GEOLOGY OF THE MONTANE ZONE OF CENTRAL COLORADO — With Emphasis on Manitou Park

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By
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Rocky Mountain Forest and
Range Experiment Station

Forest Service
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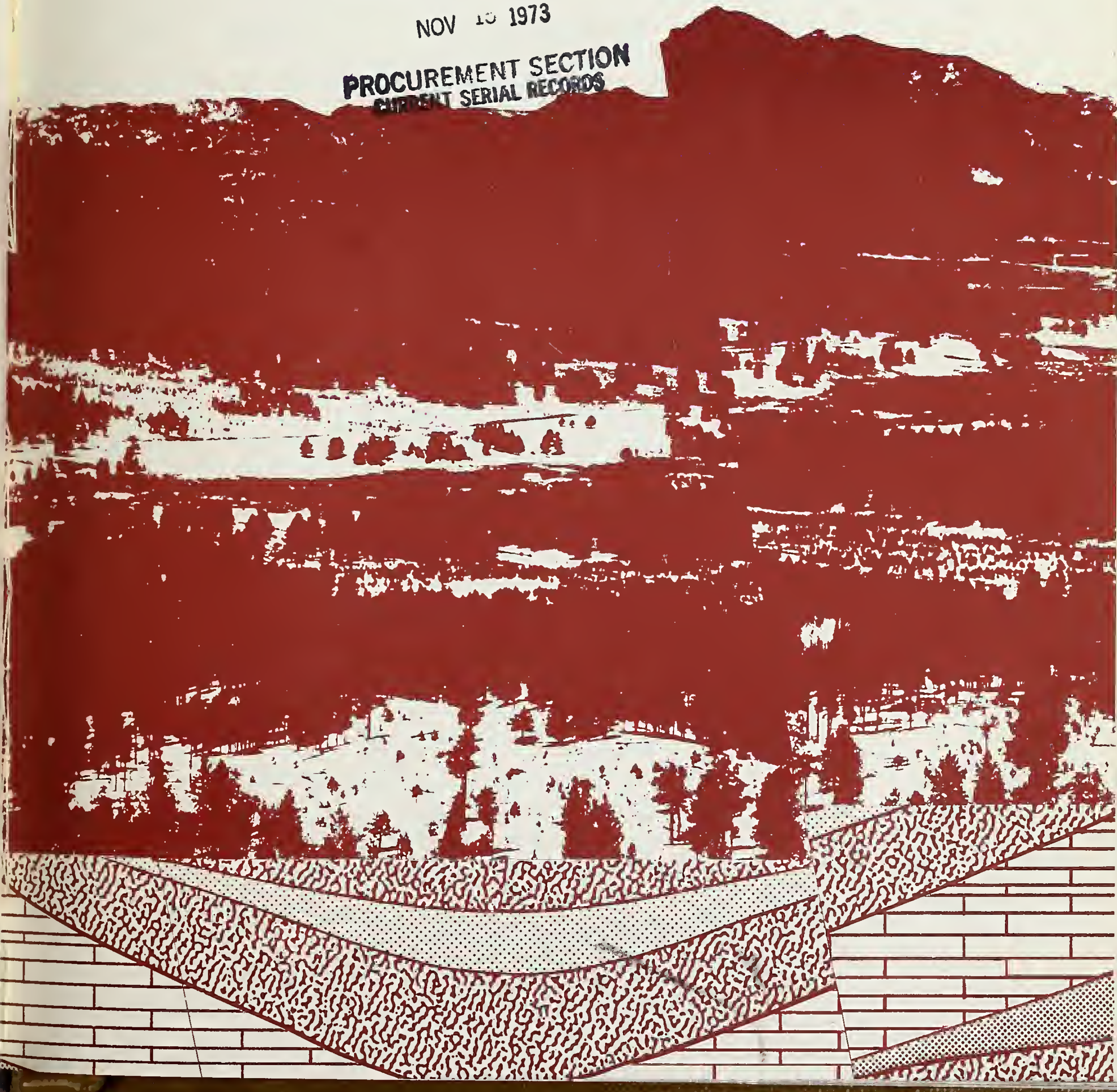

Abstract

Geologic features of four parts of the Montane Zone of central Colorado are described: (1) the Front Range, (2) the Sangre de Cristo Mountains, (3) the Spanish Peaks, and (4) the Wet Mountains. Detailed description and geologic map of the Manitou Experimental Forest are included, which provide some of the information useful in determining applicability of study results to other parts of the Zone.

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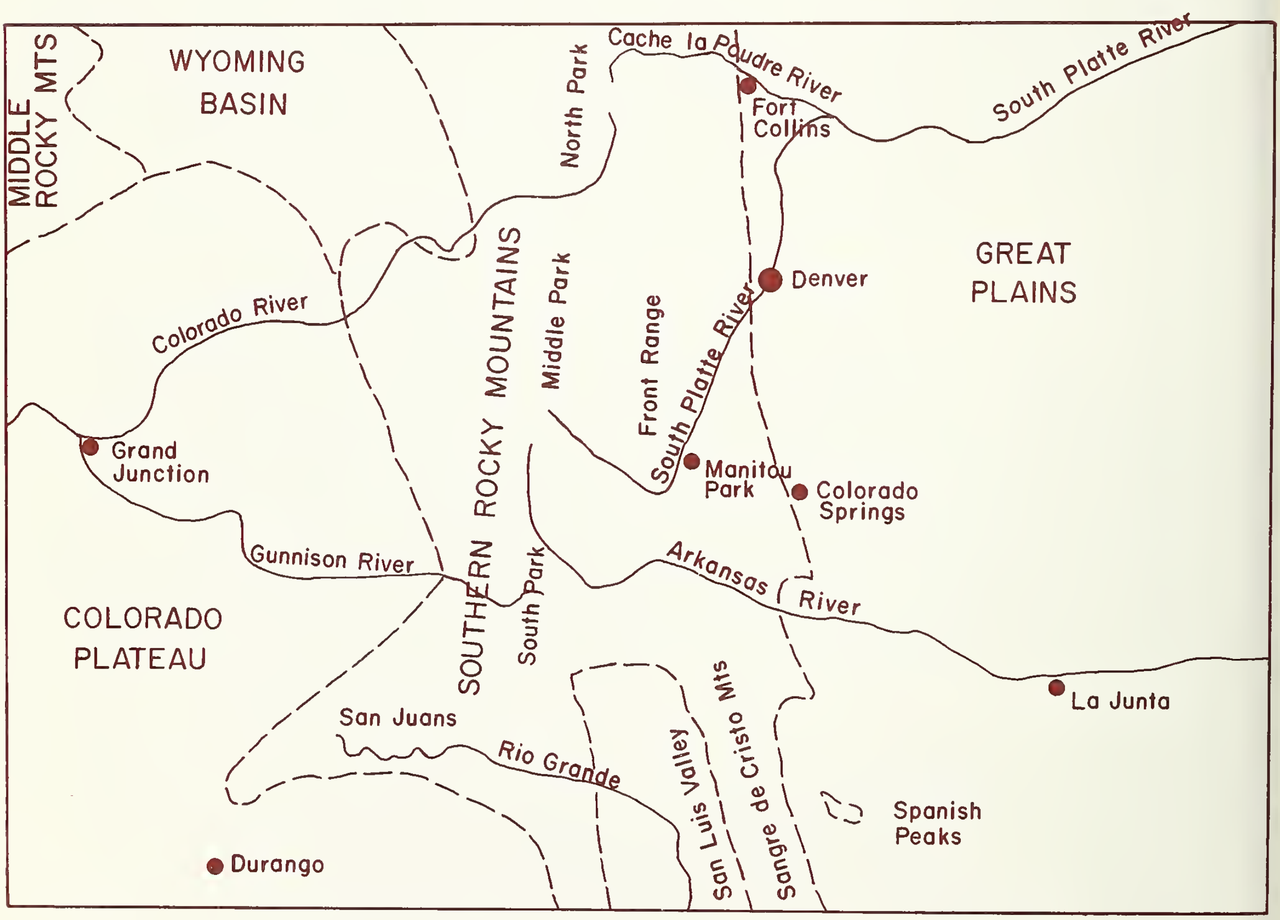

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Steven R. Marcus, Associate Geologist

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GEOLOGY OF THE MONTANE ZONE OF CENTRAL COLORADO-
With Emphasis on Manitou Park

Steven R. Marcus

Use of the Montane Zone of central Colorado for residential development and recreation is increasing rapidly. These activities, plus the need for a high level of management of all natural resources, place great demands on land managers and other decisionmakers. Complex decisions that involve people and their use of the resources must be made with knowledge of the effect of one activity on many others. A series of studies is underway to provide decision-makers with facts and tools that will help them do a better job. This publication provides a summary of some of the information that is basic to these studies.

Most of the Montane Zone of central Colorado occurs on four geologic units: (1) the Front Range, (2) the Sangre de Cristo Mountains, (3) the Spanish Peaks, and (4) the Wet Mountains. Each is described in this Paper. Detailed studies of Montane Zone resources are being conducted at the Manitou Experimental Forest, west of Colorado Springs. Geologic features on and near the Experimental Forest, the Manitou Park area, are described in detail. Decisionmakers throughout the Montane Zone of Colorado can compare conditions at Manitou Park with those of their area of interest. This provides one means of determining how well results of studies may be extrapolated to their area.

Front Range

Igneous and Metamorphic Petrology

The Front Range extends from the Wyoming border to just south of Denver on the eastern slope of the Colorado Rockies, and trends from directly north-south to N. 20° W. It consists of a wide variety of metamorphic and granitic rocks. Since the granitic rocks intrude the metamorphic layers, the metamorphics are therefore older.

There are three major granitic plutons in the Front Range: Pikes Peak Granite in the south, and Boulder Creek and Silver Plume Granites in the northern two-thirds (fig. 1). According to radiometric data cited by Hedge et al. (1967), the Boulder Creek Granite is the oldest, Silver Plume Granite intermediate, and Pikes Peak Granite is the youngest. There are only minor differences in composition between the different granitic types (Lovering and Goddard 1950); one difference is that Pikes Peak Granite is slightly richer in silica than the others (table 1).

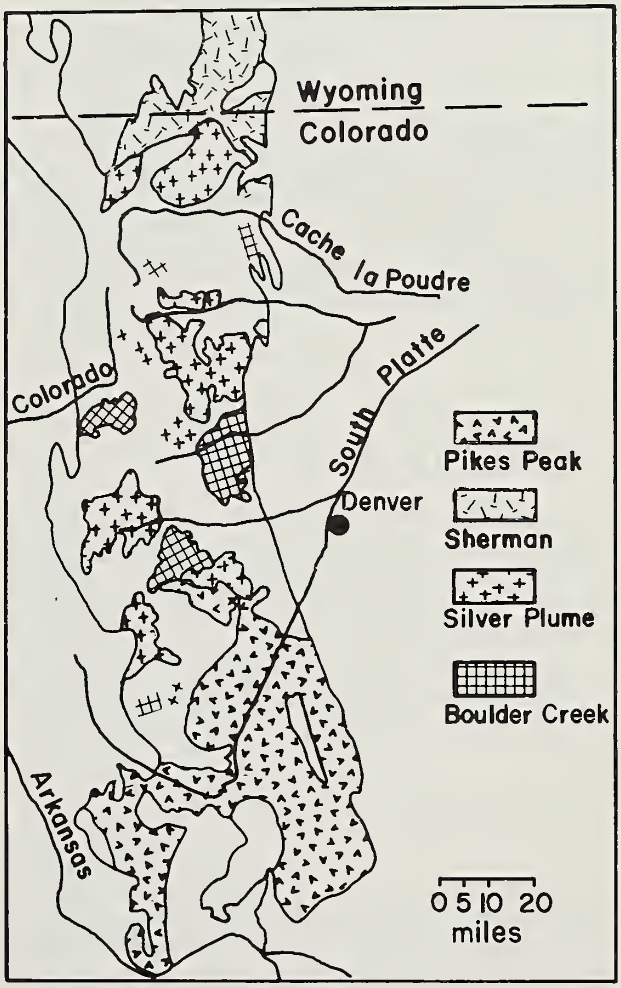


Figure 1.—Granites of the Front Range.

Table 1.--Chemical composition of the granites of the Front Range (after Lovering and Goddard 1950)

Specimen	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O-	H_2O	TiO_2	CO_2
1. Boulder Creek granite from the fifth level of the Cold Spring mine close to the new shaft, about 3 miles northeast of Nederland	68.71	14.93	1.02	2.07	1.50	2.01	2.85	5.14	0.14	0.56	0.62	0.4[illegible]
2. Local syenitic facies of the Pikes Peak granite, Ajax mine, level 6. Believed to be related to gneissic aplite.[1]	66.20	14.33	2.09	1.93	.89	1.39	2.58	7.31	.48	.83	.65	.3[illegible]
3. Gneissic aplite near the breast of the Lilly tunnel, Clyde mine, about 2 miles north-northeast of Nederland	66.31	15.07	1.35	2.71	1.03	2.06	2.48	5.96	0.06	0.90	0.66	0.9[illegible]
4. Pikes Peak granite from Sentinel Point, Pikes Peak, Colo.[2]	77.03	12.00	.76	.86	.04	.80	3.21	4.92	.14	.30	.13	--
5. Pikes Peak granite from Platte Canyon, Jefferson County, Colo.[2]	77.02	11.63	.32	1.09	.14	1.24	2.85	5.21	--	.35	--	--
6. Silver Plume granite, Silver Plume, Colo.[3]	67.38	15.22	1.49	2.58	1.12	2.12	2.73	5.41	.01	.39	.70	.18
7. Fresh pre-Cambrian Silver Plume granite from the Climax district, Colo.[4]	70.83	14.41	.35	2.94	.56	.64	2.44	6.21	.04	1.34	.24	--
8. Longs Peak granite, Longs Peak, Colorado.[3]	71.14	16.00	.00	.80	.13	.94	5.13	3.74	.09	.50	.17	.03
9. Longs peak granite from Sta. 191 South St. Vrain Highway [3]	70.85	15.14	.65	1.57	.64	.71	2.44	6.09	.06	.77	.31	.21
10. Mount Olympus granite, Glen Comfort [3]	71.40	16.34	.15	1.71	.31	1.40	4.59	3.24	.11	.22	.36	.09
Average of 4 and 5	77.02	11.81	.54	.97	.09	1.02	3.03	5.06	.07	.32	.06	--
Average of 6, 7, 8, 9, and 10	70.32	17.42	.53	1.92	.55	1.16	3.47	4.49	.06	.64	.36	.1[illegible]

Specimen	P_2O_5	SO_3	S (total)	ZrO_2	Cl	F	FeS_2	MnO	BaO	SrO	Li O	
1. Boulder Creek granite from the fifth level of the Cold Spring mine close to the new shaft, about 3 miles northeast of Nederland	0.16	--	Tr?	--	--	--	--	--	--	--	--	100.17
2. Local syenitic facies of the Pikes Peak granite, Ajax mine, level 6. Believed to be related to gneissic aplite.[1]	.25	0	--	0.02	Tr.	(?)	0.12	0.13	0.18	Tr.	Tr.	99.74
3. Gneissic aplite near the breast of the Lilly tunnel, Clyde mine, about 2 miles north-northeast of Nederland	0.32	--	0.04	--	--	--	--	--	--	--	--	99.93
4. Pikes Peak granite from Sentinel Point, Pikes Peak, Colo.[2]	Tr.	--	--	--	--	0.36	--	Tr.	Tr.	--	Tr.	100.55
5. Pikes Peak granite from Platte Canyou, Jefferson County, Colo.[2]	--	--	--	--	--	--	--	--	--	--	--	99.85
6. Silver Plume granite, Silver Plume, Colo.[3]	.32	--	.06	--	--	--	--	.04	.14	--	--	99.82
7. Fresh pre-Cambrian Silver Plume granite from the Climax district, Colo.[4]	.15	--	.01	--	0.04	--	--		.02	--	--	100.22
8. Longs Peak granite, Longs Peak, Colorado [3]	.19	--	--	--	--	--	--	.01	--	--	--	98.90
9. Longs peak granite from Sta. 191 South St. Vrain Highway [3]	.30	--	--	--	--	--	--	.02	.06	--	--	99.98
10. Mount Olympus granite, Glen Comfort [3]	.36	--	--	--	--	--	--	.02	--	--	--	100.30
Average of 4 and 5	Tr.	--	--	--	--	.25	--	Tr.	Tr.	--	Tr.	--
Average of 6, 7, 8, 9, and 10	.26	--	.03	--	.01	--	--	.02	.04	--	--	--

[1] Geology and gold deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, p. 45, 1906.
[2] U. S. Geol. Survey, Geol. Atlas, Castle Rock folio (No. 198), p. 3, 1915.
[3] Geol. Soc. America Bull., vol. 45, p. 320, 1934.
[4] U. S. Geol. Survey Bull. 846-C, p. 225, 1933.

NOTE.—Analyses 1, 3, and 7, by J. G. Fairchild; 2 and 4, by W. F. Hillebrand; 5, by H. N. Stokes; 6, by R. B. Ellestad; 8 and 10, by D. F. Higgins; 9, by T. Kameda.

Boulder Creek Granite

This granite is consistently light gray to dark gray, faintly banded to gneissic, and biotite rich. Strung-out aggregates of black biotite and embayed grains of K-feldspar distinguish the outcrops. The fresh rock is medium to coarse grained, massive, and tough. It disintegrates to gray or rusty gravel of biotite-flected quartz and feldspar crystals. Pegmatites of Boulder Creek genesis contain books of biotite.

Silver Plume Granite

This granite occurs in five small batholiths, numerous plutons, and many dikes and sills in the eastern flank of the Front Range. The granites that compose the Log Cabin, Longs Peak-St. Vrain, Kenosha, and Cripple Creek batholiths and Indian Creek plutons are variants of the typical granite of the Silver Plume batholith and have a common magmatic source. Typical, fresh Silver Plume-type granite is massive, hard, and tough. It is flesh colored to tan, fine to medium grained, and produces little gravel. Pegmatites genetically related to Silver Plume-type granites are fresh, flesh colored to gray, and consist mostly of abundant smoky quartz, flesh-colored potash feldspar, and silver-colored muscovite.

Pikes Peak Granite

The Pikes Peak batholith crops out over 80 percent, or about 1,250 square miles, of the southern third of the Front Range, while the Sherman batholith covers less than 150 square miles of the north end. These two granites are nearly identical in mineral content, texture, color, and response to weathering.

Metamorphic Rocks

The unit of biotite gneiss along the southeastern margin of the central Front Range is considered the lowest unit in the area. The Idaho Springs layer, a lenticular layer of microcline-quartz-plagioclase-biotite gneiss, overlies the biotite gneiss. This unit pinches out in depth and to the south, but appears to thicken toward the east. Another layer that differs from the lowest exposed biotite gneiss, mainly in containing less granite gneiss and pegmatite, overlies the Idaho Springs layer. Above this unit is the Central City layer of microcline-quartz-plagioclase-biotite gneiss, a unit that appears to be uniformly thick throughout the northeastern part of the central Front Range but pinches out southwest of Idaho Springs. Above the Central City layer is a thick succession of biotite gneiss, the most widespread unit at the surface in the area. It includes a lenticular layer of quartz diorite gneiss. The uppermost unit in the region is a thick body of microcline-plagioclase-biotite gneiss called the Lawson layer. All told, about 13,500 feet of metamorphic strata are exposed in the central Front Range area (Moench et al. 1962).

Structure

The Front Range is a complexly faulted, anticlinal, partly fault-bounded arch. The main body of the Range is composed of Precambrian crystalline rocks consisting of highly metamorphosed metasedimentary rocks that have been intruded by granitic masses of at least three generations. This Precambrian belt is 30 to 40 miles wide throughout the length of the Range. The uplift is bounded by several gently deformed structural basins containing sedimentary rocks ranging in age from Cambrian to Tertiary. The east flank is clearly marked by the Denver Basin, an asymmetric downwarp with the axis close to the Front Range. On the south the Range ends at the Canon City embayment, with the Wet Mountains considered as a separate unit. The west flank is less clearly defined by two elongated basins, South Park and North Park, and by a more complex intermediate basin, Middle Park. At the Wyoming border, the Front Range merges into the Laramie and Medicine Bow Ranges (Harms 1965).

Elevations of the Precambrian surface within the surrounding basins and on the prominent peaks of the Range indicate a maximum relief of about 21,000 feet. This maximum occurs near Denver where, in the Denver Basin, the crystalline basement lies at about 7,000 feet below sea level in contrast to the 14,260-foot summit of Mount Evans. Although the elevation contrasts are less along other segments of the margin, relief on the Precambrian surface of 10,000 feet or more is common (Harms 1965).

The margins of the Front Range are typically marked by major faults and/or steep monoclines. Most of these faults are reverse and dip toward the center of the Range. In areas where no major faults are known, monoclines with dips commonly more than 30° form the margin of the Range. Prominent hogbacks of resistant Paleozoic and Mesozoic strata form a narrow foothills belt in the zone of steep dips near the mountains, but dips decrease basinward to a few degrees within a few miles. This means that a large part of the structural relief between basins and peaks is concentrated within narrow belts by large reverse faults and steep monoclines (Harms 1964).

Geologic History and Development of the Area

Following complex deformation and intrusion during the Precambrian, erosion reduced the Front Range area to low relief. As noted by Crosby (1895) the Precambrian surface is very smooth.

In the early Paleozoic, the Front Range area was stable. Earliest Paleozoic deposition in Colorado was in Late Cambrian time when the Sawatch sandstone was deposited. Other marine sandstones and carbonates followed deposition of the Sawatch. They extend over broad areas and represent a period of stability. No lower Paleozoic sediments are present in the central and northern Front Range, and Pennsylvanian sediments rest directly on the Precambrian basement rocks. The southern Front Range area, with preserved lower Paleozoic sediments, has been called the Colorado Sag. It behaved differently than adjacent areas which are referred to as the Transcontinental Arch. Lower Paleozoic beds are exposed in a broken linear belt extending from Parry Park to Canon City, with a second belt extending along the east side of Manitou Park. No basins of deposition developed at this time, and the marine carbonates and sandstone show little facies change.

In Pennsylvanian time there was a pronounced uplift in the area that was called the Ancestral Rockies. This exposed the Precambrian core, and rapid stream erosion and subsequent deposition produced the arkosic and conglomeratic Fountain Formation. Widespread overlap unconformities were produced along the Front Range margins. The area of greatest uplift was slightly more northwest trending than the present Front Range, though occupying much the same position. To the north and south, Fountain sediments rest on successively older beds until the Fountain is in contact with the Precambrian at Parry Park and south of Canon City.

There is a general absence of major deformation in areas adjacent to the uplift. This indicates positive movements without broad lateral belts of deformation. In this respect, the Pennsylvanian uplift resembles the Laramide uplift, although igneous activity is absent. The coarse clastic wedges of the Pennsylvanian and Lower Permian require an uplift of only about 2,000 to 3,000 feet, and based upon this, the late Paleozoic uplift can be considered a tectonically mild feature bordered by narrow fault zones or monoclines. Tectonic stability returned to the area at the end of the Paleozoic when burial of the uplift began.

A mild epeirogenic uplift occurred in Mid-Triassic time, indicated by the truncation of Lower Triassic and Permian beds. Also, Mid- and Upper-Triassic beds are absent in an area centering upon the Wet Mountains. During the Late Cretaceous, this area became part of a major marine basin and approximately 10,000 feet of shale and siltstone, with some sandstone and limestone, was deposited. Structurally, the Front Range lost its identity at this time, and deposition was more or less continuous. The most significant orogenic movement in the post-Cambrian history of the Front Range, the Laramide orogeny, began at the end of the Cretaceous. Marine inundation ended with a regressive sequence of sandstones and coals called the Laramie Formation. Structural movement began at this time, and arkosic and tuffaceous sands and conglomerates flooded outward from the Front Range into the Denver Basin and South Park. Angular unconformities locally record the severity of the orogeny. An example of this severity is the fact that the Upper Cretaceous Laramie sandstone is overlain by Upper Cretaceous and Paleocene Dawson arkose with an angular discordance of 40° a few miles north of Colorado Springs. The nature of the Late Cretaceous and Eocene sediments also attest to the significance of the Laramide orogeny. These sediments are coarse, conglomeratic, contain volcanic fragments and tuffs, and are coarsest at the edges of the Front Range, becoming finer grained farther away. Post-Miocene deformation appears limited to regional warping, so it is apparent that major orogenic movement ended in Miocene time. The present day Front Range owes its height to orogenic uplift, but it was shaped by the erosional agents of wind, water, and ice.

The various sedimentary beds in the foothills and plains are not described here since they are not part of the Front Range proper.

The tectonic origin of the Front Range and its structural implications are a subject of debate. There are two major theories, one based on lateral compression, the other on vertical uplift. Harms (1964) supports the vertical uplift theory. Some reasons he gives are the mild deformation of adjacent basins, the fact that uplift is concentrated in relatively narrow belts along the margins of the Range, the high relief between mountains and basins of the Precambrian surface, the symmetry of the Range, and the large reverse faults and narrow monoclines along its margins.

The Laramide and late Paleozoic uplifts are of similar origin though not corresponding in outline. The zones of weakness that define Laramide structure rarely occupy positions that mark Paleozoic or Precambrian deformation. There is little evidence that early structures controlled later movements.

The Cenozoic geomorphic history of the Front Range, from Thornbury (1965), is as follows:

1. Development of the Front Range during the Laramide Revolution began with the formation of a broad anticlinal arch contemporaneously with the downwarping of the Denver Basin. Dikes, sills, and extrusive sheets are evidence for local volcanic activity at this time.
2. Truncation of the Front Range anticline during Eocene, Oligocene, and Miocene time during a period of intermittent uplift was accompanied by deposition in the Denver Basin and Great Plains. During one of the periods of less rapid uplift, the Flattop peneplain was produced. This peneplain is represented by ridges extending 1,500 to 2,000 feet above the Rocky Mountain erosion surface. Rising above the Flattop remnants are numerous peaks rising above 12,000 feet and forming a distinct axis from northern Colorado to south of Denver.
3. During a period of relative quiescence in Pliocene time, the widespread Rocky Mountain peneplain formed. This peneplain rises gradually from an elevation of about 8,000 feet at the edge of the Front Range to around 10,000 feet at the crest of the range. The sediments removed from the mountains to produce this erosion surface were deposited to the east and

may have overlapped onto the eastern edge of the Precambrian core.

4. Widespread regional uplift initiated erosion which removed most of the Tertiary sediments from the Colorado Piedmont area east of the Front Range and some of the Mesozoic sediments. This uplift also caused canyon cutting in the crystalline rock belt.

5. Alternating periods of valley cutting and pedimentation in the foothills during Pleistocene time formed a number of gravel-capped pediments and terraces. These erosional surfaces can be traced a short distance back into the mountains.

6. Periods of glaciation occurred in the high mountains, modifying valley profiles and producing glacial outwash that was carried down into the foothills and deposited as gravel caps on the Pleistocene terraces. Alternation of cutting and deposition in the foothills and on the plains was in response to the periods of glaciation in the mountains.

7. Recent erosion began at the end of the Pleistocene.

Physiography

Eleven different erosion cycles have been postulated in the Cenozoic development of the Front Range (Van Tuyl and Lovering 1934). The early cycles were terminated mainly by orogenic uplift, the intermediate cycles by combined local and regional uplift, and the later cycles by epeirogenic uplift, glacially caused climatic changes, or both. Evidence for these cycles includes the presence of benches or straths along streams, accordant summits, and imperfect peneplain surfaces.

In the eastern portion of the Range many broad "parks" of comparatively gentle relief, partly or entirely surrounded by more rugged areas, occur in that portion of the mountains varying in elevation from about 6,500 to 10,000 feet. In the case of Manitou Park, the less resistant areas represent outliers of sedimentary rocks which were either folded or faulted down into the crystalline rocks. The other parks, however, such as Estes Park, appear to have formed upon crystalline rocks. They might represent the western limits of broad valleys formed during earlier erosion cycles. Modification by rock decay, stream erosion, sheet erosion, and pedimentation also may have had some effect in the formation of these parks. There seems to be little relationship between the character of the underlying bedrock and the development and preservation of erosion surfaces in the area.

Sangre de Cristo Mountains

The Sangre de Cristo Range extends from north-central New Mexico to south-central Colorado as a long, narrow, rugged range; in Colorado it is bounded on the east by the Arkansas River Valley, Wet Mountain Valley, and Huerfano Park, while on the west it is bounded by the broad, flat San Luis Valley. To the north, the Range terminates at the Arkansas River near Salida.

Although the Sangre de Cristo Mountains are the frontal range at the southern end of the Rocky Mountains, they are classified with the western granite belt rather than the Front Range.

Geologically, the Sangre de Cristos consist of a core of Precambrian schists, gneisses, pegmatites, granites, and diorite, along with what is one of the most complexly folded belts of sedimentary rocks in the southern Rockies on its eastern side. The sedimentary rocks range from Ordovician to Cretaceous (Thornbury 1965). The belt of deformed sediments comprises most of the Range in the north, but in the south the sediments are confined mainly to the foothills belt. The Precambrian rocks, which make up the western part of the Range south of Blanca Peak, are partially covered with Tertiary lavas.

Structurally, the northern Sangre de Cristo Range is a fault block uplifted along a concealed, high-angle fault that separates the Range from the San Luis Valley to the west. The sedimentary layers strike north-northwest, nearly parallel to the trend of the Range, and dip east 30° or more, forming the east flank of the Laramide Sawatch arch. Numerous high-angle strike faults are present. Faulting is more prominent than folding. Structures other than Precambrian are Laramide or younger in age. The west slope of the Range is much steeper than the east slope, and forms a linear eroded scarp throughout its length bounding the San Luis Valley.

Butler (1949) says that sediments in the northern Sangre de Cristos range from Cambrian to Permian at a section near Bushnell Ridge. In this area, he states that tightly compressed folds and faults characterize the highland structure, with Precambrian metamorphics and granites being exposed at the crest of the Range.

Litsey (1958) says that sediments in the northern Sangre de Cristos are Ordovician through Permian. The section he describes (fig. 2) is similar to that of Butler. The pre-Pennsylvanian units are thin and consist mainly

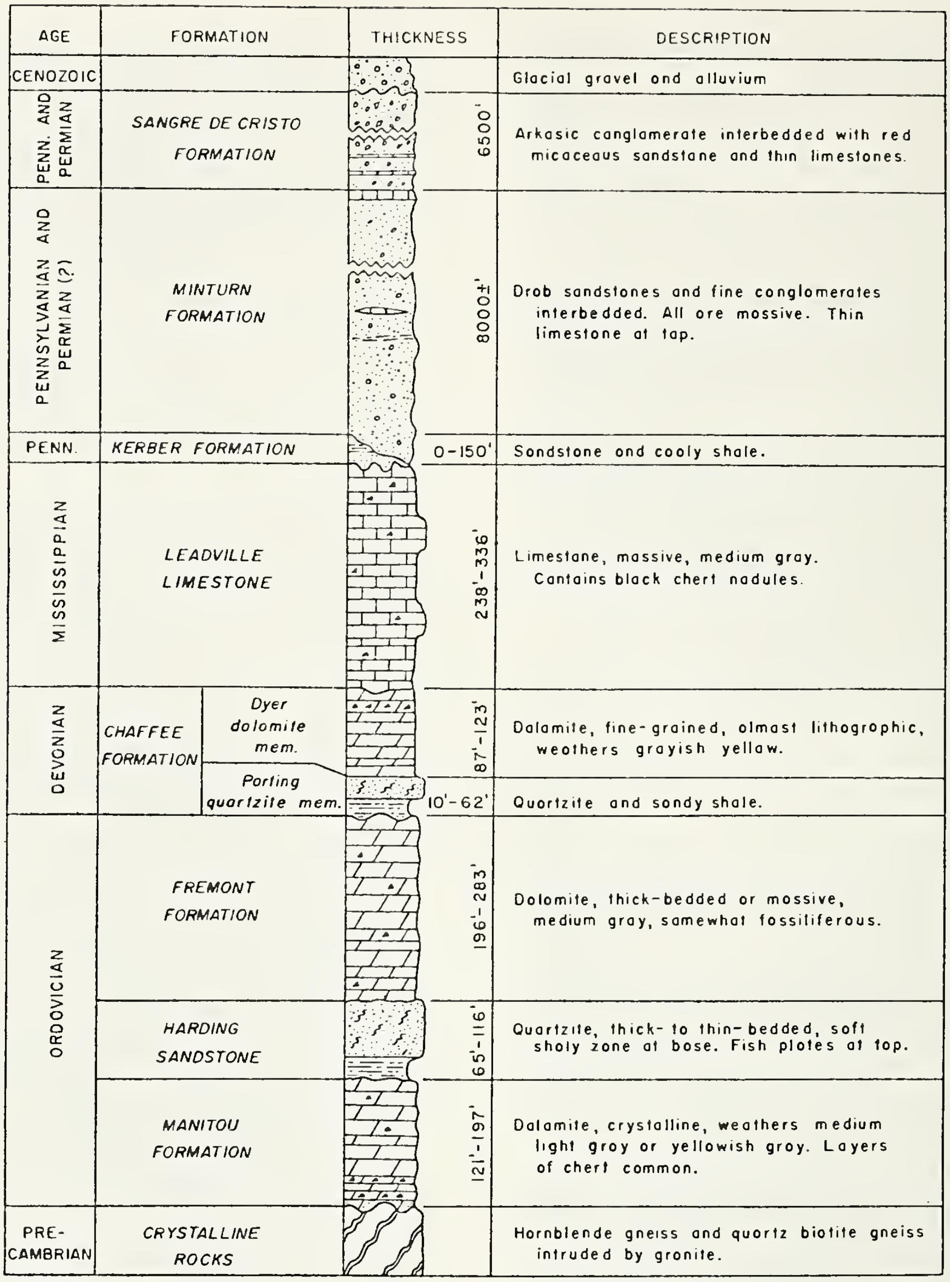


Figure 2.—Paleozoic section in northern Sangre de Cristo Mountains (after Litsey 1958).

of limestone and dolomite with some quartzite, sandstone, and shale. The lithology indicates stable shelf deposition. Pennsylvanian and Permian rocks were deposited as a thick series of clastic sediments in a geosyncline. The Ordovician Manitou Formation is found here. It is the only formation in the area that is distinctly correlated with one of the formations at Manitou Park. Here it rests on crystalline Precambrian rocks consisting of hornblende gneiss and quartz biotite gneiss intruded by granite, whereas at Manitou Park it rests on Sawatch quartzite. The Manitou Formation here is 121 to 197 feet thick, and consists of thin-bedded, siliceous dolomite. In some places the Formation is predominantly limestone or dolomitic limestone. Locally, there are sands or shales at the base. It is mostly fine to medium grained and generally medium bedded (2 inches to 2 feet). Fresh surfaces are medium gray;

weathered surfaces light to yellowish gray. The Pennsylvanian-Permian Sangre de Cristo Formation is basically an arkosic conglomerate and might be partially equivalent to the Fountain Formation.

The Precambrian crystalline rocks of the region represent an ancient complex of gneissic metasediments invaded by granite of at least two types and ages. West of the Pleasant Valley Fault the Precambrian rocks are metasedimentary, ranging from basic hornblende gneisses to acidic schists and quartzites. East of the Pleasant Valley Fault the Precambrian is composed almost entirely of Pikes Peak Granite with small inclusions of metasediments and Silver Plume Granite.

The Tertiary tectonic history of the northern Sangre de Cristo Range includes at least three distinct phases of deformation. The present range is the eastern flank of two earlier, larger uplifts.

The first phase of deformation began in Late Cretaceous as a broad domal uplift, which became elevated enough by Paleocene time to cause gravity sliding of Permian and Pennsylvanian sediments along bedding plant thrusts. Displacement is 10 to 15 miles on the northeastern and eastern flanks of the uplift. Block uplift of the San Luis Valley area caused a second stage of thrusting along boundary faults which extended eastward into the site of the present Range. This stage of thrusting folded the earlier thrusts and caused some deformation in the eastern foothills. A block which rose in the northeast interfered with thrusting and probably caused the high-angle faults found in the northern end of the Range. Collapse of the San Luis Valley uplift along steep portions of the second-stage thrusts began in Miocene and continues at present, as shown by Recent fault scarps in alluvium, along the western margin of the Range.

Spanish Peaks

The Spanish Peaks, located just east of the Sangre de Cristo Range, are famous for their unusual system of radial dikes. These dikes extend out from the peaks a distance of 25 miles or more (fig. 3). The peaks are bordered on the east by a sloping platform that extends up to an altitude of nearly 10,000 feet. Towering above this platform is the main bulk of the mountain. On the platform is a coarse, bouldery fanglomerate, consisting mainly of white porphyry. This platform has been dissected to a depth of 500 feet by valleys which extend to the foot of the mountain, but a short distance from the mountain they open out into broad, shallow, parklike valleys. Conclusive evidence of glaciation was found at only one locality on the Spanish Peaks, the north flank of West Peak. Sediments in the area range from Upper Cretaceous to Eocene.

The igneous geology of the Spanish Peaks consists of two stocks that cut through the Late Cretaceous and early Eocene strata, surrounded by an immense number of dikes and sills. The stocks have broken through an asymmetric syncline whose east limb is nearly horizontal and whose west limb is vertical or even has been overturned to the east so that locally it dips westward. Each stock is surrounded by a system of radial dikes.

The East Peak stock consists of: (1) white granite porphyry containing phenocrysts of quartz and feldspar, together with a little hornblende and biotite, in a phaneritic groundmass, and (2) granodiorite porphyry, containing accessory augite and biotite, which is intrusive into the granite porphyry and, therefore, younger. At the summit, the granodiorite is plutonic. Oligoclase is abundant, with lesser amounts of anorthoclase, augite, and biotite.

The West Peak stock, although much smaller than that of East Peak, consists of plutonic rock of several facies of syenodiorite. The summit is a pyroxene syenodiorite. The rock, comprising the bulk of the West Peak stock, contains oligoclase, augite, hypersthene, red biotite, anorthoclase, and minor amounts of interstitial quartz.

Between the two peaks is a blackish cordieritic hornfels, formed by the metamorphism of an arenaceous shale. The igneous intrusions occurred during one of the later phases of the Laramide Revolution (early Tertiary).

The area is heavily timbered, mostly second growth. The lower slopes support a dense growth of pinyon and juniper, while the higher slopes support pine forests with spruce, fir, or aspen as the elevation rises.

Wet Mountains

The Wet Mountains, located just south of the Front Range and the Canon City embayment, extend northwest-southeast about 50 miles and are about 20 miles in width. They form the central unit of an en echelon pattern with the Sangre de Cristo Range to the west and the Front Range to the north. There is a close genetic relationship with the Front Range.

The core of the southern Wet Mountains consists partially of Precambrian metasedimentary gneiss and schist concordantly foliated with granite gneiss. These rocks developed by meta-

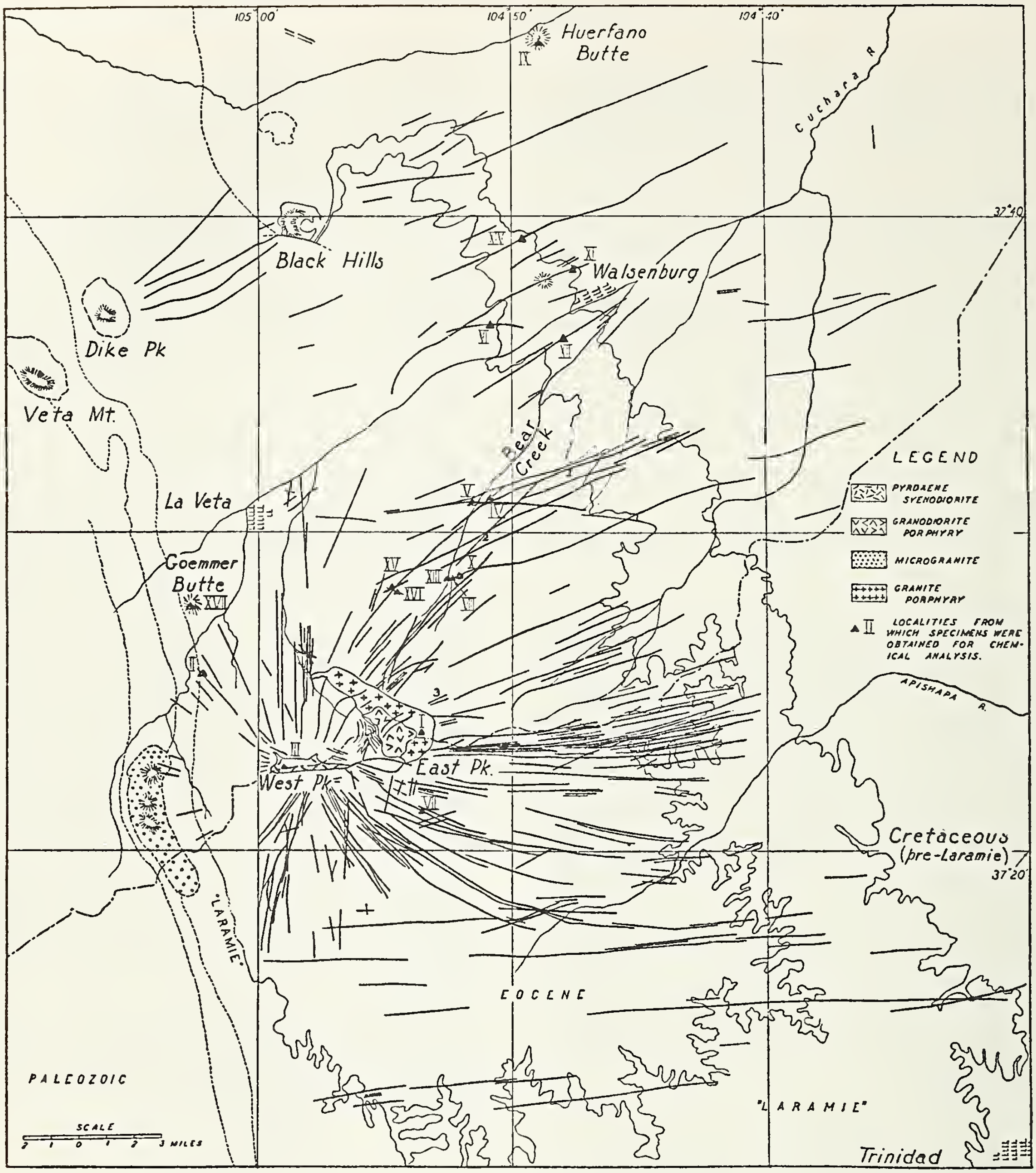


Figure 3.—Structural map of the Spanish Peaks area (after Knopf 1936).

morphic alternation during intrusion of the granitic San Isabel batholith and accessory smaller plutons. These plutons are probably offshoots of the San Isabel batholith, which is dated at about 1.5 billion years.

Structurally, the southern Wet Mountains form a southeast-plunging anticline. They were uplifted to their present elevation from middle Tertiary through Pleistocene. Uplift occurred in stages along major high-angle boundary faults and by slight displacement along the many joints in the area. The age of the sediments ranges from Permo-Pennsylvanian to Recent (fig. 4).

AGE		FORMATION		LITHOLOGY	THICKNESS IN FEET	DESCRIPTION
QUATERNARY		ALLUVIUM			Varies	Unconsolidated gravel, sand, silt and clay along streams
QUATERNARY		TERRACE GRAVEL			25 *	Poorly sorted gravel along foothills
	unconformity					
TERTIARY	PLIOCENE	CONGLOMERATE			25 *	Silica cemented conglomerate with Precambrian fragments
	unconformity					
TERTIARY	MIOCENE	VOLCANIC ROCKS			300 *	Porphyritic vesicular (in part) andesite lava underlain by lacustrine rhyolite tuff
	unconformity					
TERTIARY	EOCENE	FARIŠITA FORMATION			1 000 ?	Poorly consolidated heterogeneous yellow-brown conglomerate
TERTIARY	EOCENE	HUERFANO FORMATION			2.800	White to buff arkosic sandstone interbedded with reddish brown to green mudstone
TERTIARY	EOCENE	CUCHARA FORMATION			400	Conglomeratic arkose with partings of mudstone
TERTIARY	PALEOCENE	POISON CANYON FORMATION			1 300	Brown conglomeratic arkose and mudstone
	unconformity					
CRETACEOUS	UPPER	PIERRE SHALE			1.800	Calcareous concretionary gray shale
CRETACEOUS	UPPER	NIOBRARA	SMOKY HILL MARL		700	White to yellow calcareous foraminiferal shale
CRETACEOUS	UPPER	NIOBRARA	FORT HAYS LIMESTONE		50	White lithographic limestone with shale partings
CRETACEOUS	UPPER	BENTON SHALE	CARLILE SHALE		200	Dark calcareous shale and siltstone with arkosic sandstone at top (Codell member)
CRETACEOUS	UPPER	BENTON SHALE	GREENHORN LIMESTONE		50	Bluish-gray lithographic limestone and calcareous shale
CRETACEOUS	UPPER	BENTON SHALE	GRANEROS SHALE		225 *	Dark carbonaceous shale with bentonite partings
CRETACEOUS	UPPER	DAKOTA SANDSTONE			250	White-to-yellow quartz sandstone
CRETACEOUS	LOWER	PURGATOIRE FORMATION			50 *	Gray-white conglomeratic sandstone
JURASSIC	UPPER	MORRISON FORMATION			325 *	Mudstone with feldspathic lithic sandstone
JURASSIC	UPPER	ENTRADA SANDSTONE			35 *	Massive calcareous quartz sandstone
	unconformity					
PENNSYLVANIAN-PERMIAN		SANGRE DE CRISTO FORMATION			7 000+	Reddish-brown mudstone above gray and brown conglomeratic arkosic sandstone, siltstone, and shale.
	unconformity					
PRECAMBRIAN		CRYSTALLINE ROCK			Unknown	Gneisses and schists intruded by granites

Figure 4.—Section of the Wet Mountains area (after Boyer 1962).

The metamorphosed sediments represent a sedimentary sequence which is probably interlayered with volcanic rocks. They have undergone moderate to high-grade regional metamorphism that produced amphibolite, hornblende, biotite gneiss, schist, and granite gneiss. The gneisses and schists are the oldest and are possibly related to the Idaho Springs Formation.

Another major part of the Precambrian area consists of band, stringers, and lenses of metamorphic rocks which are closely layered with granitic material.

The youngest Precambrian rocks are igneous bodies, mostly granitic, which cover half of the area. The most extensive igneous outcrop is the San Isabel batholith.

The gneissic granite is medium grained with abundant quartz and microcline, each of these minerals accounting for more than 30 percent of the rock. Sodium-rich oligoclase constitutes 10 to 15 percent of the rock. Mafics contribute a low percentage. The rock weathers into sharp, angular-jointed blocks, rather than into rounded or smooth-faced boulders as do the other granites found in the area. The gneissic granite is found in the southern end of the Range.

The San Isabel Granite, covering 20 percent of the southern Wet Mountains, consists of two distinct facies. The more common type is coarse porphyrytic granite cropping out in large bluffs and ridges; less common is a uniformly medium-grained phase. The composition of both types is similar, with quartz accounting for 25 percent of the rock, microcline about 25 to 30 percent, oligiclase 20 percent, and biotite 15 percent. Prominent accessory minerals are apatite and sphene. The San Isabel Granite extends throughout most of the length of the Wet Mountains.

Manitou Park

Setting

The Manitou Park Basin is a fault outlier about 30 miles long and 4 miles wide, bordered on the west by the Ute Pass Fault and on the east by the Devils Head Fault and Rampart Range (Boos and Boos 1957). Fowler (1952) called this eastern fault the Mt. Deception Fault. The southern part of the Manitou Park Basin contains an area of relatively soft sediments faulted down below the general summit level. The sedimentary structure is basically a westward dipping homocline or monocline. Relief in the area is approximately 1,600 feet, ranging from 9,200 feet in the Rampart Range to the east to about 7,600 feet in the Trout Creek Valley (Sweet 1952). Trout Creek is the only permanent stream in the area, though intermittent streams flow in most of the larger gulches. Drainage in the area is north-northwest toward the South Platte River which eventually empties into the Missouri River. In the southern part of the Basin, the Pikes Peak Granite is covered with Paleozoic sediments dipping west. Above these sediments is a gravelly soil derived mostly from granite. In the northern half of the Basin, Pikes Peak Granite is not covered by any Paleozoic sediments, though it is covered by a deep layer of Quaternary alluvium.

Stratigraphy

Sediments in the Manitou Park graben range from Upper Cambrian through Pennsylvanian (figs. 5, 6). The Sawatch sandstone of Upper Cambrian age rests unconformably on Precambrian Pikes Peak Granite. It forms east-facing cuestas throughout most of the mapped area.

In the Front Range the Sawatch sandstone is found only in Manitou Park, Parry Park, Manitou Springs, and in a limestone quarry west of Colorado Springs. The Ute Pass Fault marks its southern limit. It averages 68.4 feet thick in Manitou Park. The age of the Sawatch is indicated by the presence of two brachiopods, Lingulepis and Obolella. Addy (1949) recognized three different members in the Sawatch sandstone: lower sandstone, middle sandstone, and Peerless shale. The Sawatch is highly fractured, and slickensides are found on some surfaces. The sandstone surface is grooved and pitted, and weathers to a grayish color. The sandstone of the Sawatch is composed primarily of red, pink, brown, yellow, and white subrounded to quartz grains ranging from fine grained in the upper part to coarse grained in the lower part. The basal sandstone is pebbly or conglomeratic. The lower 25 feet is ferruginous and arkosic, and glauconite is common in the upper beds.

Maher (1950) referred to the calcareous and dolomitic upper 16 to 20 feet of the Sawatch sandstone as the Ute Pass Dolomite. He described it as a red, glauconitic, partly sandy, unfossiliferous, coarsely crystalline dolomite.

Berg and Ross (1959) referred to the Ute Pass Dolomite as the Peerless Formation. They described it as a unit of sandy, glauconitic dolomite. At Missouri and Illinois Gulches the Peerless Formation is represented by dark red, finely to coarsely granular, rhombic, sandy, and glauconitic dolomite about 16 feet thick. The upper few feet are conglomeratic with small discoid pebbles of siltstone. The rest of the formation consists of a few thin beds of very fine-grained sandstone, siltstone, and gray-green shale. Berg and Ross state that, on the basis of lithology and stratigraphic position, the Ute Pass Dolomite described by Maher (1950) is the same as the Peerless Formation. In any case, the Peerless or Ute Pass Formation is gradational between the Sawatch sandstone and the overlying Manitou Limestone.

The Manitou Limestone is the only Ordovician deposit in Manitou Park. It is about 80 to 90 feet thick in Manitou Park, less than half its thickness near Colorado Springs, and is a fossiliferous, well-bedded, pink to pale red, limestone and dolomite. It is microcrystalline and weathers to an orange-red color. Some fossils described by Fowler (1952) at the fish hatchery exposure are Apheorthis, Nanorthis, Sinuites, a cystoid plate, Hystricurus, Finkelnburgia, a prorocycloceras cephalopod, Kainella, and Leiestegium manitouensis. This suite indicates a Lower Ordovician age.

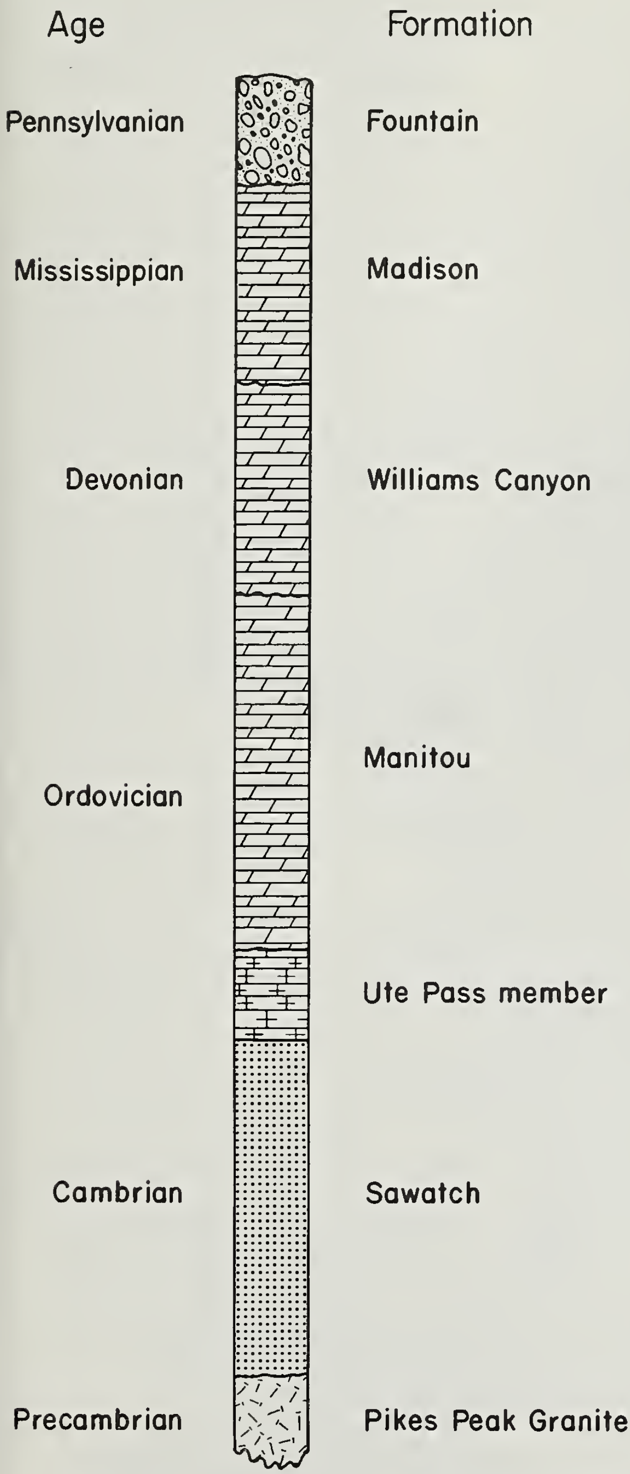


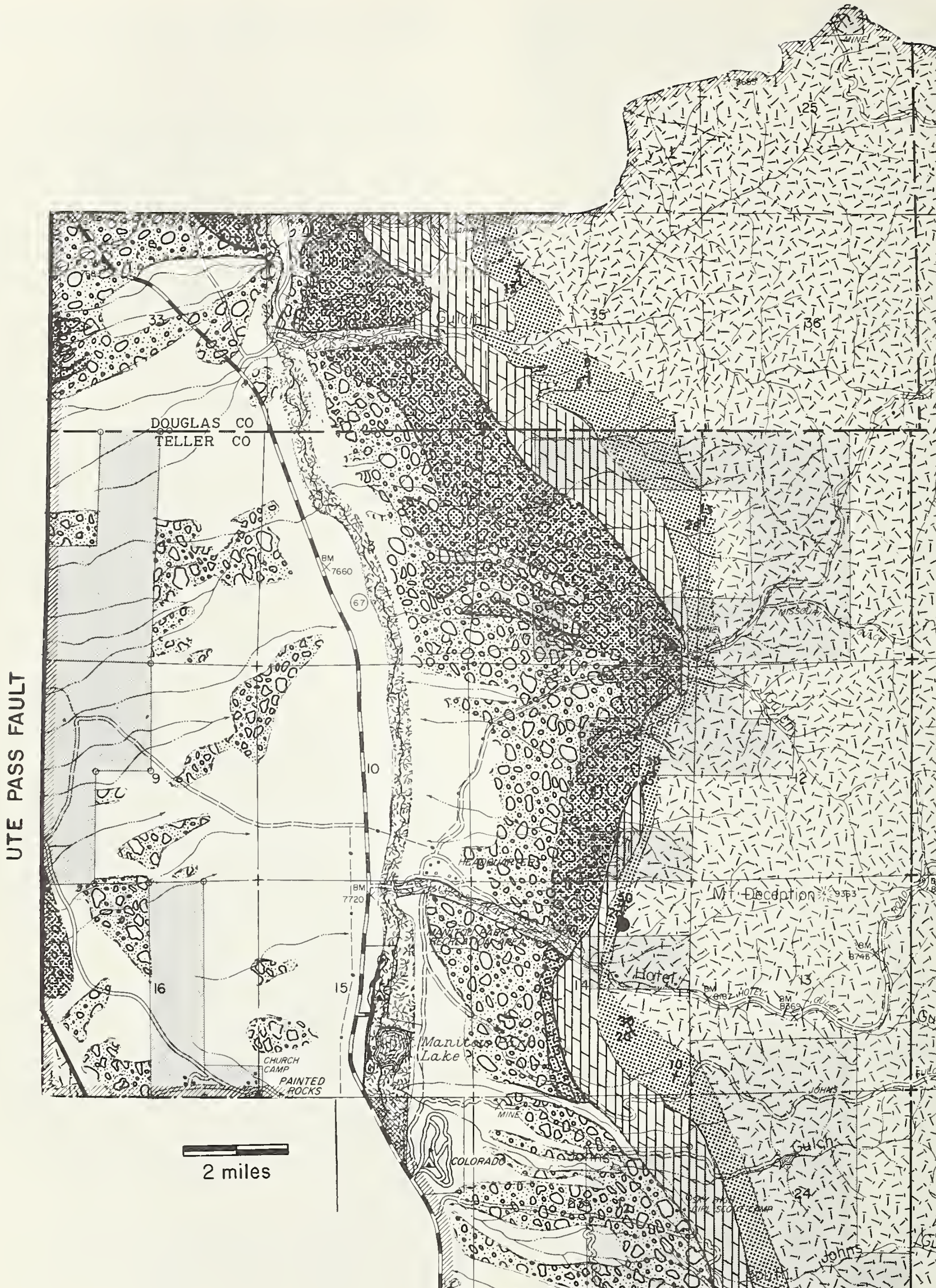
Figure 5.—Stratigraphic section of Manitou Park area.

Petrographic evidence indicates that the Manitou Formation originated in an environment of low to moderate energy. The particles show evidence of rounding and abrasion, but the energy level of the depositional environment was not sufficient to remove much of the microcrystalline material except during brief periods of high energy. Some of the minerals formed in place include dolomite, calcite, chert, limonite, hematite, and glauconite. The dolomite percentage in the samples studied by Swett (1964) ranged from 45 to 95. The dolomite can be recognized by its buff color in contrast to the grayish color of limestone. Chert is also present. Thin-section studies show evidence of five post-depositional alterations of the original limestone: (1) Grain growth caused by recrystallization of microcrystalline calcite to sparry calcite, (2) dolomitization, (3) silicification ranging from partial void filling to formation of chert layers, (4) the addition of calcite to the chert and dolomite layers, and (5) oxidation of iron-bearing minerals to limonite and hermatite.

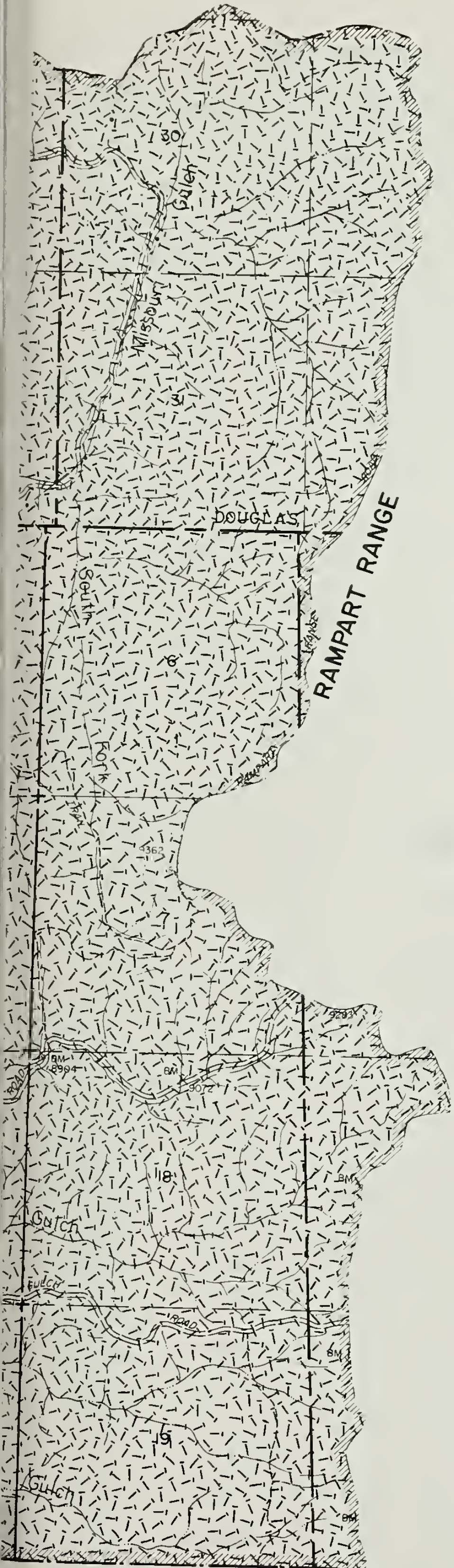
The Devonian-Mississippian Williams Canyon Limestone is of uncertain thickness and separated by nonconformities from the Mississippian Madison Limestone above and the Ordovician Manitou Limestone below. The Williams Canyon, named for its type section exposed near the Cave of the Winds in Williams Canyon, consists of thin, pale, reddish purple to gray mottled limestone and dolomite, containing partings of gray calcareous shale. The upper 2 to 4 feet is a medium-grained sandstone (Maher 1950). Maher dates the Williams Canyon as Mississippian by lithologic correlation with subsurface units of eastern Colorado. Brainerd et al. (1933) considered it Devonian, and correlated it with the Chaffee Formation of central Colorado.

Blocks of the Williams Canyon Limestone are intermingled with the Madison Limestone due to folding and faulting. The Williams Canyon is more dolomitic than the Madison and also softer. Soils developed from the Williams Canyon are dark gray to nearly black. They are relatively high in clay and have a good ability to hold water. Nitrogen and potassium levels are adequate for growing most plants, but phosphorus is deficient. Lime content is high, and the pH is about 8.0, similar to that of Madison-derived soils.

The Mississippian-Madison Formation overlies the Williams Canyon Limestone unconformably. The upper surface of the Madison is irregular with a weil-developed buried karst topography due to post-Madison and pre-Foun-



UTE PASS FAULT
DOUGLAS CO
TELLER CO
Gulch
Mt Deception
Hotel
Manitou Lake
CHURCH CAMP
PAINTED ROCKS
MISSOURI
COLORADO
Johns
Gulch
South
2 miles



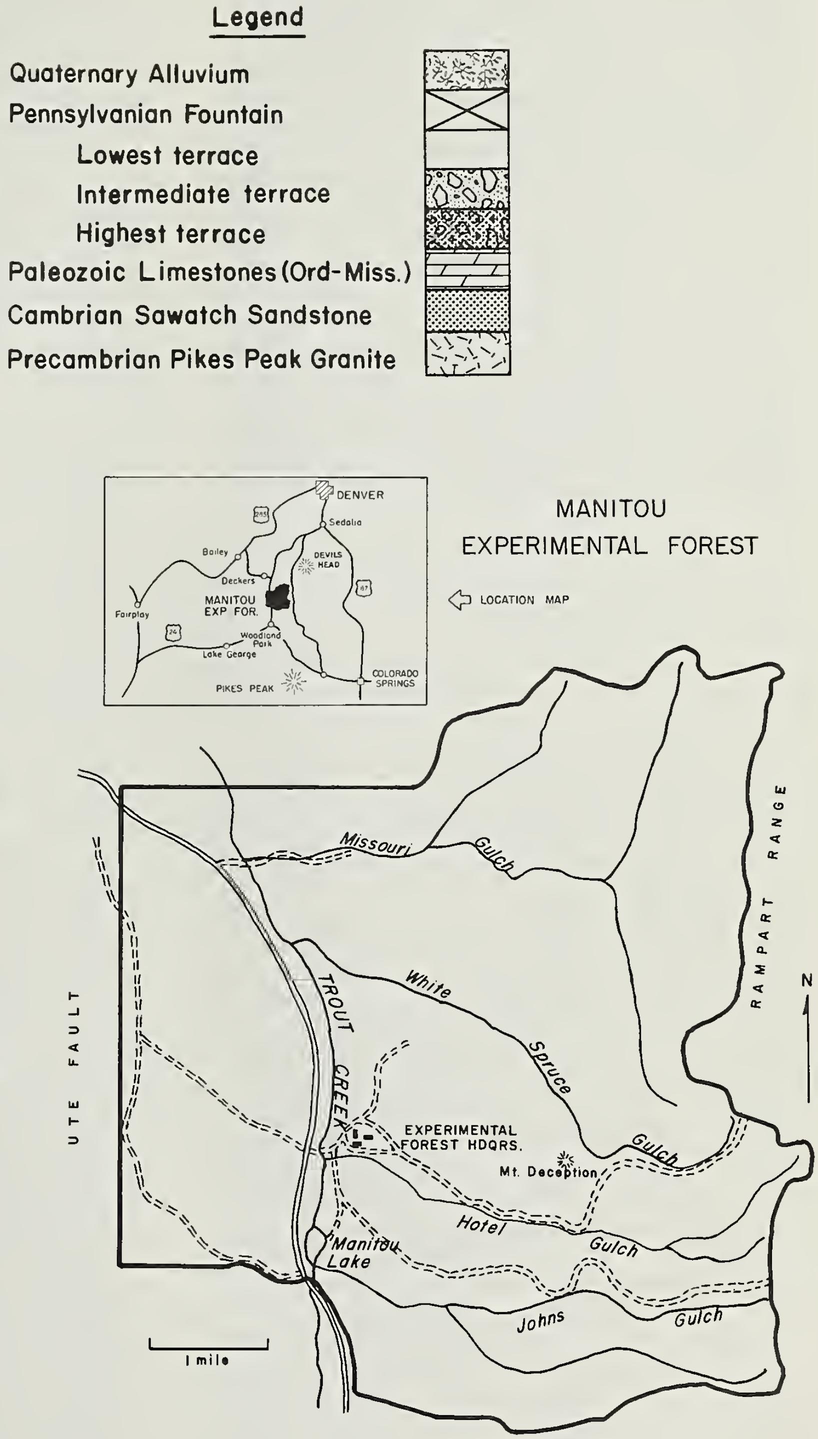


Figure 6.—Gealagic map af Manitau Experimental Farest. Stippled (gray) areas indicate private land within the Forest area.

tain weathering. Thickness varies from 0 to 200 feet (Brainerd et al. 1933). The Formation consists of massive, brown to gray, finely crystalline limestone, with occasional chert stringers and a brecciated zone near the base. Red stains are found locally in the upper part of the Formation due to the overlying Fountain beds. Solution cavities and sinkholes are filled with Fountain shales and sandstones. Because few, if any, fossils are found in the Madison, age cannot be determined more precisely than Mississippian. Maher (1950) considers the Madison to be Middle-Mississippian, and calls the upper part the Beulah Limestone and the lower part the Hardscrabble Limestone. The Beulah beds are not present in Manitou Park, and the Hardscrabble is correlated on the basis of lithologic similarity and stratigraphic position with the St. Louis Limestone of eastern Colorado and western Kansas. Bedding is practically nonexistent in the Madison, and it forms steep escarpments. Brainerd et al. (1933) found an upper brecciated zone, and attributed it to pre-Pennsylvanian weathering. They also believe that the Madison was originally deposited over the whole Front Range, but was removed by pre-Pennsylvanian erosion. Brainerd et al. (1933) were the first to designate the Williams Canyon and Madison Formations as distinct entities. They had previously been included with the Ordovician Manitou Limestone.

Soils in limestone formations generally reflect the color of the parent rock, and in the Madison Limestone they are usually a rich brown. Scattered over the surface of Madison-derived soils are rounded flint or cherty boulders greater than 1 inch in diameter. This soil is high in clay and moisture-holding capacity, and also in nitrogen, potassium, phosphorus, and organic matter; the pH is 8.0 (tables 2, 3).

Table 2.--Physical characteristics of the top 6 inches of Manitou Park soils (Smith 1971)

Soil No.	Parent material and aspect	Soil texture class			Soil moisture characteristics		
		Sand	Silt	Clay	1/3 atm	15 atm	Available water
		Percent					
12	Madison Limestone						
	NW	36	32	32	27.4	15.2	12.2
	SW	31	41	28	26.7	14.0	12.7
4	Williams Canyon Limestone						
	NW	31	45	24	30.1	16.7	13.4
	SW	39	39	22	31.1	18.6	12.5
6	Fountain Arkose						
	NW	44	33	23	18.0	10.3	7.7
	SW	65	19	16	14.7	8.0	6.7
1	Pikes Peak Granite						
	NW	47	36	17	24.8	15.1	9.7
	SW	55	36	9	17.4	6.1	11.3

Table 3.--Chemical characteristics of the top 6 inches of Manitou Park soils (Smith 1971)

Soil No.	Parent material	pH	Conductivity	Organic matter	Total nitrogen (N)	Lime	Phosphorus (P_2O_5)	Potassium (K_2O)
			mmho/cm	*Percent*			*Pounds per acre*	
12	Madison Limestone							
	NW	7.8	0.7	5.4	0.20	3.6	72	958
	SW	8.1	0.7	6.1	0.24	11.9	78	766
4	Williams Canyon Limestone							
	NW	8.0	0.8	7.6	0.29	13.0	26	450
	SW	8.0	0.9	8.8	0.33	12.3	29	508
6	Fountain Arkose							
	NW	6.9	0.5	2.2	0.06	0.4	21	187
	SW	7.3	0.6	3.4	0.10	0.8	12	383
1	Pikes Peak Granite							
	NW	7.0	0.6	5.7	0.11	0.6	31	438
	SW	6.6	0.6	5.6	0.13	0.6	19	279

The Pennsylvanian Fountain Formation lies unconformably on older formations except for the Precambrian, with which it is in fault contact. It consists of a thick series of red, cross-bedded, coarse-grained, arkosic sandstones and conglomerates sparsely interbedded with thin shales. The grains show little abrasion. Maximum thickness of the Fountain is 4,500 feet in the Manitou embayment west of Colorado Springs. In Manitou Park, thickness ranges from a few feet at the northern end to about 1,000 feet at the southern end. Geographically, it extends from Iron Mountain, Wyoming, to Canon City, Colorado, about 215 miles. Geometrically, the Fountain is a north-south trending prism that wedges out into the Denver Basin 40 miles east of the Front Range.

Pettijohn (1957) gives a good description of arkosic rocks. He defines an arkose as being a sandstone, generally coarse and angular, moderatly well sorted, composed principally of quartz and feldspar, and derived from a rock of granitic composition. Quartz is the dominant mineral, although in some arkoses feldspar exceeds quartz. Color is generally pink or red though some are pale gray. Porosity may be high due to its degree of sorting and incomplete cementation. It occurs either as a thick blanketlike residuum at the base of a sedimentary section that overlies a granite area, or as a very thick wedge-shaped deposit interbedded with much conglomerate.

The ortho-quartzites, black shales, thin coals, deltaic arkoses, and minor marine limestones of the Glen Eyrie beds, which are the basal Fountain deposits and not found in Manitou Park, were deposited in the Early Pennsylvanian. Later in the Pennsylvanian, the uplift of the ancestral Front Range accentuated the relief so that streams flowed eastward, eroding fresh arkosic detritus and transporting it to the mountain front. These streams formed coalescing alluvial fans on a piedmont plain extending eastward from the ancestral Front Range during periods of near aridity. The ancestral Front Range underwent continuous but declining uplift during Fountain and post-Fountain time. During the time of Fountain deposition, the eastern margin of the ancestral Front Range was not far west of the present foothills belt. The bottom one-fifth of the Fountain contains coarser gravels than the rest of the Formation, and grain size decreases upwards. The ratio of channel arkose deposits: floodplain micaceous arkose: deltaic-lacustrine quartzose arkose in the Fountain varies from 71:29:0 in the lower beds to 85:7:8 in the upper beds.

In the area between Eldorado Springs and Colorado Springs, the Fountain, exclusive of the Glen Eyrie, averages about 80 percent stream channel conglomerates and sandstones, 17 percent floodplain clayey siltstones and shales, and 3 percent deltaic-lacustrine clayey sandstones and siltstones (Hubert 1960). The ratio of siliceous particles: feldspathic fragments: micaceous fragments in the channel arkoses is 44:53:3, in the floodplain arkoses 41:43:16, and in the deltaic-lacustrine arkoses 72:24:4. The channel arkoses are the coarsest of the three groups.

There is no sharp distinction between many of the sandstones and conglomerates of the Fountain; coarse-grained arkosic sandstones grade laterally into conglomeratic sandstones and conglomerates. A similar gradation occurs vertically. Well-bedded sandstones are found in the lower part of the Formation. Above these beds are found discontinuous channel fillings and irregularly cross-bedded zones. Fountain sandstones are red, arkosic, medium to coarse grained, and poorly sorted. A hand-lens study of Fountain sandstone showed that 90 percent of the rock was composed of poorly sorted subrounded to angular fragments of pink feldspar and quartz less than 2 mm in diameter. The rock is well indurated (McLaughlin 1947), and weathers to a buff color.

A thin-section study of a typical Fountain layer by McLaughlin (1947) showed that angular fragments of microcline perthite constitutes about 35 percent of the rock. Plagioclase feldspar is rare. Subrounded to angular quartz makes up most of the remainder of the specimen. There are also small, scattered fragments of partially altered biotite. The study revealed a low porosity as a result of the compaction of the poorly sorted, irregularly shaped fragments and the interstitial fillings of silty and clayey material and iron oxide.

Although the name Fountain is restricted to arkoses along the east flank of the Front Range, similar coarse red arkoses, such as the Maroon, Hermosa-Culter, and Sangre de Cristo Formations, were deposited in other areas adjacent to the ancestral Rocky Mountain highlands. The Maroon ranges up to 7,000 feet in thickness in central Colorado, and the Sangre de Cristo ranges up to 13,000 feet in southern Colorado and northern New Mexico, as compared to the 4,500-foot maximum thickness of the Fountain. These different arkose deposits exhibit extreme facies changes over very short distances, probably caused by torrential deposition at the margins of rapidly rising lands.

Mallory (1958) attributes the red color of these beds to two factors: (1) An abundance of orthoclase (primarily), and (2) a coating of ferric oxide on clastic particles making up the rock. McLaughlin (1947) attributes the red color to the presence of iron oxides, which may be only a stain on the grain surfaces or may occur as interstitial cementing material.

Soils developed from the Fountain are similar to those developed from the Pikes Peak Granite, from which it was largely derived. Both are infertile (table 3). The pedestals found in the area do not appear to have been important in the development of the soil.

Soils on northerly and easterly exposures have more pronounced zones than those on southerly and westerly exposures. Southerly exposures also generally have a ponderosa pine cover, while northern slopes contain mostly Douglas-fir, a few ponderosa pines, and an occasional aspen.[2]

In general, soil erosion in the Rocky Mountains is severe only where remnants of the pre-Wisconsin soils are extensive. The difference between the soils of pre-Wisconsin, Wisconsin, and Recent age in the Rockies are best shown by the difference in weathering of the moraines and other deposits of those ages. In Recent deposits, pebbles are fresh; in Wisconsin deposits they may have a weathered rind; and in pre-Wisconsin deposits they may be altered to clay (Hunt 1967).

Overlying the Fountain Formation and covering the major portion of the Manitou Park Basin is an accumulation of coarse, angular material which has either been washed downslope from the granitic and Paleozoic outcrops, or deposited by intermittent streams during heavy rains and spring runoff. These deposits are approximately 10 to 25 feet thick. In the Manitou Experimental Forest, these deposits form a large alluvial fan with an apex in the Paleozoic hogbacks of sec. 25, T. 11 S., R. 69 W. (Sweet 1952), just southeast of the Forest. On the west side of the Basin the gravels are composed of granitic detritus with fragments of ault breccia intermixed, while on the east side there is an admixture of lower Paleozoic material with the granitic debris. The deposits are Quaternary in age and cover the Ute Pass Fault line through most of its extent. The lateral movement of the fault activity must antedate the alluvial deposits.

[2] *Fox, C. J., J. Y. Nishimura, R. F. Bauer, C. R. Armstrong, and R. F. Willmot. 1962. Soil survey report of wildlife habitat study area, Manitou Experimental Forest, Colorado. 26 p. (Unpublished report on file at Region 2 office, USDA For. Serv., Denver, Colo.)*

Igneous Petrology

Pikes Peak Granite is the only Precambrian rock in the area. In Manitou Park it is part of a large batholith of coarse, even-grained to porphyritic pink rock consisting mostly of microcline and quartz.

Biotite occurs in clusters and large flakes and is the most important accessory mineral. Other accessory minerals are oligoclase, feldspar, zircon, apatite, allanite, magnetite, fluorite, and rutile. The red-pinkish color of the rock is due to a pigment of hydrous iron oxide which colors the feldspars. The feldspar and quartz grains are relatively large, and conspicuous feldspar phenocrysts are common, often attaining a diameter of several inches. Some areas of Pikes Peak Granite, however, contain feldspar grains little more than 0.25 inch long. Percentage of constituents, according to Mathews (1900), is quartz 33.4 percent, microcline feldspar 53.3 percent, biotite 10.7 percent, and oligoclase feldspar 2.6 percent.

Fine-grained granite dikes cut the Pikes Peak Granite in places. They are red to pink in color and very poor in mica. Feldspars dominate in these dikes (Peterson 1964).

Also cutting the Pikes Peak Granite are a number of pegmatite dikes. The pegmatites contain microcline, orthoclase, albite, oligoclase, quartz, biotite, muscovite, and accessory minerals in very large individual grains, often segregated in different parts of the dikes. They are most abundant near the Platte River.

Age determinations based on Pb-U ratios give an age of about 1 billion years for the Pikes Peak Granite (Fowler 1952). This compares to Hutchinson's (1964) finding of 995 million years for the porphyritic aplitic facies of the Pikes Peak batholith.

Pikes Peak Granite has basically the same composition and grain size as the other major granites of the Front Range. However, Pikes Peak Granite is distinctively more susceptible to weathering and erosion than the Boulder Creek or Silver Plume Granites. It weathers typically into rounded masses, with great curving plates breaking away from the dome-like outcrops in the process of exfoliation. Weathering by disintegration forms an angular gravel that is widely distributed as a mantle on long, low divides. Weathering of the granite is so general that only about 10 percent of the area in Manitou Park underlain by granite contains outcrops.

Biotite is the most easily decomposed of the constituent minerals of the granite. As it weathers, iron is set free, staining the other minerals. The weathered rock shows every gradation from green through pink to deep red, the red being caused by iron oxide staining. The depth of the weathered layer averages 25 feet, due both to ease of weathering and the fact that some of the surfaces were subject to erosion during Cambrian times.

The terraces in Manitou Park are covered with gravels derived mostly from Pikes Peak Granite, though the bases of the terraces have some reworked Fountain material mixed in, since they are underlain by Fountain beds. The terrace deposits also weather very easily.

Soils developed from Pikes Peak Granite are pinkish or reddish in the lower parts of their profiles as an inheritance from the parent materials. The percentage of particles greater than 2 mm in size is greater than for any of the soils developed on sedimentary layers in the area (Smith 1971). The soil is a gravelly, sandy loam with a low clay content. Available water is slightly higher than for the Fountain-derived soil. Nitrogen, potassium, and phosphorus are deficient. The surface soil is neutral or slightly acidic, with acidity increasing with depth (tables 2, 3).

Structure

Manitou Park is a fault outlier: an outcrop of younger rocks isolated by faulting in an area of older rocks. The sedimentary structure consists of a westward-dipping homocline or monocline except for sharp drag along the fault at the west edge of the block.

The dominant structures in Manitou Park are faults. The area is bounded on the east by Mt. Deception Fault (Fowler 1952), and on the west by the Ute Pass Fault. In the Basin itself, there are no folds. The most significant structural feature in the area is the Ute Pass Fault zone, about 30 miles long and 800 to 1,700 feet wide. Fine-grained, calcium-rich breccia is found in the northern part of the fault zone, while larger uncemented breccia is found in the central and southern parts. In places, the zone can be traced by the presence of weathered or iron-stained belts in the granite. The fault plane is almost vertical with a possible eastward dip. Both horizontal and vertical movement has occurred along this fault plane. The west block has been upthrown with respect to the east block, with an estimated maximum vertical displacement of up to several thousand feet and minimum of several hundred feet. The horizontal displacement is not known. On the western side, the upthrown block of Pikes Peak Granite forms a prominent fault scarp.

There was a tremendous amount of shearing in the Ute Pass Fault zone. Movement began in the Precambrian and continued until Miocene-Pliocene time. Sweet (1952) states that the faulting is late Tertiary or early Pleistocene.

The Mt. Deception Fault zone on the east side of Manitou Park is closely related to the Ute Pass Fault zone. The trends of both fault zones are parallel for most of their extent. The sediments dip most steeply just to the west of the fault and then flatten out farther west. The west block is downthrown, probably a high-angle reverse fault dipping steeply to the east. Other minor faults in the area include the Trout Creek Fault, which extends for about 5 miles in a north-south direction halfway between the Ute Pass and Mt. Deception Faults, and the Fish Hatchery Fault, which connects the Ute Pass Fault with the Trout Creek Fault. Scott[3] referred to the Mt. Deception Fault as a branch of the Ute Pass Fault. Harms (1965) refers to the east side of the Manitou Park Basin as a monoclinal flexure rather than a fault.

Geologic History

The major events in the geologic history of the Manitou Park area, as determined by Sweet (1952), are:

1. Development of a peneplain on the surface of the Pikes Peak Granite before Late Cambrian time.
2. Advance of the Late Cambrian sea from the west around the margins of the Front Range highland, and deposition of the Sawatch Sandstone.
3. Change in depositional conditions without uplift, and deposition of the Early Ordovician Manitou Limestone.
4. Retreat of the sea at the end of Manitou deposition and erosion of the area during the remainder of the Ordovician, Silurian, and probably part of the Devonian.
5. Submergence in Devonian time, and deposition of the Williams Canyon Limestones and Sandstones.
6. Emergence and erosion during the Late Devonian and possibly the very Early Mississippian.
7. Submergence in the Early Mississippian, and deposition of the Madison Limestone.

[3] *Personal communication with Glenn R. Scott, U. S. Geological Survey, Denver Federal Center, Colorado, 1972.*

8. Uplift with mountain-building during the Early Pennsylvanian, and deposition of the Fountain Formation as a thick series of coarse clastic sediments around the margins of the mountain mass.

9. No record of the remainder of the Paleozoic and the entire Mesozoic.

10. A period of uplift and mountain-building at the close of the Cretaceous. The folding which occurred at this time probably formed the Manitou Park syncline.

11. Peneplanation on the surface of the Front Range mountains, and deposition of a thick series of stream gravels in Manitou Park by streams flowing eastward across the erosional surface.

12. Late Tertiary uplift.

13. Active stream erosion during the Quaternary, with development of narrow erosional surfaces along the major streams of Manitou Park during the Pleistocene.

Physiography

The topography of the area is mature, highly dissected, and well drained. The streams form a dendritic pattern in the east where homogeneous outcrops of granite are found. Here the relief is complex, with drainageways extending almost to the tops of the mountains, leaving only narrow summits. Limestone terrain is characterized by a trellis or blocky drainage system. Secondary drainages many times branch out perpendicular to the main drainage, forming blocks of gently sloping or rounded hills.

Broscoe (1959) divides the area in and near Manitou Park into four geomorphic districts: (1) The Pikes Peak Granite-pre-Pennsylvanian outcrop area of the Rampart Range, which he refers to as the Rampart Range granite area; (2) the widely spread outcrop area of Pikes Peak Granite west of the Ute Pass Fault, which he calls the Rule Creek granite area; (3) an area of widespread Oligocene gravels in the vicinity of the town of Divide; and (4) the lowland of the Manitou Park Basin which is underlain by the Fountain Formation.

Both the Rampart Range and Rule Creek granite areas are heavily forested. On weathering, Pikes Peak Granite forms large, rounded masses, which are surrounded by a very coarse gravel called grus. The soil developed on this material is very coarse and permeable. In several places, such as at the head of White Spruce Gulch, drainage ditches from the Rampart Range Road have been diverted into natural drainageways. Increased discharge at the head of the washes has caused active gullying. With the exception of man-disturbed areas, however, there is little erosion in the granite area. Any inequilibrium in the granite terrain is more in the direction of alluviation, rather than gullying. Broscoe (1959) considers the Rampart Range and Rule Creek areas to be unlikely sources for the sediment presently being deposited in Manitou Park Lake.

The area of gravel near Divide is similar to the granite areas, with its gravelly soil and lack of erosion, except for the man-disturbed areas. Therefore, Broscoe (1959) considers the most likely source of sediment in the area to be the Manitou Park Basin, with its extensive alluvial terrace and floodplain deposits.

Three terraces are found in the Manitou Park Basin (fig. 6), an oldest high terrace, an intermediate terrace, and a youngest low terrace (Broscoe 1959).[4] These terraces are developed on areas underlain by the Fountain Formation. The highest surface is preserved only in scattered ridges and benches. Remnants of this terrace stand approximately 80 to 100 feet above the intermediate terrace. All of the terraces are cut by numerous small channels. Many of the courses of the Trout Creek drainage system are underlain by Quaternary alluvium. Sweet (1952) called the highest terrace gravel the Woodland Park Formation and considered it to be of Tertiary age, though he thought the terrace developed in the Pleistocene.

Most of the second or intermediate terrace remnants west of highway 67 are near the west boundary of the Experimental Forest. The oldest stage of physiographic development on the lowest terrace, with a relatively flat slope, is found west of but near the highway. Here the ridges have been worn down to produce a gently rolling slope. West of the oldest stage, the low terrace consists of a mature, much dissected area with many ridges and gullies. Further west is a youthful area where ridges and gullies are just beginning to develop. The slopes on the different terraces vary from 4° to 8° with a trend of about N. 70° E. This trend accounts for the general northeast trend of the ridges and gullies. All three terraces were originally cut in Fountain arkose.

Pedestals, weirdly shaped remnants of the Fountain arkose, are scattered throughout west of highway 67 and around Manitou Park Lake. They represent remnants of the next higher terrace which has been eroded away in the surrounding area. Pedestals are not as common

[4] *Retzer, John L. 1949. Soils and physical conditions of Manitou Experimental Forest. 123 p. (Unpublished report on file at Rocky Mt. For. and Range Exp. Stn., USDA For. Serv., Fort Collins, Colo.)*

east of the highway, but outcrops of Fountain arkose are numerous, especially in northern portions of the area. Since the pedestals are being worn down, it is not possible to determine their original height and, therefore, the height of the next higher terrace in the adjacent area. Currently, the pedestals range from 20 to 50 feet in height, and strike approximately north-south and dip to the west. It is not known just why the pedestals remained while surrounding layers were eroded away, but one possibility could be that the pedestals have a slightly more durable cement than did the adjacent layers.

The pedestals, with their orange color standing in sharp contrast against the green background of the surrounding forest, add to the scenic beauty of the area. Near the Rainbow Falls Road, Trout Creek has cut through an outcrop of Fountain arkose and left orange cliffs about 100 feet high. Also, in Missouri Gulch the stream has cut a canyon about 150 feet deep, exposing the contact between the Sawatch Sandstone and the Pikes Peak Granite.

Setting of Manitou Park in the Front Range

Manitou Park is unique in that it is a structurally depressed block containing a Paleozoic sedimentary formation, while the other parklike areas in the Front Range were formed by erosional processes in crystalline rocks. The soils of Manitou Park are mostly of granitic origin, and, therefore, differ from other soils in the Front Range only because of their derivation from the distinctive Pikes Peak Granite. The erosive qualities of soils derived from Pikes Peak Granite make it imperative that extreme caution be exercised whenever any alteration of the surface profile is planned for road construction, housing developments, or other disturbance.

Reestablishment of shrubs and grasses is very slow on Pikes Peak and Fountain-derived soils. Once these plants are removed, the soil becomes greatly weakened. The soils are held together mostly by mats of needles dropped from the trees. Tramping on these soils is harmful and should be minimized to protect the area. Residential development would most likely cause a severe erosional problem. A good idea of the severe erosion potential in this area can be obtained by observing residential development just south of the town of Divide.

These restrictions apply not only to the Manitou Experimental Forest lands, but to any Front Range lands having soils derived from Pikes Peak Granite. The sedimentary formations in the area of the Experimental Forest are encountered nowhere else in the Front Range and are of minimal importance.

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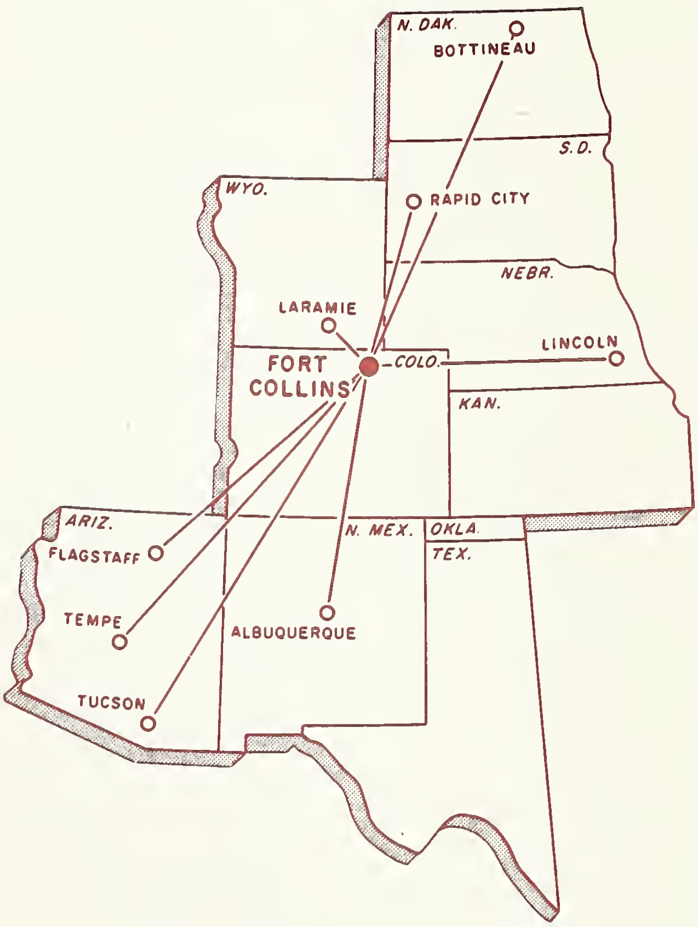
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