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# Cenozoic Geomorphic History of the Medicine Bow Mountains near the Northgate Fluorspar District, Colorado

BY

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Denver Federal Center

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## Contents



## Illustrations

# CENOZOIC GEOMORPHIC HISTORY OF THE MEDICINE BOW MOUNTAINS NEAR THE NORTHGATE FLUORSPAR DISTRICT, COLORADO [1]

By

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## Abstract

1. In early Tertiary time, deep erosion removed most of the rocks that existed above the present topographic surface prior to the Laramide orogeny, and produced a hilly terrain, the pre-White River surface, drained by southward flowing streams.

2. In early Oligocene time tuffaceous sediments of the White River formation buried the pre-White River surface.

3. No local record exists embracing late Oligocene and early Miocene time. However, the direction of stream drainage was reversed during this interval. Erosion chiefly affected the cover of White River sediments.

4. By late Miocene time, north-flowing streams had cut to essen-tially the same relative level reached by the streams of early Tertiary age, and had partially exhumed and modified the older terrain (pre-North Park surface).

5. Widespread alluviation in late Miocene or early Pliocene time resulted in deep burial of the Northgate district by clays, sands, and gravels of the North Park formation.

6. Deformation following deposition of the North Park formation resulted in widespread minor folding and local faulting in northern Colorado and southern Wyoming. The central part of the Northgate district was warped up at this time, and four minor faults developed in the central part of the district. Fluorspar was deposited along at least two of these faults.

[1] Publication authorized by the Director, U. S. Geological Survey.

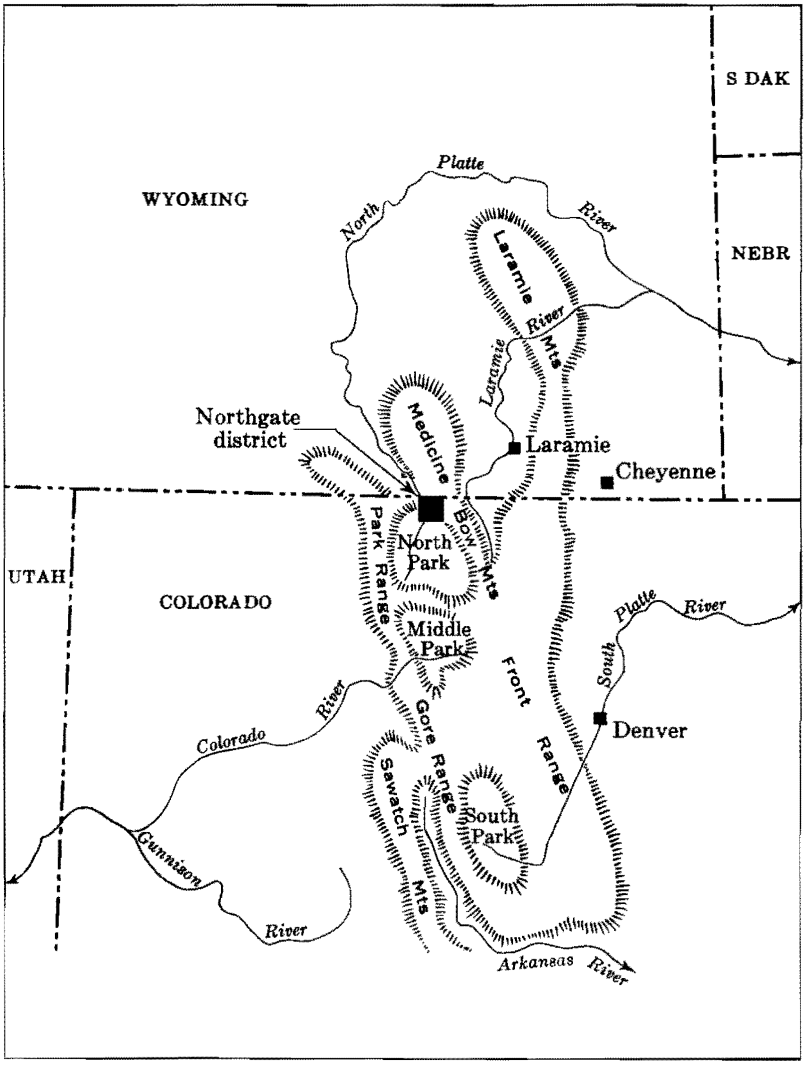


FIGURE 1.—Index Map Showing the Location of the Northgate District.

formation) age. These deposits were warped and faulted in late Tertiary time, and commercial concentrations of fluorspar were deposited along at least two of the minor faults.

Detailed data on the Precambrian rocks will be presented in a separate petrologic paper [2], and the general geology and mineral deposits

[2] Steven, T. A., Metamorphism and the origin of granitic rocks in the Northgate district, Colorado: U. S. Geological Survey manuscript, in preparation.

will be discussed in a more comprehensive report on the district [3].

The geologic studies in the Northgate district are part of a program of investigations of mineral deposits in Colorado being carried out by the U. S. Geological Survey, in cooperation with the Colorado Geological Survey Board and the Colorado Metal Mining Fund.

## LATE EOCENE-EARLY OLIGOCENE (PRE-WHITE RIVER) EROSION SURFACE

The oldest geomorphic elements of Cenozoic age recognized in the Northgate district are remnants of early Tertiary valleys (here called the pre-White River surface) preserved beneath tuffaceous sediments of the White River formation of Oligocene age. The local character of this surface can be reconstructed from the distribution of the remnants (fig. 2), and from a series of cross sections across the buried valleys (fig. 3). Only a limited picture of the early Tertiary landscape can be reconstructed, however, as the known remnants are localized in a relatively small area, and present gradients and relative elevations have little meaning because of deformation during the late Tertiary. This local picture may not have been typical for the region as a whole, and it seems more likely that the terrain indicated may more nearly represent minimum rather than average relief within the mountain areas. The remnants of White River formation are flanked on both sides by higher ground of Precambrian rocks, and the Northgate district appears to have occupied a relatively low area where the topography should have been most mature and the relief relatively subdued.

The dendritic pattern displayed by the valley remnants indicates a general southward direction of stream flow in this vicinity in late Eocene and early Oligocene time. The valleys drained into the area now occupied by the North Park basin, reaching local levels not far above the present floor of the basin. The cores of Precambrian rocks in the Medicine Bow Mountains and the Park Range, flanking most of North Park, stand higher than the remnants of the White River formation in the Northgate district. It seems likely that the south-flowing drainage previous to White River time was confined to an ancestral North Park topographic basin and may have been integrated with a drainage system of early Tertiary age in the Middle Park area, where Lovering (1930, p. 73) and Richards [4] (p. 31) report sediments of Oligocene age that probably are correlative with the White River formation.

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[3] Steven, T. A., Geology and fluorspar deposits of the Northgate district, Colorado: U. S. Geological Survey manuscript, in preparation.

[4] Richards, Arthur, 1941, Geology of the Kremmling area, Grand County, Colo.: Univ. of Michigan Ph.D. thesis.

The cross sections across the buried valleys in the Northgate district demonstrate that the drainage during early Oligocene time was fairly deeply entrenched near the margins of North Park (sec. A-A', fig. 3), and that the relief was considerably more subdued toward the headwater areas (secs. B-B', C-C', and E-E', fig. 3). The analogy to the present topography, with upland areas characterized by relatively subdued topography drained by streams whose lower courses have been rejuvenated and incised, is very suggestive, and even the oldest decipherable geomorphic elements seem to have had a complex origin. The analogy may be limited, however, as the remnants of the old upland surface area have considerably greater relief than is characteristic of the Medicine Bow surface, and the area of relatively subdued topography may have been of limited extent. Even today the Precambrian rocks in adjacent parts of the Park Range and Medicine Bow Mountains stand considerably higher than the remnants of the White River formation in the Northgate district, and the regional relief in early Tertiary time thus must have exceeded the local relief for which evidence has been preserved.

Knight (1953, p. 69) has postulated that the high-level erosion surface marking the summit of the Medicine Bow Mountains (here called the Medicine Bow surface) was cut in late Eocene time, and that the streams were incised and the adjacent basin areas were excavated as the result of regional uplift and rejuvenation during the closing stages of the Eocene epoch. The White River formation presumably buried this terrain (Knight, 1953, p. 71), and locally at least protected and preserved it through subsequent periods of erosion. This general sequence of events closely conforms to the sequence proposed in this report; the chief points of disagreement concern the age of the Medicine Bow surface, and its possible identity with an upland surface of low relief formed in late Eocene time. Although these differences of opinion will be considered fully in later paragraphs under the section on the Medicine Bow surface, a brief list of arguments for believing that the pre-White River upland surface and the Medicine Bow surface in this vicinity, although locally nearly coincident, are generally distinct in age and character are presented here:

1. The pre-White River surface of late Eocene and early Oligocene age, and the overlying White River formation have been deformed at least once, and perhaps several times, yet the Medicine Bow surface shows no sign of deformation, and locally it bevels faults that offset White River rocks and probably formed during Pliocene time.

2. The pre-White River surface is distinctly hilly, and local relief of 500 feet or more within a quarter or half a mile is common

even in the headwater areas where the topography was most subdued (secs. B-B′, C-C′, and E-E′, fig. 3). In contrast, the Medicine Bow surface has a minor local relief (fig. 2), and in several places it definitely truncates the older hilly surface and the overlying White River formation (secs. B-B′ and E-E′, fig. 3).

3. The pre-White River surface was cut by a generally south-flowing stream system, whereas contours drawn on the Medicine Bow surface (fig. 2) indicate that it was graded to a stream system that flowed generally north and west in much the same manner as the present North Platte River and its eastern tributaries.

### DEPOSITION OF THE WHITE RIVER FORMATION

Volcanic ash, derived from sources outside the area, filled the early Tertiary valleys in the Northgate district and may have completely covered the old terrain during early Oligocene time to form the White River formation. This formation is made up for the most part of white, light-gray, greenish-gray, or tan tuffaceous silts with variable amounts of intermixed clay and sand. Arkosic sands and conglomerates composed of locally derived materials are found only along the margins of the old valleys and in minor tributaries, and considering the steepness of the topography at the time of deposition, they comprise an anomalously small fraction of the formation. According to McGrew (1953, p. 63) and Knight (1953, p. 71), vertebrate fossils collected from these rocks clearly indicate that they correlate with the White River formation of early Oligocene age.

Knight (1953, p. 69) believes that the lack of coarse, locally derived rock fragments indicates low relief on the interfluve areas, which he attributes to the presence of a high-level erosion surface of late Eocene age. Although differing in the interpretation of which high-level erosion surface was present at that time, the writer agrees that a generally subdued topography in the headwater areas of the pre-White River stream systems may have been one of the reasons why local debris is so sparse in the White River formation. A more important reason, however, may have been that an outbreak of volcanic activity spread great volumes of ash over wide areas and so overloaded the streams that they rapidly aggraded their courses and were unable to erode bedrock. Such a mechanism would account for the general lack of local debris, and for the high proportion of volcanic ash that characterizes the White River formation.

Remnants of the White River formation are found near the crest of the Medicine Bow Mountains at several places in the Northgate district, and the formation undoubtedly once covered most, or perhaps all, of the Medicine Bow Mountains in this vicinity. Knight (1953,

p. 71) postulates that it may have covered all of the region with the possible exception of the higher mountain areas. No evidence is known to the writer that would permit an accurate estimate of the depth of burial for any part of the Medicine Bow Mountains. In the vicinity of the Northgate district, however, the cover of White River formation was thick enough to accommodate most of the erosion and geomorphic changes, including a complete reversal in the direction of stream drainage, that took place during the latter part of Oligocene and much of Miocene time.

### LATE MIOCENE (?) (PRE-NORTH PARK) EROSION SURFACE

Little is known of the events that took place during late Oligocene time and a large part of Miocene time, subsequent to deposition of the White River formation and prior to the cutting of the valleys in which the North Park formation was deposited in late Miocene (?) or early Pliocene (?) time. The general direction of stream drainage was southward in early Oligocene time but was reversed by late Miocene time. This change was accompanied by only moderate erosion as no streams cut through the White River sediments to present levels until the valleys now filled with the North Park formation were established. In spite of the apparently limited vertical range within which erosion operated in the Northgate district, other parts of the Rocky Mountains of northern Colorado and southern Wyoming were deeply eroded during this interval. Gravels, sands, clays, and volcanic ash were widely deposited in basins in northwestern Colorado and in southern Wyoming to form the Browns Park formation of Miocene (?) age. McGrew (1951, p. 55-56) has described this formation in the Saratoga basin, 35 to 40 miles northwest of the Northgate district.

The surface covered by the North Park formation in late Miocene (?) or early Pliocene (?) time was in many respects very similar to the present terrain, with a topographic basin in the North Park area drained by north-flowing streams superimposed across a partially exhumed surface of earlier Tertiary age.

The stream valleys that drained the North Park area in late Miocene time, just prior to the deposition of the North Park formation, were located in the same general area as the older valleys of Oligocene age that were filled with the White River formation, but the directions of stream flow had been reversed. The main stream left the basin through a narrow valley near where the present North Platte River leaves North Park, and both the present valley and the valley of Miocene age trend northwest for 30 to 35 miles across a basement of Precambrian rocks to the Saratoga basin in Wyoming.

The younger valleys (comprising the pre-North Park surface of

this report) were cut to approximately the same levels as the Oligocene (pre-White River) valleys, and the presence of remnants of both the White River formation and the North Park formation within a limited area lying between the hard crystalline cores of the Park Range and the Medicine Bow Mountains suggests that locally at least the younger drainage system was controlled by the distribution of the soft, easily eroded rocks of the White River formation. The chief difference between the terrains appears to lie in the stage of geomorphic development. The valley of late Miocene (?) age between North Park and the Saratoga basin was broad and flaring in cross section (secs. E-E′ and F-F′, fig. 3), and was considerably more mature than the youthful gorge that now confines the North Platte River.

The presence of a topographic basin in the North Park area before the deposition of the North Park formation is indicated by the widespread distribution of this formation in south-central North Park. As mapped by Beekly (1915, pl. XII), the basal contact of the North Park formation is essentially parallel to the bedding in the overlying strata, and the formation apparently was deposited on a surface of relatively low relief. This broad basin area was drained through the narrow valley now marked by the wind gap along the northern flank of Watson Mountain (fig. 2), and presumably the basin surface was graded to the resistant threshold of this exit.

The largest of the two remnants of the pre-North Park erosion surface of late Miocene (?) age still preserved in the Northgate district is along the northwestern margin of the district, where sediments of the North Park formation partly fill the southern end of a valley that trends northwestward to the Saratoga basin in Wyoming. Differential erosion of the soft North Park formation near the North Platte River has partly stripped the walls of this old valley, and in places these walls are sufficiently undissected so that their original form can be reconstructed fairly accurately. Contours drawn on reconstructed parts of the surface (fig. 2) indicate a broadly flaring valley flanked by a somewhat hilly and dissected topography. The eastern margin of the old valley apparently was destroyed by the Medicine Bow surface (sec. E-E′, fig. 3), which was eroded to its final form following a late Tertiary period of deformation that warped and faulted the North Park formation (see below).

A smaller remnant of the pre-North Park erosion surface is preserved beneath volcanic gravels of the North Park formation that partly fill an old valley near the northeast corner of the Northgate district. This valley apparently was localized in the area underlain by relatively soft White River sediments and occupied a partly exhumed

and modified valley of earlier Tertiary age. The valley of pre-North Park age truncated some of the minor buried ridges of Precambrian rocks beneath the White River sediments, but the stream course was not incised to any extent (sec. B-B′, fig. 3).

The stream that deposited the gravels of the North Park formation near the northeast corner of the Northgate district apparently flowed northward at this locality. The elevation at the base of the gravels ranges from about 8,860 feet at the southern end of their outcrop, to near 8,660 feet near their northern limit, and the directions of truncation of bedding and crossbedding within the gravels confirm this general direction of flow. The stream evidently flowed north within the same area now occupied by the south-flowing Lawrence Creek drainage and turned west near the north end of the remnant of North Park formation. The portion of the valley of late Miocene (?) age containing North Park sediments is arcuate toward the east and impinges against the eastern margin of the partly exhumed valley of early Oligocene age containing the White River formation. The exhumed valley wall has not been breached by any younger valley system. Apparently, during the Miocene the drainage bent sharply west near the northeast corner of the Northgate district following a tongue of soft White River sediments along much the same course that now is followed by Camp Creek in the north-central part of the district. This tributary is believed to have joined the northwest-trending main stream of Miocene age near Quaintance Ranch, near the northwest corner of figure 2, where contours of the pre-North Park surface indicate that an important local tributary entered the main valley. Most of the area along this indicated course was probably underlain by soft sediments of the White River formation, and the Medicine Bow surface in the northwest part of the Northgate district is graded to some such stream course (sec. D-D′, fig. 3).

### DEPOSITION OF THE NORTH PARK FORMATION

Alluviation in late Miocene (?) or early Pliocene (?) time deposited silt, sand, gravel, and volcanic ash comprising the North Park formation over wide areas in the North Park basin in Colorado and the Saratoga basin in Wyoming, and in a long, northwest-trending valley between them.

In the Northgate district, the North Park formation comprises two strongly contrasting types of material. Light-gray to tan silty sand predominates in the old valley extending northwest from the western margin of the Northgate district; thin pebbly beds and clay layers locally comprise as much as 10 percent of the formation here, but gen-

erally they are less abundant. A remnant of North Park formation near the northeast corner of the Northgate district, on the other hand, is composed largely of poorly sorted sand and gravel, in which distinctive volcanic rock fragments predominate.

The maximum depth of fill in the Northgate district cannot be told, but McGrew (1951, p. 56) reports a thickness of at least 1,000 feet, and perhaps more than 1,600 feet along the northwest-trending valley near Encampment, Wyo., and Beekly (1915, p. 67) believed that the formation was 1,000 feet or more thick in the southeastern part of North Park. It seems unlikely, therefore, that the maximum thickness of fill in the vicinity of the Northgate district, which lies between these two areas, was less than 1,000 feet, and it may have been considerably more. Thickness of this magnitude would have been sufficient to cover the present surface of the Northgate district with the possible exception of the higher parts of the Medicine Bow Mountains near the southeast corner of the district.

The stream gravels of the North Park formation near the northeast corner of the Northgate district give positive evidence for deep burial by the North Park formation in this vicinity. They here reach an altitude of about 9,050 feet, which is only about 200 feet below the adjacent crest of the Medicine Bow Mountains and is slightly higher than the crest of the mountains along the Colorado-Wyoming State line. In addition, Knight (1953, p. 75) noted similar volcanic gravels near Mountain Home, Wyoming, a few miles to the northeast and at about the same altitude. The gravels near Mountain Home, however, are on the east flank of the Medicine Bow Mountains, and the conclusion seems inescapable that the North Park formation covered the mountains in this vicinity at one time.

The North Platte River and lower Camp Creek were cut through the North Park formation onto an irregular buried surface (see following section). The highest point on the buried surface that was encountered by the downcutting streams was between Independence Mountain and Watson Mountain, where the North Platte River appears to have encountered a ridge of Precambrian rocks at an altitude of about 8,900 feet (sec. F-F′, fig. 3). The maximum present altitude in the central and northern parts of the Northgate district is about 9,260 feet, only a few hundred feet above the altitudes of hills known to have been buried by the North Park formation. Thus local evidence supports the suggestion from regional considerations that most and perhaps all of the Northgate district was covered at one time by the North Park formation.

The North Park formation has not been dated closely at its type

locality in south-central North Park, or in the Northgate district. McGrew (1951, p. 57), however, has reported lower Pliocene vertebrate fossils in rocks of the North Park formation in Saratoga basin, Wyoming, that are continuous with those along the western margin of the Northgate district, and de la Montagne (1953, p. 103) reports a Pliocene horse tooth from the North Park formation in Cunningham Park, a few miles west of the Northgate district. More recently, de la Montagne (1955, oral communication) has discovered vertebrate fossils of probable late Miocene age in the North Park formation even nearer the western edge of the Northgate district. In this report, therefore, the age of the North Park formation will be given as late Miocene(?) or early Pliocene(?).

The cause of the alluviation that resulted in deposition of the North Park formation cannot be determined from the Northgate district. The late Tertiary period of deformation that disturbed this general area affected the North Park formation both in the south-central part of North Park and in the Northgate district, and thus the deformation took place after deposition. Rhyolitic fragments are abundant in the North Park formation, and the writer favors the suggestion made by Knight (1953, p. 76) that an outbreak of volcanic activity in the headwater areas may have provided more debris than the streams could remove, and the downstream areas were widely alluviated. Both Knight (1953, p. 76) and McGrew (1951, p. 57) point out that coarse volcanic debris in the North Park formation is progressively more abundant to the south indicating a source in this general direction.

### LATE TERTIARY DEFORMATION

The North Park formation was widely deformed in late Tertiary time. In its type locality in south-central North Park it now comprises a northwest-trending syncline that extends nearly across North Park. The limbs of this syncline locally attain dips near 35°, indicating moderately intense warping. Within the Northgate district, a general westward tilting of the North Park formation in the vicinity of the North Platte River is shown by an anomalously steep gradient at the base of the old valley now buried by the North Park formation. Although this valley appears to have been broader and more mature than the present gorge of the North Platte River (sec. E-E′, fig. 3), the minimum present gradient at the base of this old valley, as measured from the southeast end of outcrop of the North Park formation to a point beneath the level of the North Platte River, is in excess of 150 feet per mile. This contrasts strongly with the gradient of about 20 feet per mile for the present North Platte River.

Contradictory evidence from the North Park formation gravels

near the northeast corner of the Northgate district suggests that this local area was tilted eastward. A general northwesterly direction of stream flow is suggested by truncated bedding and crossbedding within the gravels. The dips exposed in the walls of a gravel pit near the Colorado-Wyoming State line, however, show a statistical concentration in a northeasterly direction, about at right angles to the elongation of the valley filled by the gravels; and minor clay and fine silt beds, which probably were deposited nearly horizontally, dip east in contradiction to the direction of flow suggested by truncated beds and crossbeds.

Four north- to northwest-trending faults cut the Precambrian rocks and White River formation on Pinkham Mountain and the area to the southeast. No evidence was seen in the Northgate district for determining the age of faulting closer than post-White River formation, but de la Montagne (1953, p. 103) and Walters [5] (p. 49) have described similar northwest-trending faults cutting the North Park formation in an area 2-½ to 15 miles west and northwest of the Northgate district. It appears likely, therefore, that the post-White River formation faults in the Northgate district also formed during the late Tertiary period of deformation.

## THE MEDICINE BOW SURFACE

The Medicine Bow surface is one of the most prominent geomorphic features in the Rocky Mountains of northern Colorado and southern Wyoming, and it has long attracted the attention of physiographers and geologists. It comprises much of the broad summit of the Medicine Bow Mountains and is manifested by accordant ridge crests and upland areas of low relief. Some of the flat summit areas are very extensive, and even in an area as well dissected as the Northgate district, essentially unmodified remnants from several thousand feet to a mile or more in diameter still exist (fig. 2).

From a distance, the Medicine Bow surface appears almost as a smooth plain that descends gradually from the base of the higher mountains comprising the Rawah Peaks in the southern Medicine Bow Mountains and the Snowy Range in the northern Medicine Bow Mountains to a central low area near the northern margin of the Northgate district. In detail, however, the surface is not smooth, and contours on the Medicine Bow surface in the Northgate district (fig. 2) indicate a low rolling topography with a well-integrated drainage system. The total relief within the Northgate district is on the order of 2,000 feet, ranging from an altitude of about 8,200 feet near the North Platte River

[5] Walters, R. F., 1953, Geology of the Independence Mountain area, North Park, Colo.: Univ. of Wyoming, thesis.

to almost 10,200 feet along the crest of the Medicine Bow Mountains near the southeast corner of the district. Local relief ranges from a few feet to as much as 400 feet within a mile.

This high-level erosion surface has been referred to as the Medicine Bow plateau by Blackwelder (1909, p. 432), and as the Medicine Bow peneplain by Van Tuyl and Lovering (1935, p. 1304) and others. In the present report it will be called the Medicine Bow surface; the proper name will be used to avoid confusion with other less well-preserved erosion surfaces that will be discussed, and the noncommittal noun "surface" will be used to avoid any implication as to its flatness over wide areas.

The first mention of the upland surface on the Medicine Bow Mountains in geologic literature seems to be an incidental description by Arnold Hague (Hague and Emmons, 1877, p. 95), who noted that the summit of the range was ". . . an elevated plateau country, nearly 10,000 feet above sea level, gently undulating, but without any marked topographical features, covered with timber, and dotted over with open glades and numerous alpine lakes." Blackwelder (1909, p. 430-432) recognized that the surface was cut prior to the present geomorphic cycle, and tentatively suggested that it may have been cut during Eocene time. Subsequently, two general points of view have developed as to the age of this surface, and other surfaces that have been correlated with it. It has been considered equivalent or partly equivalent to the Rocky Mountain peneplain, which, according to Lee (1923, p. 15-16), Little (1925, p. 509), Mather (1925, p. 134), Atwood (1940, p. 304-305), and others, reached its most mature state in late Tertiary, following a long period of erosion during middle Tertiary. Van Tuyl and Lovering (1935), on the other hand, believe that the Rocky Mountain peneplain comprises a number of individual surfaces, all of which are middle Miocene or older in age; they specifically correlate the Medicine Bow surface with the Green Ridge peneplain (p. 1304), which they consider to have formed in middle Eocene time. The most comprehensive statement favoring an early Tertiary age for the Medicine Bow surface has been made by Knight (1953, p. 67-71), who concludes that the surface formed largely during Eocene time, and was preserved by burial through most of the remainder of the Cenozoic era.

Evidence from the Northgate district suggests that the Medicine Bow surface in this vicinity is of composite origin and attained a state of low relief as the combined result of at least three periods of erosion separated by two periods of deep burial. Erosion during early Tertiary time reduced the area to a hilly region with moderate local relief and possibly stronger regional relief (the pre-White River surface). This

surface was buried in early Oligocene time by the White River formation, which apparently covered the area to heights above those of the present surface. The White River formation was locally stripped from the area by late Miocene (?) time, when the streams cut approximately to the same relative depths as the streams of early Tertiary age. Those parts of the pre-Tertiary rocks that projected above the White River formation at this time undoubtedly were reduced somewhat, but the evidence is too fragmentary for the pre-North Park surface to be reconstructed in more than local areas. This period of erosion ended with the deposition of the North Park formation, which probably completely covered the older terrain in the Northgate district. Warping and faulting followed deposition of the North Park formation and deformed a widespread area around the Northgate district, undoubtedly disturbing the earlier surfaces. Subsequent erosion stripped off most of the North Park formation, and reduced the exposed basement rocks to the state of low relief now represented by the Medicine Bow surface. In places, particularly in the northwest part of the Northgate district, this surface is nearly coincident with and includes remnants of the earlier surfaces, but over much of the district the late Tertiary period of erosion significantly modified the exhumed terrains and destroyed all topographic evidence of the post-North Park formation period of deformation.

## RESTORATION OF THE SURFACE

As a primary step in working out the geomorphic history of the Northgate district, the configuration of the Medicine Bow surface was restored over as much of the district as the available data permitted (fig. 2). Relatively unmodified remnants of the surface were outlined on a topographic map of the district, and interpolated contours with a hundred-foot interval were drawn through the intervening areas. The contours on the relict and restored portions of the surface indicate the general terrain just prior to the time the major streams became sharply incised in their present canyons. This incising, according to the interpretations outlined in the present report, took place in middle Pleistocene time.

The essentially unmodified remnants of the Medicine Bow surface were determined by examining aerial photographs in great detail under a stereoscope, and the areas chosen were plotted directly on a topographic map of the district. The areas were outlined conservatively, and in all probability, unmodified or slightly modified remnants comprise a larger proportion of the surface than is shown on figure 2.

Although the position of the restored contours is more or less closely controlled over a large part of the district, a considerable element of interpretation is involved in certain areas. In such places, the

positions shown were chosen as the most probable after a series of trials. More interpretation was required in restoring the contours in the vicinity of lower Camp Creek than anywhere else in the district. This was unfortunate as the Medicine Bow surface in this vicinity comprises segments of several different ages, and the relations between the different segments are important in determining the history of development of the surface. The interpretation shown (fig. 2) assumes that the main stream had been superimposed through the North Park formation onto the basement of Precambrian rocks by the time the Medicine Bow surface had attained its final form and that the youngest elements of this surface were developed subsequent to the post-North Park formation period of deformation. Both of these assumptions are based on geologic evidence from other parts of the district (see following sections).

### SURFACE SEGMENTS OF EARLY AND MIDDLE TERTIARY AGE

The extensive remnants of White River sediments in the Northgate district and the local general coincidence of the floor of the White River formation, the floor of the North Park formation, and the Medicine Bow surface indicate that most of the Precambrian rocks that protuded above the present surface before the Laramide orogeny were removed by erosion in early Tertiary time. Although subsequent erosion has modified the surface on the Precambrian rocks several times, the relative level of this basement surface in the Northgate district has not been reduced greatly since then. In spite of this evidence, however, very little of the Medicine Bow surface can be said to date from early Tertiary time. Even in the vicinity of the isolated patch of White River formation in the northwest part of the Northgate district, where the remnants of the Medicine Bow surface are most nearly coincident with the floor of the White River formation (sec. E-E', fig. 3), the Medicine Bow surface slopes west, in contrast with the general southeast slope of the valley beneath the White River sediments. Although the actual difference in levels between the two surfaces is slight in this vicinity, the conformation of the Medicine Bow surface is clearly related to a more recent and markedly different drainage system and thus is classified as younger. Elsewhere in the Northgate district, the higher parts of the hilly surface below the White River formation have been truncated by subsequent periods of erosion, and the Medicine Bow surface bears little resemblance to the surface of early Tertiary age (secs. A-A', B-B', and C-C', fig. 3).

Most of the Medicine Bow surface in the northwest part of the Northgate district appears graded to the course postulated for the tributary of late Miocene (?) age that joined the main drainage near

Quaintance Ranch. The present course of lower Camp Creek cuts across the flank of the valley that contained this stream (sec. D-D', fig. 3), and undoubtedly was superimposed through the North Park formation onto the underlying Precambrian rocks. The restored portions of the Medicine Bow surface along the trend of lower Camp Creek reflect this superimposition (fig. 2), but the adjacent parts of the surface are clearly older than the present course of Camp Creek, and they probably are exhumed remnants of the pre-North Park surface that were integrated with the younger Medicine Bow surface.

Parts of the Medicine Bow surface adjacent to the remnant of North Park formation near the northeast corner of the Northgate district also may conform closely to the pre-North Park erosion surface. It was extremely difficult to determine the limits of relatively unmodified remnants of the Medicine Bow surface in this vicinity when aerial photographs were studied under a stereoscope; the present land surface appeared to be a composite of several different surfaces that merged imperceptibly. The surface on the Precambrian rocks adjacent to the remnant of North Park formation, although more or less dissected, is clearly an exhumed surface that passes beneath the gravels of the North Park formation and obviously was not integrated with the Medicine Bow surface. The limits of these exhumed and relatively unmodified parts of the pre-North Park surface could not be determined with any accuracy as they merged laterally with adjacent parts of the Medicine Bow surface that show no evidence of the deformation that followed deposition of the North Park formation and thus must be distinctly younger.

### SURFACE SEGMENTS OF LATE TERTIARY AND EARLY QUATERNARY AGE

Most of the higher parts of the Medicine Bow surface appear to have attained their present form in late Tertiary or early Quaternary time, subsequent to the period of deformation that followed deposition of the North Park formation in late Miocene (?) or early Pliocene (?) time. Relations are clearest on the summit of Pinkham Mountain, where the surface bevels a fault of post-Oligocene—probably Pliocene—age (secs. A-A' and B-B', fig. 3). The maximum displacement on this fault is about 150 feet, and at present levels Precambrian rocks comprise both walls of the fault for most of its length. In spite of the relative hardness of the rocks now exposed, this fault has no surface expression, and for considerable distances the hanging-wall block actually is slightly higher topographically than the footwall block. This part of the Medicine Bow surface, therefore, was cut subsequent to the period of faulting, and must be late Pliocene or younger in age.

The higher parts of the Medicine Bow surface along the eastern

and north-central margins of the Northgate district also appear to have been cut in late Cenozoic time. Although the surface in these areas has moderate local relief, it apparently is undeformed, and the general altitude of the surface decreases rather regularly from about 10,200 feet near the southeast corner of the district to about 8,900 feet along the northern margin of the district. Cross sections extending east-northeast from the summit of Pinkham Mountain to the crest of the mountains along the eastern margin of the district (secs. A-A′ and B-B′, fig. 3) also show no topographic evidence of deformation. Thus the higher parts of the Medicine Bow surface appear to have formed subsequent to the warping following deposition of the North Park formation. Love (1939, p. 114) postulates a similar late Cenozoic age for the high-level erosion surfaces on the Medicine Bow and other mountain ranges in Wyoming.

The higher and apparently younger segments of the Medicine Bow surface merge with the lower lying segments that were exhumed remnants of earlier surfaces integrated with the Medicine Bow surface along slopes that are relatively steep compared to the general slopes on the Medicine Bow surface. The summit of Pinkham Mountain, where a late Cenozoic (late Pliocene or early Pleistocene) age for the Medicine Bow surface can be demonstrated, is quite flat, in contrast with the rolling topography on the northwest slope of the mountain, where the Medicine Bow surface is graded to the exhumed and slightly modified valley in the northwest part of the district (sec. D-D′, fig. 3). Similar steeper slopes separate the higher and lower segments of the Medicine Bow surface in the northeast part of the district, adjacent to the area underlain by North Park formation, and in the north-central part of the district, adjacent to the isolated remnant of White River formation.

This two-level aspect of the Medicine Bow surface in the Northgate district suggests that the North Park formation was stripped from the area in several stages. The higher parts of the buried late Miocene (?) (pre-North Park) surface, which would have been exposed first, appear to have been truncated following deformation after deposition of the North Park formation and before the lower parts of the surface were exposed. This implies that a temporary base level was established to which these higher levels were graded, and that erosion to this base level took place over a long enough period to remove all topographic evidence for the preceding period of deformation.

Minor rejuvenation resulted in stripping of the soft North Park formation remaining in the buried valleys of late Miocene(?) age, and in superimposing the courses of lower Camp Creek and North

Platte River across this earlier topography. This stripping and superimposition could have resulted from a minor uplift at any time during late Pliocene or early Pleistocene, or it may have been the initial effect of the regional rejuvenation of the Rocky Mountain region in late Cenozoic time, which culminated in the cutting of the present canyons in middle Pleistocene time (see following sections). In either case, intermittent uplift, with erosion taking place with relation to a series of temporary base levels, seems more probable than a general uplift accompanied by concurrent stripping and downcutting to present levels. This is indicated in the northwest part of the Northgate district, where the Medicine Bow surface cuts across hard Precambrian rocks and soft White River sediments without noticeable topographic change (sec. E-E', fig. 3), suggesting that the stripping of older surfaces and integration of them with the Medicine Bow surface took place with respect to a relatively stable base level, marked locally by the restored contours on the Medicine Bow surface in the vicinity of the North Platte River (fig. 2). Were the surface stripped with relation to actively downcutting streams, the soft White River formation in this vicinity probably would have been removed along with the overlying North Park formation, leaving an exhumed and somewhat modified surface on the harder Precambrian rocks.

The temporary base level apparently was effective long enough for weathering and erosion to strip off most of the North Park formation east of the North Platte River and to integrate the various segments of the Medicine Bow surface into a relatively homogeneous landscape.

## PLEISTOCENE REJUVENATION

The present gorge of the North Platte River north of North Park and the incised lower courses of the adjacent tributaries resulted from accelerated erosion following rejuvenation, which probably began with the widespread uplift of the Rocky Mountain region between late Pliocene and middle Pleistocene time. The broad basin of North Park is graded to the threshold of the North Platte gorge between Watson Mountain and Independence Mountain, and it evidently resulted from relatively rapid erosion of the soft sedimentary rocks in North Park during the same geomorphic cycle.

The time of the rejuvenation cannot be dated closely in the Northgate district, but the canyon cutting in other parts of the Rocky Mountain region apparently took place largely in middle Pleistocene time. Atwood and Atwood (1938, p. 230-247) report many occurrences of early Pleistocene till at high levels in the mountains of Colorado and Wyoming, and in many places the till was clearly deposited before the cutting of the present canyons. The Atwoods refer these older glacial

deposits to the Cerro stage, named from the deposits at Cerro Summit in southwest Colorado, and correlate them with the Buffalo drift in the Teton Mountains of Wyoming (Blackwelder, 1915, p. 328-329; Fryxell, 1930, p. 26-31), which was deposited before the present canyons were cut. Recent work by Richmond in the La Sal Mountains of Utah [6], has demonstrated that pre-Wisconsin till of two ages was deposited before canyon cutting, that another pre-Wisconsin till was deposited during canyon cutting, and that Wisconsin till was deposited at present canyon levels.

Eschman (1955, p. 197-213) has differentiated seven terrace levels, ranging from 18 to 350 feet above the present streams, along the Michigan River drainage in southern and central North Park. These terraces mark stages in the excavation of the North Park basin, and longitudinal profiles of the terraces are essentially parallel to one another, indicating that the excavation of the basin must have been concurrent with downcutting in the gorge of the North Platte River to the north. Eschman related the oldest glacial stage that he recognized in the headwater areas, which he called the Owl Mountain stage, with a terrace (the Western Divide surface) that ranges from 75 to 95 feet above present stream levels. He tentatively correlated his Owl Mountain glacial stage with the Cerro stage of Atwood, and if this correlation is proper, considerable excavation of the North Park basin would have taken place before middle Pleistocene time. The last major glacial advance recognized by Eschman was correlated with a terrace that ranges from only 20 to 30 feet above present stream levels, indicating that most of the excavation of North Park had been accomplished by late Pleistocene time.

## MINOR TOPOGRAPHIC READJUSTMENTS

Minor readjustments in drainage incidental to the cutting of the canyons and excavation of North Park have produced some anomalous topographic features in the Northgate district. The most prominent of these readjustments took place near the northeast corner of North Park, where Pinkham Creek worked its way headward through the broken rocks of Precambrian age along the Independence Mountain fault zone, cutting the youthful gorge of Kings Canyon and pirating the headwaters of a stream that formerly flowed south along the eastern flank of Sentinal Mountain. The beheaded stream is now markedly underfit, having only a minor, intermittent flow that begins in a broad wind gap about half a mile south of Camp Nelson and trends southwest and south through a mature valley to join Government Creek near the southern

[6] Richmond, G. M., Quaternary geology of the La Sal Mountains, Utah: U. S. Geol. Survey Prof. Paper, in preparation.

margin of the Northgate district. Pinkham Creek, on the other hand, has a strong permanent flow that emerges from youthful canyons in the mountains to a relatively broad valley cut in the softer sedimentary rocks of North Park.

The stream piracy by Pinkham Creek caused local rejuvenation in the headwater areas of the pirated stream. The effects are well shown within the area underlain by soft White River sediments, where lower Lawrence Creek and its tributaries are cutting sharp gullies in an irregular but rolling topography.

The irregular topography and relatively steep gradient of the valley along Lawrence Creek stands in sharp contrast with the nearly flat valley along upper Camp Creek. Headward erosion along the favored Lawrence Creek and its tributaries has reversed the direction of drainage of the headwater areas of several of the minor tributaries of Camp Creek, and it seems inevitable that Lawrence Creek will eventually capture all of the upper Camp Creek drainage.

Stream terraces flank the major streams in North Park. The most prominent of these in the Northgate district is on the eastern margin of the floodplain along the North Platte and Canadian Rivers: it is capped in most places by a thin layer of gravel. A veneer of stabilized dune sand covers almost all of the interfluve areas along the southern margin of the Northgate district between the Canadian River and the base of the Medicine Bow Mountains. Active sand dunes comprise the North Sand Hills near the southeast corner of the Northgate district, and represent an unstabilized local concentration of the same windblown sand that veneers the surface of North Park to the west. Little or no sand is being added to this active dune area at the present time, and the movement involves a general eastward shift of the sand that has not yet been fixed by plant growth.

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