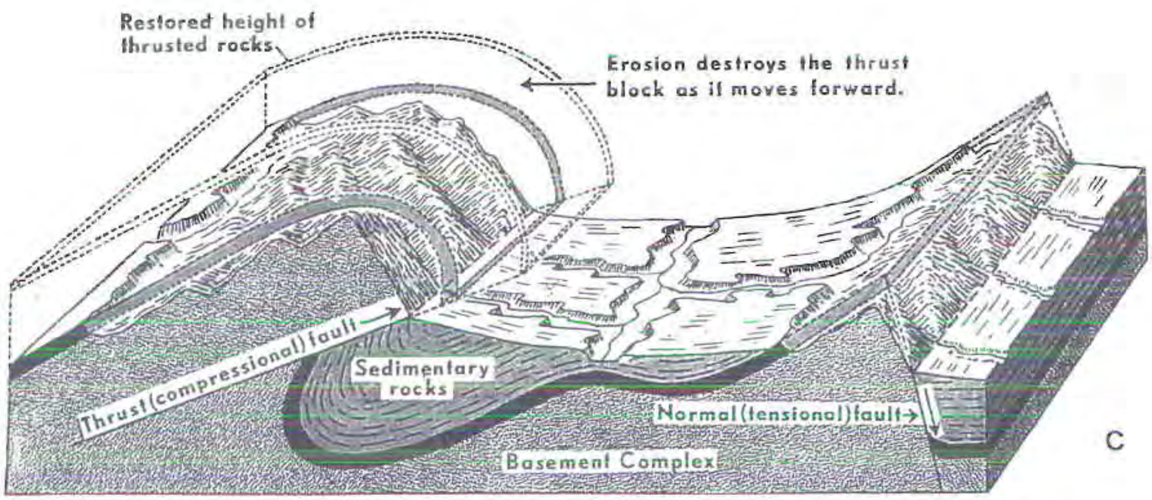


Figure 7. Diagrams illustrating geologic processes.

A. The cycle of erosion, transport, and deposition. (1) Erosion destroys the highlands, (2) rock fragments are transported from the highlands, and (3) this clastic debris is deposited on the lowlands and in the sea. Skeletal remains of marine organisms also form extensive deposits on the sea floor.

B. Intrusive and extrusive igneous occurrences. The intrusive occurrences shown are dikes, sills, and a batholith. Dikes cut pre-existing rocks at high angles. Sills parallel bedding or schistocity and are roughly tabular masses. Batholiths are vast invasions of magma into the crust. Extrusive occurrences shown are volcanoes, which vary from mountainous cones (strato volcanoes) to widespread outpourings with little relief (shield volcanoes).

C. Formation of mountains due to movements in the crust caused by compressional and tensional stresses. The mountain on the left is an eroded upfold, which broke along its overturned right flank and was thrust over the adjacent downfold. Movements along thrust faults are frequently on the order of 1,000s to 10,000s of feet. Tensional stresses may pull the upper crust apart. Relief between the mountain on the right and the adjacent valley formed when a large block dropped along a tension (normal) fault.

the wind, and the mechanical and chemical actions that disintegrate, decompose, and erode rocks.

If these processes had been allowed to continue unopposed, any initial relief above sea level that the Earth may have possessed would have long since disappeared and the Earth would be covered by a universal ocean. Instead, the forces that operate beneath the surface have created new relief from time to time, through the extrusion of lava onto the surface or intrusion of magma into the crust (**Figure 7B**) and by mountain-building movements within the crust (**Figure 7C**).

Volcanic mountains are built by outpourings of lava and eruptions of fragmental debris. When a number of volcanoes are sufficiently closely spaced so that outpourings join, extensive highlands form.

Movement resulting from compression and tension within the crust have uplifted, depressed, folded, broken, and shifted portions of the crust from time to time, with resulting changes in the surface relief. Over large portions of the continents, the sea has advanced and retreated many times in response to changing sea levels and depression or elevation of the land surface. The Medicine Bow Mountains area has been beneath and above the sea many times during its history.

The great mountain systems, such as the Rocky Mountains, have come into being by folding and fracturing of the crust. Individual mountain ranges, such as the Medicine Bow Mountains, are large complex upfolds (anticlines) while the adjacent lowlands are downfolds (synclines). When *compression* of the outer crust is intense, mountainous upfolds may be overturned. When the stress is great enough, the rocks break along fractures (shear zones) and give rise to thrust faults. (See the left-hand mountains in **Figure 7C**, which is a simplified reconstruction of the Medicine Bow Mountains as they looked early in their history.) **Figure 8** shows the results of compression at a small scale.

Tension stretches the outer crust, creating normal faults. The mountains on the extreme right-hand block of **Figure 7C** dropped with respect to the left-hand block along a high-angle normal fault. The precipitous east face of the Teton Range of northwestern Wyoming has also been carved from the surface of a steep normal fault. The adjacent Jackson Hole depression is the down-dropped block. The total movement along fault zones may aggregate tens of thousands of feet. Recorded movements at any one time are generally no more than a few tens of feet. However, movements may continue intermittently over a long time.

As soon as highlands rise above the base level of erosion (sea level or local base level), they are attacked by the destructive forces operating on the surface. The highlands continue to rise at the same time that their upper portions are destroyed. The two groups of forces are in conflict, with one group building and the other group destroying. When the building forces cease, the destructive attack continues, and in time the highlands are destroyed as relief features. Later, renewed movements in the crust may create new highlands, which are in turn destroyed by the never-ending forces of erosion.

The rocks exposed in the Medicine Bow Mountains and flanking lowlands tell us that the area occupied by them has gone through a number of cycles of crustal unrest, during which the region was either depressed below sea level, elevated above sea level, or folded and faulted. During prolonged periods of relative crustal stability, the highlands were destroyed and vast amounts of rock fragments were transported to and deposited on the lowlands and on the floors of shallow seas. Large amounts of magma were intruded into the crust from time to time (**Figure 7B**), especially during the earlier history of the mountain area.

A third type of very specialized process operating on the surface of the Earth is life. One of the most fascinating features of sedimentary rocks is the fossil record preserved in them.

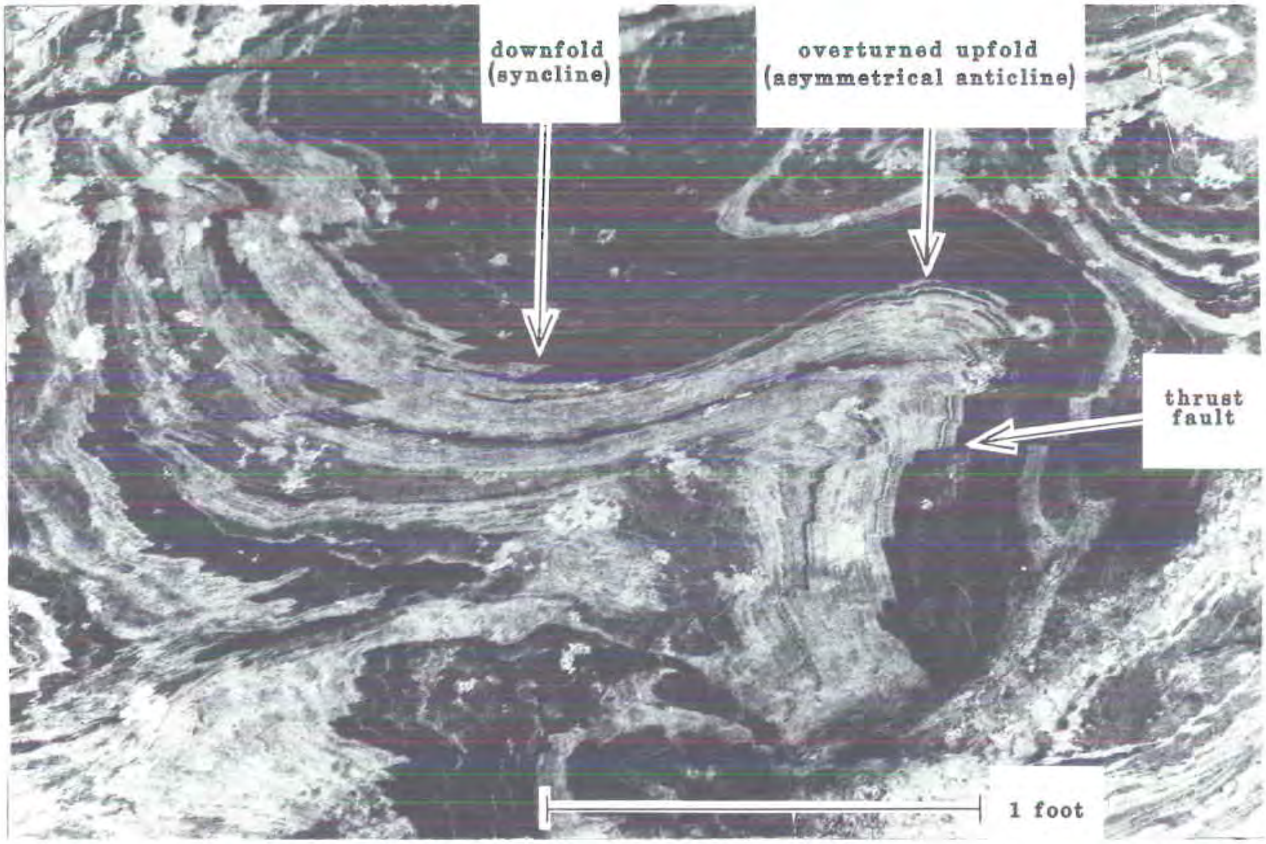


Figure 8. Photograph of a vertical face of sandstone that was folded and thrust faulted by local deformation. Here, on a small scale, are structural features characteristic of the Medicine Bow Mountains and adjacent basins. Magnify this occurrence 100,000 times and the overturned upfold becomes a mountain and the downfolds become intermountain basins. In the dynamics of the Earth's crust, small-scale features often reflect large-scale features.

Lake Marie fills a glacier-cut basin

Geologic History of the Medicine Bow Mountains and adjacent areas

Ancient landscapes are reconstructed from a wealth of information preserved in rocks. The information includes the character of the rocks, their inherited features, their extent, their included fossils, their attitude (whether flat lying or folded), and their relations to older or younger rock successions. Ancient highlands may have been destroyed as relief features but their roots may still exist. Vast accumulations of rock fragments derived from pre-existing rocks demand the existence of highlands as a source. The grain size of sediments increases, as a rule, in the direction of the source of supply. Sedimentary rocks deposited on the land or beneath the sea often contain characteristic fossils. A fossil oyster tells us that the rock in which it is entombed was probably deposited beneath the sea. A fossil forest could only have originated on land.

Figure 9 is included to assist the viewer in interpreting the scenes that follow. The two views in **Figure 9** are of imaginary landscapes as they may have existed at two different times in the past, designated time X and time Y. Time X precedes time Y. With the advance and retreat of the sea in response to movements within the crust, the shoreline changes its position, moving landward when the crust is depressed and seaward when the crust is elevated. Such advances and retreats may consume vast time spans.

In the following scenes (1-26), the shoreline is shown at the maximum advance of the sea during the interval pictured. If subsequent erosion has not removed the sediments that were deposited at that time of maximum advance of the sea, the position of the shoreline can be drawn with some precision. If subsequent erosion removed a portion of the rocks deposited at the time of maximum advance, then the position of the shoreline is an approximation because the physical evidence of its position has been destroyed.

The index map in the lower left-hand corner of each scene shows the area covered by the scene. The sketches of life forms on the diagrams are representative of the kinds of life that inhabited the world at the time depicted in the scene.

The Precambrian

(3.5+ b.y. - 570 m.y.)[1]

In Wyoming, rocks of Precambrian age were buried under thick successions of younger rocks of Paleozoic, Mesozoic, and Cenozoic ages. However, there are extensive areas where erosion has removed these younger rocks and the older Precambrian rocks are exposed. The uplifted and exposed core of the Medicine Bow Mountains is such an area.

For the purpose of this summary, Precambrian time is informally divided into early (3.5+ to 2.5 b.y.), middle (2.5 to 1.7 b.y.), and late (1.7 b.y. to 570 m.y.). The informal early Precambrian division used here corresponds to the Archean of **Figure 2**. Informal middle and late Precambrian divisions correspond to the Proterozoic of **Figure 2**. This vast time span of nearly three billion years consumed the first five-sixths of the known history of the Earth. The history of the Earth is less well documented as we go back in time due to the fragmentary character of the record and the changes the older rocks have undergone through folding, faulting, and metamorphism. The Precambrian rocks of the Medicine Bow Mountains include rocks dated as early, middle, and late Precambrian.

Early Precambrian

(2.5+ b.y. or older)

Scene 1.

The first event of record in the history of the mountain area was the deposition of a vast succession of lava flows and fragmental debris upon a crust whose composition is unknown. Evidence indicates that the succession was deposited in a sea. The original extent and thickness of this succession cannot be determined exactly because the record is only fragmentary. It was, in all probability, not less than several thousand feet thick. These rocks are known to be more than 2.5 b.y. old; they may actually be several hundred million years older.

[1] Editor's note: In the following discussion, numerical ages in years for the various time intervals will be given as b.y. for billions of years and m.y. for millions of years. These numerical ages have been somewhat modified from Dr. Knight's original designations in order to conform to the geological time scale for the Decade of North American Geology (Geological Society of America, 1983).

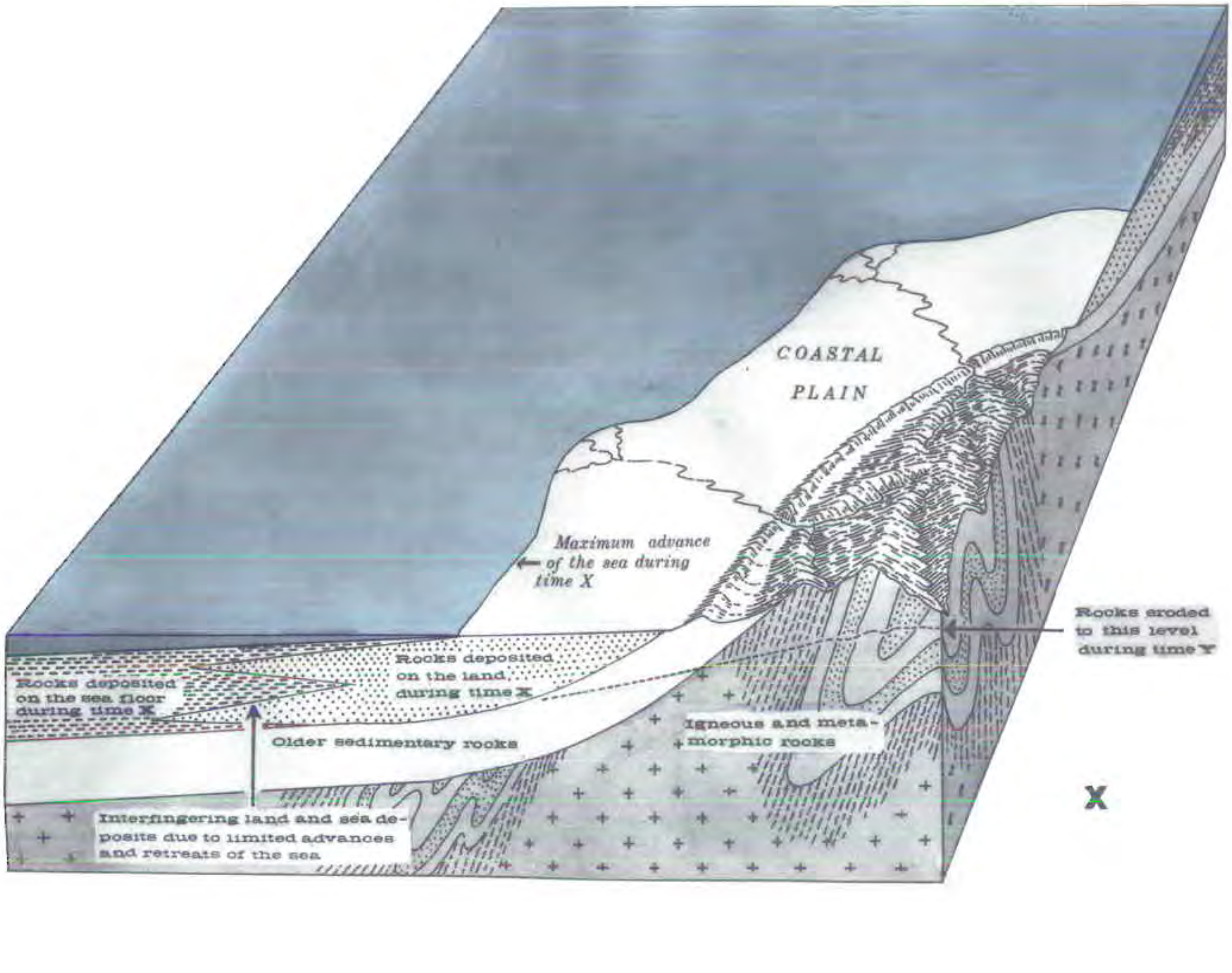
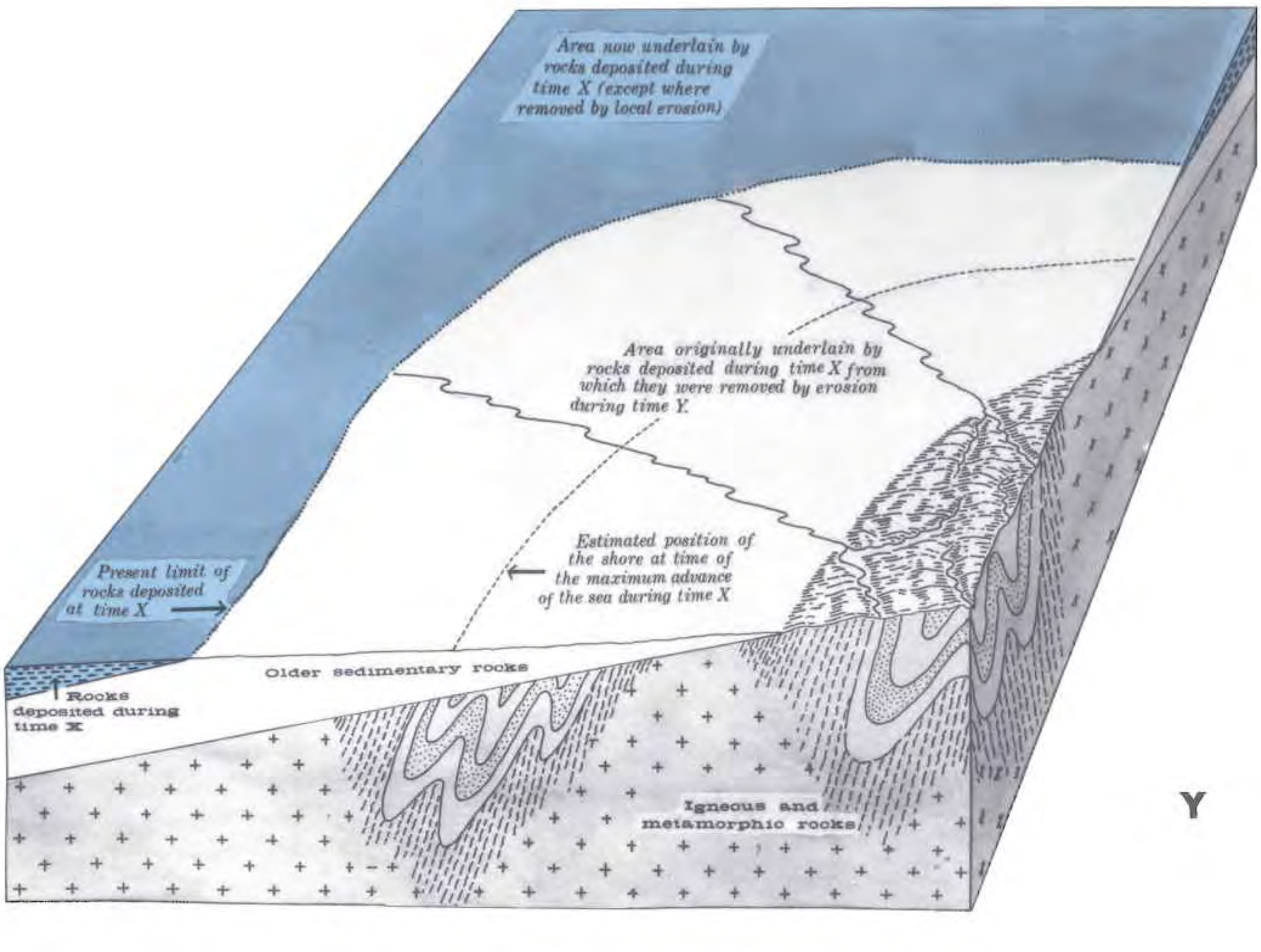
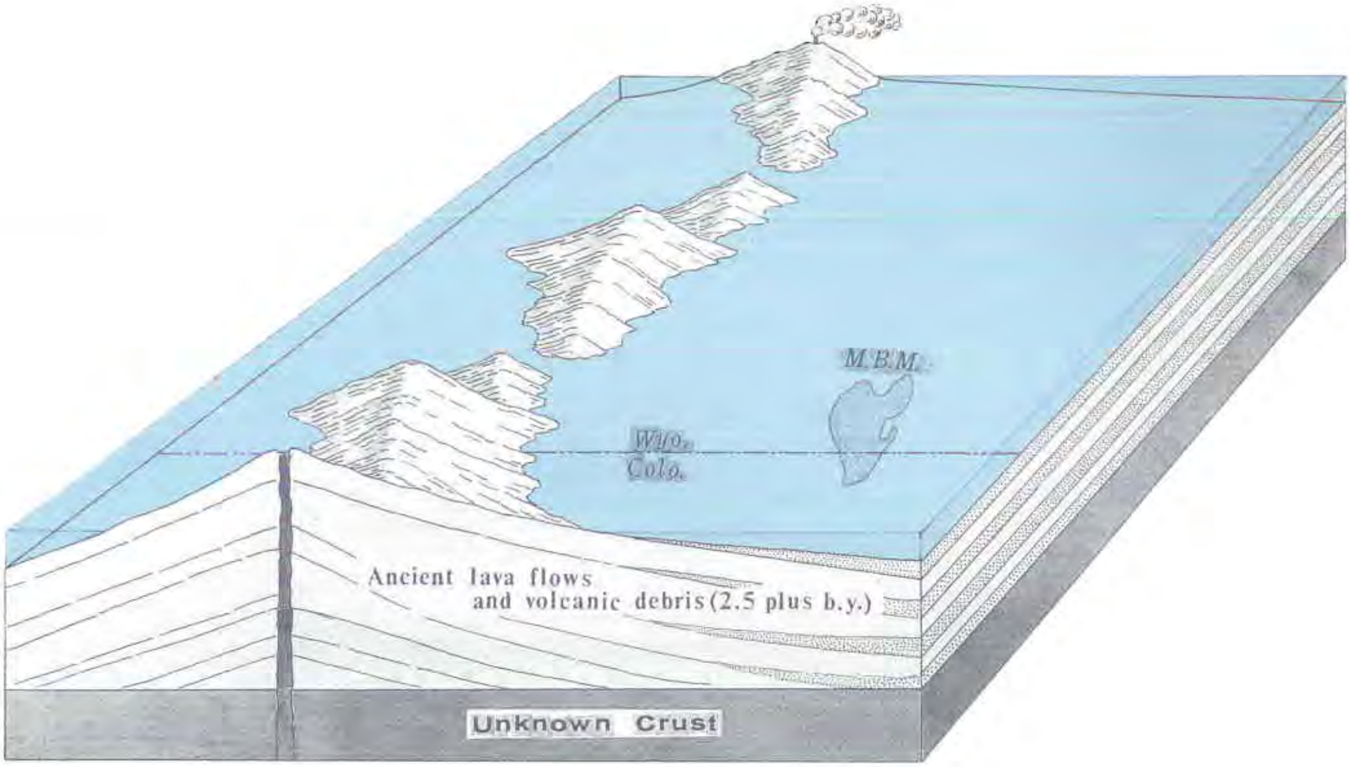
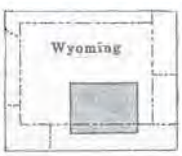


Figure 9. Block diagrams illustrating transgression and regression of the sea in the Medicine Bow Mountains region during theoretical times X and Y. (X) Maximum advance of the sea (transgression). The sea is shown at the time of maximum advance during time X. Rock fragments are being transported from the highlands and deposited on the coastal plain (alluvial deposits) and on the floor of the sea (marine deposits);. The skeletal remains of marine organisms may also form deposits on the sea floor. (Y) Regional uplift and retreat (regression) of the sea. This is the same area shown in Figure 9X, as it existed at a later time Y. Regional uplift has caused the sea to withdraw from a portion of the area, and erosion has removed rocks deposited during time X together with some of the older rocks. When such conditions prevail, the maximum position of the shoreline during time X can only be estimated because the rock record is incomplete.


Area now underlain by rocks deposited during time X (except where removed by local erosion)
Area originally underlain by rocks deposited during time X from which they were removed by erosion during time Y.
Estimated position of the shore at time of the maximum advance of the sea during time X
Present limit of rocks deposited at time X
Older sedimentary rocks
Rocks deposited during time X
Igneous and metamorphic rocks
Y





Scene 1. Early Precambrian. The earliest geological event of record was the deposition of an alternating succession of lava flows and fragmental volcanic debris on a crust of unknown composition. (M.B.M. = future site of Medicine Bow Mountains.)

This succession is believed to have been derived from a volcanic island arc, the position of which cannot be determined due to the limited exposures of these rocks. In the scene, the volcanoes are pictured as lying west of the present area of the Medicine Bow Mountains. They could have been located in any other direction. The succession was deposited upon an older crust, the nature of which cannot be determined. It is extremely doubtful that any vestige of this older crust survives in anything like its original character. It could have been composed of older sedimentary, igneous, or metamorphic rocks.

Late early Precambrian

(2.5+ b.y.or older)

Scene 2.

Following the deposition of the volcanic succession shown in **Scene 1**, the region was subjected to mountain-building forces that intensely folded the existing crust. As the mountains rose, they were attacked by erosion and their inevitable destruction began. During or after the time of folding, vast amounts of magma invaded the crust and the ancient granites and gneisses formed. The invading magma was on such a scale that the crust upon which the volcanic succession was deposited lost its identity through melting and recrystallization. The gneisses are complex, coarsely banded metamorphic rocks, which were derived, in large part, from the volcanic succession.

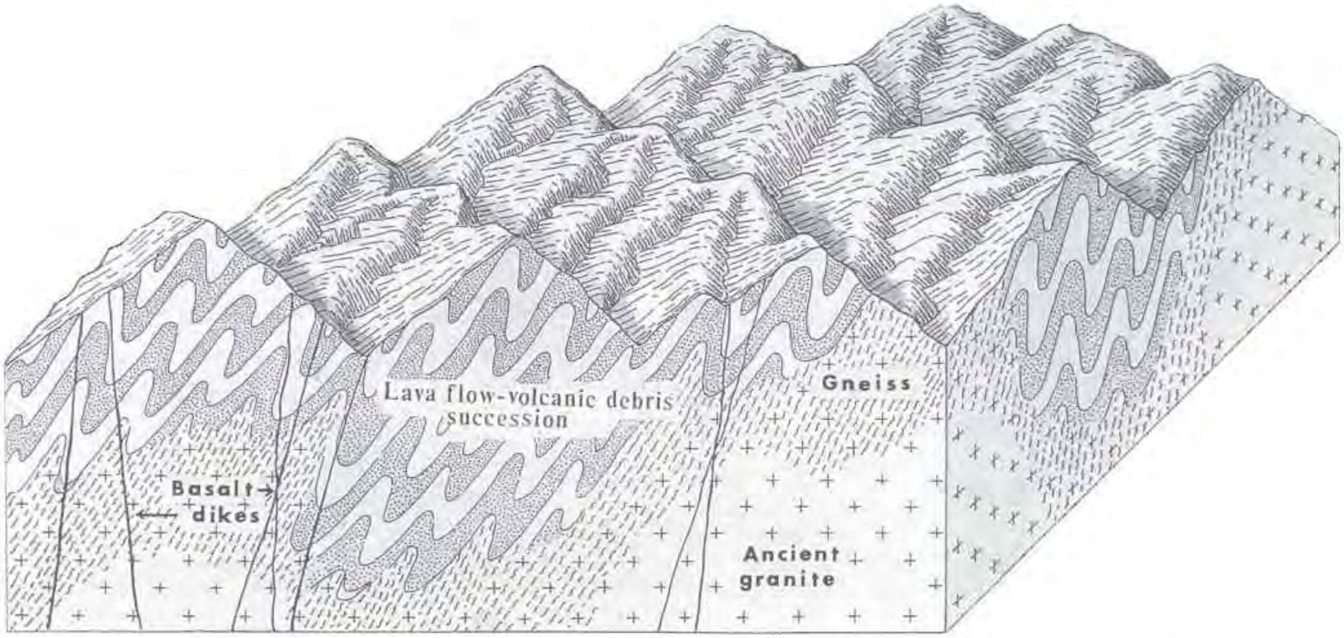
The last event pictured in the diagram was the intrusion of large numbers of basaltic dikes.

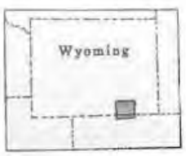
End of early Precambrian

(around 2.5 b.y.)

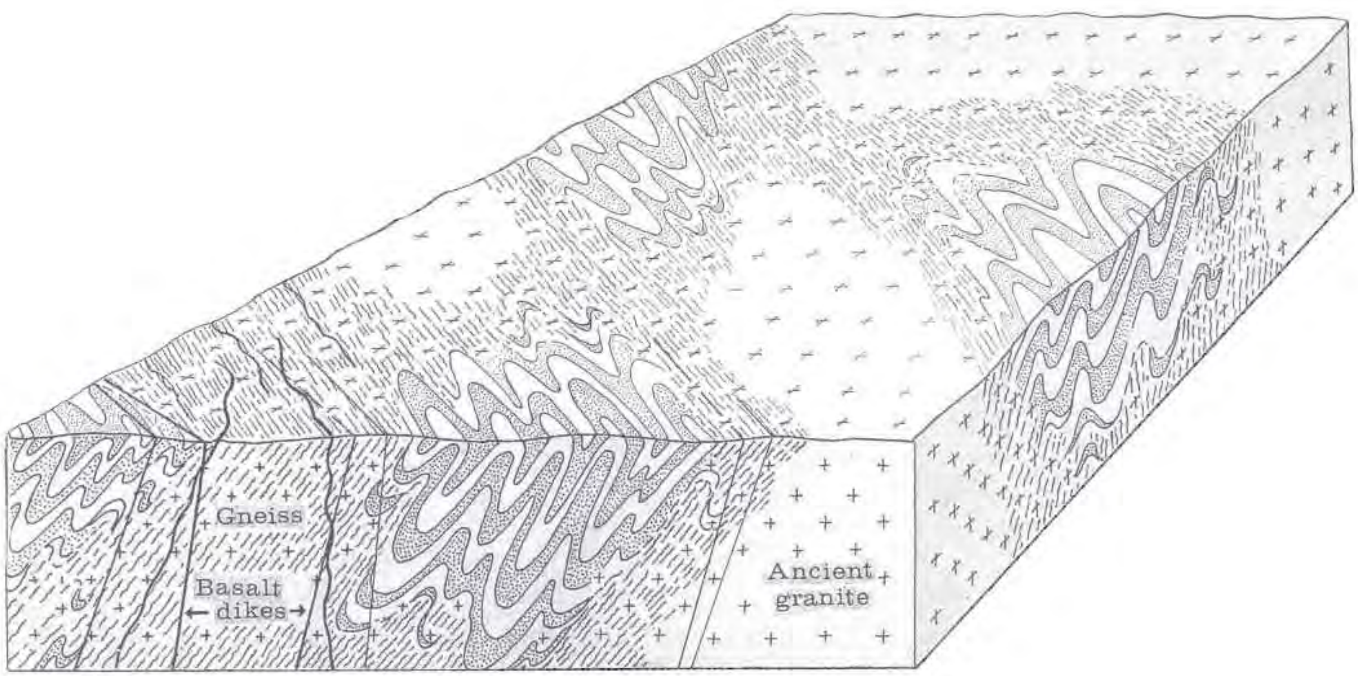
Scene 3.

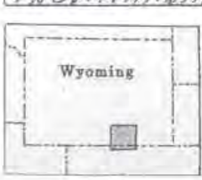
During a long interval of crustal stability, the highlands shown in **Scene 2** were destroyed by erosion and the region was reduced to low relief. This is one of the lost intervals of time, when the rock debris eroded from the highlands was transported and deposited elsewhere. Consequently, there is no positive record in the form of a rock succession within the area that was being eroded.





Scene 2. Late early Precambrian. The lava succession of Scene 1 was intensely folded and metamorphosed. Large amounts of granite and gneiss formed and many basaltic dikes intruded. The crust beneath this succession lost its identity by melting and recrystallization.





Scene 3. End of early Precambrian. Profound erosion destroyed the highlands of Scene 2 and reduced the region to low relief.

Middle Precambrian

(2.5 to 1.7 b.y.)

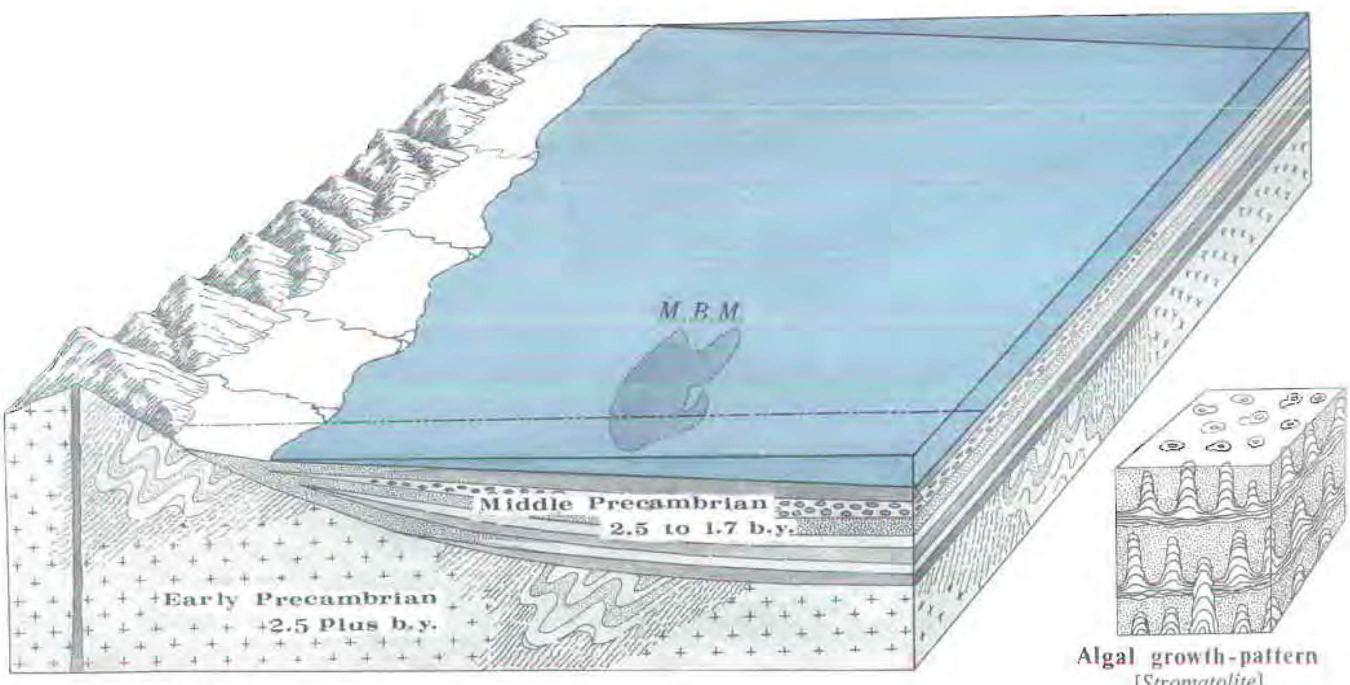
Scene 4.

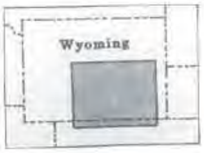
Following the long period of relative crustal stability, during which the mountain highlands shown in **Scene 2** were reduced to low relief (**Scene 3**), vast new mountain highlands came into being at an unknown locality some distance from the present Medicine Bow Mountain region. The position and extent of these highlands cannot be determined because the area they occupied now lies buried under younger rocks. The presence of the highlands and some appreciation of their magnitude is known from the enormous amount of rock debris that was eroded from them and deposited as sediments on adjacent lowlands. The region now occupied by the Medicine Bow Mountains was a part of those lowlands.

During this prolonged interval of more than half a billion years, a vast succession of sediments, aggregating more than 25,000 feet thick, was deposited. Since this succession was deposited, the sediments of which it was originally composed have undergone low-grade metamorphism. The sands were converted to quartzites, the silts to phyllites and slates, and the calcareous sediments to marble. All available information from present inherited features tell us that the succession was deposited, for the most part, in shallow seas.

The most spectacular formation in this succession, from a scenic point of view, is the Medicine Peak Quartzite. Quartzite is a metamorphic rock derived from sandstone, in which the interstitial spaces between the sand grains are filled with silica. It is very hard and resistant to weathering and erosion. This formation is 6,000 feet thick and today it forms a conspicuous northeast-southwest trending, snow-capped, glaciated ridge that rises precipitously a thousand feet above its surroundings (**front cover**). Seldom does a single geological formation command such an imposing view. The quartzite is predominantly milk-white in color although there are bands in pastel shades of green and blue. Lens-shaped beds of rounded pebbles are common. Ripple-marked surfaces and cross-laminated beds are conspicuous features.

It is not to be wondered that the casual observer is awed when told that this bold ridge, now standing at elevations from 11,000 to 12,000 feet, is composed of rock that began as sand derived from still older rocks, which was deposited on or near a sea beach some two billion years ago.





Scene 4. Middle Precambrian. A vast succession of sand, silt, and calcareous sediments, aggregating 25,000 feet thick, was deposited over the area. The sediments have been metamorphosed to quartzite, phyllite, slate, and marble. Growth patterns of blue-green algae [cyanobacteria] are well preserved in some of the marbles as stromatolites. (M.B.M.=future site of Medicine Bow Mountains.)

The most interesting formation in this vast succession, insofar as the record of early life is concerned, is the Nash Fork Formation. This formation is 7,000 feet thick and is composed of three strongly contrasting rock types. The most abundant type originated as fine-grained rock particles deposited as silt and later metamorphosed into dense, finely laminated, brown to black slates and phyllites. The presence of such vast quantities of fine-grained rock debris suggests that the highlands from which the sediment was derived were rejuvenated by uplift from time to time and that the rock particles were transported a considerable distance before being deposited at the site of the present Medicine Bow Mountains. The second most abundant rock type consisted originally of heads, domes, and reefs of calcareous sediment deposited by simple single-celled marine organisms, probably blue-green algae [cyanobacteria]. Many of these occurrences preserve, in various degrees of perfection, the laminated growth pattern of the organically deposited calcium carbonate, called stromatolites (**Scene 4** and **Figures 10** and **11**). These growth patterns are some of the best preserved to be found in rocks of such antiquity. The third rock type common to the Nash Fork Formation is a dark, fine-grained, igneous rock (gabbro) that occurs as irregular tabular masses (sills). The time of the intrusion of these masses has not been determined. It is believed that they were intruded early in the period of folding shown in the next scene.

Figure 10. Stromatolite growth pattern in middle Precambrian rocks of the Nash Fork Formation. Two linked domes rest on an oblong growth. The Nash Fork Formation crops out at numerous places in the area between Little Brooklyn Lake and Mirror Lake.

Late middle Precambrian

(1.7 b.y.)

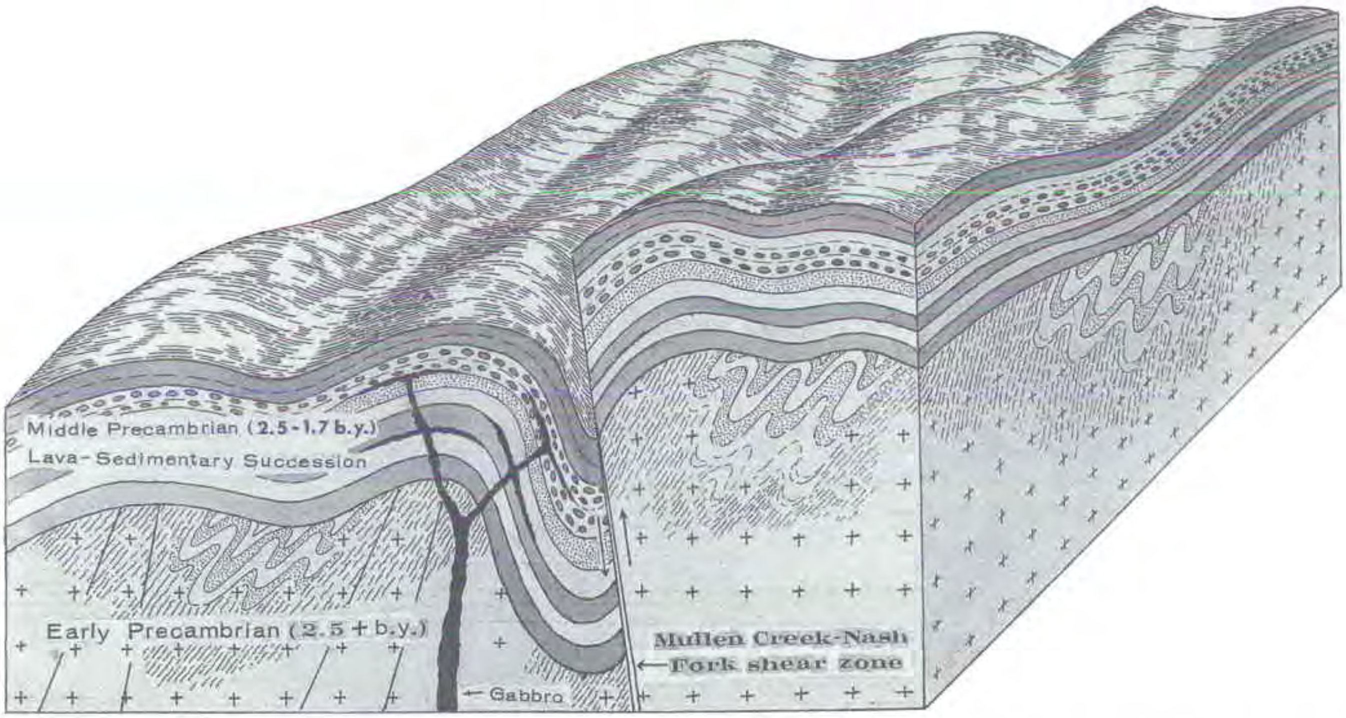
Scene 5.

At or near the close of middle Precambrian time, compressional forces folded and faulted the thick sedimentary rock succession that was deposited during middle Precambrian time and all other underlying rocks as well. The folding at this time was much less intense than the folding that took place at the close of early Precambrian time (**Scene 2**).

The most conspicuous feature developed during this period of crustal unrest is the great Mullen Creek-Nash Fork shear zone [now called the Cheyenne belt][2]. This shear zone transects the mountains in a north-

Figure 11. Stromatolite growth pattern seen on the weathered surface of a silicified dome.

[2]Editor's note: The Mullen Creek-Nash Fork shear zone was renamed the Cheyenne belt and references to it in the rest of this text have been changed accordingly. (See Karlstrom K.E., and Houston, R.S., 1984, The Cheyenne belt: analysis of a Proterozoic suture in southern Wyoming: Precambrian Research, v. 25, p. 415-446.)



Scene 5. Late middle Precambrian. This was a time of folding and faulting, when the crust was displaced thousands of feet along a great northeast-southwest trending shear zone, the Mullen Creek-Nash Fork shear zone [now called the Cheyenne belt]. The southeast block was elevated with respect to the northwest block. Large amounts of gabbroic magma were intruded.

east-southwest direction. The east segment, as shown in the diagram, moved up with respect to the west segment. The total amount of movement between the two segments cannot be determined due to subsequent erosion. However, it was on the order of tens of thousands of feet.

Late Precambrian

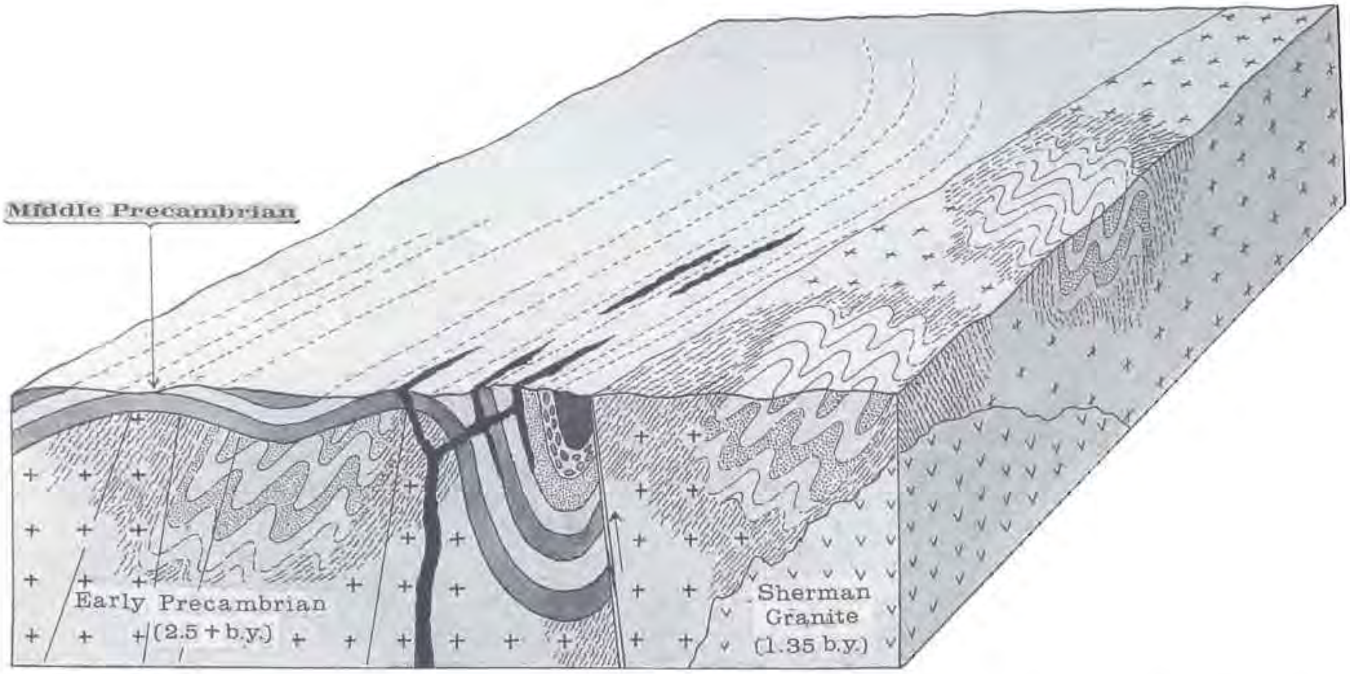
(1.7 b.y. to 570 m.y.)

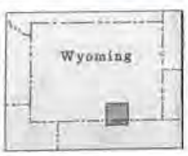
Scene 6.

Following the period of folding and faulting shown in Scene 5, there was a long interval of time — more than a billion years — during which the area was eroded and the region was reduced to low relief. The emplacement of the Sherman Granite along the eastern margin of the Medicine Bow Mountains region 1.35 billion years ago was a significant event. If any volcanic or sedimentary rocks were deposited during this long interval, they were removed by erosion by the end of Precambrian time. Erosion removed the thick middle Precambrian sedimentary succession from the upthrown segment southeast of the Mullen Creek-Nash Fork shear zone [Cheyenne belt]. These rocks are preserved in the segment northwest of the shear zone, where they were deeply down-folded.

Exposed on the eroded surface of low relief was a complex assemblage of igneous and metamorphic rocks, which had come into being during the first two billion years of the known history of the area. This igneous and metamorphic assemblage, known as the Precambrian basement complex, is the foundation upon which the Cambrian and younger sedimentary rocks were deposited. The pattern of the Precambrian rocks in the following scenes of the Cambrian and younger periods is generalized to allow the diagrams to emphasize the patterns of the younger rock successions.

Centennial Mountain - winter scene





Scene 6. Late Precambrian. Profound erosion during late Precambrian time reduced the region to low relief. Middle Precambrian rocks were removed from the upthrown block southeast of the Mullen Creek-Nash Fork shear zone [Cheyenne belt]. Sherman Granite invaded the eastern margin of the area 1.35 billion years ago.

The Paleozoic Era

(570 to 245 m.y.)

The Paleozoic Era is divided into seven periods: the first, the Cambrian, began 570 million years ago and the last, the Permian, ended 245 million years ago. During the greater part of this span of 325 million years, the future Medicine Bow Mountains region was part of an extensive surface devoid of marked relief. This shelf was below and then above sea level a number of times. When below sea level, relatively thin deposits of marine rocks, chiefly limestones, were laid down on the sea floor. When the seas withdrew, erosion removed the previously deposited rocks from large areas. For the most part, the seas advanced over the shelf from west to east and withdrew in the direction from which they came. The Paleozoic Era closed with a time of great crustal unrest, during which mountain systems came into being elsewhere, notably in the eastern United States. However, the Medicine Bow Mountains region remained stable during this time of crustal movement; so stable, in fact, that in the absence of diagnostic fossils it has not been possible to determine, in the rock succession, the boundary between late Paleozoic rocks and the overlying younger Mesozoic rocks. Available evidence indicates that the boundary between rocks of Paleozoic and Mesozoic age lies within the redbeds and gypsum of the Goose Egg Formation.

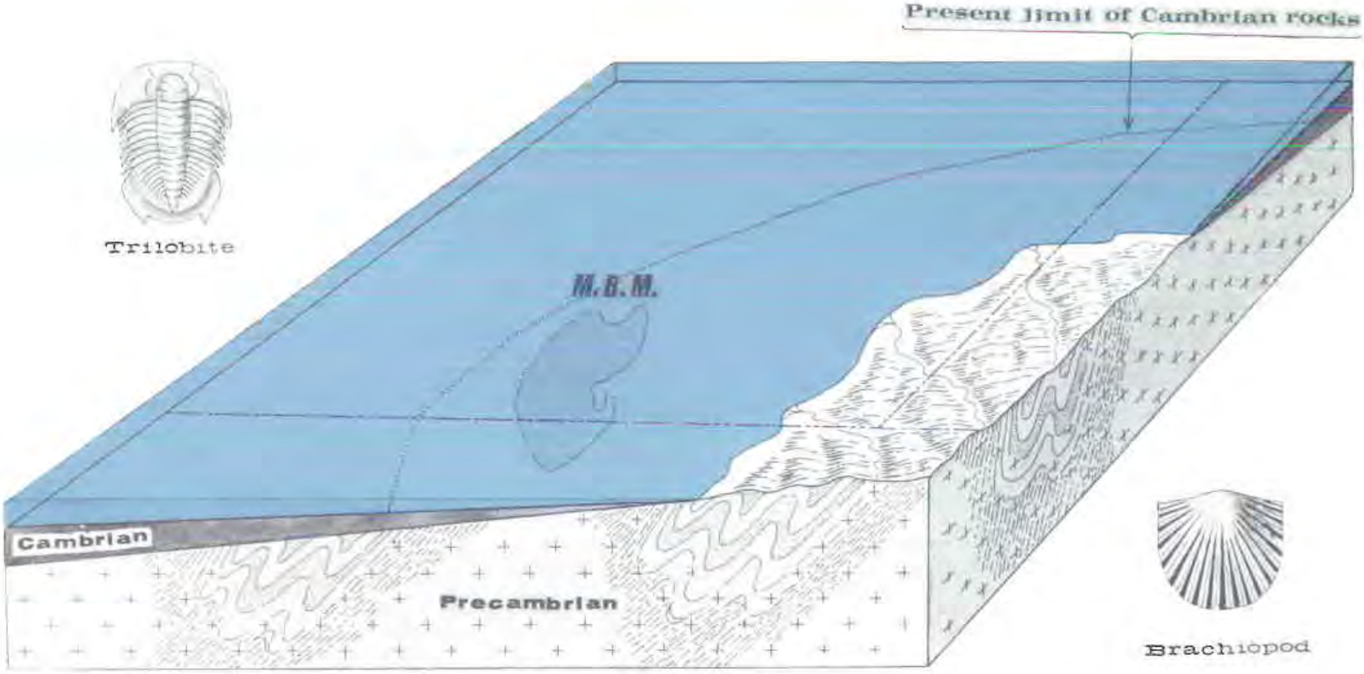
The Cambrian Period

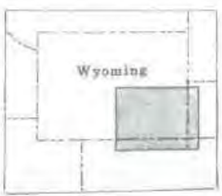
(570-505 m.y.)

Scene 7.

The Cambrian Period, the first of the seven periods of the Paleozoic Era, lasted for 65 million years. During Cambrian time, a sea advanced from west to east across the future mountain area and later withdrew in the direction from which it came. A sequence of marine sediments (now conglomerates, sandstones, shales, and limestones) was deposited. The sequence thickens when traced westward from the present eastern limit. As pictured in the diagram, the sea covered much of Wyoming during the time of its maximum advance. Due to later erosion, the position of the shoreline at the time of maximum advance can only be estimated. The present limit of the eroded edge of Cambrian rocks lies just west of the Medicine Bow Mountains.

A notable feature of Cambrian rocks is the presence of abundant fossil remains of a well-developed





Scene 7. Cambrian Period. No Cambrian rocks occur in the Medicine Bow Mountains region although their present eastern limit lies nearby. The Cambrian sea is believed to have covered the area at the time of its maximum advance. Subsequent erosion removed the Cambrian rocks to their present limit and the position of the shoreline at the time of its maximum advance can only be approximated. (M.B.M. = future site of Medicine Bow Mountains.)

and diversified marine invertebrate fauna. Although life had been in existence for some two billion years or more prior to Cambrian time, it was not until Cambrian time that most of the major divisions (phyla) of modern animal groups were present. The vertebrates had yet to appear.

The Ordovician Period

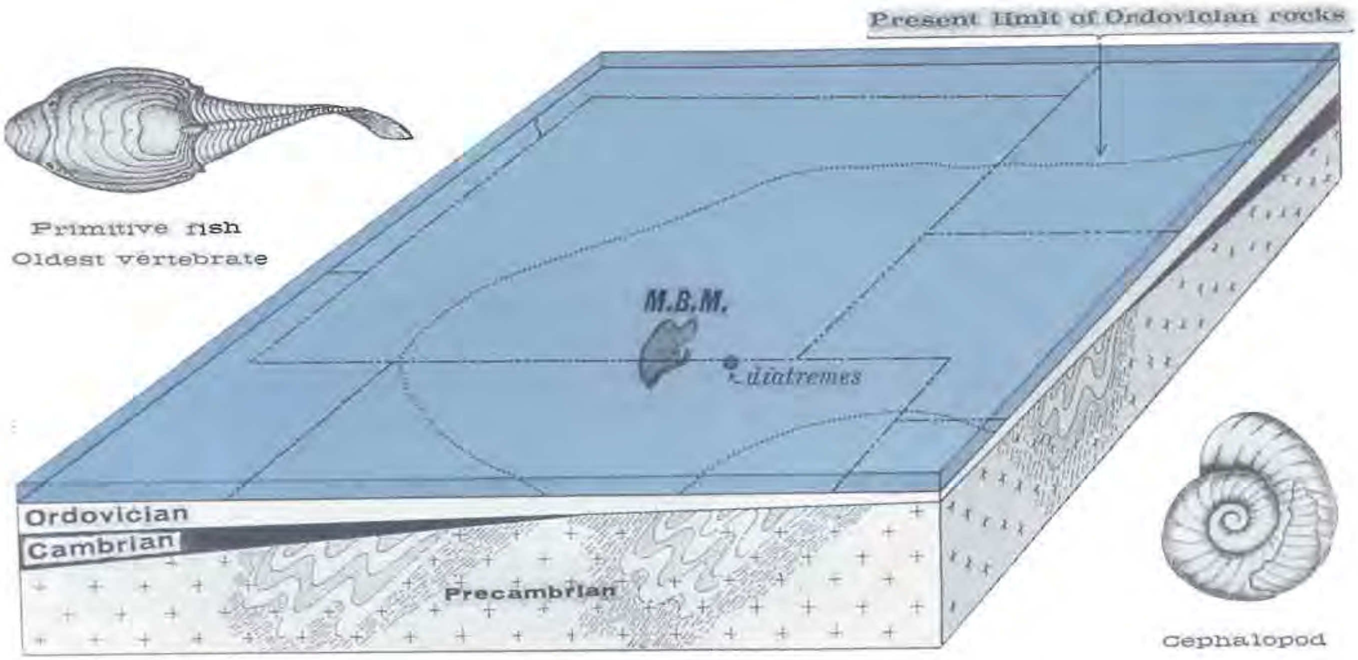
(505-438 m.y.)

Scene 8.

There was no evidence that rocks of Ordovician age once covered the Medicine Bow Mountains region until the recent discovery of fossils of Ordovician age in diatremes in the Laramie Mountains, east of the Medicine Bow Mountains. A diatreme is a breccia-filled volcanic pipe formed by a gaseous explosion. Blocks of overlying Ordovician fossiliferous limestone fell into the volcanic pipes and were preserved after the rest of the formation was removed by erosion. The occurrence of these fossils, beyond the present limit of Ordovician rocks, leads to the conclusion that the Ordovician sea covered, for a time at least, the future mountain area.

The Ordovician rocks of the Rocky Mountain region contain fragmental remains of the armour of primitive fish. These bony plates are the only portions of the animals that have been preserved. Comparison with better preserved remains of the same class of fish (Agnatha) occurring in Devonian rocks in Wyoming and elsewhere shows that the bony plates were the protective armour of the primitive fish. The remains are of Ordovician age and represent the oldest known vertebrates.

The primitive fish shown in **Scene 8** is a reconstruction of the same class of fish found in rocks of Early Devonian age and is believed to resemble the Ordovician fish.



Scene 8. Ordovician Period. Evidence that the Ordovician sea covered the future Medicine Bow Mountains area consists of diagnostic marine fossils of Ordovician age preserved in blocks of rock that fell into volcanic vents (diatremes) close to the mountains. Subsequent erosion removed the Ordovician rocks, from which the blocks were derived, to the limit shown in the diagram. (M.B.M. = future site of Medicine Bow Mountains.)

The Silurian Period

(438-408 m.y.)

Scene 9.

The only evidence that the Silurian sea covered the mountain area is the presence of fossils of Silurian age, also preserved in diatremes east of the Medicine Bow Mountains. With that exception, the present limits of Silurian rocks are far removed, as shown in the diagram. The Silurian fossils in the diatremes lead to the conclusion that deposits of the Silurian sea once covered the area, but were eroded from most of Wyoming and adjacent areas before the advance of the Devonian sea.

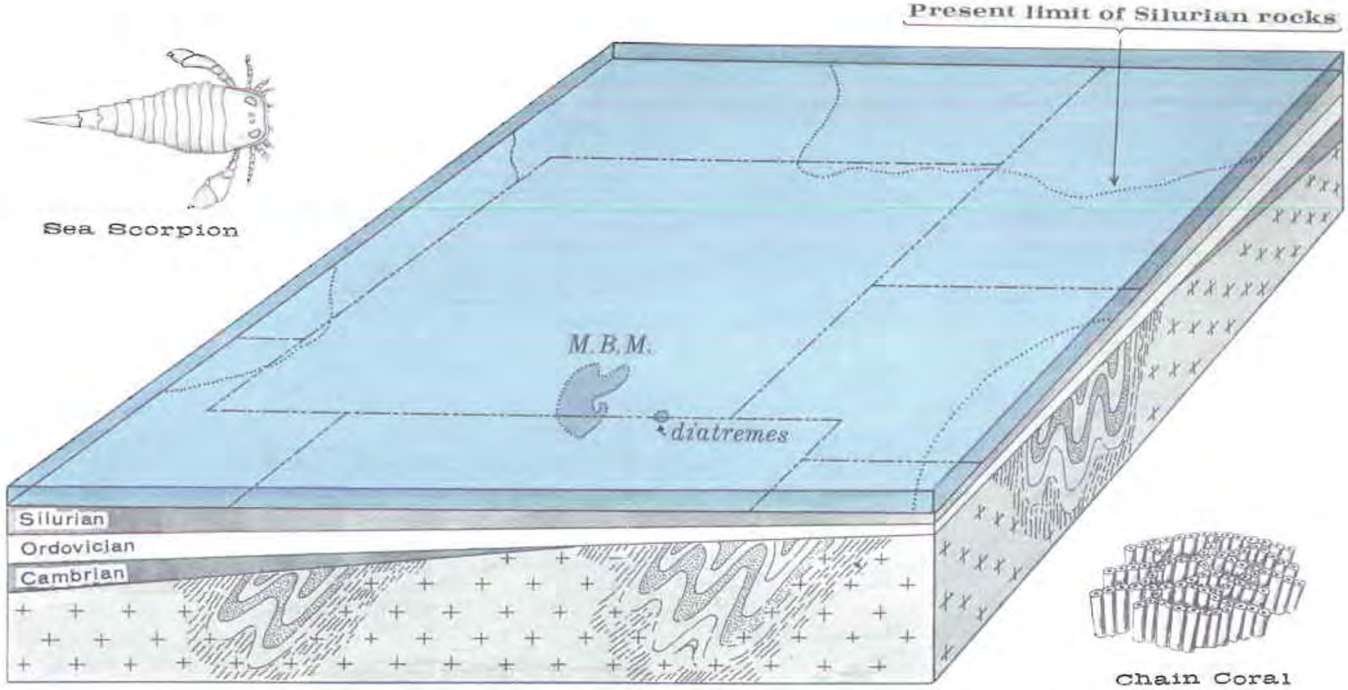
The sea scorpion (an arthropod) shown in the diagram is representative of a host of similar marine animals that lived during Silurian time. While most of these animals were small (a foot or less in length) some were several feet long. The first evidence of land life, fragmentary remains of terrestrial plants, occurs in rocks of Silurian age outside Wyoming. There is some evidence that the first air-breathing animals may also have made their appearance in late Silurian time.

The Devonian Period

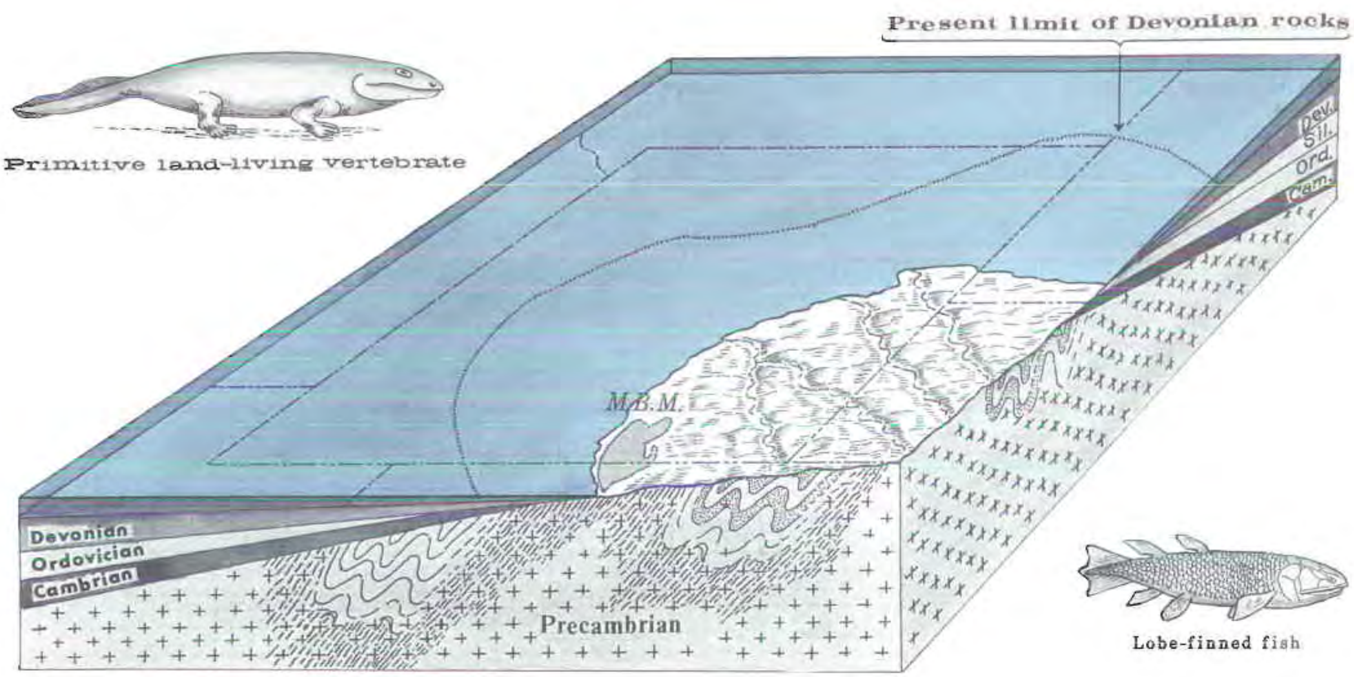
(408-360 m.y.)

Scene 10.

The position of the shoreline at the time of the maximum advance of the Devonian sea can only be estimated. As pictured (**Scene 10**), the sea reached the western margin of the future Medicine Bow Mountains region, and the southeastern portion of Wyoming is shown as a land area. The shoreline, as illustrated, lies a hundred miles east of the present limit of Devonian rocks. The maximum advance of the sea could have been positioned at any place between the present limit of the Devonian rocks and the shoreline shown.



Scene 9. Silurian Period. The presence of marine Silurian fossils in blocks of rock preserved in volcanic vents (diatremes) located close to the Medicine Bow Mountains tells us that the Silurian sea covered the area for a limited time. With this exception, no Silurian rocks are known to occur closer to the mountain area than the northern and western boundaries of Wyoming and western Nebraska. (M.B.M. = future site of Medicine Bow Mountains.)



Scene 10. Devonian Period. The maximum extent of the eastward transgression of the sea during Devonian time is not known. An estimated position of the shoreline is shown in the diagram, with southeastern Wyoming pictured above sea level. Fossil remains of the earliest land-living vertebrates (ancestral amphibians) occur in rocks of late Devonian age elsewhere in the world. (M.B.M. = future site of Medicine Bow Mountains.)

The animal pictured in the upper left of the scene is a reconstruction of an early amphibian, the first of the land-living vertebrates, which evolved from the lobe-finned fish pictured in the lower right of the scene. Many different kinds of fish lived in the Devonian sea, so many that the Devonian is known as the Age of Fishes. Primitive land plants were well established. Several herbaceous species occur in Devonian rocks in northwestern Wyoming (Beartooth Butte) and elsewhere. Forests first appeared during Devonian time.

The Mississippian Period

(360-320 m.y.)

Scene 11.

Rocks deposited during the Mississippian Period occur along the northwestern margin of the Medicine Bow Mountains and are absent along the southeastern margin. On the basis of this relationship, the maximum limit of the advance of the Mississippian sea is pictured as traversing the southeast portion of the future site of the Medicine Bow Mountains and the future site of the Laramie Basin is shown as a land area. It is possible that erosion during late Mississippian time removed Mississippian rocks deposited over the area pictured as land.

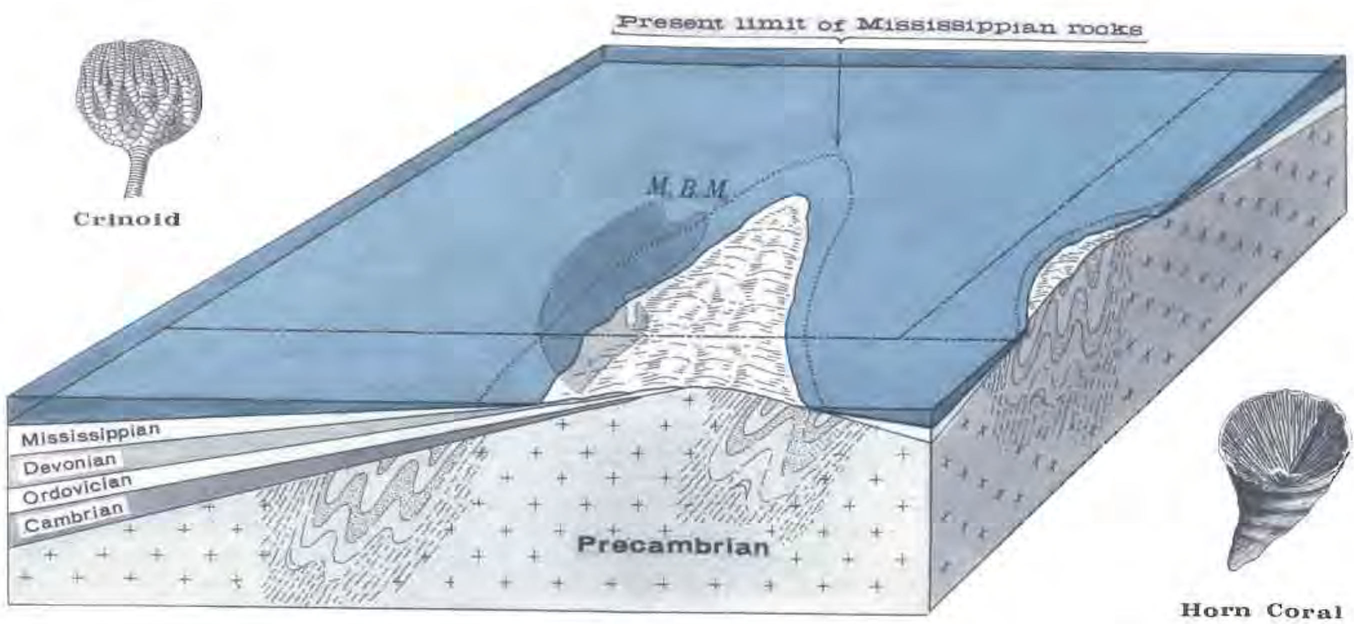
The land life of the Mississippian Period is less well known than the marine life. It appears that where land deposits accumulated, conditions were not suited for the preservation of fossils. Life in the shallow seas was luxuriant and is well preserved, especially the echinoids. The crinoid pictured in the upper left of the scene belongs to this class.

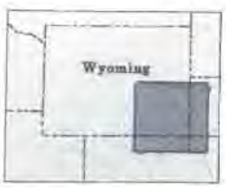
The Pennsylvanian Period

(320-286 m.y.)

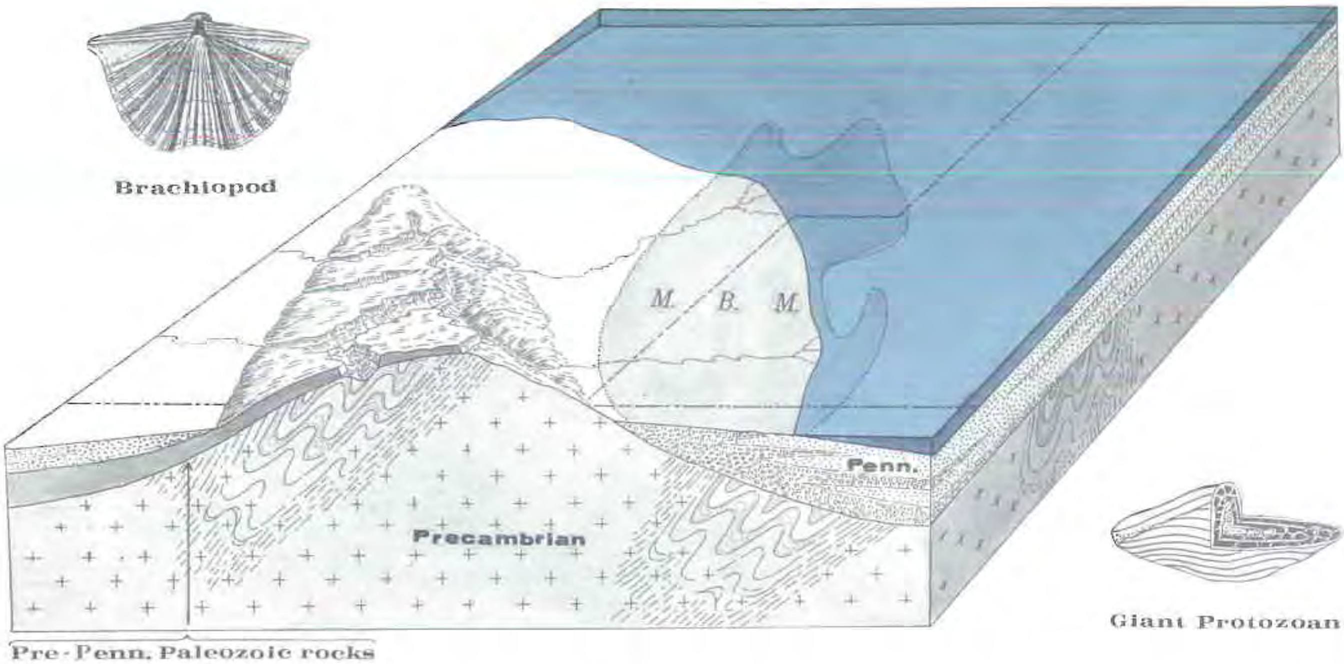
Scene 12.

During Pennsylvanian time, a highland known as the Ancestral Rocky Mountains dominated the region. This highland is pictured as lying west of the present Medicine Bow Mountains region and continuing south into Colorado. The Pennsylvanian sea advanced over a broad coastal plain until it covered at least a portion of the area. Rivers flowing from the highlands trans-





Scene 11. Mississippian Period. The western portion of the future Medicine Bow Mountains region was covered for a short time by the Mississippian sea. No rocks of Mississippian age occur along the southeast margin of the mountains. The southeast portion of the mountains and adjacent area to the east may have been a land area. (M.B.M. = future site of Medicine Bow Mountains.)



Scene 12. Pennsylvanian Period. The Ancestral Rocky Mountains dominated the region during Pennsylvanian time, occupying an area west of the future site of the Medicine Bow Mountains and extending south into Colorado. Coarse gravels were deposited on an adjacent coastal plain while fine-textured sands and lime muds were deposited in the nearby Pennsylvanian sea. (M.B.M. = future site of Medicine Bow Mountains.)

ported and deposited sediments derived from the highlands onto the coastal plain and in the sea. The coastal plain deposits are made up, in large measure, of coarse-textured fragments (cobbles, pebbles, and granules) derived from Precambrian granites and gneisses exposed in the highlands. Finer textured beds of sand and thin beds of limestone were deposited in the sea. No fossils have been found in the coarse-textured debris deposited on the coastal plain. The fossil remains of marine invertebrates occur in limestones.

Numerous examples of contemporary erosion are conspicuous features in the coarse fragmental debris. **Figure 12** shows a 7-foot block of sandstone buried in a conglomerate. The block fell into a stream channel from an undercut bed of sandstone and was buried in the coarse fragmental debris being transported by the stream.

An interesting feature of the coastal plain deposits is the presence of numerous sand-filled cracks (sand dikes) that cut the uppermost bed of the coarse fragmental debris. They are interpreted as earthquake cracks that became filled with sand. Some of them descend twenty feet or more. No coarse-textured debris was deposited after the earthquake episode. It appears that crustal movements, which gave rise to the earthquakes, depressed the coastal plain with an accompanying advance of the sea over the area.

Figure 12. Large angular block of sandstone embedded in a coarse fluvial conglomerate (hammer for scale).

Crossbedding is a striking feature of the sandstones. This feature is especially well displayed in erosional remnants in the Red Buttes and Sand Creek areas (**Figure 4**) southwest of Laramie. Local slumping at the time of deposition on over-steepened surfaces gave rise to intricate small-scale folds and faults in the sediments.

The Permian Period

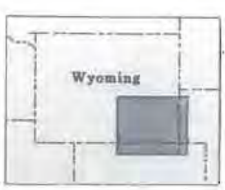
(286-245 m.y.)

Scene 13.

The Permian was a time of great crustal unrest, when extensive highlands came into being in various places throughout the world. However, the Medicine Bow Mountains region remained relatively stable throughout Permian time. Erosion had reduced the Ancestral Rocky Mountains to low relief and a relatively thin succession of sands, silts, and calcareous sediments was deposited over the area. The sands and silts are stained red by thin films of iron oxide that coat the rock particles. Beds of gypsum (hydrous calcium sulfate), some of which are many feet thick, occur in the succession. The gypsum is believed to have been precipitated from evaporating sea water in isolated embayments.

No fossils are known to occur in the red shales within the area, but fossils of marine invertebrates do occur in the limestones. During Permian time, a variety of reptiles dominated the land although none have been found within the Medicine Bow Mountains region. The fin-back reptile shown in the scene was one of the most bizarre.

Mirror Lake fills a glacier-cut basin



Scene 13. Permian Period. A sea covered the region for a short time during the Permian Period, after erosion reduced the Ancestral Rockies (Scene 12) to low relief. Red shales (Satanka Formation) and a thin limestone (Forelle Formation) record the deposits of that sea. (M.B.M. = future site of Medicine Bow Mountains.)

The Mesozoic Era

(245-66 m.y.)

The history of the Medicine Bow Mountains region during the Mesozoic Era contrasts strongly with that of the preceding Paleozoic Era. Vast accumulations of sands, silts, and volcanic ash, aggregating thousands of feet thick, were deposited over the area. These sediments were derived, in large measure, from highlands lying some hundreds of miles to the west. The sediments accumulated in part on broad featureless lowlands and in part on the floors of shallow seas that covered the region from time to time. The seas advanced from the north and east.

Life during the Mesozoic was abundant and spectacular. Reptiles ruled both on land and in the sea. Giant dinosaurs occupied the land areas until the close of the era; their time span was some seventy million years. Large swimming reptiles lived in the sea. Flying reptiles and birds evolved. Mammals made their first appearance early in the Era. Clams, oysters, protozoans, cephalopods (the chambered nautilus is a living representative), and many other invertebrates lived in the sea. Major changes took place in the plant kingdom. Great forests, which covered much of the land area of Wyoming during Cretaceous time, formed peat swamps that later became coal. A single thick coal seam may represent the accumulation of plant debris through thousands of years. Porous Mesozoic sandstones later became the reservoirs of extensive accumulations of oil and gas.

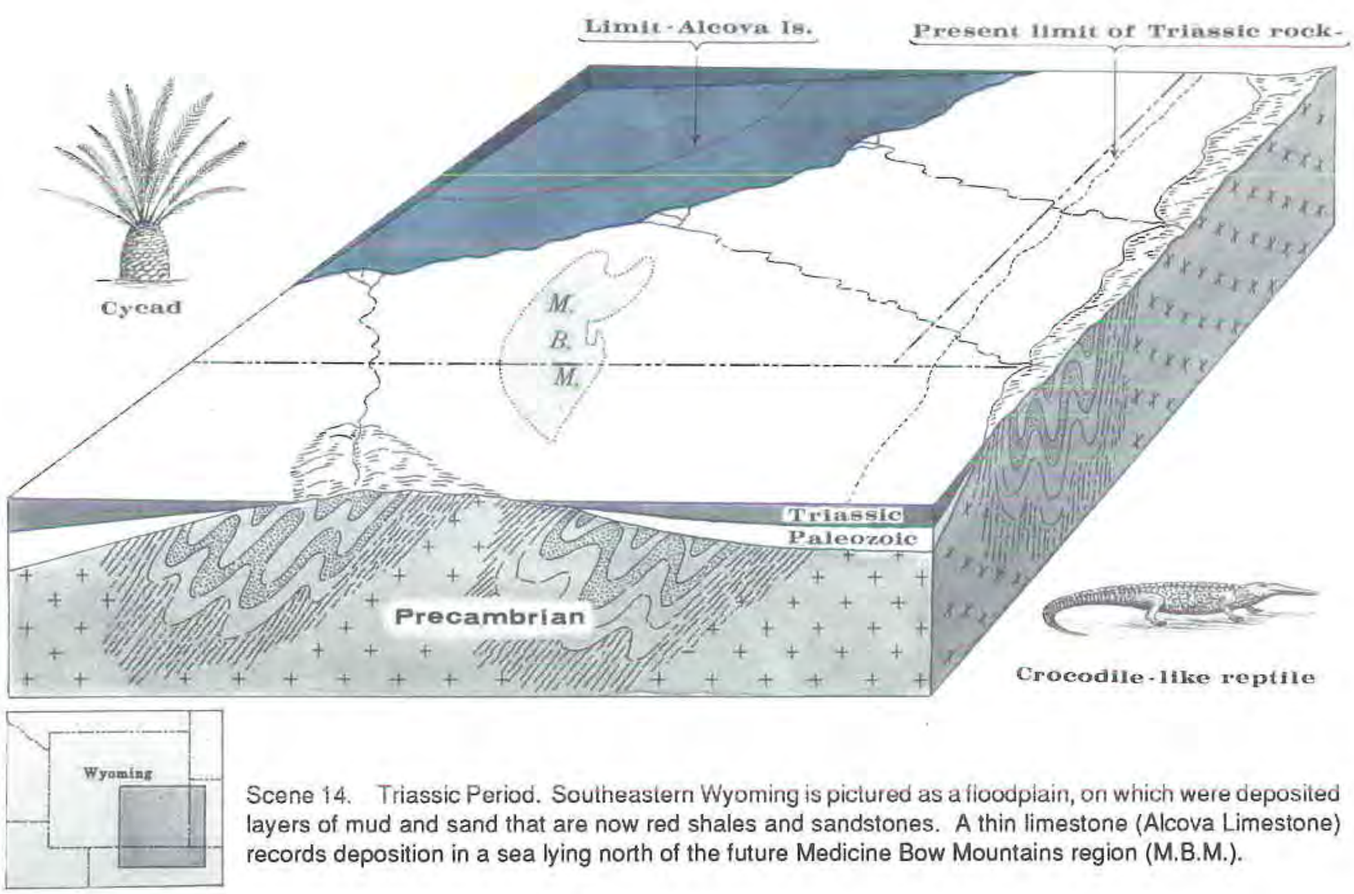
The Mesozoic Era is divided into three Periods — the Triassic, the Jurassic, and the Cretaceous. The Medicine Bow Mountains first came into being during the closing stages of the era, some seventy million years ago, in the Late Cretaceous.

The Triassic Period

(245-208 m.y.)

Scene 14.

After the withdrawal of the Permian sea, the future site of the Medicine Bow Mountains consisted of a low-lying, featureless plain, upon which was



Scene 14. Triassic Period. Southeastern Wyoming is pictured as a floodplain, on which were deposited layers of mud and sand that are now red shales and sandstones. A thin limestone (Alcova Limestone) records deposition in a sea lying north of the future Medicine Bow Mountains region (M.B.M.).

deposited a sequence of sediments that became the colorful red shales, siltstones, and sandstones of the Chugwater Formation. These several-hundred-foot-thick redbeds are unique in that, so far as we know, they are unfossiliferous. It is believed that the time boundary between the Permian and Triassic Periods falls somewhere within this sequence. The absence of fossils and the red color (iron oxide) leads to the interpretation that a severely arid climate prevailed during deposition.

During Late Triassic time, a sea advanced to within a short distance of the future mountain area. A thin limestone deposited in this sea (Alcova Limestone Member of the Chugwater Formation) has yielded a fairly complete skeleton of a small semi-aquatic reptile that foreshadows the aquatic reptiles of later periods.

The final event of Triassic time was the deposition of some two hundred feet of sand (Jelm Formation), which contains local pebble lenses made up for the most part of limestone fragments. Some of these lenses contain broken and worn pieces of the skeleton and teeth of a late Triassic reptile.

The Jurassic Period

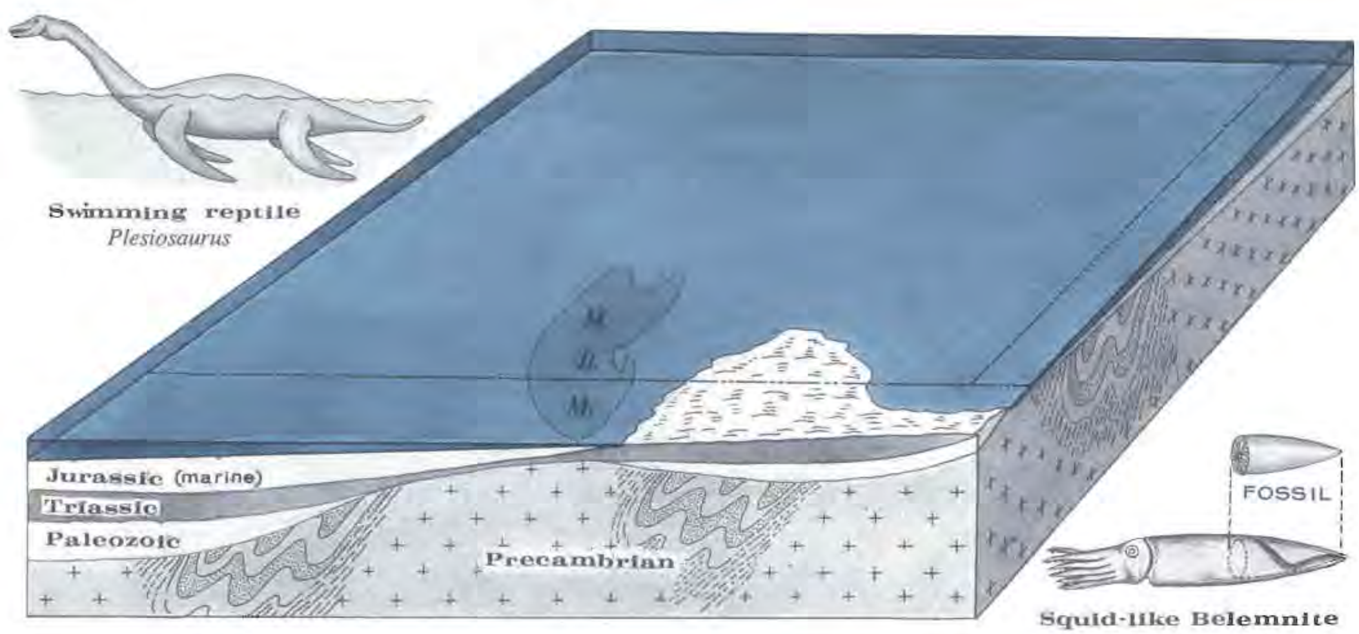
(208-144 m.y.)

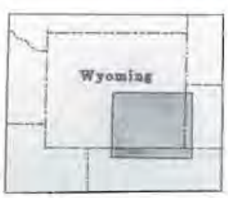
Scenes 15 and 16

Late Jurassic I

In early Late Jurassic time (**Scene 15**), a sea, known as the Sundance Sea advanced from the north until it covered much of what is now the Rocky Mountain region. This sea covered the area for a relatively short time and left a thin sequence of fossiliferous shales and sands, the Sundance Formation.

Two strongly contrasting kinds of swimming reptiles inhabited this sea. One kind, *Ichthyosaurus* (from *ichthys*, Greek for fish; *sauros*, Greek for reptile), resembled a fish in body form while the other kind, *Plesiosaurus* (from *plesio*, Greek for near; *sauros*, Greek for reptile), was more reptile-like, with a long slender neck and tail attached to a thick body. Fragmentary remains of one of these swimming reptiles from central Wyoming indicates that the animal was 40 or more feet long.





Scene 15. Jurassic Period. During Late Jurassic I time, a sea covered the area, leaving a thin sequence of shales and sandstones. The internal skeleton of the squid-like belemnite is an abundant fossil in these rocks. Large swimming reptiles, like *Plesiosaurus*, depicted above, inhabited the sea. (M.B.M. = future site of Medicine Bow Mountains.)

Elsewhere, notably at the famous lithographic stone quarries near Solenhofen, Bavaria, rocks of this age have yielded remarkably well-preserved fossils of bat-like flying reptiles (ranging from sparrow-sized to eagle-sized) and the earliest known feathered animal. This first known bird was about the size of a crow and possessed several reptilian features, such as teeth, clawed digits on the front edge of the wings, and a long reptile-like tail.

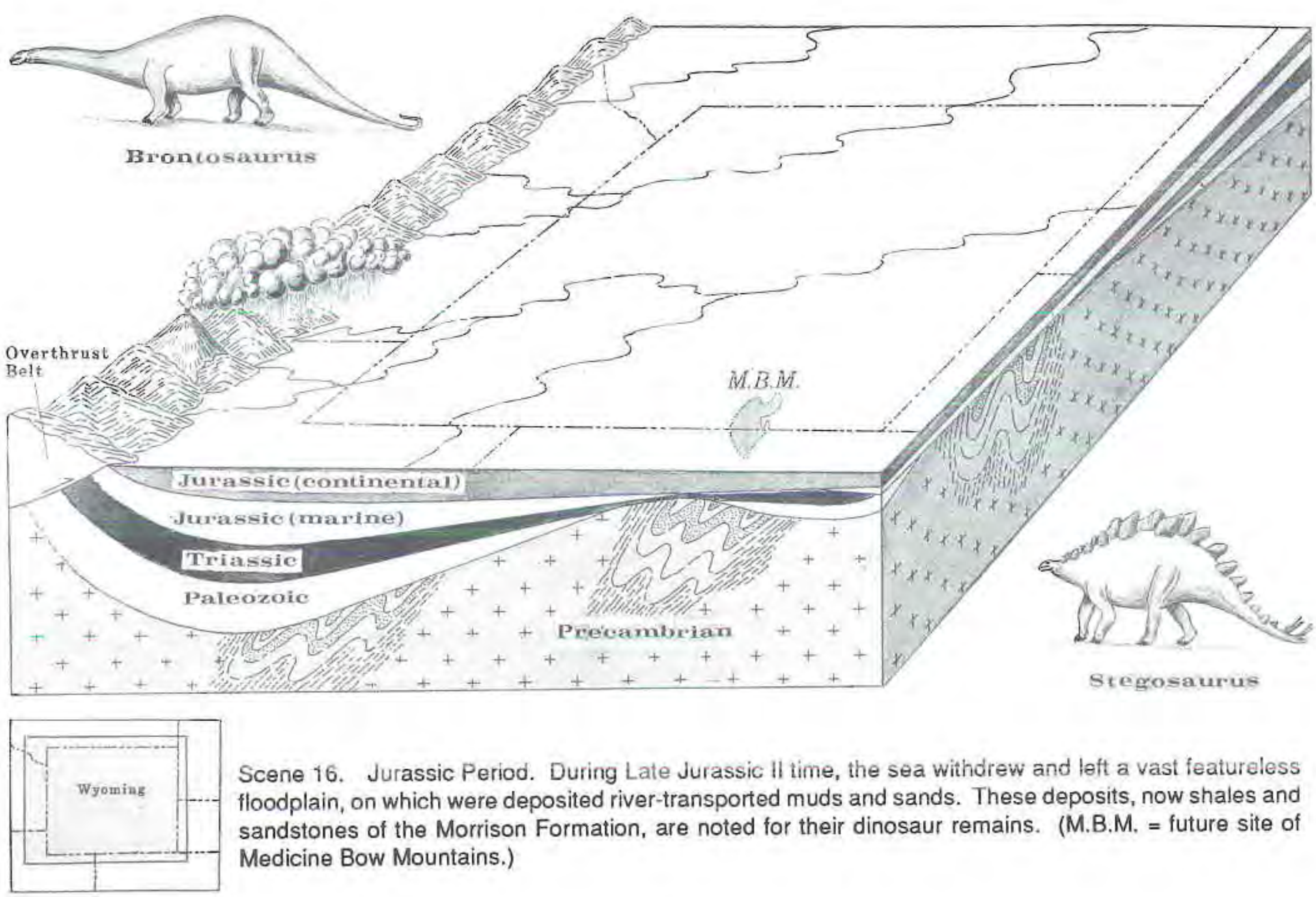
The marine invertebrates of Jurassic time were profuse and varied. Many kinds of corals, oysters, clams, snails, crinoids, starfish, squids, shrimps, lobsters, and other forms are known. The most abundant fossil in the Sundance Formation is the cigar-shaped internal skeleton of a squid-like animal (see the belemnite in the lower right-hand corner of the scene).

Late Jurassic II

When the Sundance Sea withdrew, it left a vast featureless plain (**Scene 16**). Its swamps and floodplains covered Wyoming and extended north into Montana, south across Colorado into New Mexico and Arizona, and west into Utah. Rivers from highlands to the west deposited muds and sands, now claystones, siltstones, and sandstones of the Morrison Formation, on this plain.

Skeletal remains of land animals and plants are preserved in Morrison Formation rocks in such profusion that today the formation is one of the most spectacular graveyards of past life. Fossil remains of more than 150 kinds of animals and plants have been collected from the Morrison Formation. Fossils of some of the largest land animals that ever lived are found in these rocks, including the gigantic sauropod dinosaurs, of which *Brontosaurus* [now called *Apatosaurus*] (from *bronto*, Greek for thunder; *sauros*, Greek for reptile) is a well-known form. Some 70 different species of dinosaurs inhabited this floodplain. They arrived as migratory transients, having evolved elsewhere during Triassic and Early Jurassic time, and remained for some seventy million years before becoming extinct.

Far less spectacular than the giant dinosaurs, but of great interest, is the presence of fragmentary remains of a number of different kinds of tiny primitive mammals, known chiefly from teeth and fragments of jaws.



Scene 16. Jurassic Period. During Late Jurassic II time, the sea withdrew and left a vast featureless floodplain, on which were deposited river-transported muds and sands. These deposits, now shales and sandstones of the Morrison Formation, are noted for their dinosaur remains. (M.B.M. = future site of Medicine Bow Mountains.)

The Cretaceous Period

(144-66 m.y.)

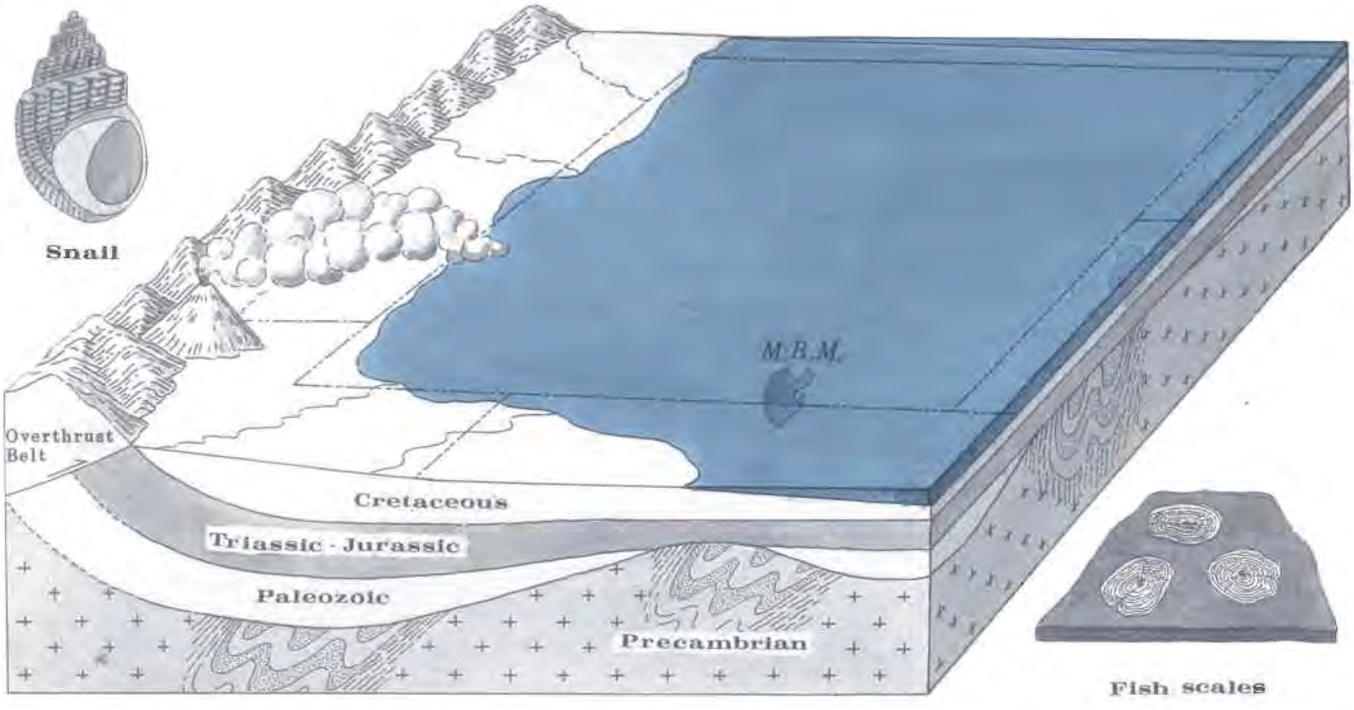
Scene 17.

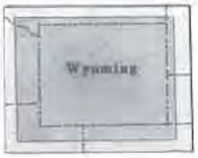
The sediments deposited in the Medicine Bow Mountains region and over much of the Rocky Mountain region during the Cretaceous Period far exceed in total thickness the entire sedimentary rock succession that was deposited in the same region from Cambrian to Cretaceous time (at least as it is now preserved). The Cretaceous sequence of alternating beds of shale and sandstone, aggregating thousands of feet thick, was deposited in part on the sea floor and in part on an adjacent coastal plain. The sea advanced and retreated a number of times across the Rocky Mountain region during the Period. When the sea advanced, previously deposited coastal plain sediments were buried by marine sediments and conversely, when the sea retreated, the expanded coastal plain was covered by younger fluvial deposits.

Dinosaurs roamed the coastal plain. Giant swimming reptiles — *Ichthyosaurus, Plesiosaurus,* and *Mosasaurus* (a swimming lizard) — lived in the sea. Flying reptiles attained their greatest size; the largest known had an astounding wing spread of 25 feet. Giant marine turtles, crocodiles, and large toothed diving birds were also present. Several new orders of mammals appeared late in the Period, including the marsupials (opossum-like) and insectivores (distant ancestors of shrews and moles).

The marine invertebrates had, for the most part, a modern aspect. Oysters, clams, snails, coiled and uncoiled cephalopods, and other forms occur abundantly in the marine rocks.

A great change took place in land vegetation during the Cretaceous. The angiosperms (from *angeion*, Greek for capsule; *sperma*, Greek for seed), which include most trees that shed their leaves and all true flowering plants, dominated the luxuriant forests of the coastal plain. Insofar as the future of the land-living animals is concerned, the coming of the angiosperms was the most important development since the establishment of plants on the land some 300 million years earlier. Many of the more primitive types of vegetation survive up to the present, but they





Scene 17. Cretaceous Period. An inland sea advanced and retreated over Wyoming during Cretaceous time. A thick succession of sediments was deposited on the sea floor and adjacent coastal plain. Coal swamps covered the coastal plain from time to time. Much of the oil produced in Wyoming is now found in sandstones deposited in this sea. (M.B.M. = future site of Medicine Bow Mountains.)

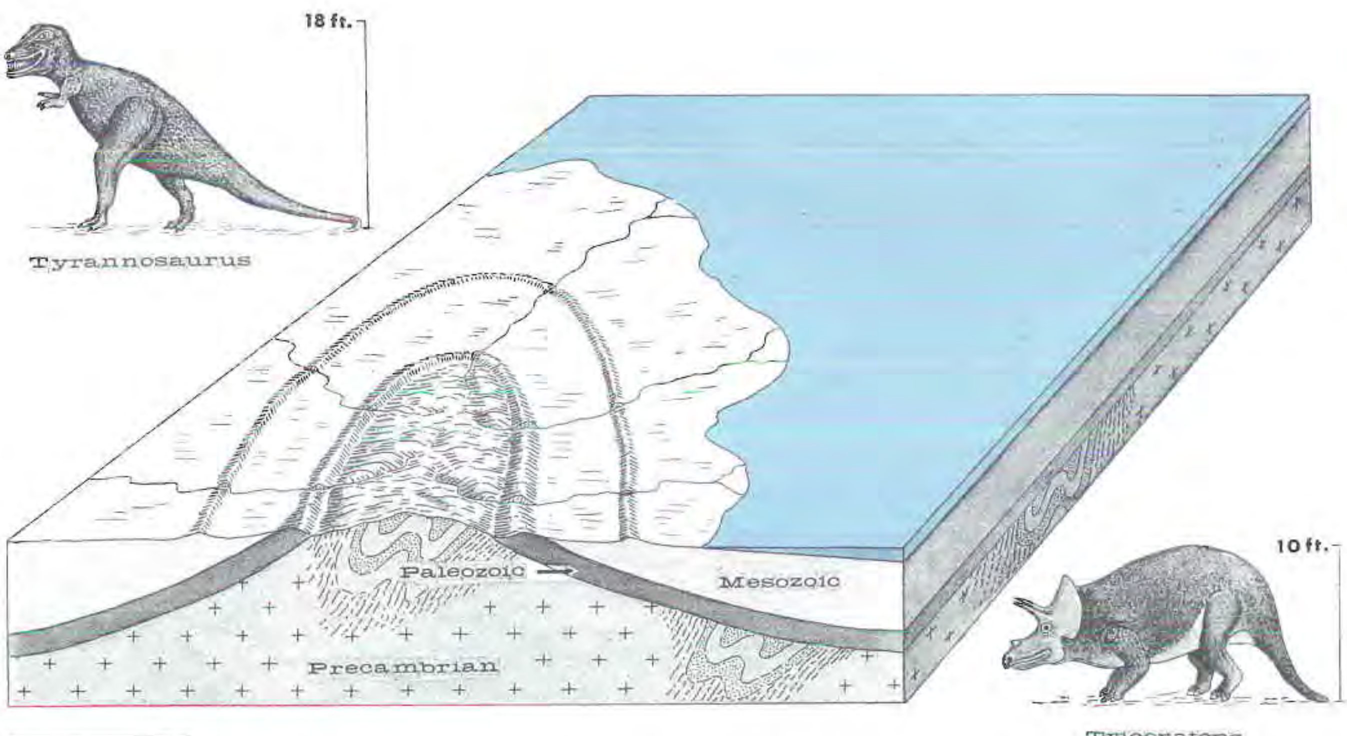
play a far less important role as a source of food for the new land animals, especially the great mammalian class.

The abundant fossil remains of land plants were converted to extensive coal deposits. It must have taken thousands of years for accumulated plant debris to produce a coal seam 15 or more feet thick. Under favorable structural and stratigraphic conditions, marine sandstones became the reservoirs of extensive oil and gas deposits.

Close of the Cretaceous Period

Scene 18.

Near the close of Cretaceous time, the Rocky Mountain region witnessed the beginning of a period of crustal movement that continued with varying degrees of intensity for millions of years. This great period of crustal unrest is called the Laramide orogeny. Compressional forces buckled the crust into upfolds (anticlines) and downfolds (synclines) on a gigantic scale. The large upfolds became the mountain ranges and the large downfolds become the intermountain basins. **Scene 18** depicts an early stage in the development of the Medicine Bow Mountains upfold as it appeared at the end of Cretaceous time. It is likely that this and other large upfolds rose as islands out of the Cretaceous sea. As soon as the crests of the upfolds rose above base-level, they were attacked by erosion and another episode in the eternal conflict between movements of the crust, which create relief, and the processes of erosion, which destroy relief, began. It was not long, geologically speaking, before the less durable Paleozoic and Mesozoic sedimentary rocks were stripped from the crests of the rising upwarps, exposing the underlying, far more durable, Precambrian rocks in the cores (**Scene 18**). For a time, the rock debris transported from the upfolds was deposited on local floodplains and in embayments of the sea, which lingered on in the deeper parts of some of the basins. The sea withdrew at the end of Cretaceous time.



Scene 18. Near the close of the Cretaceous Period. This scene depicts an early stage in the folding of the Medicine Bow Mountains. Erosion had removed the sedimentary rocks from the crest of the rising fold. Dinosaurs became extinct at the close of Cretaceous time; two late survivors are shown.

Profound changes took place in animal life forms during the closing stages of Cretaceous time. Probably the most dramatic change was the disappearance of the dinosaurs, not only from the Rocky Mountain region but from the rest of the world as well. The dinosaurs lived on swampy semitropical coastal plains in the Rocky Mountain region from Late Jurassic to the end of the Cretaceous, a span of 70 million years, during which a host of fantastic forms evolved. Two of the late forms are pictured (**Scene 18**). The giant swimming and flying reptiles had also vanished by the end of the Cretaceous.

Snow patterns

The Cenozoic Era

(66.4 m.y. - Present)

The last era of geologic time, the Cenozoic (from *ceno*, Greek for new; *zoon*, Greek for animal), is divided into the Tertiary Period (66.4-1.6 m.y.) and the Quaternary Period (1.6 m.y.-Present). These periods are, in turn, divided into epochs.

The Tertiary Period, Paleocene Epoch

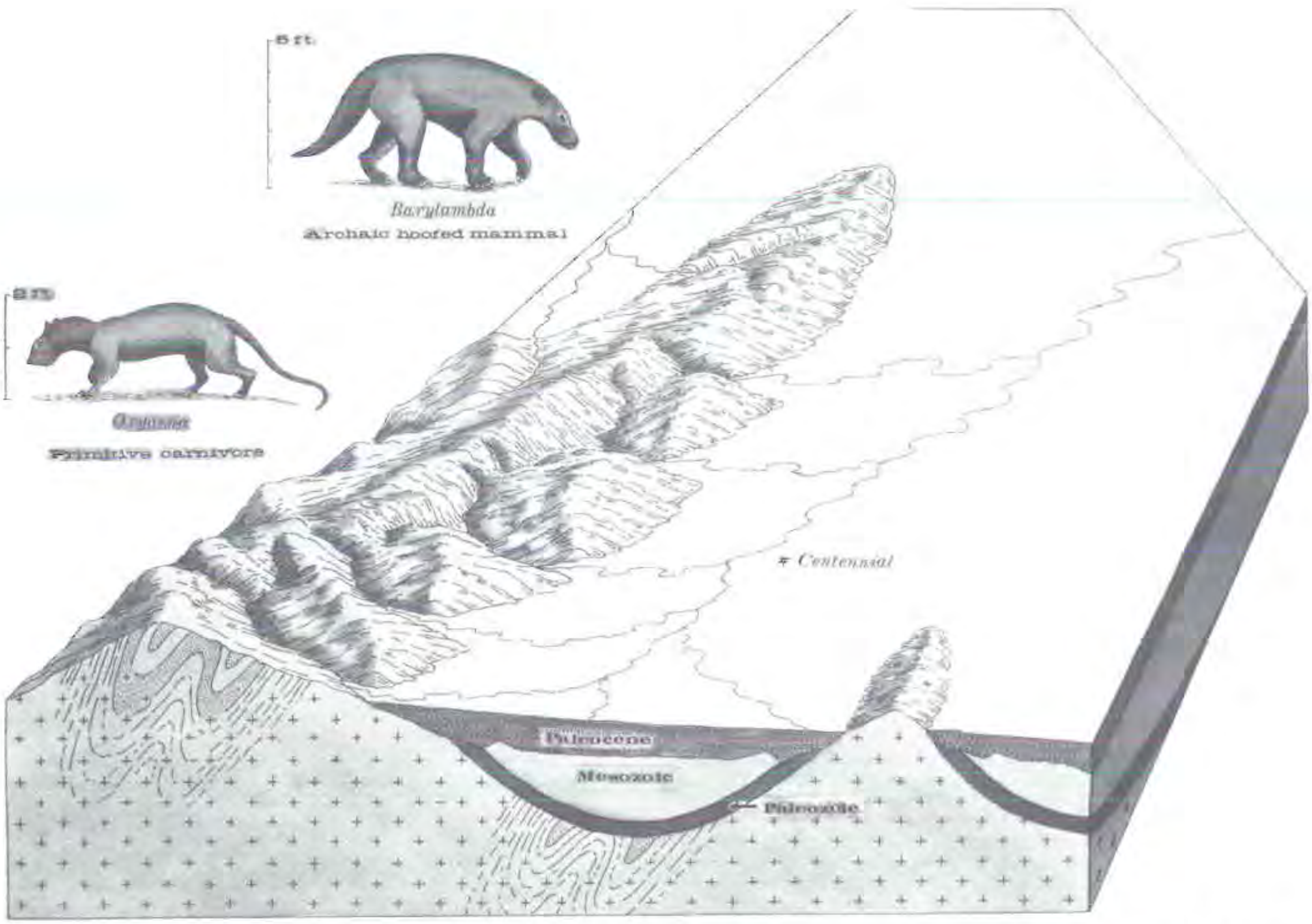
(66.4-57.8 m.y.)

Scene 19.

The first Epoch of the Tertiary Period is the Paleocene (from *paleo*, Greek for ancient; *ceno*, Greek for new), which lasted 8 million years. The forces that folded and broke the crust during the Laramide orogeny continued to operate throughout Paleocene time. At the time shown in **Scene 19**, the older sedimentary rocks had been folded to angles of 45 degrees or more. Eventually, the mountain upfold developed a high degree of asymmetry, with a relatively gentle west flank and a steep (overturned in places) east flank. Where the stress exceeded the ability of the rocks to fold, they broke along fractures, and large masses of rock moved with respect to one another along the fracture surfaces. Differential movements of blocks along fractures create faults. Thrust faults are characterized by movements along relatively low-angle fractures where blocks of older (underlying) rocks are thrust over younger (overlying) rocks.

As the mountains rose they were attacked by erosion, and vast amounts of rock debris, aggregating thousands of feet thick, were torn from their higher reaches, transported, and deposited on the adjacent basin floors. Near the front of the Medicine Bow Mountains, Paleocene rocks contain extensive deposits of rounded, water-worn boulders and cobbles, which came from Precambrian rocks exposed in the core of the mountains. When the sedimentary rocks are traced away from the mountain front, boulders and cobbles rapidly give way to finer textured sands and silts. In time, these deposits buried the older Paleozoic and Mesozoic rocks and overlapped still older Precambrian rocks along the lower reaches of the mountains.

The great class of mammals had its beginning in Triassic time; however, it showed comparatively little of its potential until Cenozoic time. During the Jurassic and Cretaceous Periods, mammals were small mouse- to rat-sized animals. During Cenozoic time, they began to evolve rapidly into larger sized and more diverse forms. Thus began a spectacular evolutionary trend that has continued for the past 60 million years. The relatively sudden evolutionary explosion of this class of animals, which had been in existence for more than 100 million years, is puzzling. Reduced competition with reptiles (the dinosaurs had vanished) may have played a significant role. Two Paleocene mammals of considerable size, one a primitive hoofed mammal and the other a primitive meat eater, are shown in the scene.



Scene 19. Tertiary Period, Paleocene Epoch. As the mountains rose, vast amounts of fragmental debris (boulders, cobbles, pebbles, sand, and silt) were eroded from the mountains and deposited in the adjacent basins. Primitive mammals roamed the floodplains. Many modern types of vegetation were present. The climate was subtropical. (The present-day location of Centennial is shown on the diagram.)

Extensive coal-producing forests, dominated by modern types of trees, grew on the basin floors. A single coal seam represents the accumulation of plant debris during many thousands of years. Some early Tertiary coal beds are more than 50 feet thick.

The Tertiary Period, Eocene Epoch

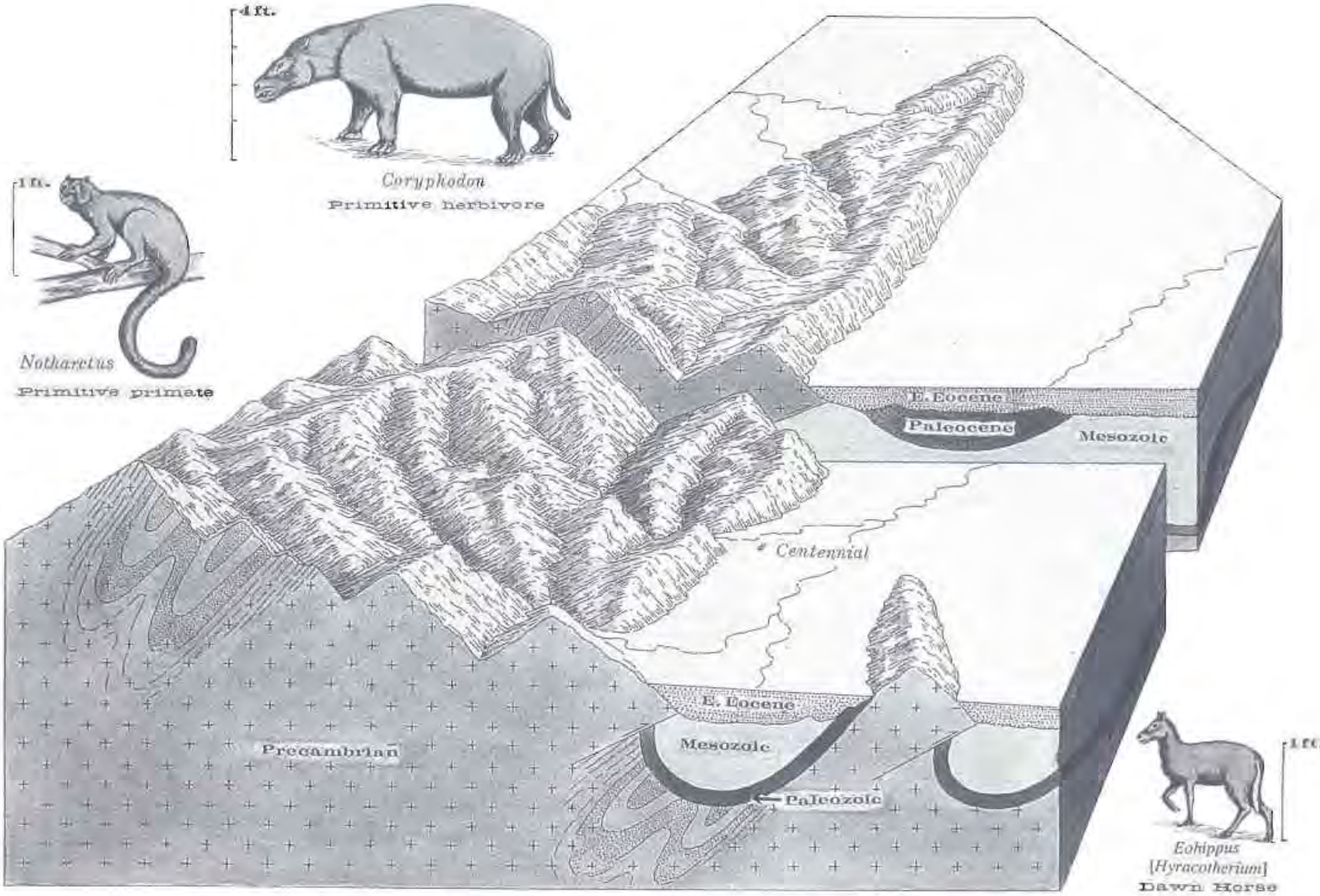
(57.8-36.6 m.y.)

Scenes 20, 21, and 22.

The Medicine Bow Mountains region was subjected to great physical changes during the 21 million years of the Eocene Epoch. **Scenes 20, 21,** and **22** illustrate three stages in the Eocene history of the mountains.

Early Eocene

As far as can be determined, the final impulse of the compressional forces affecting the mountain area began at or near the close of Paleocene time. The previously deposited Paleocene rocks were strongly folded and the underlying Paleozoic and Mesozoic rocks assumed a vertical or overturned position where they were overridden by large thrust blocks (**Scene 20**). It is believed that the mountains reached their greatest relief during this impulse. More than 15,000 feet of rock were removed from the crest of the mountain upfold between the time it was first elevated above sea level in Late Cretaceous time and the close of Eocene time. This does not imply that the mountains stood 15,000 feet above their base at any time, for they suffered extensive erosion as they were being uplifted during an interval of some 20 million years.



Scene 20. Tertiary Period, Early Eocene Epoch. Extensive folding accompanied by thrust faulting continued into early Eocene time. The Medicine Bow Mountains reached their greatest relief at this time. The "dawn horse", primitive primates, and a host of other early mammals appeared. (The present-day location of Centennial is shown on the diagram.)

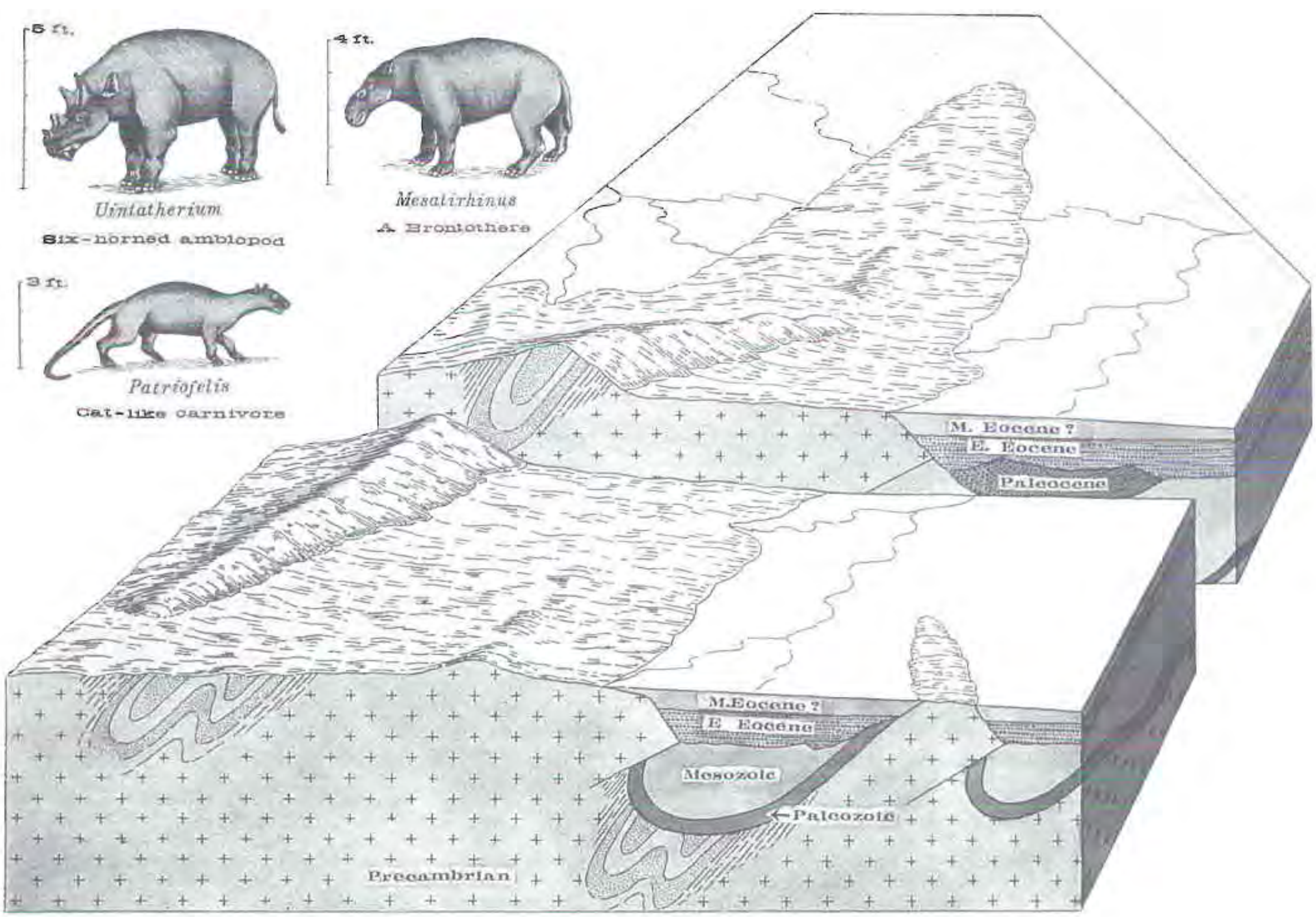
Today, the maximum relief of the mountains from their eastern base to the highest point is 4,000 feet. It is conservatively estimated that in early Eocene time the relief was more than twice as great.

Fossil remains found in rocks of early Eocene age reveal the presence of numerous kinds of mammals, some of which were side-tracked along the evolutionary road and failed to evolve or survive. Others were the progenitors of living forms. One of the most interesting was the "dawn horse", the diminutive *Eohippus* [now called *Hyracotherium*], which stood a foot high. There were several families of meat-eaters, only one of which survived to give rise to living carnivores. There were numerous small primates, large herbivorous rodents, insectivores (shrew-like animals), and bats, to mention a few forms that have living representatives.

Extensive forests grew on the basin floors, which at the time were much nearer sea level than they are today. The forests were made up of many kinds of deciduous trees, palms, and conifers characteristic of a mild climate. Giant redwood trees, now restricted to the Pacific coastal region, were present. Crocodiles and alligators inhabited the swamps.

Early late Eocene

The folding and thrust faulting of the crust throughout the mountain area came to an end with the final impulse of the Laramide Revolution, at or near the end of Paleocene time. The mountains ceased to be upfolded and the adjacent basins downfolded under the impact of compressional forces. During early and middle Eocene time, an interval of almost 18 million years, the mountains were in large measure destroyed as



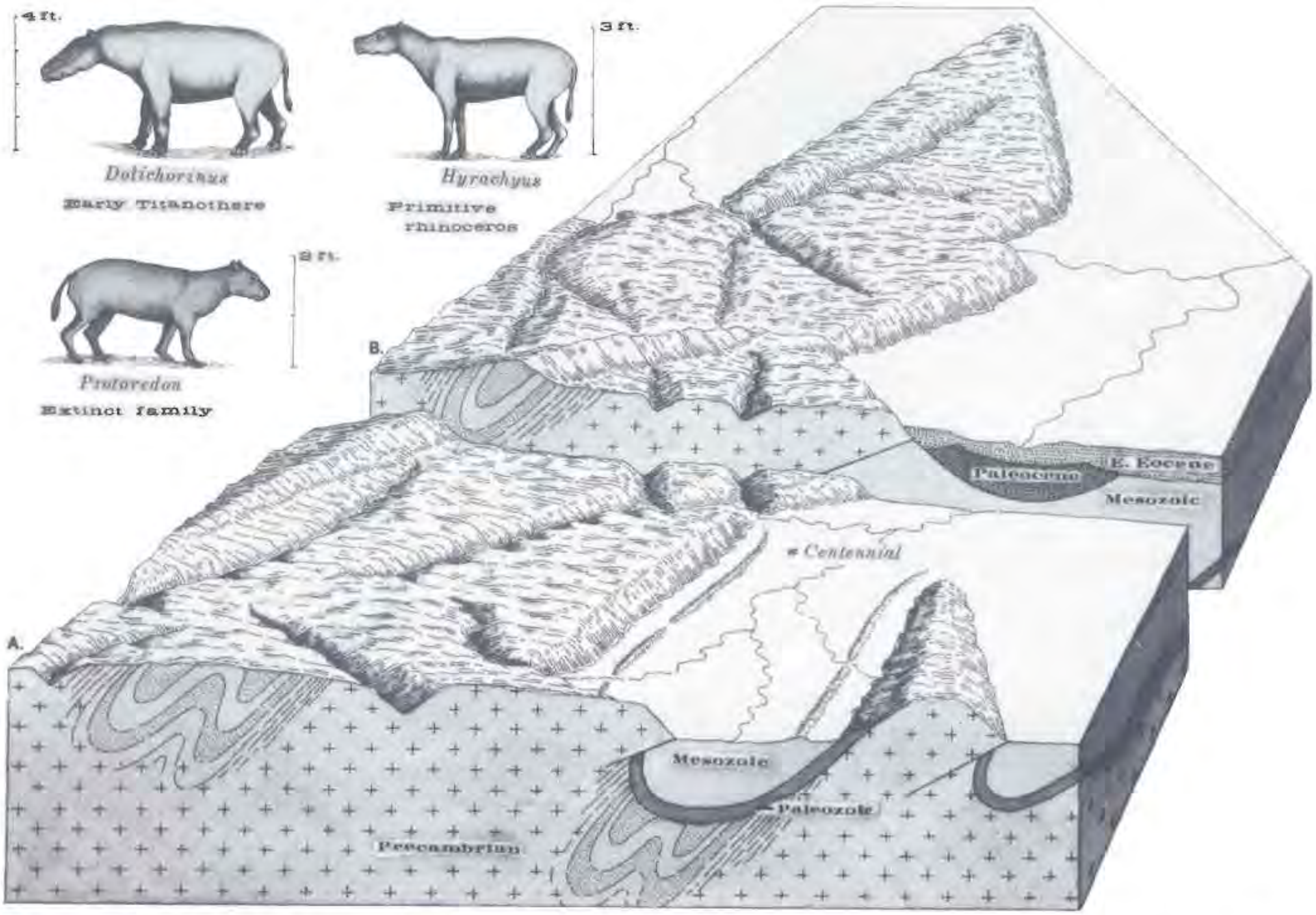
Scene 21. Tertiary Period early late Eocene Epoch. After folding and faulting ceased, prolonged erosion reduced the higher portions of the mountains and the debris filled the basins, giving rise to a region of low relief. The resistant Medicine Peak Quartzite stood as a prominent ridge above the erosional surface.

relief features (**Scene 21**). This destruction was comparable to a giant bulldozing operation, in that the eroded debris from the higher portions was transported and deposited in the adjacent basins. Thus the mountains were destroyed as relief features by the combined action of the removal of rock debris from their upper reaches and the burial of their lower flanks.

In time, there came into being an erosional surface devoid of marked relief except where residual remnants of the Medicine Bow Mountains survived. When viewing the mountains from the floor of the Laramie Basin, from a position 10 or more miles east of the mountain front, the observer sees what appears to be a skyline devoid of marked relief except where a snow-capped ridge (the Snowy Range) rises precipitously 1,000 feet above the skyline (**Front cover**). This ridge is 7 miles long and its southern end lies 10 miles west of the mountain front. The ridge is a remnant of the early Eocene mountains, which owes its existence to the fact that it is made of quartzite, by far the most durable rock in the core of the mountains.

Close of the Eocene Epoch

As previously stated, the compressional forces that folded the crust into mountain upwarps and basin downwarps ceased at or near the close of Paleocene time, some 58 million years ago. This does not imply that the crust of the Medicine Bow Mountains region has been stable since that time. Sometime in either late middle Eocene or early late Eocene, the mountains and surrounding region were elevated 1,000 feet or more and a new cycle of erosion began. During late Eocene time, the uplifted erosional surface (**Scene 21**) formed on the resistant Precambrian rocks was dissected by youthful canyons and the less durable Tertiary sediments, which had buried the lower flanks of the mountains, were in large measure removed (**Scene**



Scene 22. Tertiary Period, close of the Eocene Epoch. Following the long interval of erosion and deposition that reduced the region to low relief, a new erosion cycle due to uplift began. Youthful canyons were cut in the resistant Precambrian rocks while the less resistant sedimentary rocks that filled the adjacent basins were partially removed. (The present-day location of Centennial is shown on the diagram.)

22). In some places (see front face of block A, **Scene 22**), all the Paleocene and early and middle Eocene(?) rocks were completely removed and the underlying older sediments were exposed. In other places (see front face of block B, **Scene 22**), remnants of Paleocene and early Eocene formations still exist. There is no evidence that sediments were deposited in the Medicine Bow Mountains region during late Eocene time. Thus, the mountains were reborn as a feature of marked relief during this cycle of erosion.

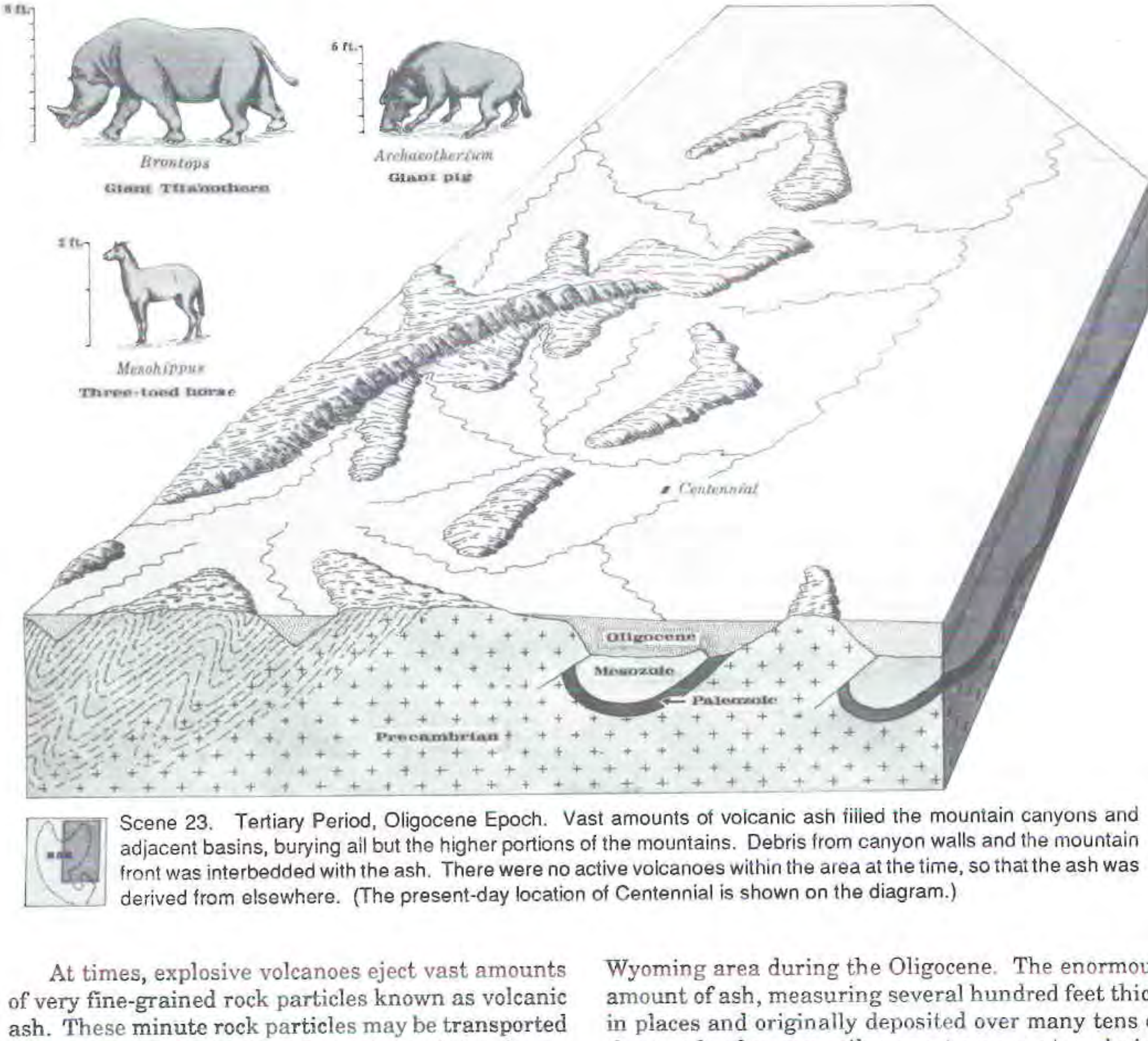
Approaching the present-day mountains, the view is of a landscape very much as it looked at the close of Eocene time. The reason for the lack of significant change in the physical character of the mountains during this prolonged period of more than 30 million years is that they were, in large measure, buried during the Oligocene and Miocene Epochs and were therefore protected from erosion for a long time. The Snowy Range remnant must have stood even higher above its base than at present; because there is no evidence that it was buried, it must have been subject to erosion.

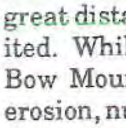
The Tertiary Period, Oligocene Epoch

(36.6-23.7 m.y.)

Scene 23.

During Paleocene and Eocene times, vast amounts of rock debris were transported from the higher portions of Wyoming's mountains and deposited in the adjacent basins. In contrast, during Oligocene time, there were deposited, both on the mountains and on the adjacent basin floors, materials that were for the most part derived from remote sources. These deposits are volcanic ash with minor amounts of debris from rocks in the Precambrian cores of the mountains.





Scene 23. Tertiary Period, Oligocene Epoch. Vast amounts of volcanic ash filled the mountain canyons and adjacent basins, burying all but the higher portions of the mountains. Debris from canyon walls and the mountain front was interbedded with the ash. There were no active volcanoes within the area at the time, so that the ash was derived from elsewhere. (The present-day location of Centennial is shown on the diagram.)

At times, explosive volcanoes eject vast amounts of very fine-grained rock particles known as volcanic ash. These minute rock particles may be transported great distances in the atmosphere before being deposited. While many of the ash deposits in the Medicine Bow Mountains have been removed by subsequent erosion, numerous erosional remnants still exist along the mountain front and in the mountain valleys. These remnants tell us that, at or near the end of Oligocene time, all except the higher portions of the mountains were buried by volcanic ash as pictured in the scene.

In the Medicine Bow Mountains region, there were no Oligocene volcanoes from which the ash deposits could have come; therefore we must look elsewhere for their source. There is abundant evidence of intermittent volcanic activity during Tertiary time throughout the mountain complex of central Colorado. Volcanoes in this area at the time are a possible source of the ash. Other volcanic areas that were active at the time, such as the Basin and Range region of Utah and Nevada, may also have supplied airborne ash to the Wyoming area during the Oligocene. The enormous amount of ash, measuring several hundred feet thick in places and originally deposited over many tens of thousands of square miles, must represent explosive volcanic activity on a grand scale, which continued intermittently for a long time.

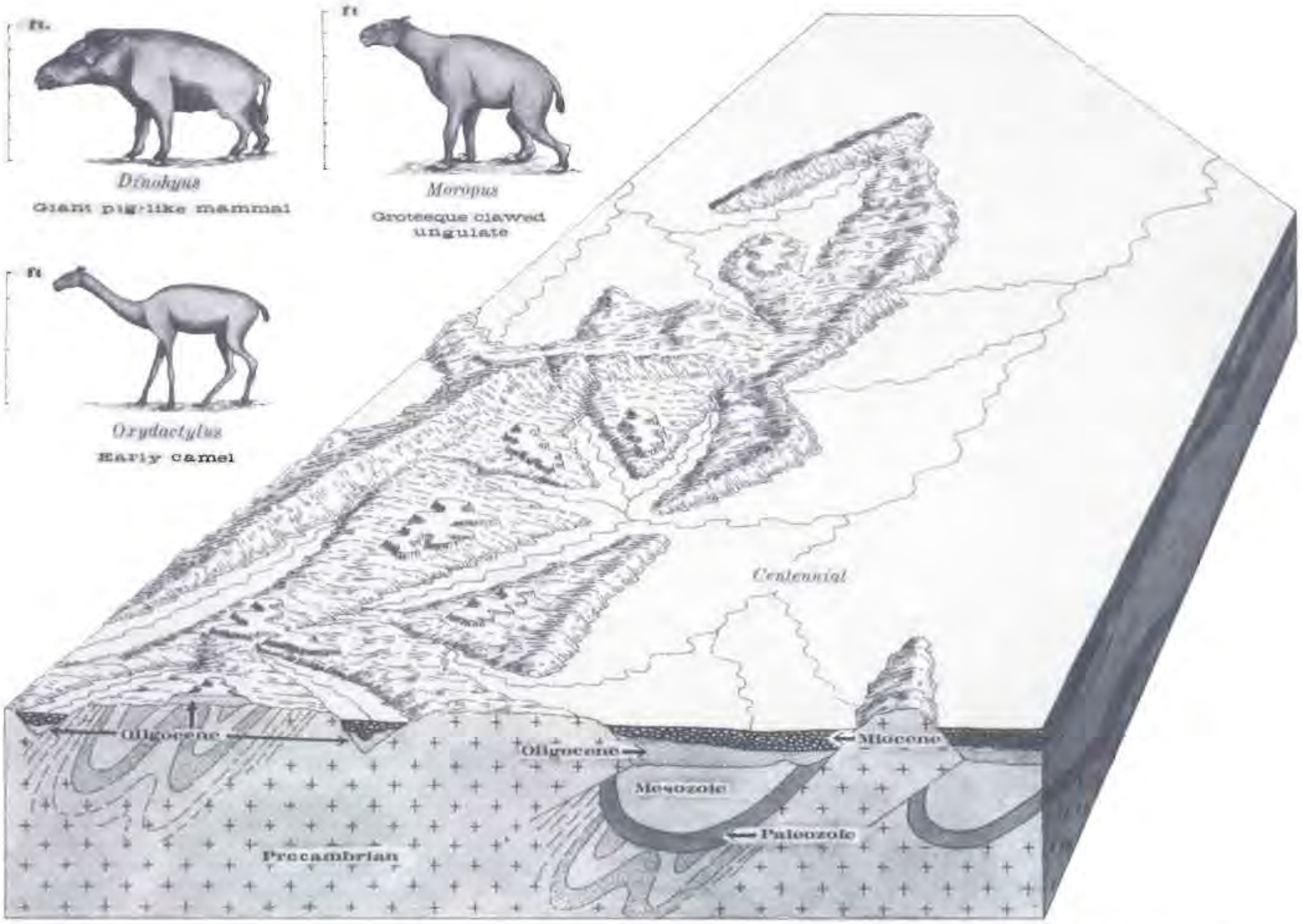
The fine-textured volcanic ash deposits proved an excellent medium for preservation of the skeletal remains of animals. Complete or nearly complete skeletons of many different kinds of animals have been recovered from these deposits. While there was no sudden change in the evolution of the mammals from Eocene into Oligocene time, many of the more primitive types characteristic of the Eocene disappeared during the Oligocene and most modern families made their appearance. Most of the archaic carnivores, the creodonts (see *Patriofelis*, **Scene 21**), disappeared and true cats and dogs appeared. The primitive "dawn horse," *Eophippus* [*Hyracotherium*] (**Scene 20**), evolved into the three-toed *Mesohippus*.

A dramatic feature of the Tertiary Period was the coming of the grasses, which became a chief source of food for the grazing mammals. Grasses were virtually unknown throughout the Mesozoic Era. Today, there are some 5,000 species of grasses and they are adapted to all climates except the most severe desert and arctic conditions.

The Tertiary Period, Miocene Epoch
(23.7-5.3 m.y.)

Scene 24.

During Miocene time, a new cycle of erosion and deposition began. The previously deposited Oligocene volcanic ash deposits were removed, in large measure, from the mountain valleys and to some extent from the Laramie Basin. A period of deposition followed the interval of erosion, during which a mixture of volcanic ash derived from Oligocene erosional remnants and fragments of Precambrian rocks was deposited in the valleys and on the floor of the adjacent basin. Near the mountain front, these deposits are largely boulders, cobbles, and pebbles imbedded in a matrix of volcanic ash (**Figure 13**). Extensive remnants of these deposits occur along the southwest mountain front. In places, they bury the mountain front up to elevations of 9,000 feet. An erosional remnant of rocks of similar character occurs in the valley of Nash Fork at an elevation of 10,000 feet. Here, these rocks rest upon Precambrian rocks. No fossils are known in the occurrences mentioned above; however, their relative positions and relations to dated Miocene rocks in the North Platte valley west of the mountains indicate they are probably Miocene.



Scene 24. Tertiary Period, Miocene Epoch. The mountain valleys and the adjacent basin, which had been filled with Oligocene ash deposits, were largely re-excavated. Following this period of erosion, the valleys and the adjacent basin were filled, in large measure, with Precambrian boulders, cobbles, and pebbles, imbedded in a matrix of volcanic ash. (The present-day location of Centennial is shown on the diagram.)

Figure 13. View of Miocene conglomerate made up of angular fragments of Precambrian rocks embedded in an ash-clay matrix. This photograph was taken at an elevation of 8,800 feet above sea level. (Hat indicates scale.)

During Miocene time, the great mammalian class continued its spectacular evolution. As previously mentioned, no fossils have been found in the Miocene remnants within the Medicine Bow Mountains area; however, a wealth of mammal remains have been recovered from rocks of Miocene age that lie east of the Rocky Mountain front, where conditions were exceptionally favorable for their preservation. These remains, together with those found elsewhere, demonstrate a rapid and extensive evolution of the mammals, so that representatives of virtually all living mammal families had made their appearance before the close of Miocene time.

The horse continued to evolve, and by the end of Miocene time it had grown to the size of a small pony. The middle toe carried its weight. The two adjacent toes were present but they did not touch the ground and were probably non-functional. Various types of antelope and deer were represented. The earliest known ancestor of the highly specialized elephant tribe made its appearance in Africa during late Eocene time; however, its descendants did not reach North America until middle Miocene time. They continued to survive there until the end of the Pleistocene. The camel began as a diminutive animal in Late Eocene time. Many divergent types were present during the Miocene and they continued to survive in North America throughout the Pleistocene. Meat eaters were represented by a variety of dogs, cats, bears, etc. Primitive primates disappeared from the area of the future United States in early Miocene time. While monkeys made their appearance elsewhere in Miocene time, there is no evidence that the ancestors of the higher primates (monkeys, apes, and man) ever inhabited the Medicine Bow Mountain region until the coming of man about 12,000 years ago.

The Tertiary Period, Pliocene Epoch

(5.3-1.6 m.y.)

Scene 25.

The history of the Medicine Bow Mountains region during Pliocene time is less well documented than the preceding Tertiary epochs due to extensive erosion. Occurrences of Pliocene sediments east of the Rocky Mountain front in southeast Wyoming and adjacent areas were derived from the mountains. There are limited deposits of possible Pliocene age in the valley of the North Platte River west of the Medicine Bow Mountains. On the basis of these occurrences, it is concluded that sediments of Pliocene age were deposited in the area as shown in **Scene 25**.

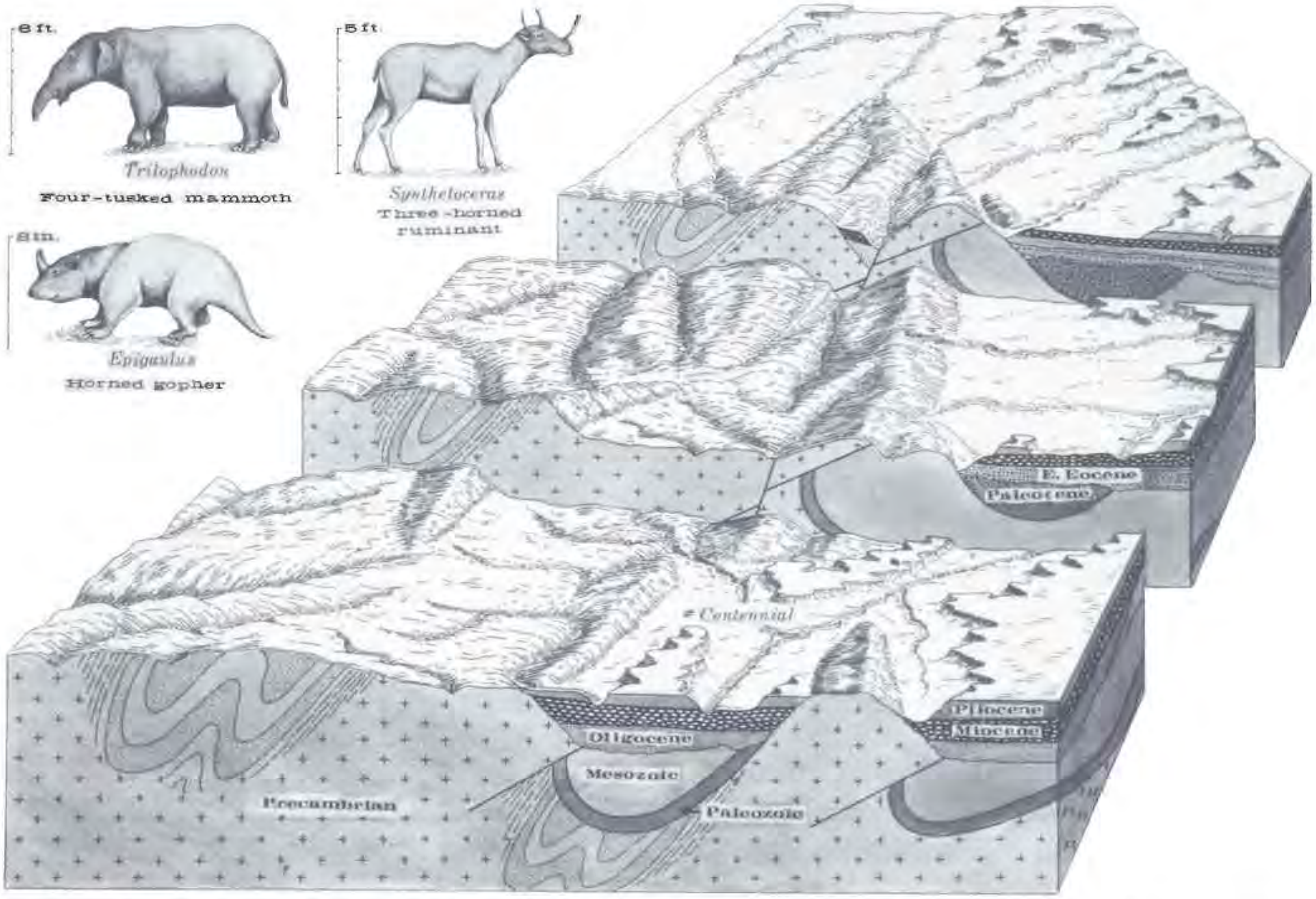
On the mountain divide, where it crosses the Colorado-Wyoming boundary, there is an interesting erosional remnant of a conglomerate made up of water-worn cobbles and pebbles of lava mixed with fragments of Precambrian rock. This conglomerate rests in part on Precambrian rock and in part on remnants of Oligocene ash that filled valleys cut in the Precambrian rocks. The lava cobbles are erosional debris from a volcano, possibly from the Specimen Mountain volcano, the neck of which lies 45 miles to the south. All that is definitely known about the age of this conglomerate is that it is post-Oligocene; however, it might be Pliocene.

The Quaternary Period, Pleistocene Epoch

(1.6 m.y.-10,000 years ago)

Scene 26.

The most dramatic feature of Pleistocene time was the climatic change that brought on what has been

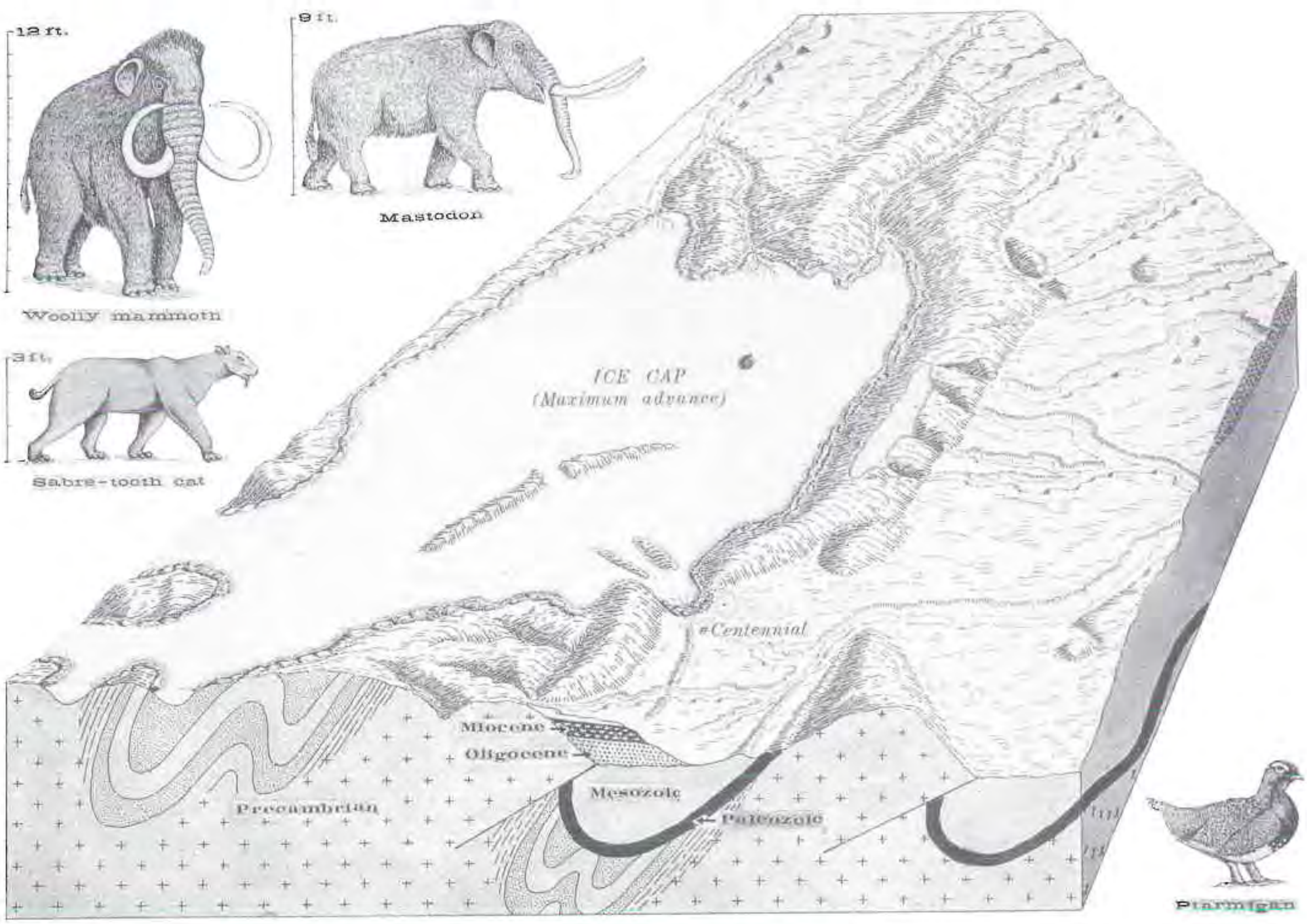


Scene 25. Tertiary Period, Pliocene Epoch. This scene depicts a portion of the mountains and adjacent Laramie Basin as it is believed to have looked early in the cycle of erosion following regional uplift that took place at or near the close of Miocene time. Rocks of Pliocene age(?) are pictured as having been already partially removed by erosion. (The present-day location of Centennial is shown on the diagram.)

called the Ice Age. Great continental ice sheets, which came and went at least four times, covered the northern portion of North American (Canada, the upper portion of the Mississippi River valley, and New England). Accumulating snow falls were converted into ice, which, when it reached a critical thickness, flowed slowly under the influence of gravity. At the same time the great continental ice sheets existed, local ice caps covered the upper portions of the higher mountains to the south. Valley glaciers fed from the ice caps extended down the pre-existing canyons for varying distances. Some reached the basin floors at or near the mouths of their canyons. **Scene 26** shows the maximum extent of the last local ice cap that covered much of the Medicine Bow Mountains upland and extended down valleys.

Moving ice is a powerful erosion and transport agent and it leaves distinctive imprints on landscapes over which it flows. Originally V-shaped river valleys are eroded into precipitous-walled U-shaped valleys, whose upper ends terminate in shear-walled amphitheaters (cirques). Glacier-cut basins are conspicuous features. Lakes in the upper reaches of the mountains fill such depressions. Accumulations of unsorted rock fragments transported by ice were deposited in moraines on valley floors, behind which lakes were impounded (**Figure 14**) in which distinctly laminated, fine-grained sediments (varves) were deposited (**Figure 15**).

These and many other features are so distinctive that a student of landforms can tell at a glance



Scene 26. Quaternary Period, Pleistocene Epoch (the Ice Age). This scene depicts the maximum area covered by ice during Pleistocene time. Valley glaciers, fed from alpine ice caps, flowed down valleys where terminal moraines mark their lower ends. The last major advance receded some 10,000 years ago. (The location of present-day Centennial is shown on the diagram.)

whether a region has been glaciated. It is believed that the valley glaciers and ice caps began to recede about 15,000 years ago. Today in the Medicine Bow Mountains, the glaciers are gone and all that remains are a few snow banks in sheltered places in the Snowy Range.

A great variety of mammals lived throughout North America during Pleistocene time. The Proboscideans (animals with a proboscis, or trunk) were represented by various species of elephants (mammoths and mastodons). Some of the elephants were larger than modern elephants. A number of species of horses were present. They were mostly pony-sized, although some were as large as the largest modern horse. There were bison, some much larger than the living bison, with a horn spread of 6 feet. Camels were numerous and varied. The great saber-tooth cat was the most striking of the meat eaters. The primates, which were present during earlier Tertiary time, disappeared from North American before Pliocene time and did not return until the coming of man some 12,000 or more years ago.

The disappearance from North America of elephants, mastodons, horses, camels, giant cats, and other kinds of animals during the last few thousand years is an unexplained mystery. It has been suggested that human activities contributed to their extinction, although other factors such as climatic changes and diseases may have played an even more important role.

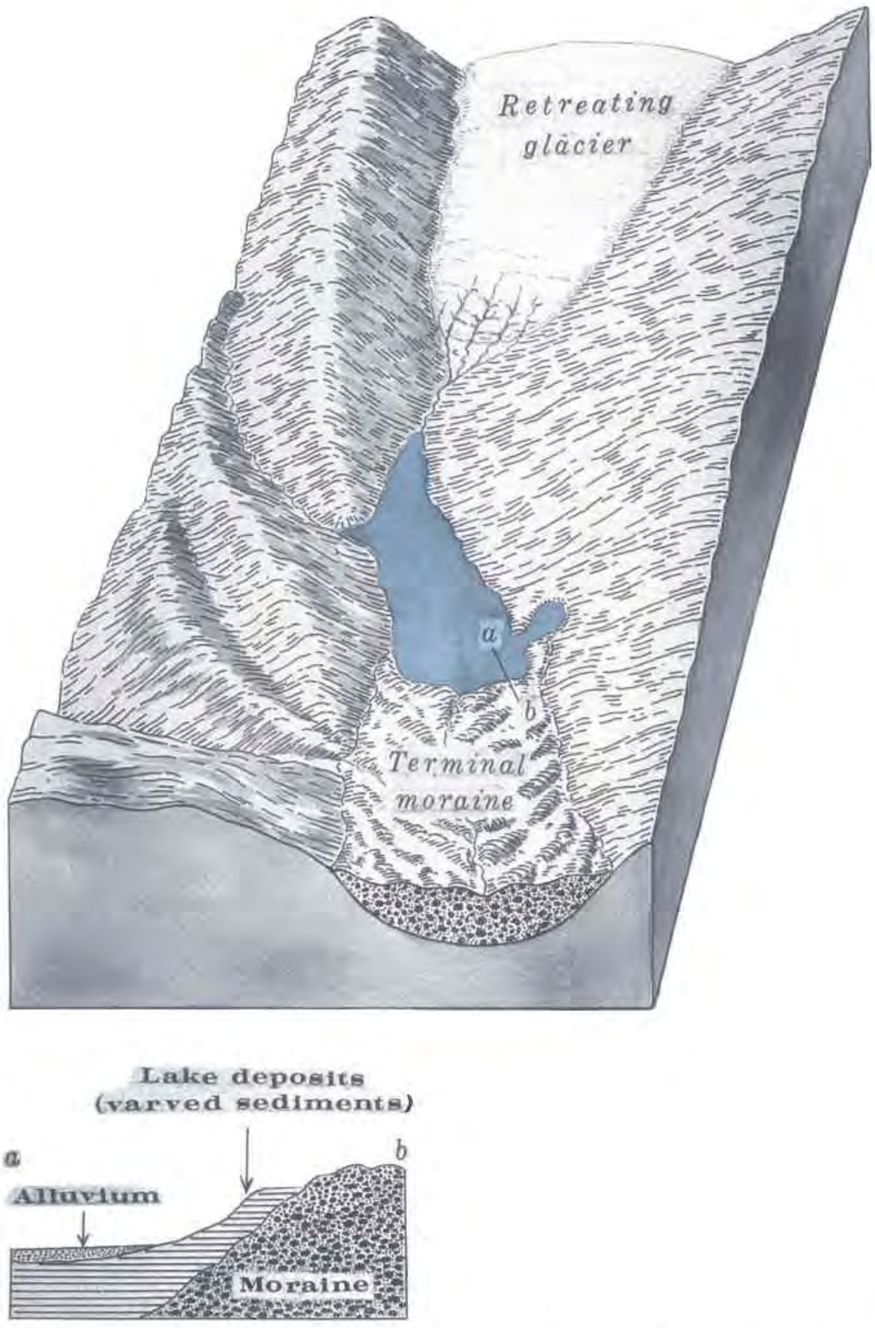


Figure 14. Diagram of the Libby Creek terminal moraine and impounded lake in which varved sediments were deposited. Below the diagram is a cross section showing the relationships of different glacial sediments.

Figure 15. Varved sediments deposited in a lake that was impounded by the Libby Creek morainal dam shown in Figure 14.

The Gap, a col cut by the headward erosion of glaciers

The present landscape of the Medicine Bow Mountains and adjacent areas

The events of the long history of the Medicine Bow Mountains and surrounding region have been described. After all this, what does the area look like today? The diagrams that follow show some of the major features of the modern landscape of the Medicine Bow Mountains and wild inhabitants of the mountain and basin region.

Landforms of the Medicine Bow Mountains

Figure 16

The main mass of the Medicine Bow Mountains is a complex upfold (anticline) that has experienced several periods of crustal movement, during which it was folded and thrust faulted or uplifted with tilting and normal faulting. Since the mountains first came into being, some 70 million years ago, perhaps more than 15,000 feet of rock have been removed by erosion.

Landforms of the Laramie Basin

Figure 17

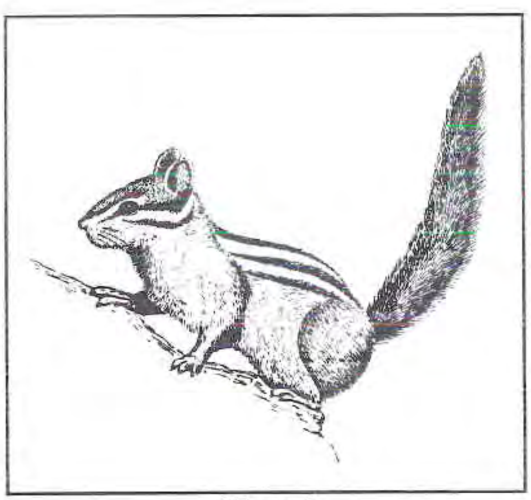
The Laramie Basin is a north-south trending downwarp (syncline), some 20 miles wide and 100 miles long. It is flanked on its west and south sides by the Medicine Bow Mountains and on its east side by the Laramie Mountains. The floor of the basin ranges in elevation from 7,000 to 8,000 feet above sea level. It is one of the highest intermountain basins in the Rocky Mountain region.

Since the beginning of the present cycle of erosion, at least two million years ago, running water and wind have removed most of the Tertiary sediments that filled the pre-existing basin and covered all but the higher parts of the adjacent mountains. It is estimated that more than 1,000 feet of sedimentary rocks of Oligocene, Miocene, and Pliocene(?) age have been removed from the Laramie Basin during the present cycle of erosion. The present landscape is exhumed, very much as it existed at the close of Eocene time, before it was buried by sediments of later Tertiary age.

The floor of the basin is dominated by two contrasting types of landforms. These are river-cut surfaces and depressions scooped out by the wind. The river-cut surfaces, which stand at various levels above the present river floodplain, are erosional remnants of formerly more extensive surfaces. Although these surfaces are cut in fine-grained sedimentary rocks, they are capped, for the most part, with a veneer of water-worn cobbles and pebbles of resistant rock types derived from the adjacent mountains. The surfaces are remnants of abandoned floodplains formed at various times during the progressive excavation of the basin; they reflect changes in the erosive power of the streams that formed them. These changes could have resulted from changes in the gradients of the rivers caused by crustal movements or by variations in the volume of flow of the rivers due to changes in climate.

A comparison of the gradients of the present river floodplains with the gradients of the older abandoned floodplain surfaces indicates that there has been no measurable change in the gradients since the Pliocene uplift that caused the present cycle of erosion. There is abundant evidence that the volume of flow of the rivers varied greatly due to changes in climate throughout the Pleistocene. During that time, the rivers established new floodplains, entrenched in existing floodplains, at times when their erosive power was augmented by increases in flow volume. It is axiomatic that the highest surface is the oldest and the lowest is the youngest.

Elk



Chipmunk

Pika

Figure 16 (opposite). Landforms of the Medicine Bow Mountains. Features described are numbered on the figure.

1. The Snowy Range ridge. Standing above the main mass of the mountains, this ridge is the most conspicuous feature on the horizon. It rises abruptly 1,000 feet above the lakes along its base to a height of 12,013 feet and trends northeast for 8 miles. The Snowy Range owes its existence to the extremely resistant character of the Medicine Peak Quartzite, of which it is composed. Its east face is a steep glaciated wall. The west face is less extensively glaciated due, in part at least, to the drifting of snow along the east face by prevailing westerly winds.

2. A glacially eroded depression. Numerous local depressions have been gouged out by glacial action. They now contain such lakes as Lookout Lake, Mirror Lake, and Lake Marie.

3. The high-level erosion surface. One of the most striking physical features of the mountains is the nearly concordant level of the interstream areas, giving rise to a skyline devoid of marked relief except for erosional remnants of once-higher mountains. This surface was deeply dissected when the present valleys were excavated.

4, 5, and 6. These are erosional remnants, of limited size, which rise above the high-level erosion surface and owe their existence to the resistant character of the rocks of which they are composed.

7. Rock Creek ridge. This ridge, forming the northeast flank of the Medicine Bow Mountains, extends northward from Centennial Valley for 16 miles and rises to a maximum elevation of 10,640 feet. It is separated, for the most part, from the main mountain mass by the north trending Rock Creek canyon. This ridge lies along the upthrown west side of a normal fault. The core of the ridge is composed of Precambrian rocks. The east flank is overlapped by early Tertiary rocks. Along the ridge crest are island-like occurrences of massive conglomerate, composed of rounded quartzite boulders several feet in diameter, which are believed to be early Tertiary.

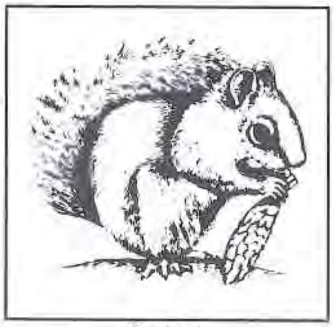
8. Centennial Ridge. This 6-mile-long mountain (maximum elevation 9,800 feet) is the flank of the main mountain upfold from which Paleozoic, Mesozoic, and Cenozoic rocks have been removed by erosion. The ridge is composed of a complex assemblage of Precambrian gneiss and granite. The truncated edges of upturned Paleozoic and Mesozoic rocks parallel its eastern flank.

9. Centennial Valley. The valley is a symmetrical downwarp (syncline) underlain by Paleozoic and Mesozoic rocks and Quaternary alluvium. At its south end a remnant of undeformed late Tertiary sediments is preserved. The northwest part of the valley floor is covered by a boulder-strewn Pleistocene outwash plain.

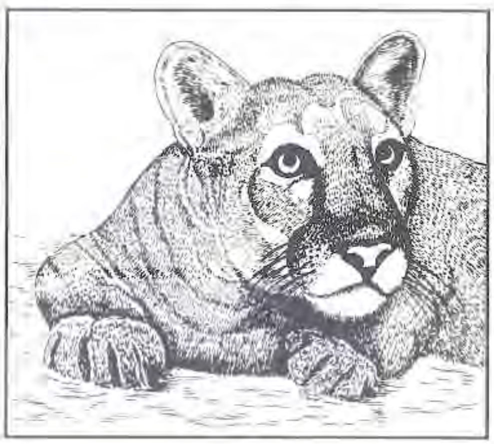
10. Sheep Mountain. This north trending anticline branches off the main mountain mass. It is composed largely of Sherman Granite, and is extensively thrust faulted along its east flank.

Chickadee

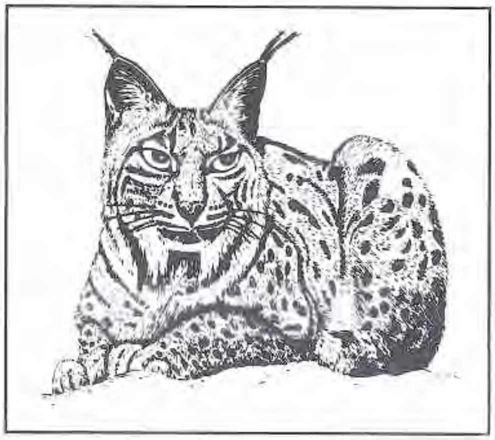
Black bear



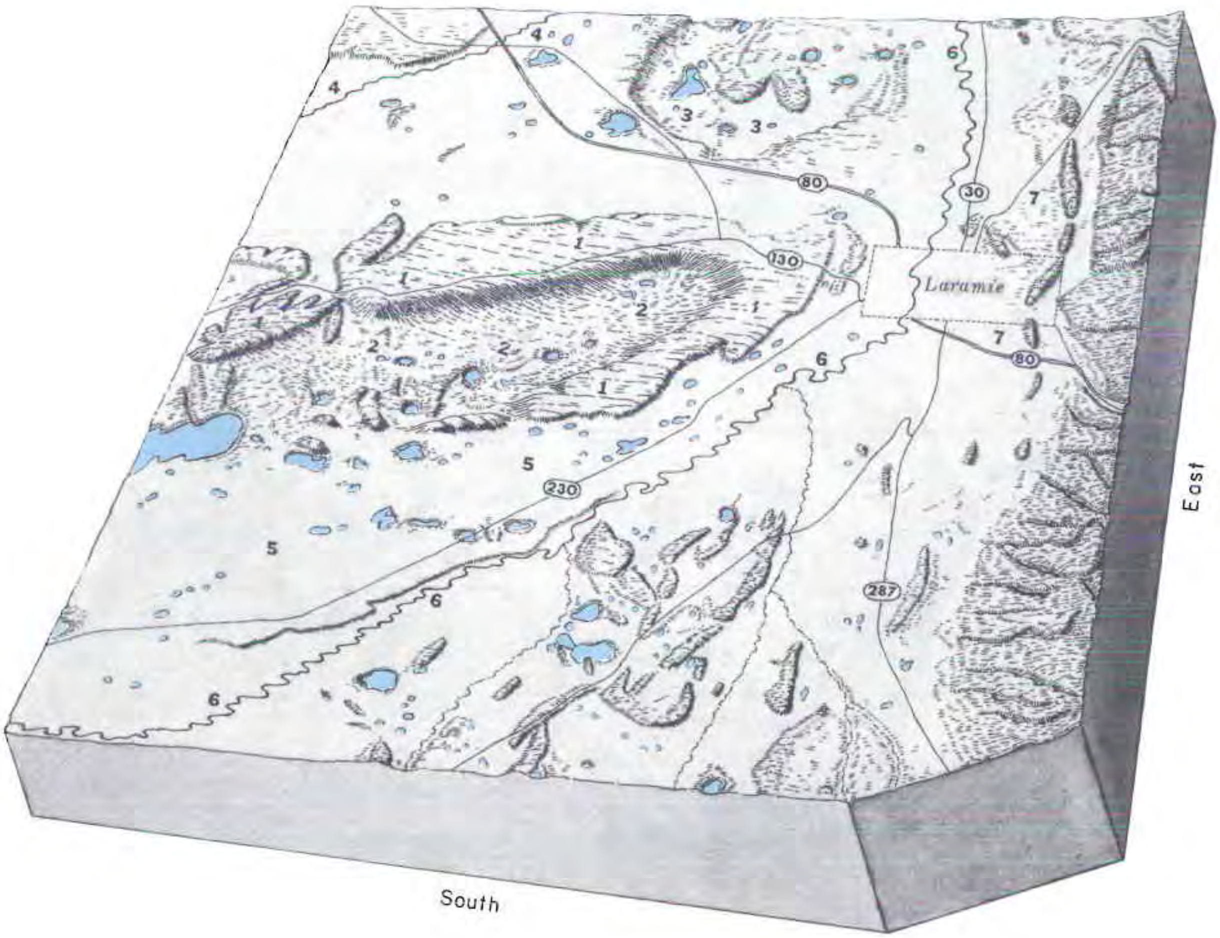
Squirrel

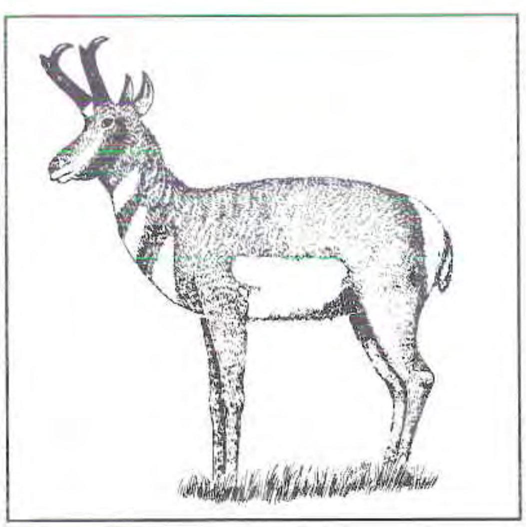


Mountain lion



Lynx





Pronghorn

Prairie dog

Figure 17 (opposite). Landforms of the Laramie Basin. Features described are numbered on the figure.

1. The Airport surface. Remnants of this high old surface extend from the Laramie airport westward 17 miles to the valley of the Little Laramie River. The surface slopes eastward from its western margin (elevation 7,820 feet) to the airport (7,250 feet). The gradient of the surface decreases from 60 feet per mile at its western end to 20 feet per mile at its eastern extremity. The surface is cut in Cretaceous shales and sandstones and is capped by a thin veneer of water-worn cobbles and pebbles of resistant rocks from the mountains to the west. The rock fragments decease in size from the western to the eastern ends of the surface.
2. The Big Hollow. This wind-excavated depression is one of the most conspicuous landforms on the basin floor. The depression is 11 miles long, 4 miles wide, and as much as 200 feet deep. The elongate axis parallels the prevailing westerly winds. It is cut into Cretaceous shales.
3. The Big Basin. This is another large wind-excavated depression: it has an area of some 13 square miles and a maximum depth of 360 feet.
4. Floodplain of the Little Laramie River.
5. Stream terrace 50 feet above the Laramie River, a relic of a former floodplain of the Big Laramie River.
6. The Big Laramie River floodplain. The river is slowly degrading its floodplain. In a number of places it is eroding bedrock; however, most of the floodplain is thin alluvium. Rock fragments in the floodplain become progressively smaller downstream on the basin floor.
7. The Laramie surface. This surface slopes westward from the base of the Laramie Mountains and is about 2 miles wide. The surface cuts Triassic shales and sandstones and is veneered by limestone fragments derived from the flank of the Laramie Mountains. The town of Laramie is built, for the most part, on this surface.

Badger

Coyote

Superimposed drainages

Figures 18 and 19

A seemingly anomalous relationship exists between the mountains and streams throughout the central Rocky Mountain region. The master rivers are no respecters of the mountains. The rivers that drain the intermountain basins escape from them through precipitous canyons excavated through flanking mountain ranges (**Figure 18**). It is a novel experience to travel down a river flowing on a basin floor and suddenly enter a canyon a thousand or more feet deep, which cuts across a flanking mountain range. It is little wonder the early explorers and map makers of the region experienced difficulties when they attempted to relate the drainage patterns to the relief.

The Laramie Basin and Mountains clearly exhibit this phenomenon of superimposed drainages (**Figure 19**). The rise of the flanking mountains and the downfolding of the basin began in the latest Cretaceous and continued through the Paleocene and early Eocene, a span of more than 20 million years. A vast amount of rock debris was eroded from the rising mountains and either deposited in the basin or transported out of the basin by streams. During later Tertiary time (Oligocene and Miocene), when the basin was filled with sediments from the adjacent mountains and extensive volcanic ash falls, the low places on the Laramie Mountains were covered by the deposits. During the Pliocene episode of crustal uplift, the basin floor attained its relative great height. The uplift was not uniform; the newly uplifted surface was warped and, in places, faulted. Uplift increased the gradients of the rivers and the present cycle of erosion began. In this episode, the Laramie River flowed northward for a distance of 60 miles. It then turned northeast and flowed across the Laramie Mountains, where the late Tertiary sediments extended through a low saddle. Thereafter, the river excavated the late Tertiary sediments and, where it crossed the mountains, cut a canyon a thousand feet deep through the resistant Precambrian rocks.

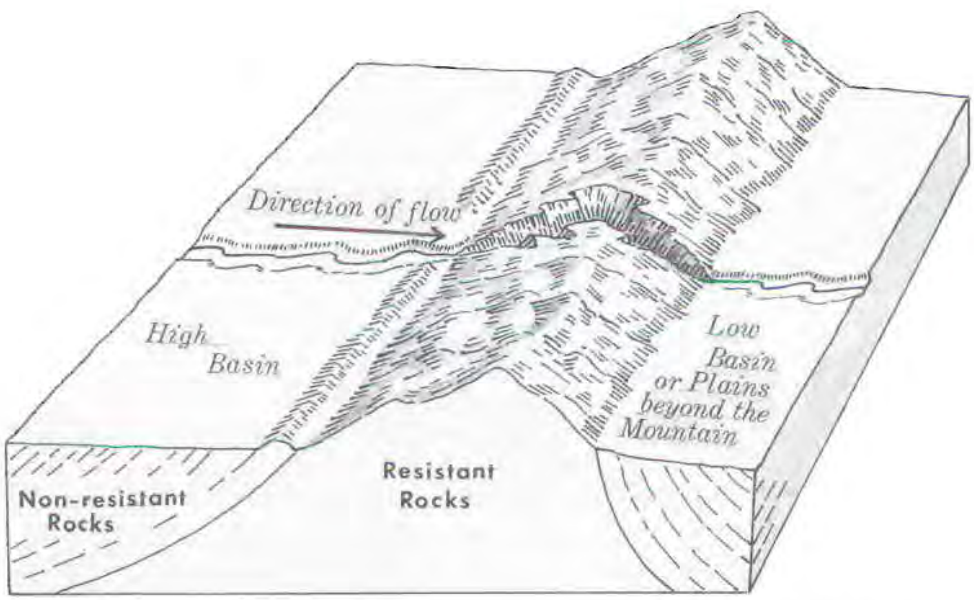
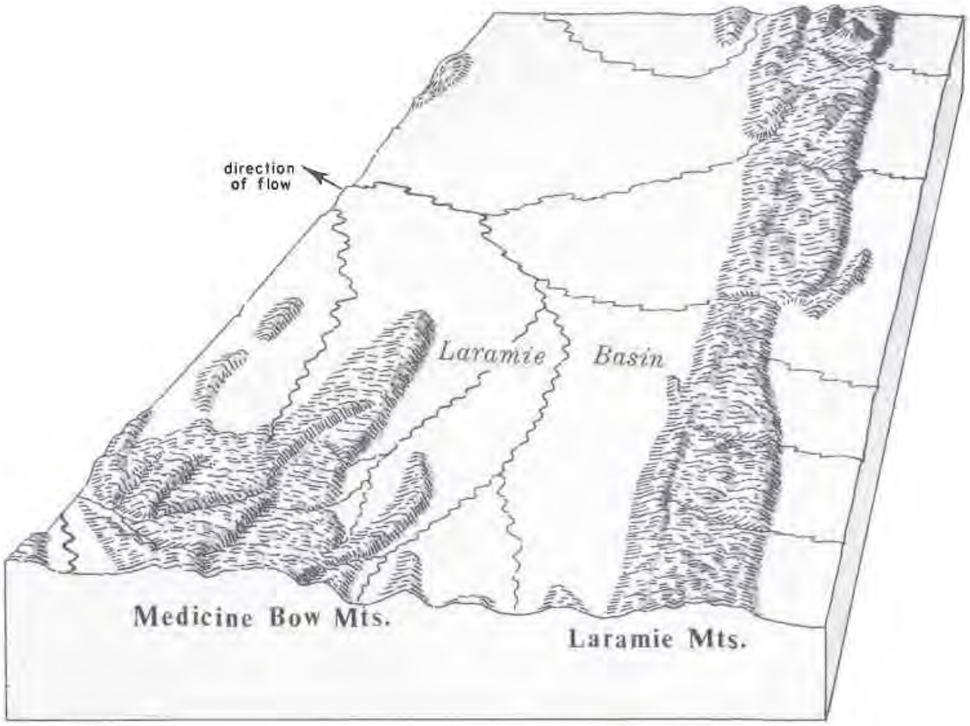
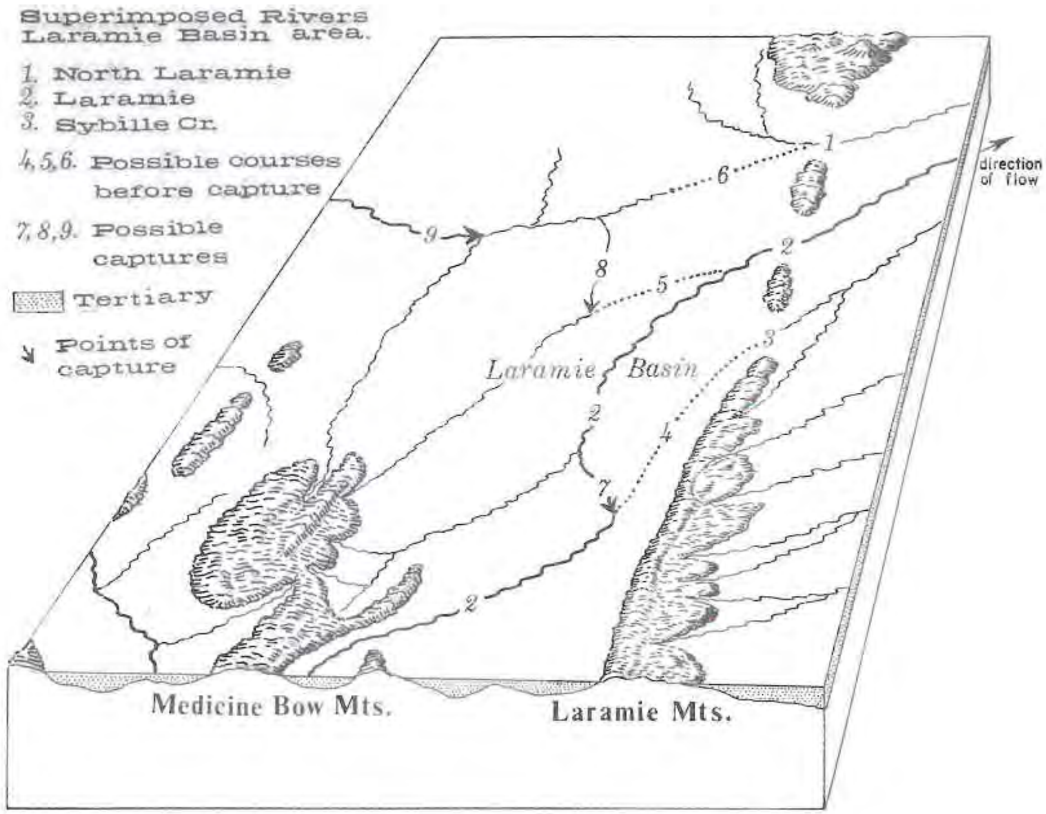


Figure 18. Diagram of a superimposed river flowing from a high basin to a lower basin or the plains beyond the mountains through a precipitous canyon across a flanking mountain range

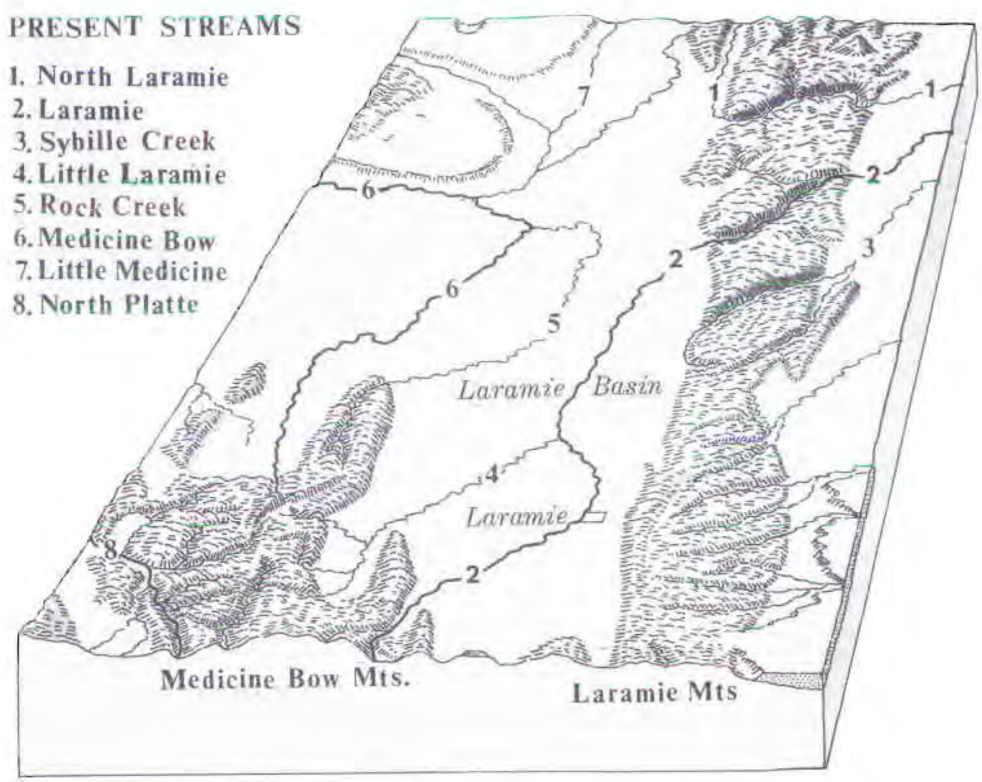


A. Close of the Eocene.

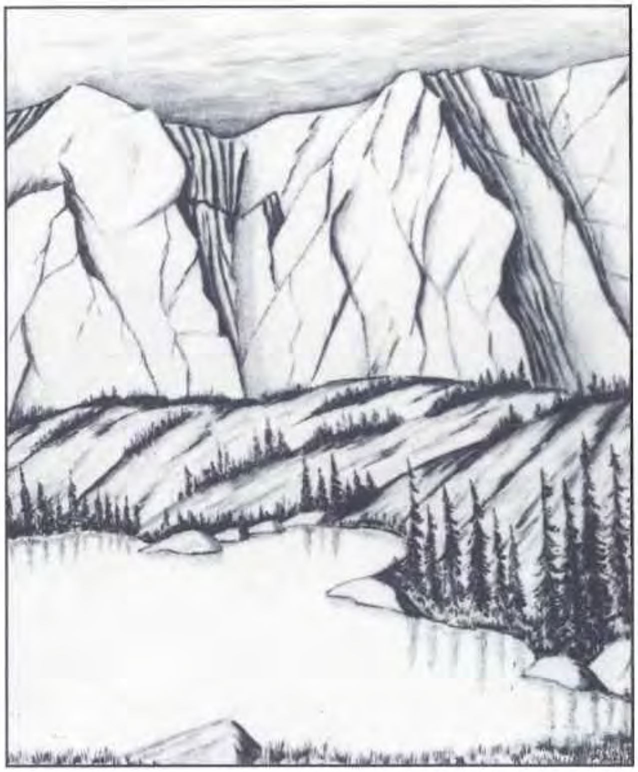
Figure 19 (above and next page). Series of events that resulted in superimposed drainages through the Laramie Mountains: (A) Reconstructed diagram of the Laramie Basin, enclosing mountains, and projected drainage pattern as they existed at the close of Eocene time, about 37 million years ago. Drainage in the basin is primarily to the north and west with streams originating in the mountains but not superimposed on them. (B) Reconstructed diagram of the same area and the drainage pattern after the uplift of the region here at the close of Pliocene time, around 2 million years ago. Direction of flow in the basin is primarily north and east, with rivers crossing sediment fill over the partly buried Laramie Mountains. (C) Diagram of the same area as it exists today. The North Laramie River (1), the Laramie River (2), and Sybille Creek (3) flow in superimposed canyons across the Laramie Mountains.



B. Close of the Pliocene.



C. Today.



Glaciated east face, Medicine Peak Quartzite ridge

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Geology--Interpreting the past to provide for the future