COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 5—Part 1

RECONNAISSANCE

OF THE

GEOLOGY

OF THE

RABBIT EARS REGION

ROUTT, GRAND AND JACKSON COUNTIES, COLORADO

BY
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JUNIUS HENDERSON

DOI: https://doi.org/10.58783/cgs.b05.opgt3971

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LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, December 1, 1912.

Governor John F. Shafroth, Chairman, and Members of the Advisory Board of the State Geological Survey,

GENTLEMEN—I have the honor to transmit herewith Bulletins 4 and 5 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

CONTENTS

INTRODUCTION

BY P. G. WORCESTER

LOCATION

The area considered in this report consists of about 212 square miles of territory in Routt, Grand and Jackson Counties, along and near the west end of the Rabbit Ears Range. This range, which leaves the Park Range just south of Rabbit Ears Mountain, extends in a general easterly direction to the Medicine Bow Range and forms between these ranges the Continental Divide, the boundary between Grand and Jackson Counties, and the dividing line between North and Middle Parks.

The whole area is included between range lines 79 and 84 west of the ninety-eighth meridian, and between township lines 3 and 7 north of the fortieth parallel base-line. It may, however, be more definitely located by noting its relation to certain prominent points whose latitude and longitude can be given. Whiteley Peak, the Upper Muddy Butte or Conical Butte of the Hayden Survey, is about midway between the east and west sides near the southern boundary of the area. The Hayden survey[1] gives the location of this peak as Lat. 40° 19′ 1″ N. and Long. 106° 29′ 2″ W. The position of Rabbit Ears Mountain is given by the same authority[1] as Lat. 40° 25′ 9″ N. and Long. 106° 36′ 6″ W.

RAILROAD FACILITIES

At the time this area was surveyed the nearest railroad towns were Steamboat Springs, about twenty-five miles west, and Kremmling, about forty miles south of Rabbit Ears Mountain. Both towns are on the Denver, Northwestern & Pacific Railroad. During the summer of 1911 a new railroad, the Laramie & Routt County, was under construction in North Park. The present terminals are Laramie, Wyoming, and Coalmont, a coal camp about six miles north of Spicer.

[1] Hayden, Ninth Annual Report, U. S. Geol. and Geog. Surv. of the Terr., 1875, p. 408.

FIELD-WORK AND DIVISION OF THE REPORT

SCOPE OF THE SURVEY

The object of the work was to make a rapid reconnaissance mineral survey of the area along the Rabbit Ears Range. Special attention was given to contacts, outcrops and exposures of any kind which might lead to the location of economically important minerals. With the addition of Professor Henderson to the party, it was possible to make a thorough examination of the stratigraphy of the region.

FIELD SEASON

The mapping was done during the months of July and August, 1911.

PERSONNEL OF THE PARTY

The members of the party were Junius Henderson, Frank F. Grout, P. G. Worcester, A. C. Smith, N. E. Hinds, A. P. Russell, cook, and R. L. Wetherspoon, teamster.

DIVISION OF THE WORK

Professor Junius Henderson, who was in the field about a month, gave nearly his whole time to the examination of sedimentary rocks, and he is the author of the chapter on "Stratigraphy," included in this report. F. F. Grout and P. G. Worcester, who were jointly in charge of the field party, did most of the geologic mapping. They were, however, assisted by A. C. Smith and N. E. Hinds. P. G. Worcester had charge of the control in the field and prepared the map for the engraver. He is responsible for the "Introduction" and the chapters on "Physiography" and "Outline of Geology." F. F. Grout made the microscopic examination of the igneous rocks and is the author of the chapters on "Igneous Rocks" and "Economic Geology." N. E. Hinds assisted Professor Henderson in collecting fossils, traversed some of the roads, and assisted in the geologic mapping. A. C. Smith spent considerable time in panning the many creeks of the district. He also made some road traverses, and in other ways assisted in the mapping.

ACKNOWLEDGMENTS

The United States Geological Survey furnished the Colorado State Geological Survey with an advance geologic sheet of North

Park, from which was taken most of the geologic section shown as Plate I, on page 25.

The writers are indebted to Professors R. D. George and R. D. Crawford for many suggestions regarding the work, and to P. J. Martin, Frank Murphy and others for courtesies extended to the party in the field.

Each of the writers has drawn on the notes of the other members of the party for data bearing on his particular part of the work.

OTHER SURVEYS

Previous to 1911 the only geologic map of this region was that made by the Hayden Survey in 1873-74, under the direction of A. R. Marvine. As is well known, the mapping done by that survey was of a very general nature, and it was found necessary to change many details in the topography shown by the older map, as well as to revise to a large degree the geology.

During the field season of 1911 a United States Geological Survey party, with A. L. Beekly in charge, worked on the classification of the North Park coal lands, and overlapped to some extent the eastern and northern part of the area included in this report.

METHODS OF MAPPING

For control purposes a Gannet traverse plane table with a ten-inch open sight alidade was used. Rabbit Ears Mountain and Whiteley Peak were plotted from the Hayden atlas sheet[1] and used as ends of a base-line for triangulation. Spicer Peak (Arapahoe) was then located by sights from these two points, the three peaks forming the vertices of a nearly equilateral triangle. The sides of this triangle were used as base-lines, and about seventy points in the area were located by triangulation. The points located in this way were used as control for Brunton compass sights in pace and notebook traverses, by means of which most of the mapping was done.

The scale used in the primary triangulation was one inch to one mile. In the notebook traverses the larger scale of two inches to one mile was used, to allow more detail in mapping.

Elevations were obtained by the use of aneroid barometers.

In some places, due to the large amount of iron present in the lava flows, there was much local attraction, which seriously interfered with the accuracy of the compass readings. Another

[1] Hayden, Geological and Geographical Atlas of Colorado and Portions of Adjacent Territory. Atlas sheet No. XII.

obstacle to rapid or absolutely accurate work was the great amount of heavily forested land, especially on the west side of the area.

The heavy timber, luxuriant vegetation, water-worked moraines, and lava debris in many cases cover large areas and effectively conceal all outcrops of the underlying formations. Where exposures of formations, found in stream channels or elsewhere, were not more than a quarter of a mile apart, boundary lines between formations were sketched on that evidence; but if outcrops were concealed for greater distances, the area was mapped debris (*db*), even when in many cases there was good reason to believe that the debris was quite superficial. The boundaries of igneous bodies were, as a rule, more easily traced, and it is believed that they occur nearly as represented on the map, although in a few cases only approximate boundary lines could be placed between the lava flows and the great areas of debris intimately associated with them.

PROSPECTING AND MINERAL PRODUCTION

A glance at the accompanying map will show that the region has not been very thoroughly prospected; for all of the prospect holes, more than twenty feet deep, that were found, are shown on the map.

Some placer mining has been attempted at various places, but, so far as could be learned, very little gold has been obtained. The creeks have been prospected more or less thoroughly, and were sampled at various places by members of our party, but no gold was found. In brief, the district examined has not produced much ore, and the field offers but little encouragement to prospectors. A discussion of the coal horizons, fire-clays, and other important economic products will be found in the chapter on "Economic Geology."

PHYSIOGRAPHY

BY P. G. WORCESTER

TOPOGRAPHY

GENERAL STATEMENT

The area, as a whole, has low relief, although in the eastern, and to some extent in the northwestern part of the field there are prominent points and high ridges. The Continental Divide, which is extremely high, rocky and ragged farther south in Colorado, here consists of low, broad hills or wide, flat-topped ridges. High, ragged cliffs and snow-clad peaks are almost entirely absent.

The topography of North Park is in sharp contrast to that of Middle Park. Middle Park is an open, intermountain area, composed of the various valleys containing the headwaters of the Grand River and its tributaries. The upper courses of the main stream occupy the east-west axis of the park, and flow westward eventually into the Gulf of California via the Colorado River. The park, which is virtually coextensive with Grand County, is bounded on the east by the rugged crest of the Front Range of the Colorado Rockies; on the south, by the Williams Mountains; on the west, by the Park Range; on the north, by the less rugged Rabbit Ears Range. The general level of this park is broken by many minor peaks and mountain ranges, high divides and deep gulches; hence, it is somewhat less evidently a single topographic unit than North Park. Yet it is so evidently set apart from the surrounding region by lofty mountain ranges as to impress even the most casual observer with its unity. North Park, on the other hand, viewed from any high point on its rim or within its borders, presents to the eye a comparatively flat expanse, broken only by erosion remnants which form small, prominent elevations. It is sharply defined on three sides by mountains, with the opening to the north. It comprises the new county of Jackson, bounded on the east by the Medicine Bow

Range; on the west, by the Park Range; on the south, by the Rabbit Ears Range. The North Platte River rises in North Park and flows northward and eastward, eventually reaching the Gulf of Mexico via the Mississippi.

TOPOGRAPHY CONTROLLED BY VULCANISM

In the area here described there are some cliffs and low peaks which have been carved out of more or less stratified volcanic, fragmental rocks, by the action of streams and the atmospheric agents. There are also many low mountains, or monadnocks, standing from 100 to 1,000 feet above the general level of the surrounding country, which are the remnants of igneous intrusions. Most of the peaks of this type are not named, but among those which have names are Spicer and Whiteley Peaks, Haystack, Ironclad, Bear and Baker Mountains.

Throughout the district are found many broad ridges and flat-topped hills, the remnants of igneous flows, which cap the sediments and protect them from erosion. Diamond Mountain is an excellent example of this type.

Other types of hills or ridges, due directly to vulcanism, are those, like Rabbit Ears Mountain and many in the eastern part of the area, which have been formed by the erosion of a series of lava flows, intermingled with great thicknesses of breccia, or volcanic agglomerate. The head of Arapahoe Creek is surrounded on three sides by high ridges of this character, which form a steep-walled basin with the opening toward the northwest, the east ridge forming the Continental Divide. The inside walls of the basin are rugged cliffs, formed by stream erosion, and carved by the agents of weathering into pillars, spires, caves, and innumerable fantastic shapes. In many places erosion remnants, such as blocks or columns, are found several hundred feet away from the main cliffs.

GLACIAL TOPOGRAPHY

There is considerable evidence of glaciation along the western border of the area, particularly near Rabbit Ears Mountain. Northwest of this mountain in the granite are many striated surfaces, the grooves trending about S. 60° E. In some places the typical sheep-backs, or roches moutonnees, are seen. A large area about two miles north of Rabbit Ears Mountain is covered with moraines. There are many small lakes, and some bogs and marshes, which evidently were once lakes, scattered through the

moraines. The morainal material is all granitic, and many of the boulders are quite large. There is also much granitic morainal material found short distances northeast, south and southwest of Rabbit Ears Mountain. The amount of material indicates large or long-existing glaciers, and the glacial striæ on the granite surfaces, and the trend of lateral and terminal moraines, indicate that the glaciers came from the high granite mountains to the northwest. The glacier probably divided near Rabbit Ears Ridge, part of it going north and part south. In the eastern part of the area there are evidences of glaciation, which was not so extensive as that in the northwestern part of the field.

ALLUVIAL FLATS

Alluvial flats occur in several places along the tributaries of the Muddy and along the Muddy itself. They are formed by the constriction of stream valleys, when the streams cut through hard sedimentary strata or dikes.

SLUMP TOPOGRAPHY

Slumps occur in many places on the steep hillsides, especially in the clay and shale areas near Muddy Creek. As a result of these slumps, many small basins, more or less completely filled with water, occur on the sides and at the bottom of many steep hills.

TERRACES

In the southwest part of the field, and along Muddy Creek south of this area, the river has cut a series of terraces, which extend from the present stream channel back to the west to the Park Range. The terraces are much less well-defined east of the creek.

HOG-BACKS

The Dakota formation forms a well-defined hog-back in many places, but, on the whole, is not so prominent a topographic feature as it is east of the Front Range. The hog-backs in the Niobrara, so common in many places where that formation occurs, are not found at all in this area. The Benton limestone forms low ridges both north and south of Rabbit Ears Mountain.

WATER SUPPLY

STREAMS

The chief streams are Colorado, Little Grizzly, Indian and Arapahoe Creeks in North Park, and Muddy, Diamond and Lindsey Creeks in Middle Park. All are strong, permanent streams, fed by many tributary streams and springs. They carry more than sufficient water to irrigate the agricultural land in this area.

LAKES

There are several types of lake basins in the area studied. Morainal lakes are by far the most common and occur mainly in the northwestern part of the field. Small lakes, due to land slumps, are found in considerable numbers above the Muddy, near Whiteley Peak; they are, however, of little importance. There are many small lakes in the eroded breccia areas and in the Eocene rocks southeast of Spicer Peak, which resemble morainal lakes, and may be of this origin; but the evidence of glaciation is slight. Several of these lakes are natural reservoirs, and are connected by artificial ditches with larger reservoirs from which the water is taken for irrigation.

An unusual type of lake basin was found on a bench south of Bear Mountain. An intrusion of basalt has lifted up a mass of Montana shale, in which a lake basin has been formed, either by wind erosion, or by the unequal upward movement or irregularities of the intrusion.

South of Baker Mountain several lake basins seem to have been formed by the folding of the Dakota sandstone. The largest lake of all has no visible outlet and is drained only by the underground seepage through the fractured Dakota rocks.

In North Park there are many shallow lakes, whose basins were originally formed by the wind. Subsequently some of them have been deepened by artificial dams, and are now used as storage reservoirs for irrigation waters.

CLIMATE AND VEGETATION

VEGETATION

Reference has already been made to the heavy timber and luxuriant vegetation in certain parts of the area. This applies particularly to the ridges and higher hills, where there are in many cases dense forests of conifers and aspens, with a heavy

growth of grass and underbrush. Practically all the heavy timber is included in the United States Forest Reservations: the Arapahoe in the southeastern, and the Routt in the northwestern part of the area.

The flat bottom-lands along the streams have rich, fertile soil, which is utilized largely in the production of hay—the main crop in both North and Middle Parks. Most of the hay is fed out in the winter on the local ranches, where large numbers of cattle are raised. Cattle-raising is the principal industry of the district.

The slopes away from the creeks have a coarser soil, which loses its moisture quickly after storms, and is capable of supporting only a little or no vegetation. The vegetation which does occur there is mainly sage-brush and other types characteristic of semi-arid climates.

CLIMATE

The summers are rather short and warm, but not exceedingly hot. The winters are rather long and cold. Generally considerable rain falls during the summer, and there are heavy snows in the winter.

OUTLINE OF GEOLOGY

BY P. G. WORCESTER

The rocks of this area may be roughly grouped into three great classes: the Archean schists, gneisses and granites, which occur all along the western border of the field; the sedimentary rocks of various ages from late Paleozoic to the Present; and the igneous rocks, probably of Tertiary age, which cut or rest upon the sediments, and in a few places cut the Archean rocks.

ARCHEAN

GNEISSES AND SCHISTS

The gneisses and schists which occur in a large part of the Archean area seem to grade into one another. Their color is prevailingly dark, due to the presence of large quantities of biotite and hornblende. Quartz is almost always present, and feldspars occur in varying amounts. These rocks are intensely crumpled and minutely folded, and are nearly everywhere cut by strong quartz veins. The microscopic description of these and the following rocks will be found in the chapter on "Igneous Activity and Igneous Rocks."

GRANITES

There are three common granite rocks in the area, none of which can be fully described, as they were not studied in detail. The most important one is a fine, medium-grained, pink, almost binary granite, which occurs in many places bordering, or in, the gneisses and schists. Closely associated with this rock is a coarser pink granite, which contains a good deal of hornblende. It often has well-developed gneissoid structure, and in such cases its contact with the schists is generally hard to follow. The third granite is a pegmatite, which occurs as large and small dikes cutting the other Archean rocks. It is composed of large pink feldspar and white quartz grains, with only a little mica.

The disintegration of these rocks furnishes a large amount of residual soil, as well as angular and partially rounded fragments, which are carried considerable distances by the streams.

The topography of the Archean area is noticeable on account of its simplicity. The region has all been glaciated and presents low, rounded hills and ridges, with broad, shallow gulches and basins. Many surfaces are bare and show glacial striæ, but a large part of the area is covered with vegetation.

TERTIARY (?) IGNEOUS ROCKS

The igneous rocks of late Cretaceous or Tertiary age are of six principal varieties: basalt, breccia, volcanic ash, andesite porphyry, dacite porphyry, and quartz latite. Some of these rocks occur in several different forms.

BASALT

Basalt, rich in olivine, occurs as flows, dikes, small batholiths, and sheets, which were probably once flows in the great areas of igneous breccia. Its color is generally black or very dark gray, but in some places it is a rich red or reddish brown. Small phenocrysts of olivine, augite and plagioclase sometimes occur, although the texture is generally fine-grained and non-porphyritic, except on the surfaces of lava flows, where it is vesicular, and on the walls of some dikes, where it is quite glassy. The vesicular rock is often amygdaloidal; that is, it contains secondary minerals filling the rounded holes in the lava which were left by the explosion of gases when the rock was cooling.

A peculiar instance of secondary mineralization occurs about a mile and a half northwest of Rabbit Ears Mountain. A band of chert nodules, which would be called chert concretions if they were in sedimentary rocks, lies directly on a reddish-brown, compact lava flow. The nodules are about one foot in diameter, and the band is at least fifty or sixty feet long. A short distance away another flow of brown vesicular lava, which has been eroded away from its original position above the chert, overlies the compact flow. Along the contact of these beds is another narrow band of chert or chalcedony. The origin and formation of bands of silica of this size in the basic rocks are questions which the limited study of the area failed to answer.

Platy and columnar jointing are common in the basalt. About four and one-half miles northeast of Whiteley Peak, on the southeast border of the map, a small area of basalt occurs between two areas of breccia. The north boundary of the basalt is exposed in the form of a cliff sixty or seventy feet high, on whose face columnar jointing occurs, which rivals "The Devil's

Post Pile" and other similar examples. The columns are generally four- or five-sided figures, varying in size from those whose joint faces are only a few inches across, to those whose faces are two or three feet across. The length of the columns averages about twelve feet, although many are shorter. Whiteley Peak and other exposures also show good columnar jointing.

The vesicular and coarser-grained basalts weather rapidly and form a rich residual soil, which supports abundant vegetation.

BRECCIA

Breccia occurs more extensively than any other igneous rock in the area. Small outcrops are scattered all over the field, but the main exposure, which evidently is only the border of a much larger mass, occurs all along the southeastern border of the area. This rock varies greatly in color and composition. It consists of irregular fragments of scoria, vesicular and solid lava, all of red, black, gray or brown color, imbedded in white, pink or black volcanic ash, gray mud, or calcite cement. The prevailing colors of large masses of the breccia are red, pink and gray. Lava flows, mainly of andesite porphyry, some 150 feet thick, and large fragments of the same rock, occur in the breccia. Volcanic ash appears as lenses and irregularly shaped masses, as well as a cementing material for the lava fragments. From a distance the cliffs of breccia appear roughly stratified, due to the presence of various-colored lava flows, and to the rather sharp changes in the color of the breccia itself.

The poor cementing materials allow the rock to weather very rapidly. The loosened rock, easily washed down by rain and running waters, lies at the foot of the cliff, where it is slowly disintegrated. The large blocks of lava in layers of rock of varying hardness furnish an admirable opportunity for unequal erosion, and the result is a great number of balanced rocks, capped pillars, and other unusual erosion remnants.

The main areas of breccia are shown on the map, but particular attention is called to the fact that in a few cases, as at Rabbit Ears Mountain, small areas of breccia, which are surrounded by basalt flows, are included with and mapped as basalts.

ANDESITE PORPHYRY

Andesite porphyry occurs in rather small amounts in the field. It is generally a dark-colored rock, with phenocrysts of

hornblende, and could hardly be separated from the basalt without microscopic examination. Some of the light-colored forms, however, have large feldspar phenocrysts and are easily distinguished from the basalts, but resemble the dacite porphyry. A more complete description of this and the following rocks will be found in the chapter on "Igneous Activity."

DACITE PORPHYRY

The color of the dacite porphyry is generally a light gray. It contains large feldspar and occasional large quartz grains, which make it easily distinguishable from the basalt.

QUARTZ LATITE

Quartz latite is a white or gray, fine-grained rock, which always contains quartz grains. It weathers quickly, turns brown on the joint faces, and disintegrates into a soft, crumbling, iron-stained mass. Its occurrence is confined to three rather small areas, which are fully described in a later chapter of this report.

SEDIMENTARY ROCKS

These rocks are so fully discussed by Professor Henderson under "Stratigraphy" that only brief descriptions will be given here. All the sediments, with the exception of the Coal Measures and younger rocks, are correlated with the formations east of the Front Range on evidence stated by Professor Henderson.

"RED BEDS"

The Red Beds, which are probably of late Paleozoic age, are very much like the brick-red clays and argillaceous sandstones of the Lykins east of the Front Range. The formation is a distinct valley-maker; it weathers into a soft, red soil, and has, in the areas studied, many of the characteristic features of the Lykins. Noticeable exceptions to this similarity are the absence of the basal limestone, "crinkled sandstone," and the rather resistent red sandstone, all of which are found quite extensively in the Lykins.

MORRISON

This formation is composed of green and gray clays and gray limestones.

Because of the great similarity of these rocks to those of the Morrison in other parts of the state, it was immediately

assigned, in the field, to that formation. It occurs as low, well-defined ridges, both northwest and southwest of Rabbit Ears Mountain. In the latter case a valley between the Morrison and the Archean has been eroded out of the Red Beds, if they ever occurred there, leaving a gently rounded ridge of Morrison between the granites and schists and the Dakota.

DAKOTA

The principal rocks of the Dakota are: a conglomerate which occurs at the base of the formation and reappears at various higher horizons; fine-grained, thick-bedded white sandstone, and thin beds of fire-clay. For some distance south of the Rabbit Ears Ridge the Dakota forms the Continental Divide, but in the northwest part of the area the outcrops are irregular and hard to follow, due in large part to the great amount of basaltic and granitic debris that covers the older rocks.

COLORADO

This group consists of the Benton and Niobrara formations. They are not separated on the map, because few good exposures were found in the field, and it was not possible to establish boundary lines with any degree of certainty. The important rocks are: gray or black clays, shales and limestones. The basal Niobrara limestone, which occurs east of the range, seems to be absent here, but a strong fossil-bearing limestone horizon, near the top of the Benton, takes its place as a low-ridge maker. Fossils are found at many horizons in both formations.

MONTANA

The area mapped as Montana represents only imperfectly the formations usually included in that group; for the Fox Hills was not identified in this area. A great thickness of Pierre shales, with many fossil horizons, occurs. In some places, however, it was not possible to draw an exact boundary line between the Niobrara and the Pierre. The rocks of this formation are mainly gray or black shales and clay, with a strong stratum of friable sandstone, corresponding to the Hygiene sandstone of the Pierre. east of the Front Range. Thin beds of limestone, and lime or clay-iron concretions, are common.

TERTIARY

The Coal Measures of North Park and the same horizons near Whiteley Peak in Middle Park can only be provisionally assigned to the Eocene, as, on account of the short field season, it was not possible to make a detailed study of this formation. The work of the United States Geological Survey in North Park will undoubtedly determine the age of these beds.

For the description of this formation the reader is referred to the discussion under "Stratigraphy."

QUATERNARY

Great blocks and residual soil from recent disintegrated lava flows; boulders, gravel and soil from the granite and schist areas; and gravel resulting from the weathering of the conglomerate in the Coal Measures cover large areas in the Rabbit Ears region. The first two types of debris support a great amount of vegetation, but the disintegrated conglomerate gives a coarse-texture soil, which is not fertile.

Deposits of alluvium occur in considerable quantities along stream channels and on old valley flats.

Moraines and water-worn morainal material are found in many places around Rabbit Ears Mountain, and in the regions to the north and south of this point. The moraines have been so thoroughly water-worn in many places that their original characteristic features have been almost entirely removed.

STRATIGRAPHY

BY JUNIUS HENDERSON

I was able to spend but a short time in the field, with several difficult problems to work out, and consequently my own observations cover only a small portion of the area mapped; so I have freely drawn upon the notes of other members of the party, Messrs. P. G. Worcester, F. F. Grout, A. C. Smith and N. E. Hinds.

The North Central Colorado sheet of the Hayden Atlas[1] exhibits North Park and Middle Park as a very broad syncline, the tilted sedimentary rocks of the east limb resting upon the granite of Medicine Bow Range and Front Range, those of the west limb resting upon the granite of Park Range. The map prepared by the United States Geological Survey under Mr. A. L. Beekly in 1911 (not yet published at the time of the present writing) exhibits this feature more in detail for the North Park section. From the latter map we have drawn a generalized section running from the Rabbit Ears N. 63° E. through North Park.

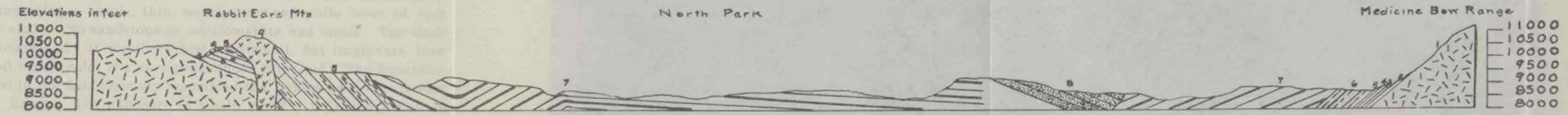
As this syncline is so broad and our work was confined to the west limb and its vicinity, it may be more convenient to think of our area as a great monocline, caused by the uplift of Park Range, dragging the sedimentary strata up along the margin, so that the eroded edges of the older beds are now exposed, with easterly dips, as a narrow fringe next to the granite near the western edge of our map, while the greater part of the map is occupied by much later formations. Beginning, then, at the west, each successive formation carries us farther east.

PROTEROZOIC

ARCHEAN

Archean granites and gneisses of the lower slopes of Park Range occupy the western edge of the map, and doubtless underlie

[1] U. S. Geol. and Geog. Surv. of the Terr., Atlas of Colorado, Sheet XII.



GEOLOGIC SECTION IN NORTH PARK

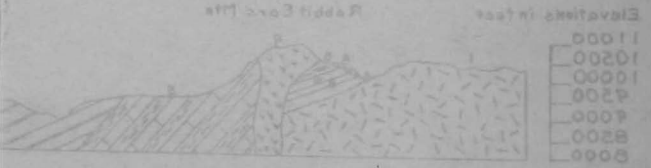
Horizontal Scale 4 miles to the inch

4 0 4 8 miles

Geology from
U.S. Geological Survey
Advance sheet of North Park.
Topography from Hayden.

LEGEND

1	ARCHEAN	Granite and Gneiss
2	PERMIAN?	"Red-Beds"
3	JURASSIC	Morrison
4	— — — — —	Dakota
5	CRETACEOUS	Colorado {Benton / Niobrara
6	— — — — —	Pierre
7	— — — — —	Eocene? Lake and Coal Beds
8	TERTIARY	Sandstones
9	— — — — —	Basalt Lava Flows Ash &c.



the sedimentaries of both parks, deeply buried, reappearing a long distance to the east of the area mapped.

PALEOZOIC (?)

The age of the small exposure of "Red Beds" next above the granite-gneiss complex cannot be stated with certainty. The best exposure was examined by Mr. Worcester, who summarizes his notes as follows:

> Exposure about a mile and a half west of Rabbit Ears Pass. At south end of exposure it is not possible to determine dip, strike or thickness of the formation, but three-quarters of a mile farther north the dip is 20° east, strike north and south. Here the beds consist of thin-bedded brick-red shales, including a single, thin, mottled red-and-white layer of very friable sandy shale. No sandstone or conglomerate was found. The shale is mostly fine-grained. It weathers first into small, flat fragments, then into a fine soil whose color is a very pronounced brick-red. The formation as it appeared in the field strongly resembled the Lykins as it occurs east of the Front Range. The exposure is small, about a mile and a half in length, and only a few hundred feet wide in its widest place.

Both the Hayden map and the 1911 map of the United States Geological Survey show Red Beds reappearing north of the Rabbit Ears Ridge—a region very rough, swampy and well covered by heavy timber, much of which is fallen, making geological work very difficult. Mr. Worcester spent considerable time in that vicinity, searching for the formation, without success, and I traversed the valley from the upper Colorado formation to the granite, without finding any trace of it. Hence it is omitted from our map. In places the Morrison is almost in contact with the granite, while in other places small areas of granitic debris intervene, which may or may not be underlain by Red Beds. As the formation rests upon an eroded granite surface, it is probable that it varies considerably in thickness. Professor Grout, who visited the exposure discussed by Mr. Worcester, and also found others farther south, says:

> The main body of the formation is apparently quite uniformly red. There are some red bands of much smaller dimensions high above this large mass, which can hardly be classed with it, though similar in the hand specimens. The best estimate which could be made of the thickness was at the south of the area, where it is thought to be 160 feet.

East of the Front Range the Red Beds consist of a basal series of strong red conglomerates and coarse sandstones, aggregating several hundred feet in thickness (Fountain formation),

overlain by a fine, uniform, resistant red-and-pink sandstone (Lyons formation), which in turn is overlain by the yielding, brick-red shales of the Lykins formation, also several hundred feet in thickness, upon which rests the Morrison formation.[1] The Fountain and Lyons formations, though once supposed to be Triassic, have now long been known to be late Carboniferous (Pennsylvanian). Fossils recently discovered well up in the Lykins show that at least half of that formation must be assigned to either late Pennsylvanian or Permain, leaving the upper part in doubt; but as the lithological character of the formation above and below the fossils is very much the same, the natural supposition is that the whole formation is pre-Triassic, though of this one cannot feel at all certain. The overlying Morrison is considered late Jurassic, or, according to some authors, even Cretaceous. Therefore the narrow space intervening between the mid-Lykins fossils and the Morrison must represent all of Triassic, at least part of Jurassic, and probably at least part of Permian time. The thickness of the strata is not sufficient to indicate that they represent continuous deposition through those periods. If the strata assigned to the Lykins (all from Lyons to Morrison) are, as they appear to be, a single formational unit, representing an unbroken period of deposition, then, the lower part being Permian or earlier, the conclusion that the upper part also is Permian or earlier is almost irresistible.

In the Rabbit Ears region the stratigraphic relations and lithologic characters of the limited exposures of Red Beds indicate that the formation is the equivalent of the upper Lykins; hence it is tentatively assigned to the Paleozoic era.

MESOZOIC

TRIASSIC

No known Triassic is found in this area, unless all or part of the Red Beds hereinbefore considered should be assigned to that age.

JURASSIC

Morrison.—West of Park Range marine Jurassic beds are found, containing *Pseudomonotis curta* and *Belemnites densus.* In our area, which is east of Park Range, no such strata were found, and it is likely that they do not exist. In this respect

[1] N. M. Fenneman, Geology of the Boulder District, Colorado, U. S. Geol. Surv., Bull. No. 265. Junius Henderson, "The Foothills Formations of North Central Colorado," First Report of Colo. Geol. Surv., pp. 144-188.

the region is to be likened to that east of Front Range. Small exposures of the Morrison formation, usually considered upper Jurassic, though possibly it is lower Cretaceous, are found at intervals between the granite and Red Beds to the west and the Dakota to the east, forming in places a minor ridge, due to the resistance of the harder strata. The general character of the formation is the same as east of Front Range and elsewhere in Colorado, and deposition probably occurred in fresh water, as usual, though we found no fossils, and so have no direct evidence to support this probability. Mr. Worcester's summary of notes on the exposures northwest of the Rabbit Ears is as follows:

About a mile and a half northwest of Rabbit Ears Mountain is a small area of Morrison directly under Dakota sandstone and conglomerate. The rock is a fine-grained, green shale or clay, somewhat calcareous. No sandstone was found in it and no fossils. Thickness is indeterminable, but evidently twenty feet or more. The extent is probably greater than mapped, but the whole is so thickly covered with debris that it is impossible to map a larger area here. In all probability it underlies the Dakota all along the ridge and would appear all along the basal part of the Dakota bluff, if not covered by the basaltic debris. The dip is 21° east.

Another larger area of Morrison occurs about half a mile north of this first exposure. It consists of green and gray shale, with at least two strata of limestone. The one at the base is probably six or eight feet thick and the upper one half as thick. No sandstone was found and no fossils. The shales are calcereous. Exposures are very irregular, and a large part of the area is covered with basaltic debris, apparently the remnants of a great lava flow. Dip and strike cannot be determined accurately, but general dip is easterly and strike northerly.

Professor Grout, who mapped the Morrison areas to the south of Rabbit Ears, furnishes the following notes:

Small exposures of green shales and sandy shales are the only signs of these beds along most of the area between Red Beds and Dakota. The very characteristic green shale forms a float rock that identifies the formation lithologically with that east of the front range. At various points a minor hog-back develops from some hard layer in the formation. Where Muddy Creek crosses the formation at the south, exposures are good in a cliff below the Dakota, and the most characteristic thing is a rapid alternation of shales, sands and marls, usually light green and gray, but with bands of darker color. A thin band of solid limestone occurs, and some thin layers are as red as the Red Beds below, and quite indistinguishable therefrom in hand specimens. The red color of sandy shale in some cases seems to be due to oxidation, as cores of green shale may be found in the centers of the red blocks. The estimated thickness at the south is 600 feet, but folding makes it a little uncertain. This large thickness of Morrison is determined almost entirely on lithologic grounds.

East of the front range only an average of about 200 feet is found, while the Dakota is much thicker there than in our area. Since part of this formation is sandy, it may be that the line is drawn too high and that the red and green shales are in the Dakota, but in Rio Blanco County the Morrison is reported to be 800 feet in thickness.

East of the Front Range an unconformity is known to separate the Morrison from the base of the Dakota, which is usually a conglomerate. Northwest of Rabbit Ears a conglomerate is found at the base of the series mapped as Dakota, which is immediately underlain by the shales having the characteristics of the Morrison east of the Front Range. This conglomerate also occurs at the south of our area, and probably all along the western part of our map, though usually covered by debris. It therefore seems much more likely that, if any strata are erroneously included in the above estimate of thickness, they would be the lower strata. The actual exposures of shales northwest of Rabbit Ears which can be safely assigned to the Morrison would not exceed sixty feet in thickness. Fossil dinosaur bones are reported in the southwestern part of our area.

CRETACEOUS

Dakota?—Resting upon the Morrison are beds which from stratigraphic relations and lithologic characters are believed to be equivalent to the so-called "Dakota," which constitutes the outer hog-back of the eastern foothills of the Front Range, from the Denver basin northward. The coarse conglomerate at the base suggests an unconformity, but lack of good exposures of the actual contact with the Morrison, as usual, prevents the determination of that question. As is the case east of the Front Range, the formation is here tripartite, with a hard sandstone-conglomerate zone at the base, a medial zone of clays and softer, thinner-bedded sandstones, and an upper massive sandstone zone. Owing to the hard sandstones and conglomerates, it is a ridge-making formation, and, owing to easterly dips, the ridge in a few places presents west-facing escarpments, though, because of the mantle of debris and the heavy forest-covering, very few good exposures are found. A Dakota ridge which extends southward from the west end of Rabbit Ears Ridge forms the Continental Divide, separating the North Platte drainage from Pacific drainage, where the Kremmling-Steamboat wagon-road crosses the divide in passing from North Park westward. North of this road the ridge shows a very slight tendency to split, as it does so

frequently from Boulder northward. The bluffs northwest of Rabbit Ears and west of Baker Mountain also divide into two benches, for the same reason—the existence of the softer medial zone, intervening between the hard sandstones of the upper and lower members of the formation. Mr. Worcester thus describes the best exposure of the formation in the mapped area:

It occurs in a strip nearly two miles long and a quarter of a mile wide, extending northeasterly from a basalt bluff a mile and a half northwest of Rabbit Ears Mountain. A rough sections follows.

1. Conglomerate at base, made up largely of green, gray and white chert grains, with white quartz grains and some iron.
2. Thin bed (one foot?) of fine white sandstone.
3. Very glassy, flint-like quartzite, very hard, fracture conchoidal, 2 ft.
4. Fine white sandstone, 1 ft.
5. Conglomerate like No. 1, irregular thickness.
6. Sandstone, white, rather soft and friable.
7. Fire-clay, gray to black, 5 to 10 ft.
8. Sandstone extending to top of ridge.

Total thickness, measured with aneroid and correction for dip estimated, 200 ft.

The dip varies somewhat, but the average is from 20° to 22° east.

The strike does not conform to the outcrop. The outcrop is N. E., while the strike is nearly due N.

Near the northwest corner of the sheet is another area of Dakota, nearly surrounded by morainal material, but in contact with the overlying Colorado formation on the east. The thickness and general characteristics are the same as at the locality first described. The west exposures of both these areas form sharp, steep cliffs in places, but in other places they are much weathered and vegetation and debris have formed gentle slopes. In this second area I did not find any quartzite. Conglomerate, clay and rather soft sandstone were the only rocks found, and their relations are practically the same as outlined above.

Professor Grout furnishes the following notes:

The sandstones form a hog-back, as they do in most of the foothill region. The ridge can be traced nearly across the areas studied, but has two interruptions—one where the Rabbit Ears lava covers it, and one south of Baker Mountain, where some sharp folds and probably some faults spread out the outcrop into a series of low ridges and valleys, containing several lakes. The basal conglomerate is coarse and furnishes a large amount of debris on the slope toward the valley of the Red Beds. Flints and quartz pebbles are common. South of Baker Mountain and south of the area of complex folding the cliff of the regular hog-back exposes a quartzite layer about fifteen feet thick in the midst of the main sandstone. This is local, though other localities may have other similar developments. Thinner quartzite beds lie above and below it. They may be due to the action of hot water which resulted from near-by igneous activity. A series

of shaley bands appear in several exposures and in the southern part of the area become a persistent three-foot bed of black fire-clay. The resistant sandstone as mapped is about 180 feet thick.

Marvine[1] combined the Red Beds, Morrison and Dakota, estimated their thickness at 1,200 feet, and tentatively referred them to No. 1 of Hayden's division of the Cretaceous east of the Front Range, which is the so-called "Dakota." In this he was mistaken, as the Morrison is clearly recognizable, and the Red Beds are quite probably the same as the upper Lykins east of the range.

The upper sandstone in places is strongly ripple-marked. Both northwest of Rabbit Ears and west of Baker Mountain we found many leaf impressions, but they are so poorly preserved as to make satisfactory identification impossible; so no evidence was obtained which throws any light upon the age of the formation. A long, slender species, resembling in outline *Ficus proteides* Lx., but displaying no venation except the mid-rib, predominates at the Baker Mountain locality. From the lithological characters, and the fact that the formation immediately overlies the Morrison and immediately underlies the Benton shales, it is likely that it represents the same period of time as that of the formation called Dakota east of the mountains, but as yet no satisfactory conclusion has been reached concerning its age—a matter more fully discussed elsewhere.[2]

Benton.—The several divisions of the Colorado and Montana groups (Benton, Niobrara, Pierre and Fox Hills) in the area mapped are not easily recognizable as lithological units, but several definite paleontological horizons are found which may be correlated with similar horizons in those formations. The difficulty of definitely separating these formations lithologically suggests that perhaps they should be correlated with the Mancos to the west of Park Range, but this is partly due to lack of exposures, and practically every good exposure may be assigned, upon paleontological evidence, to one or another of the formations recognized to the east of the Front Range; so for convenience they may be thus treated. In our area the only really good section of the Cretaceous as a whole is along the creek south of the Martin ranch, and there the portion of the section where

[1] Seventh Annual Report, U. S. Geol. and Geog. Surv. Terr. (Hayden Survey), for 1873, pp. 154-155, 178.

[2] Junius Henderson, "Foothills Formations of North Central Colorado," First Report Colo. Geol. Surv., 1908, pp. 172-176, citing various publications on the subject.

the base of the Niobrara would be expected is covered by debris. The Niobrara-Pierre contact is by no means so definite as it is east of the Front Range. The Benton, as usual, consists chiefly of partly calcareous black or dark-gray shales and limestones. Its thickness could not be determined because of lack of good exposures, but is likely from 300 to 400 feet. The only fossils found are unidentified teleost scales and bones, except in a rather thin-bedded, sandy-looking limestone, from ten to fifteen feet or more in thickness, which is probably near the top of the formation here, as it certainly is at Kremmling. From the hardness of this limestone it is a ridge-making horizon in many places, the underlying shales occupying a valley between this ridge and the Dakota ridge. This limestone contains great numbers of *Inoceramus fragilis* H. & M., while *Prionocyclus wyomingensis* Meek and *Scaphites warreni* M. & H. are common, a few specimens of *Baculites* cf. *gracilis* Shumard were found, and one *Anomia* cf. *subquadrata* Stanton. The absence in this vicinity of any definitely recognizable outcrops of the massive, hard limestone, so characteristic of the base of the Niobrara east of the Front Range, makes the exact position of this upper Benton fossiliferous limestone uncertain, the space between it and the *Ostrea congesta* horizon in the Niobrara being everywhere in this vicinity pretty well covered by debris, but exposures of Niobrara and Benton at Kremmling throw some light upon the subject.

Niobrara.—The absence of outcrops of the usual hard basal limestone in this region makes it seem quite possible that it does not occur, perhaps through local differences in sedimentation conditions. It may be, however, that it does occur, but is too weak and soft to resist erosion and form recognizable outcrops. A very small exposure of limestone about a mile south of Muddy Pass, west of the Kremmling-Steamboat wagon-road, containing a few fragments of *Ostrea congesta* Conrad, is perhaps a portion of this limestone. At Kremmling, about twenty-five miles farther south and in the same sedimentation basin, the basal limestone is well developed, containing the characteristic *Inoceramus deformis* Meek. A good exposure occurs a mile or two east of Muddy Creek, at the south base of Lower Muddy Butte—a prominent igneous mountain north of the town. Only a few feet below this is the fossiliferous limestone which we considered near the top of the Benton farther north. Above the basal limestone of the Niobrara here are calcareous shales, including thin-bedded limestones composed chiefly of large, flattened *Inoceramus* sp.,

covered with *Ostrea congesta* Conrad, exactly as found at the same horizon from Boulder northward. The *Ostrea congesta* limestones, in turn, are overlain by what has in the Boulder district been aptly termed "paper shale," because of the extreme thinness of the separable strata. These same conditions are found at Sulphur Springs, up the Grand River from Kremmling. The formation is well exposed west and southwest of Lower Muddy Butte, where the creek cuts through it, the *Ostrea congesta* limestones forming a bluff east of the creek. This *Ostrea congesta* horizon, with its characteristic fossils, is found exposed at various places in the area mapped, especially in the vicinity of the Martin ranch. A mile or so south of Muddy Pass, west of the wagon-road, a soft, black limestone or very calcareous shale exposed in the creek bank, at what I considered about the middle of the formation, contains numerous *Inoceramus deformis* Meek, much flattened and distorted by pressure, but quite recognizable. A similar condition was found north of the Rabbit Ears. The Niobrara, on the whole, weathers white. Fish scales and bones are common.

Pierre.—A very large part of the area in the valley of the Muddy, which is designated "Uinta (Tertiary) Lake Beds" on Sheet XII of the Hayden atlas, is clearly Pierre Cretaceous, though often with a slight covering of debris. At every good exposure *Baculites ovatus* Say or *B. compressus* Say were found, often with other cephalopods and *Inoceramus*. At Kremmling the great cliff, with several terraces back of it, exposes hundreds of feet of shales and sandstones containing Pierre fossils, spreading over several square miles, where the Hayden atlas has mapped only "Lake Beds" and "Colorado." Time did not permit a thorough examination of all the valley between Kremmling and the southern edge of our area, but at every good exposure examined in traveling up the valley in the area mapped as "Lake Beds," we found marine Cretaceous fossils. Marvine[1] mapped his "Lake Beds" and his alluvium together, without any attempt to differentiate them, but in his section south of Upper Muddy Butte (Whiteley Peak) he indicates only lake beds, ignoring the alluvium. The area thus mapped by him is largely a superficial sheet of alluvium and loose debris, resting upon Cretaceous shales, and presents many large exposures of the latter which he does not indicate on his map. We saw nothing which we could call

[1] Seventh Annual Report, U. S. Geol. and Geog. Surv. Terr. (Hayden Survey), for 1873, fig. 8, opposite p. 155. See also his several sections on Plate III, opposite p. 192.

lake beds anywhere in the region, and from Whiteley Peak northward, where our search was somewhat thorough and where a large area of Uinta is mapped in the Hayden sheet, such beds do not occur. The Hayden sheet ignores the alluvium of Marvine's description and map, putting it all in as lake beds and definitely assigning it to the Uinta. A careful reading of Marvine's description of his lake beds (pages 157, 178, 179, 181 of his report), in the light of our own observations in the upper Muddy valley, leads to the conclusion that he considered the numerous stream terraces cut in the approximately level Cretaceous shales, lake beds. These terraces, in most instances where we examined them, have their flat or slightly sloping tops covered by soil deposited by the streams while working at higher levels before the beginning of the last cycle of erosion, or by coarser and more angular outwash from the adjacent hills brought down by storm waters. Marvine (page 157 of his report) confines his lake beds to the lower basins, remarking that they are not found at higher levels. Whatever may be true of the lower Muddy valley, not closely examined by us, certainly such lake beds must be eliminated from the lower basins of the map in the southern part of our area. If we have any lake beds, they are in the formation designated "Laramie" by Marvine and the Hayden atlas.

A persistent sandstone, overlain and underlain by hundreds of feet of black shales, is found in the middle Pierre, exposed at many places in the valley of the Muddy, much as the Hygiene sandstone occurs at approximately the same horizon in the Boulder district. Typical Pierre concretions are common, usually seamed with calcite and containing only *Baculites*, but *Avicula linguiformis* was found in several places, and south and southeast of Whiteley Peak the following species were found:

Chaetetes ?? dimissus White
Serpula markmani Henderson
Nucula obsoletistriata M. & H.
Inoceramus sagensis Owen
Avicula linguiformis E. & S.
Ostrea cf. patina M. & H.
Syncyclonema rigida H. & M.
Crenella elegantula M. & H.
Lucina occidentalis Morton
Thetis circularis M. & H. ?
Tellina scitula M. & H.
Anchura nebrascensis E. & S.
Ptychoceras crassum Whitfield
Baculites compressus Say
Baculites ovatus Say
Scaphites nodosus quadrangularis M. & H.
Heteroceras cochleatum H. & M. ?
Ancyloceras sp.

In a baked shale overlying an igneous sheet which forms a terrace south of Bear Mountain we found *Inoceramus sagensis*,

Baculites sp. and *Placenticeras* sp. North of the West Grizzly, east of the Rabbit Ears, we found young *Baculites* which exhibit the initial whorls.

It is probable that the Pierre at the southern edge of our area is from 6,000 to 7,000 feet in thickness. Farther north the later fresh-water beds containing many net-veined leaves, and including coal beds, overlap the slightly dipping Pierre strata, and in the area northeast of Rabbit Ears this overlap is so extensive that the fresh-water beds rest directly upon Colorado shales. The evidence indicates that the Pierre is not missing there, but is merely covered by the transgression of the later formation. In the bluffs just north of Whiteley Peak, and again south of that peak, the fresh-water strata would, if extended westward as they originally were, cover the Pierre. No exposures of strata definitely assignable to the Fox Hills formation were found by us.

The thoroughly weathered Niobrara is very light-colored, almost white, while the weathered Pierre is brown, gray or dull yellowish. On the map no effort is made to distinguish Benton from Niobrara, because of lack of good continuous exposures, the two being combined under the name "Colorado;" and for the same reason the boundary between the Colorado and the Montana is only approximate.

CENOZOIC

TERTIARY

Overlying the Pierre, and separated from it by an unconformity which is probably both angular and erosional, is the formation which King called the "North Park Group," Marvine called the "Lignitic," and which is designated "Laramie" on Sheet XII of the Hayden atlas of Colorado. This formation is of economic importance, because it contains the coal beds of North Park and Muddy Pass. It seems that two distinct formations in North Park and Middle Park have been included under the above names. These beds were first described by Hayden[1] after a rather hasty examination, especially at Sulphur Springs, and more fully described for Middle Park by Marvine.[2] Marvine included in his Lignitic everything above the unconformity, giving it a thickness of 5,500 feet. In 1874 he worked in North Park, but owing to his death his report upon that region was not completed.

[1] F. V. Hayden, Preliminary Field Report of the United States Geological Survey of Colorado and New Mexico, for 1869, pp. 81-86.

[2] Seventh Annual Report, U. S. Geol. and Geog. Survey. Terr., for 1873, pp. 156-192.

The formations in the vicinity of Sulphur Springs have been more recently re-examined by Cross,[1] who correlated the post-Cretaceous of that vicinity with the Denver beds, upon both lithological and paleontological grounds. It is not at all certain, however, that the formation in Mount Bross, at Sulphur Springs, is the chronological equivalent of the strata which contain the coal at Muddy Pass and in North Park.

By general agreement, the name "Laramie" is confined to the fresh-water and brackish-water beds resting conformably upon the latest marine beds. The fresh-water beds of Sulphur Springs and the coal formation of North Park are separated from the marine beds by a decided unconformity, which is perhaps best shown at Sulphur Springs, as pointed out by both Marvine and Cross in their descriptions and figures. Within the limits of our map there are few exposures of the fresh-water beds resting directly upon marine beds where the dips may be measured to furnish direct and positive evidence of the unconformity, but so many differences of dip are noticeable in exposures not far distant as to leave no doubt of the fact, and in a few places the unconformity is very clear. For example, Professor Grout reports that "about a mile east of Whiteley Peak the coal formation overlies the Pierre in a cliff where dip and strike can be measured, the former dipping 10° N. 70° E. (?), Pierre dipping 20° S. 80° E." The same thing is indicated by the fact that the Pierre shales, everywhere dipping markedly to the east, northeast or southeast, are transgressed by the nearly horizontal fresh-water beds until in the northern part of the area mapped for the present report the latter partly covers the Colorado. It is clear that the Pierre and Colorado shales were tilted in varying degrees before the fresh-water beds were deposited, and, as would be expected, some erosion took place in the interim, though positive proof of this was difficult to find in our area. In the north slope of a small valley, just north of West Grizzly Creek, east of Rabbit Ears Mountain, is a bluff of coarse, micaceous, stream-laid sandstone, very irregularly bedded, occupying a valley which had been eroded in the Middle Pierre. Though entirely isolated, presumably by erosion, it is just like portions of the fresh-water beds, a short distance to the east, which evidently once covered the whole region, but have been removed by erosion. If this de-

[1] Whitman Cross, "Post-Laramie Deposits of Colorado," Amer. Journ. Sci., Vol. XLIV, pp. 27-31, 1892; "The Post-Laramie Beds of Middle Park, Colo.," Proc. Colo. Sci. Soc., Vol. IV, pp. 192-213, 1892.

posit is in fact a remnant of the coal formation, as seems probable, it shows just such erosion as would be expected to follow the retreat of the sea and the tilting of the shales before the deposition of the coal formation.

Professor Grout, who spent more time upon the coal formation than any other member of our party, furnishes the following account:

> The lowest member deposited is usually a fine white sandstone, containing a large amount of muscovite, apparently secondary, but above this are many variations, several of which are noteworthy. A large portion of the formation is coarse, granitic debris (arkose). Coal occurs usually in the sandstone. The shales are also micaceous. A bed of conglomerate occurs near Whiteley Peak and Diamond Mountain, with rounded pebbles up to two or three inches in diameter, many of which are porphyry. Not only does the formation vary in petrological characters in short distances, but also in thickness, which can hardly be accurately estimated. At the south there is probably only 300 feet exposed, but at the north there may be considerably more. The coal seams vary from one to six or more in a distance of two or three miles. In our area most of the coal is thin, sandy and impure, none being mined successfully. A coal seam about sixty feet thick is being worked north of our area.

As erosion has been very active in our area, and the coal formation is the highest, and therefore fully exposed to extensive denudation, it is difficult to say how thick the formation may have been before active erosion began. The source of the porphyry fragments in the conglomerate at Whiteley Peak is unknown to us. It is quite possible that the deposit from which they were derived is buried by the upper beds of the coal formation.

In the bluff north of Whiteley Peak the lowest exposure above the talus is a very massive, white sandstone, partly oxidized to yellow in places, bedding planes seldom showing, containing many concretions impregnated with iron, which in general appearance reminded me of the basal Laramie sandstone in the Boulder district. These concretions weathered into cavities. Well up in this sandstone I was surprised to find *Halymenites major* Lx., a supposed alga which is found associated with marine and brackish-water faunas at many localities in Colorado, in Fox Hills, upper Mancos and Laramie strata, a small form occurring also in the Pierre near Fort Collins and in the Benton in Huerfano Park; but I have never seen it associated with freshwater or land species. Above this massive sandstone are shales and softer sandstone strata, not well exposed on account of their

crumbling character, but they may reach a thickness of twenty-five feet or more. They in turn are overlain by a thick bed of coarse conglomerate, which contains the porphyry fragments before mentioned. At the top of the bluff is a curly, irregularly bedded sandstone, containing numerous poorly preserved leaves of land plants. Some very fine leaves were found just beneath the conglomerate at the south end of the bluff, including *Juglans rugosa* Lx., *J. thermalis* Lx. and *Plantanus nobilis* Newberry, all of them Eocene species. The lack of definite bedding planes in the lower sandstone and conglomerate, the poor exposurees of the soft sandstone-shale zone, and the irregular bedding of the upper sandstone made it difficult to obtain dips which may be depended upon; so I am not certain whether there is any difference in dip between the lower and upper strata. If so, it is slight. The presence of *Halymenites* at about the middle of this bluff leads to the query as to whether there is not here a little of the true Laramie. If so, it should be separated from the overlying beds by an unconformity. The contact of the massive sandstone with the underlying shales of undoubted marine origin is covered. We cannot, therefore, ascertain whether it is an unconformity, the nearest exposures of the shale being some distance to the west, so that differences in dip would not be significant. With the known unconformity between the North Park coal formation and the Cretaceous shales, it would not be surprising to find a few remnants of the Laramie. It would be expected that, as the subsidence of the sea bottom ceased and emergence from the sea began, the transition to land conditions would be marked by low-lying shore and swamp conditions, with fresh-water and brackish-water lagoons, during which more or less Laramie would be deposited, as east of the Front Range. Then, upon the tilting of the Cretaceous formations, a period of erosion would likely follow, during which part or most of the Laramie would be removed, leaving remnants here and there, before the deposition of the fresh-water formations would begin.

A few fragments of shells from the fork of Arapahoe Creek, two miles N. 30° W. of Haystack Mountain, appear to be *Corbula* rel. *undifera* Meek, associated with fish scales and a single fragment of *Goniobasis* ? sp. If *Corbula* really does occur, it may indicate that local folding and erosion have brought some long-buried Laramie to the surface, but the fossils are altogether too imperfect to form the basis for any definite conclusion.

Mr. Ellsworth Bethel, of Denver East Side High School, found a number of *Vivipara paludinæformis* Hall, an Eocene species of fresh-water snail, near the Riach coal mine, northeast of Rabbit Ears.

Hayden in 1874[1] published a list of fossil plants purporting to have been obtained in Middle Park, which list must be almost ignored, for the reason that a considerable part of the species reported appear to have been obtained elsewhere in later formations, instead of in Middle Park, as Cross has shown. Cross himself records[2] the following species from the "post-Laramie" of Middle Park, chiefly from the forks of Kinney Creek and Mount Bross, at Sulphur Springs:

?*Pteris pennæformis* Heer.
P. pseudopennæformis Lx.
Asplenium erosum Lx. sp.
Aspidium polypodioides (Ett.) Heer.
Woodwardia latilobia Lx.
Anemia subcretacea (Sap.) Gard. & Ett.
Sabalites campbellii Newb.
Populus arctica Heer.
Juglans rugosa Lx.
J. thermalis Lx.
J. denticulata Heer.
Plantanus marginatus Lx. Heer.
P. raynoldsii Newb.
Ficus spectabilis Lx.
Laurus brossianus Lx.
Cinnamomum polymorphum Al. Br
Cornus impressa Lx.
C. studeri Heer.
?*C. acuminata* Newb.
?*Aralia notata* Lx.
?*Leguminosites arachioides* Lx.
Cinchonidium ovale Lx.
Cissus lobato-crenata Lx.
Vitis (Cissus) olriki Heer.
V. (Cissus) tricuspidata Heer.
Rhamnus goldianus Lx.
R. cleburni Lx.
Zizyphus meekii Lx.

Four of the determinations were considered doubtful, three were known only from that locality, and, of the remaining twenty-one, at least twelve occur in the Denver beds.

Of the above species, *Juglans rugosa* and *J. thermalis* I have recognized among the fossils from the bluff north of Whiteley Peak, associated with fine large leaves of *Plantanus nobilis* Newberry.

So far as I am able to tell from my own limited observations and the notes which have come to me from other members of our party, we found none of the marls of the later Eocene which are said to rest unconformably upon the coal formation in the great basin of North Park, though there may be some in the northeastern part of our area.

[1] Seventh Annual Report, U. S. Geol. and Geog. Surv. Terr., for 1873, p. 81.
[2] "The Post-Laramie Beds of Middle Park, Colo.," Proc. Colo. Sci. Soc., Vol. IV, p. 25.

Volcanic Breccias.—Resting upon the coal formation of our area are volcanic breccias in many places, which are more fully discussed in another part of this report. Their main area is to the southeast.

A fragment of a jaw of *Parahippus,* found thirty feet beneath the surface, in red soil, at the Stein ranch on Troublesome Creek, and recorded by Professor Cockerell,[1] indicates the probable existence of Miocene at that locality, but none is known within our area.

QUATERNARY

Moraines.—Extensive glacial moraines occur in the northwest part of our area. They may be observed to advantage just west of the Continental Divide, north of the Kremmling-Steamboat road where it passes from the southeast corner of North Park over the divide. In the area north and northwest of Rabbit Ears Mountain they are more difficult of access because of the roughness of the country, the fallen timber and the morasses. The moraines consist almost entirely of granitic debris, which, in connection with their positions and contours, plainly indicate that, as would be expected, the ice formed upon and moved from the high granitic mountains to the northwest. The absence of basalt from the moraines naturally raises the question whether the igneous activity which brought in the basalt was post-glacial —a matter not easy to determine definitely from the evidence now at hand, though my opinion is that the basalt is much older than the glaciation. Some small deposits of material much resembling the morainal material are overlain with lava in such a way as to show that the latter is older than the former, but such deposits may quite as well be pre-glacial water-laid gravels. There is no evidence which would indicate that the glaciation of this region was earlier than that of other portions of the Colorado Rockies. Indeed, from the present condition of the moraines I should be inclined to assign them to the middle or later period of glacial extension, rather than to the earliest. In other portions of our area the evidence of glaciation is not clear. The occurrence of numerous small lakes and other topographic features in one or two places, as near the foot of a very prominent cliff near the northeastern corner of our area, suggests the action of glaciers, but may be quite as easily accounted for on other grounds, and my opinion is that they are not of glacial origin.

[1] T. D. A. Cockerell, "A New Locality for Miocene Mammals," Science, N. S., Vol. XXVIII, p. 683, 1908.

Debris.—Many areas are mapped as debris which are quite distinct from the morainal deposits. It varies greatly in coarseness, angularity and composition, much of it consisting of basalt fragments, much of it of granite fragments, the latter possibly largely derived from the weathering of the Tertiary conglomerates. On the hills and ridges the debris areas support conifer and aspen forests, often dense, and their outcrops are usually found only where streams cut through the harder portions of the formations. Where the debris-covered areas were not more than a quarter of a mile wide, and the sediments on each side were uniform in character and dip, it was usually considered safe to map them across the concealed area, but lavas and igneous breccias were not mapped much beyond actual exposures. For example, Professor Grout believes that in the headwaters of Arapahoe and Indian Creeks the breccia with a flow of porphyry in its midst probably nearly encircles the valleys, but debris covers the outcrops.

The flat lands along the bottoms of the valleys are generally covered by alluvium to a depth of several feet. Two or three small patches of conglomerate were observed well up the slopes of the eroded Cretaceous shales, which may be quaternary, though it is more likely that they are remnants of Tertiary conglomerates. The outcrops were too insignificant in size to represent on the map.

STRUCTURE

FOLDS AND FAULTS

In the sediments there are several folds and a few faults. An anticline or dome, slightly broken, near the southwest part of the area, brings up an inlier of Morrison along Muddy Creek. A similar structure brings up a large area of Montana shales in the midst of the coal formation east of Whiteleys Peak. Except for the minute crumpling of the shales at igneous contacts, the sharpest folds seen were those in the Dakota sandstone at the lakes south of Baker Mountain. Here is a series of sharp folds, with dips as high as 80°. Probably some faulting accompanies these folds in the sandstone.

Besides the small fractures due to sharp folds, there is only one clear case of faulting mapped. This is at the creek southwest of Ironclad, where a ravine cuts through a gorge with vertical banks, and shale appears in one bank and sandstone in the

other. The throw is not extreme, as both banks are members of the coal formation.

RESUMÉ OF HISTORICAL GEOLOGY

We have no evidence throwing any light upon the pre-Permian geology of the region. The earliest sedimentaries—the Red Beds—are believed to be Permian or possibly Triassic, about equivalent to the upper Lykins, and are probably marine. If not Triassic, then the Triassic was here a period of non-deposition, or the deposits were eroded away before the next deposition period. The marine Jurassic is also missing. The Morrison epoch, generally considered late Jurassic, was a period of land and fresh-water conditions, doubtless, as elsewhere in the Colorado Rockies. If the Morrison is Jurassic, then probably the Lower Cretaceous is entirely missing. The so-called Dakota is probably upper Cretaceous and was mostly deposited by fresh water, as shown by the character of the sediments, taken in connection with the fossil leaves of land plants, fragments of which are numerous, but undeterminable. Then followed a long period of marine deposition upon a subsiding sea bottom, during which in the neighborhood of 7,000 or 8,000 feet of fine shales, limestones and a little fine sandstone were deposited, representing Benton, Niobrara, Pierre, and probably Fox Hills time. Then the sea retreated. Whether any Laramie was deposited during the transition from marine to land conditions is not certain, but, if so, most of it was probably eroded away before the next series of strata was deposited. In the emergence of the land from the sea, the Cretaceous shales were more or less tilted so as to assume easterly dips. In early Eocene time the sandstones, shales and conglomerates containing the coal beds of North Park were deposited, probably by aggradation, such as is now being carried on in many places by streams working back and forth over broad areas, as many of the deposits of the West which were once considered lacustrine are now believed to have been deposited. Subsequent to the deposition of these beds, extensive dikes and sheets of lava were intruded, which through their resistance to erosion now form the prominent knobs, ridges and mountains of the area. Volcanic activity was accompanied by local folding. During Pleistocene time glaciers formed on the mountains to the northwest and swept down into the northwestern portion of our area. Prior to this time, erosion had been active and had formed

valleys for the accommodation of the glaciers. The work of aqueous and subaerial erosion in tearing and grinding to pieces the formations deposited during Mesozoic and early Cenozoic time, as well as the Archean granites, is still in active progress. The folding which began at or just after the close of Cretaceous time, probably continuing for some time into the Tertiary, gave to North and Middle Parks their present basin-like appearance, tilting the sedimentaries up along the flanks of the uprising mountain ranges which now surround them.

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IGNEOUS ACTIVITY AND IGNEOUS ROCKS

BY F. F. GROUT

ARCHEAN

The earliest igneous activity recognizable in the region resulted in acid and basic intrusives of some variety in the Archean complex. Whether or not the gneisses and schists now forming a small portion of the surface exposure of Archean are of igneous origin, it is certain that the granite and pyroxenite intruded into them were the results of profound and extensive volcanism. But while varying in petrographic detail, the Archean has no clearly marked division which it is practicable to represent on the map. Along the contact of more recent sediments with the Archean, intrusive granite is the most abundant Archean rock, and for several miles along Muddy Creek the granite forms a belt nearly a mile wide before gneisses or schists are at all prominent. The basic rocks form much smaller masses.

SCHIST

The schist is usually dark and decidedly variable, and the planes of schistosity show no regular dip. In the field nearly all the large exposures show quartz, hornblende, biotite, muscovite and epidote. The microscope reveals also feldspars—both orthoclase and plagioclase—augite, magnetite and actinolite. Garnets were found in the gravels of several streams, and were probably derived from the schists.

GRANITE

The granites are a common type, of pink to red color. They vary from fine to medium grain, and contain inclusions of schist, aplite and pegmatite, and are cut by dikes. Porphyritic phases are common. The microcline phenocrysts show Carlsbad twinning, and sometimes attain a length of two inches. Contacts with the schist are extremely intricate wherever seen.

The minerals of the granites vary. There is an occasional increase of oligoclase over orthoclase, till the rock approaches a quartz diorite. Both orthoclase and microcline are abundant. Surface samples usually show muscovite and biotite as the varietal minerals. The microscope shows that augite was primary in some cases, and hornblende has formed from it, as has possibly biotite also. Magnetite and apatite appear only as small inclusions. Kaolinization of the feldspars has not gone far. Weathering yields arkose sand rather than clay. It is especially noticeable that the pegmatites break up into feldspathic debris, which has been carried in the form of angular gravel to a distance of half a mile from the dikes.

The pyroxenite found in a few outcrops in the granite region —probably as a dike—has a medium-granitoid texture. The nearly colorless augite is partly altered to blue-green hornblende, which commonly forms a fringe around the augite, but in some cases occupies the whole area of the original pyroxene.

POST-ARCHEAN

The very wide-spread post-Archean igneous activity, evident in the region, cannot be accurately discussed from our local work. The topographic effects of this activity are more prominent than those of the earlier intrusions. It is clear that there have been several periods of activity, as is known to be the case elsewhere in the state.

Within the area mapped are many varieties of eruptive rocks. They appear in all formations from the oldest to the youngest of the sedimentary series, with the possible exception of the glacial drift. The intrusives and extrusives are clearly similar types, and outside the Archean area no plutonic rocks are exposed. The intrusions and extrusions are thought to be largely contemporaneous. Certainly dikes and sheets can be correlated on Baker Mountain, and in the region to the south. Some occurrences make it probable that dikes and flows may be equally well correlated.

TYPES

The lavas found in a flow at Rabbit Ears Mountain, in a sheet six miles south, in the plug of Spicer Mountain, in the dikes of Grizzly Creek, and in the laccolith of Ironclad, are so similar in chemical composition that, in mapping, no attempt has been made to distinguish these various occurrences. The dis-

tinctions made are based on the general appearance, texture and mineral content. Gradational changes appear, and it seems probable that all the lavas of the district belong in a single series. This is borne out by the chemical characters discussed below.

A study of the rocks leads to a division of the lavas into four main classes, called here: 1, the basalts; 2, the dacite porphyries; 3, the quartz latites; and, 4, the andesites. The fifth symbol used in mapping is for the breccia and an occasional flow of Types 1 and 2. The distinction in general is clear; for with olivine the basalts invariably contained labradorite, while the dacites, with few exceptions, had no olivine, but little augite, much hornblende or biotite, and usually oligoclase. The latites contain orthoclase.

AGE

In a general way, the age of the lavas can be determined from two occurrences: (1) At a cliff two miles N. 60° E. from Whiteley Peak, and from there several miles to the northwest the rocks of the coal formation (Eocene?) contain numerous pebbles of porphyry. The pebbles are from a rock more like the latites than the other types. The occurrence of other masses of latite confirms the view that they are rather old. (2) Since the coal beds were formed there have been two periods of eruptive activity, as shown on Diamond Mountain, where a large sheet of lava rests on coal-bearing sediments, and both sediments and lava are cut by a basalt dike.

The exact time at which the eruptions ceased is not certain, but it was probably quite recent, judging by an occurrence on Rabbit Ears Mountain. Here the truncated edges of sediments of the Colorado group have been covered with 100 feet of wash or drift from the granite area some distance away. This deposit is covered by a flow of basalt. The tilting and erosion of the Colorado formation and the deposition of the wash represent a long period of time, suggesting that the basalt flow may be late Tertiary or even more recent.

It is therefore probable that igneous activity began in late Cretaceous or very early Eocene time, and continued till very recently, and that there were several quite distinct periods. It is true, however, that two periods of eruption do not necessarily involve radically different types of lava. The case cited on Dia-

mond Mountain shows only slight differences between the sheet and the dike.

Now the common impression exists that volcanic activity began in Colorado in Tertiary times, and that coal formation ceased by that time. Cross and Howe state[1] that "Nowhere in Colorado is there evidence of volcanic eruptions in the Cretaceous period until after the close of the Laramie proper."

As the present work shows a very close relation between the coal beds and the porphyry (eruption occurring both before and after), it may be best to describe this occurrence in more detail. At the cliff mentioned the coal formation lies unconformably over Montana shales, but the outcrop shows no other unconformity in a large, clear exposure. The section is:

	Feet
Coarse brown sand of the cliff	125
Conglomerate with porphyry and granite pebbles	5
Yellowish arkose sand	75
Coal	3
White shaly and micaceous sand	75
(Unconformity)	

Here the conglomerate is above a coal seam, but coal occurs at several horizons in the formation, and three miles northwest at Arapahoe Pass a conglomerate of identical appearance dips at an angle which would carry it below a coal bed outcropping at the top of the pass. As the dip of the coal formation is rather uniform through the area, it is quite certain that coal lies both above and below the conglomerate.

CONTACTS

In the few contacts well exposed, the effects of intrusion upon the sediments were extremely slight. Benton shales were crumpled or brecciated for a distance of only a few feet. At several places they were silicified or impregnated with pyrite. Sediments of the coal formation seem entirely unaffected. A rather extensive alteration of Dakota sandstone to quartzite near Baker Mountain may be due to igneous action.

QUARTZ LATITE

Description. — This rock is so white and chalky, and is jointed in such plate-like, shaly forms, that in some outcrops it resembles shaly limestone. In the field it was called rhyolite.

[1] Folio 153, U. S. Geol. Surv., p. 8.

On freshly broken, unweathered surfaces it may be very light, dull red or gray, but this color bleaches out completely or may be turned brown by ferruginous solutions, as in one place on Haystack Mountain. The rock occurs in laccoliths and dikes, without any vesicular structure, but often with lines of flowage, and alternating color from gray to white. Megascopic examination reveals only a few quartz grains, and an even smaller number of feldspar and biotite grains, in a very fine, light groundmass.

Under the microscope it becomes apparent that quartz is not very abundant, as several sections, cut from rock showing quartz phenocrysts, missed them entirely. The large quartz crystals are slightly corroded, and feldspars of smaller size are much more numerous. Albite in automorphic crystals is usually more abundant than orthoclase. A test for alkalies shows that the rock is intermediate between the potash and soda types of composition. Biotite is very sparingly present, and magnetite is even less abundant. The groundmass is microfelsitic, and appears to be composed of glass, quartz and orthoclase. Trachytic texture is evident in the specimens that show flowage lines on a large scale. From the certainty of quartz in nearly every outcrop, and the high percentage of silica, it is clear that the rock is properly called quartz-latite. (In the absence of lime-feldspars, it might be called a rhyolite.)

The pebbles of porphyry from the coal formation yield a modification of this type. With a texture and groundmass almost identical, none of the six pebbles examined shows quartz, and only a few sections show orthoclase. They thus approach the andesite type.

Age.—As only laccoliths and dikes occur, it seems likely that any extrusives have been entirely eroded. The relation to sediments of known age is not clear, except that the lava intrudes Montana shales. These points uphold the evidence furnished by the pebbles occurring in the coal formation, that the rocks are of early date.

Distribution.—There are three main masses, none of which appears on earlier maps. Haystack Mountain is the largest. In contact with the Whiteley Peak basalt is another laccolith, and a short distance north is a much smaller mass.

OLIVINE-RICH BASALT

Description.—These rocks usually show no phenocrysts to the naked eye, except small olivine and rarely plagioclase grains, in a groundmass which is very black when fresh and which weathers brown or gray. Some masses have a platy jointing, some columnar. Weathering has developed a decided spheroidal structure in several places. The type occurs in all varieties of position, and extrusive masses are vesicular or even scoriaceous. Amygdaloidal filling is found occasionally. Fragments of this type occur in the breccia also.

The texture, seen under the microscope, varies from uniform microgranular to decidedly porphyritic, though phenocrysts are not very large. The groundmass often shows a trachytic arrangement. Rarely there is a tendency to a diabasic texture, but much more commonly the augite is older than the plagioclase. The feldspar present is labradorite in all the samples taken, and is usually zonally built. A large proportion of the plagioclase phenocrysts show the effects of dynamic action —irregular twinning bands, crossed twinning and wavy extinction. Olivine occurs in grains larger than the average, frequently in well-formed automorphic crystals in various states of alteration to iddingsite, serpentine and calcite pseudomorphs. Augite is especially abundant, both as small phenocrysts and as a prominent part of the groundmass, even exceeding plagioclase in many sections. In the groundmass, and less often in larger crystals, it has a decidedly needle-like habit, which is unusual in this mineral. The extinction angles and lack of pleochrism, however, make its identity clear. It is very light brown or green, twinned, and rarely zonally built. Alteration yields a mass of green or brown chlorite, and calcite. Less often a fringe of hornblende borders the augite. Magnetite octahedrons and much dust are noteworthy. When not a mixture of augite and plagioclase needles, the groundmass is augite in an isotropic matrix. This may be largely glass, but from the analyses it is thought more probable that analcite is abundant. Though olivine may give a silica jelly, the ease with which one can be obtained from the powder of this rock is further evidence of analcite. A late stage of alteration of the groundmass forms a mass containing a high percentage of calcite.

Very striking, and appearing very much out of place in these rocks, are occasional large corroded grains of quartz and orthoclase. One or two real inclusions of granite and other

rocks are so different that these quartz and feldspar crystals probably belong to the original rock and are not accidental inclusions. The corrosion rims along the borders indicate extensive resorption and reaction, but are too fine-grained for accurate determination. Less corroded, but equally striking, and exceptional also, are large feldspar crystals of mottled or graphic appearance. The increase of hornblende marks a gradation to the dacite porphyry. Amygdaloidal cavity fillings have been found to include calcite, chlorite, natrolite, and probably other zeolites.

Age.—Many surface flows remain as prominent features in the topography. Dikes of this rock cut earlier igneous rocks. Both these facts seem to indicate relatively recent formation. The Rabbit Ears flow probably gives the best evidence at hand of the lateness of the eruption. The conformable Colorado-Montana groups were tilted, eroded, and later covered with 100 feet of debris from granite rocks, before the eruption. The debris has the character of the glacial debris now found in the immediate neighborhood, but may very possibly have had another origin.

Distribution.—This is the most abundant type in the district, occurring in masses both large and small, and as fragments in the breccia.

DACITE PORPHYRY

Description.—In the field the dacites are usually so different from the basalts that they are readily recognized as different rocks. They have a lighter-gray groundmass, and have many phenocrysts of white plagioclase and a few of quartz, which reach a maximum width of a quarter of an inch. The rocks weather to a darker brown than they are when fresh, and a few develop spheroidal structure. The common jointing is columnar. The dacites form sheets and small laccoliths, and fragments of dacite occur in the breccia. These fragments may be very vesicular, but still bear phenocrysts.

Under the microscope the phenocrysts still appear prominent, and augite occurs as a common accessory, as well as hornblende or biotite. Olivine is absent. The plagioclase is usually oligoclase or andesine, rarely labradorite, and is a very variable constituent. It may seem of doubtful propriety to include in one group rocks with feldspars as different as oligoclase and labradorite. These varying specimens are much alike, however, in associated min-

erals. In some specimens the feldspar of the phenocrysts may differ from that in the groundmass. Many are zonal in structure. The quartz appears—as in the basalts—only as much-corroded crystals, which, however, are certainly not accidental inclusions. Orthoclase likewise appears. These minerals are much more abundant than in the basalts and are not quite so much corroded. Augite forms a few such automorphic phenocrysts as are found in the basalts. Hornblende of the brown basaltic type occurs in crystals of good size, but it forms a widely varying proportion of the rock in the specimens examined. Decrease in hornblende and increase of augite mark the gradation to basalts and quartz basalts. A green type of hornblende is sometimes found. The hornblende is commonly altered along the borders, and sometimes a complete pseudomorph of spotted, dusty magnetite occurs. Crystals without some change of this sort are rare. A less common alteration in this series yields fibrous chlorite and calcite. Biotite forms crystals of the same general color and appearance as the hornblende. Hornblende of a light blue-green color forms fringes around some of the nearly colorless augite. Magnetite is quite abundant, and pyrite was seen in a few sections. The grounmass is rarely coarse, varying from fine-grained to glassy. It lacks the augite needles so characteristic of some of the basalts. Extreme alteration results in a mixture of calcite and clay.

Age.—There is little to indicate the age of these rocks, but their occurrence in laccoliths, now eroded, indicates a long time interval. If the pebbles of the coal formation are of a related type, this is further evidence of their early formation.

Distribution.—Baker Mountain and a small laccolith just east of Muddy Pass are the noteworthy exposures.

ANDESITE PORPHYRY

Description.—The field appearance of the andesite is variable. Some of it resembles the dacites, while in other outcrops it is a dark rock with large phenocrysts of hornblende or biotite. It forms fragments and flows in the breccia, several dikes, and possibly a small plug.

The microscope shows the presence of phenocrysts of plagioclase and augite.

Age.—Its age is not clearly determined, but, from the remnants of surface flows above all the sedimentary series, it may well be a product of the more recent eruptions.

Distribution.—The prominent dike along Muddy Creek is a biotite andesite which shows a transition, at the south, to a rock consisting of biotite in a mass of light-colored grains having an extremely wavy extinction. The other outcrops of andesite are more closely associated with the breccia.

MODIFIED TYPES AND GRADATIONS

Diamond, Bear and Whiteley Mountains consist of material varying slightly from the types described, in that they have small amounts of ferromagnesian minerals. The main masses of Bear and Diamond Mountains consist of a rock nearly 90 per cent plagioclase. This weathers to a very light brown, but is otherwise much like the basalts, and is mapped with them. Olivine is represented only by doubtful pseudomorphs.

The olivine rocks of Rabbit Ears Mountain, when traced northwest for about two miles, grade into a rock containing both olivine and hornblende. As the feldspar of this rock is labradorite, and as the rock forms but a small part of a large mass, it is not shown on the map as a distinct type.

In two localities outcrops of shale contain a small layer parallel to the bedding, which is so different from any other sediment that it is thought to be a decomposed lava sheet. On the northeast slope of Baker Mountain, not far from some dikes and other larger masses, in Benton shales is a sheet which seems to be an altered amygdaloidal rock, now thoroughly softened to kaolin and chlorite. The other outcrop is in the shale of the coal formation, about a mile east of Collins' ranch, and, although equally altered, it appears to consist of spherulitic masses of light-yellow mineral in a dark-brown matrix, all now altered to a ferruginous clay.

South of Buffalo Mountain, on the northeast side of the area, is a pink porphyry, in which quartz and vitreous oligoclase and orthoclase form phenocrysts in the pink groundmass. Under the microscope the groundmass proves to be glass. It is best classed as rhyolite from its proportion of potash.

BRECCIA

Description.—This term is used for an immense deposit of fragments, with some flows, found mostly in the eastern and southeastern part of the area. Only very small parts of the mass would properly be called tuffs. The material forms promi-

nent cliffs, mountains and monadnocks, usually brown, red or pink in color. It is over a thousand feet in thickness and consists entirely of igneous material, mostly angular, and often scoriaceous or vesicular. The fragments range up to ten feet or more in diameter, and vary from that size to fine ashy powder. An occasional lava flow is included. Ashy beds are local and irregular and, as a rule, fine, and coarse particles have accumulated in a mass showing very little evidence of stratification or assortment. Some of the larger cliffs contain layers of slightly varying color, and the presence of a flow may give the appearance of stratification. Where a little indistinct bedding is found in the smaller cliffs, it is extremely irregular. It is evident that water action has been slight. In following exposures either laterally or vertically, there is no evidence of regular progressive changes in the character of the material. At any one place no great variety of rock fragments can be found. Various textures of one type may appear. Scoria fragments appear red as compared with more compact masses of the same type; and the finer ashy material may also vary from white, through red and brown, to black. The basalts and andesites are the most common rocks, and both occur near the base and near the top of the breccia mass.

A bed of similar material at the base of some of the cliffs shows rounded boulders and evidences of water action. This probably belongs to the coal formation.

In many cases the cementing material is ash, but in the isolated Rabbit Ears mass, calcite is prominent, and in others chalcedony and hematite play important parts. In material selected for sections, fine ashy particles fill the main part of the space between large fragments. Between the visible grains the groundmass seems to be, in some cases calcite, and in others an isotropic filling, possibly opaline in character. Hyalite was found in the cliffs. Some of the breccia may have igneous cement, resulting from the flow of a lava over loose fragments.

Age.—This is discussed in the section on "Historical Geology," and is believed to be post-Eocene or late Eocene, from its unconformable relations above the Eocene coal measures. No attempt has been made to correlate these eruptions with the periods of igneous activity in the San Juan and elsewhere in Colorado. Its unconformity with the coal measures is proved by specific localities on upper Arapahoe and Indian Creeks.

Distribution.—The western boundary of the breccia mass is approximately that of a large area mapped by the Hayden survey as basalt. If this consists of similar material farther east, there is an area of over 140 square miles, covered with breccia, with its center outside our map. West of the main area are a few scattered outliers as far as Arapahoe Pass, and then an isolated patch of rather different character at Rabbit Ears Mountain, and the cliffs near by.

Source.—The actual source of the breccia fragments is unknown. The fragments at the isolated Rabbit Ears outcrop suggest explosive eruptions, which produced bombs and ash, and ejected fragments of at least partially molten material. The main masses in the eastern area show less of such material, and the origin of the greatest area of breccia may have been somewhat different. In the larger cliffs there are usually one or more flows in which the vesicular upper layer has not been deeply eroded.

It has been noted that few of the fragments or beds indicate any extensive water action. No powerful erosive agent was operating on the material at the time of its formation. Much more probably some immense masses of lava, in a solid or nearly solid state, were shattered and blown up in a series of explosive eruptions, and the debris was both widely scattered and piled high. Less explosive outpouring of lava alternated with the violent eruptions. Possibly mud flows are responsible for some of the finer layers.

Nothing yet observed has given any key to the location of the center of activity. The center of the present area is east of the region visited, but dikes and other intrusions occur on all sides of it, and there is no certainty that the present area is the central portion of the volcanic area. It may be only a remnant on one side of the volcano.

CHEMICAL EXAMINATION OF THE IGNEOUS ROCKS

An approximate analysis of the rock of the laccolith east of Whiteley Peak, with special care in the estimation of alkalies, gave these figures and calculations:

APPROXIMATE CHARACTER OF QUARTZ LATITE

SiO_2	73.80	Orthoclase	26.60
Al_2O_3	not determined	Albite	42.75
TiO_2	Not determined	Anorthite	2.50
Fe_2O_3	Trace	Quartz	26.00
MgO	Trace	Not determined	2.15
CaO	.50		
Na_2O	5.06		
K_2O	4.50		

The rock is high in alkali, but the alkali is very largely soda.

ESTIMATE OF ALKALI IN OTHER TYPES

	DACITE FROM MUDDY PASS	RED ROCK FROM BUFFALO PEAK
Na_2O	4.47	2.52
K_2O	3.04	4.20

ANALYSIS OF BASALT

		NORM	
SiO_2	47.03+	Orthoclase	9.45
Al_2O_3	13.83	Albite	21.48
Fe_2O_3	4.12	Anorthite	18.90
FeO	8.37	Nephelite	2.56
MgO	7.95	Diopside	22.40
CaO	10.15	Olivine	12.76
Na_2O	3.08	Magnetite	6.03
K_2O	1.58+	Ilmenite	4.56
H_2O+	1.10	Apatite	1.34
H_2O-	.30	Combined water	1.10
TiO_2	2.39	Moisture	.30
P_2O_5	.51		
Cr_2O_3	.02		100.88
MnO	.33		
SrO	Trace, less than .10		
Li_2O	Trace, less than .06		
	100.92		

In the quantitative chemico-mineralogic classification the rock is a camptonose.

TABLE OF ALKALIES IN THE SERIES OF ROCKS

This series of chemical results brings out a point in the relationship of the rocks of the district. From basic to acid rocks there is a rather definite gradation, shown quite clearly in the proportion of potash and soda:

	BASALT	DACITE	QUARTZ LATITE	RHYOLITE
Na_2O	3.08	4.47	5.06	2.52
K_2O	1.58	3.04	4.50	4.20
SiO_2	47.03	...	73.80	...

The analyses confirm the impression obtained from a study of the rocks in the field and with the microscope, that the types and gradations may all be members of a single series which differentiated rather widely.

ECONOMIC GEOLOGY

BY F. F. GROUT

PRECIOUS METALS

There has never been any noteworthy production from the region, and the prospects for agriculture are better than those for mining. The old residents have long known of the existence of gold on several streams in the area. At Grizzly placer mining was carried on for a short time, but work was not continued, and the gold is reported to have been rather fine. Coarser gold is reported from Diamond Creek and from Muddy Creek, near Barbours Basin, but no mining has been done. These various locations do not show drainage from any uniform type of rock, and it does not seem probable that any one igneous intrusion, or any one sediment, is entirely responsible for the gold now in the stream-beds. Rather careful work and test-pits to bed-rock are usually needed to find the gold as reported.

In an effort to locate the bed-rock deposits which might yield placer gold, the igneous contacts and veins of all visible types and sizes were studied. The brecciated shales near the contacts of igneous and sedimentary rocks about Baker Mountain and Bear Mountain were silicified and impregnated with pyrite. The upper parts are now oxidized. All these and various outcrops, and the test-pits just west of Muddy Pass, were sampled, but no gold was found. No other contacts appeared more promising. Some shear zones and highly ferruginous zones in the lavas of all three types yielded nothing of value. No strong, persistent veins of any type were discovered. A few irregular calcite veins in the shales in the neighborhood of some lava masses, and some green-stained chalcedony veins in the lavas, were tested without result. Basic dikes in the sediments have been prospected in several places, but there is slight evidence of mineralization. The absence of deep-seated rocks may be taken, in a general way, as a geologic indication that slight mineralization is to be expected along the contacts.

The discussion would not be complete without reference to the legendary "lost mine." The legend is based on a rumor that a mysterious stranger occasionally visited the Rabbit Ears region, and, though alone, soon came away with a bag full of gold. Whether he took it all, or died leaving a rich deposit incompletely developed, none can say, for he never told the secret, but ceased to pay his visits.

FUEL AND STRUCTURAL MATERIAL

COAL

The coal formation of the central eastern part of the area has been prospected for coal at several horizons. Many thin seams occur, usually with sandstone roof and floor, and the usual variable thickness to be expected with such associations. A few miles north of this area a coal seam sixty feet thick is being opened by the Riach Mining Company, but within the area mapped no workable seam is known. The coal weathers to a brown color and develops platy structure, but is black and conchoidal and lustrous on fresh surfaces. No analyses were made, as the larger beds were so sandy as to be of no value.

BUILDING-STONE

With the development of the country and the coming of railroads, building-stone of local deposits may be valuable. A gray granite northwest of Rabbit Ears is of promising quality. Parts of the Dakota sandstone may be available. The clays of the Cretaceous seem to be of about the same general quality as those east of the Front Range. The valuable Dakota fire-clay is represented by thin seams, not exceeding three feet.

OTHER MINERALS

Gilsonite, or some related hydrocarbon, probably ozocerite, occurs locally in the Dakota sandstone. This is probably responsible for the mistaken idea of the settlers that several black shale banks are gilsonite. The most notable occurrence is about five miles north of Rabbit Ears, where a layer of the Dakota sandstone is sufficiently charged with hydrocarbons to give it a black or dark-brown color. The extent of the layer is probably small, as the Dakota is here faulted out as a block, and is not continuous with the hog-backs north and south of it.

The soils of the area are similar to those developed from the corresponding formations east of the Front Range.

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 5—Part 2

PERMIAN OR "PERMO-CARBONIFEROUS"

OF THE

EASTERN FOOTHILLS

OF THE

ROCKY MOUNTAINS *IN* COLORADO

BY

R. M. BUTTERS

CONTENTS

INTRODUCTION

Lykins is the name given by Fenneman, in his bulletin on the geology of the Boulder district, to the upper portion of the "Red Beds" in the Front Range of eastern Colorado. The age of this formation has never been settled. It has been assigned to various ages from the Upper Carboniferous to the Triassic, but is commonly spoken of as Triassic. This is due primarily to the almost total lack of fossil evidence. Up to the summer of 1910 there had been no well-authenticated report of fossils from this formation along the entire range.

In the summer of 1910 the Colorado Geological Survey sent out the writer and Mr. David L. Curtis to examine the formation with special reference to the determination of its age. The last direction from the state geologist was: "Bring back fossils from the Lykins formation." During the summer and fall we followed, with considerable care, the foothills from the Wyoming line down to the New Mexico line, keeping as close to the outcrop of the Lykins as possible. In this work it was found necessary to study, to a greater or less extent, the underlying Lyons, Fountain and other Upper Carboniferous formations, and the overlying Morrison or Jurassic formations. That is, we had to keep in touch with practically all the sedimentary formations from the pre-Cambrian to the Cretaceous. The topographic sheets of the United States Geological Survey were used for the geographical work.

ACKNOWLEDGMENTS

In this work the writer is greatly indebted to Mr. David L. Curtis for his able assistance in the field-work. Professor Junius Henderson furnished us his notes on field-work in the northern part of the state. These were very useful and saved us much time. He also gave valuable assistance in the determination of the fossils. The Lykins fossils were turned over to Dr. G. H. Girty for final determination. Professor R. D. George made the work possible and assisted very much with advice, information and in proof-reading. Notes from his lectures on the geology

of Colorado were used in the correlation. In this correlation the writer has looked up all the literature he could find on the subject, and the bibliography will be found at the end of this paper.

GEOGRAPHY

The general trend of the outcrop studied is very nearly north and south. A strip of country from ten to twenty miles wide, extending from the 105th meridian westward, would include practically all of the outcrops of the upturned sedimentary formations from the pre-Cambrian to the Montana. From Pikes Peak south they are found somewhat farther west. In general, the Carboniferous outcrops form the eastern flank of the foothills; however, in places, several ridges of low hills of more recent sediments parallel the outcrops of the older formations.

FORMATION NAMES

The Lykins formation is a part of that which the Hayden and later geologists have called the "Red Beds" of the Rocky Mountain region. Emmons, in the Denver Basin Monograph, divides the "Red Beds" into Lower and Upper Wyoming. Cross, in the Pikes Peak Folio, has called them the Fountain formation. Fenneman [1] divides the Lower Wyoming of Emmons into the Fountain and Lyons. The Upper Wyoming he calls the Lykins. Fenneman's names will be used in this paper, as far as possible. Fenneman correlates his Fountain with the lower part of the Fountain of Cross in the Pikes Peak area. The Fountain of Fenneman is lithologically and stratigraphically identical with the typical Fountain at Fountain Creek; the red shales and the "crinkled sandstone" are lithologically the same as the Lykins at Boulder; and there can be very little doubt that they are the same formations, even though the continuity cannot be established so completely as can that of the Fountain. The strata corresponding to the Lyons were recognized at this point also, but the formation is not nearly so distinctive as it is at Boulder. In the Walsenburg Folio (22) Hills gives the name Badito formation to the "Red Beds." Hills discusses the "Red Beds" of the Sangre de Cristo Mountains west of Trinidad as the

[1] Geology of the Boulder District: U. S. Geol. Survey, Bull. 265.

Sangre de Cristo formation. A portion of the "Red Beds" in the southern part of the state has been named the Arkansas sandstone.

Darton has given the name Sundance to a buff-to-yellow sandstone series which occurs between the red shale series and the Morrison formation in the Sherman quadrangle and elsewhere in Wyoming. He records from the Sundance *Belemnites densus, Gryphæa calceola* and *Pentacrinus asteriscus,* "of late Jurassic age." In the summer of 1912 I followed this formation from Darton's Horse Creek locality, in Wyoming, southward into Colorado. The formation is not exposed continuously, but there is very little doubt that it extends into Colorado as far south as the Cache la Poudre River. South of this river there are one or two places where it may be exposed, but there are no fossils, and a safe correlation cannot be made on lithological grounds; so, south of the river no Sundance is mapped. Darton[1] says that the "Sundance formation extends only a few miles into Colorado from the northward, finally thinning out." Hayden[2] reports the finding of *Ostrea* and *Pentacrinus asteriscus* on Box Elder Creek, in "thin layers of fine-grained, grayish, calcareous sandstone," near the base of a series of strata consisting of "ashen-brown nodular or indurated clay, with deep, dull-purple bands, with some layers of brown and yellow fine-grained sandstone, undoubtedly the usual Jurassic beds with all the lithological characters as seen near Lake Como, on the Union Pacific Railroad—150 to 200 feet." Marvine and Darton both quote Hayden's report without any further information. No one since appears to have been able to locate that fossil horizon.

Fenneman's Lyons (16) is the Creamy sandstone of Emmons (15). The Lyons is in part equivalent to Darton's Tensleep sandstone (9), but the formation I have called "Ingleside" is more nearly the equivalent of the Tensleep. Darton's Chugwater (9) is equivalent to the Lykins. The Sundance has been traced from Wyoming southward practically to the Cache la Poudre. In this paper the names Fountain, Ingleside, Lyons, Lykins and Sundance will be used for the equivalent subdivisions of the "Red Beds," wherever they have been found in the area studied. In southern Colorado it is not easy to subdivide the "Red Beds" on lithological or structural grounds, and sufficient paleontological evidence is

[1] U. S. Geol. Survey, Prof. Paper No. 32, p.96.
[2] Third Annual Report, 1869, p. 119.

not at hand; so that subdivision has not been attempted in this paper.

I have hesitated to burden the literature of the "Red Beds" with a new name; but, in order to make myself clearly understood, and to avoid confusion by the use of the term Lyons in too broad a sense, it has been thought advisable by Dr. Girty, Professor Henderson and others. I have, therefore, given the name Ingleside to a sandstone-limestone series extending geographically from beyond the state line to the north, to a point a little north of Lyons. It is typically developed at the Ingleside quarries and also at Owl Canyon. (See section at Owl Canyon.) These places are a few miles north of La Porte on the Fort Collins-Livermore stage-road. This formation lies apparently conformably upon the Fountain, and consists of an alternating series of limestones and fine-grained sandstones, varying from 100 to 125 feet in thickness—possibly a little more at the state line. These sandstones and limestones vary in color from gray to almost white, through pink to almost red. This formation is quite different from the Lyons as described by Fenneman, especially in the fact that it contains the limestone bands, some of them very pure. It is also in a different and lower horizon than the Lyons. It is possible that the Ingleside should be regarded as merely a lithological unit in the Fountain, showing a change in conditions of sedimentation, transitional to Lykins conditions.

STRATIGRAPHIC RELATIONS

The Fountain formation, as a rule, lies unconformably upon the pre-Cambrian rocks, but in a few places it lies upon pre-Pennsylvanian rocks. These range in age from Cambrian to Mississippian. In no place was it possible to detect angular unconformity, from the base of the Fountain to the top of the Lyons or Ingleside. The fact that the Ingleside plays out just north of Lyons, and that from this point southward there is a marked and decided change from the coarser Fountain sediments to the finer Lyons, would suggest a possible unconformity, although the angular difference is so slight, if present at all, as to defy detection thus far. But this decided change from Lyons southward, coupled with the fact that northward from Lyons there is no such abrupt change, and that the contact is hard to place, as though sedimentation had been continuous, has for a long time given rise to the belief that southward from Lyons we

have a slight unconformity, as though the sea withdrew from this portion of the area for a short time. The Fountain material is such that erosion would not be shown unless it were quite marked. However, if there is an unconformity here, it is probably small and of merely local importance.

In most places the contact between the Fountain and the Lyons, and in many between the Lyons and Lykins, is clean-cut and distinct; but in other places it is quite indistinct, and its position is more or less arbitrarily chosen. Field observations have shown that the subdivisions of the "Red Beds," as made in some places, are not the exact equivalent of these divisions as made in others.

At the Wyoming line the Fountain is immediately overlain by the Ingleside formation—a series of about 100 feet of hard, fine-grained sandstones and limestones of a light-pink color. These strata maintain their thickness and lithological character to a point a short distance north of the Cache la Poudre River. From this point south the limestone becomes less and less important, and the sandstone proportionately more important; but the series as a whole gradually decreases in thickness, and finally disappears a short distance north of Lyons. Immediately overlying this series, at the state line, is a thick shale and shaly sandstone series of dark brick-red color. As the basal portion of this series is traced southward, it becomes more and more arenaceous, and lighter in color, and numerous thin bands of sandstone appear. Of these sandstone bands the most prominent is one that appears at the south end of North Table Mountain, north of Owl Canyon, where it consists of from 15 to 20 feet of light-colored, rather hard, crossbedded sandstone, separated from the Ingleside formation by from 60 to 80 feet of red shale and shaly sandstone. At Owl Canyon it decreases to from 6 to 10 feet. From this point southward this band increases in thickness and approaches somewhat closer to the Ingleside formation. Just north of Lyons the crossbedded sandstone is about 50 feet thick, and as the quarries are practically all in the upper part of the ridge, this crossbedded band furnishes the bulk of the rock quarried. From Owl Canyon southward other sandstone bands appear in the shales between the Ingleside formation and the crossbedded sandstone just described. Toward the south these bands increase in importance, and just north of Lyons they occupy practically the entire space between the crossbedded

sandstone above and the hard rock in contact with the Fountain —that is, what is left of the Ingleside formation. To the south of Lyons these sandstones and the crossbedded sandstone are lithologically alike, and together constitute the Lyons, as that formation is known south of Boulder, and no strata corresponding to the Ingleside are to be found. At the Wyoming line all the strata between the Ingleside formation and the Sundance are lithologically and stratigraphically a unit, and must therefore be included in the Lykins. Since the sandstone bands which unite to form the entire body of the Lyons, at the town of Lyons, first appear within these Lykins strata, entirely above the Ingleside formation, and since the Ingleside wedges out at a short distance north of Lyons, it is evident that the Lyons formation is but a hard sandstone series developed in the basal part of the Lykins. It would therefore seem desirable to regard the Lyons as a lithological, rather than a stratigraphical, unit. Otherwise the Lyons must be regarded as merging laterally into the Lykins north of the town of Lyons.

Overlying the Lykins formation between the Wyoming line and the Cache la Poudre River is a series of massive sandstones from 100 to 150 feet thick, the lower two-thirds of which is pink, grading to yellow, and the upper one-third yellow to creamy white. There as an abrupt and very pronounced lithological break between the soft, brick-red Lykins shales and shaly sandstones, and this overlying massive, harder, pink sandstone, but no discovered unconformity, either angular or erosional. This abrupt change in sedimentation conditions is wide-spread. No unconformity has been noted between the pink, massive sandstone and the yellow sandstone, though there are a lithological change, a difference in color and a difference in cross-bedding, indicating a change in sedimentation conditions. We have no fossils from the pink sandstone and no identifiable specimens from the yellow. The yellow portion—upper one-third—is undoubtedly equivalent to Darton's Sundance; and the pink lower two-thirds may be also, or may be transitional between Lykins and Sundance. I have confined the Sundance in Colorado to the yellow upper third, which forms a series of from 25 to 40 feet of yellow and white sandstone at the northern Colorado line. This gets thinner and thinner southward toward the Cache la Poudre, beyond which it is not found. Hence no Sundance is mapped south of that river. If the pink sandstone is regarded

as Sundance, it would have to be carried to about the Big Thompson River, west of Loveland.[1]

Overlying the Sundance where present, and the Lykins where the Sundance is absent, is a series of strata containing a fresh-water fauna, principally *Unios* and fresh-water algæ, and these are considered of Jurassic age, the equivalent of the Morrison at Morrison. There is an unconformity between the Lykins and the Morrison, but it is slight and very difficult to detect, due to the character of the beds and the slight difference in dip between the strata of the two formations. In fact, in northern Larimer County the exact contact of Lykins, Sundance and Morrison is hard to place. The basal Morrison varies from sandstone in some places to shale, and possibly limestone, in others. There is a marked change in color from the red or brown of the Lykins to the yellowish white or ash-gray of the Morrison. In places in northern Larimer County the Lykins gradually gets lighter in color, and there is almost a transition from the red Lykins to the gray Morrison.

Within the "Red Beds" there are conditions which suggest interrupted deposition, such as the change in character and color of the sediments, and the presence of beds of gypsum; but there is no angular unconformity, unless it is the small one noted at the top of the Fountain formation, from about the town of Lyons southward. North of Lyons there was probably continuous deposition, or nearly so, to the end of the Lykins period.

LOCAL SECTIONS

Fountain and Ingleside at North Table Mountain, Larimer County, Colorado.—At the Wyoming line there is, at the base of the Fountain, a shale horizon containing chert boulders in which occur fossils of Mississippian age, identical with those of the

[1] EDITOR'S NOTE.—Professor Henderson furnishes the following note upon this subject:

"The slight thickness of the strata between Butters' Lykins fossils, which are considered late Carboniferous or Permian, and the Morrison, which is late Jurassic or possibly Cretaceous, points emphatically to the probability of a non-deposition or erosion period or periods during Permian, Triassic and early Jurassic time. The most likely place for such a break appears to be just at the top of the soft, brick-red Lykins material. My impression in the field was that the massive, pink sandstone above this break is much more nearly related to the yellow sandstone above, which Mr. Butters correlates with the Sundance, than to the underlying brick-red strata. Probably the upper limit of the Lykins should be placed at the top of the brick-red series, and the pink sandstone either placed in the Sundance, or, which is quite as likely, considered a distinct formation. As both these massive sandstones, the pink and the yellow, thin out and finally disappear in coming southward from Wyoming, and the upper Lykins, as developed farther south, seems to belong with the strata in which a late Paleozoic fauna has been found, it is extremely likely that at least from the Big Thompson southward there is a marked, though not easily discovered, unconformity, representing Triassic and early Jurassic time."

Millsap of Perry Park. These chert boulders seem not to have been formed in place, as they are somewhat rounded themselves, and are associated with smaller quartz pebbles, also somewhat rounded, and feldspar but little altered. Also, the chert boulders contain no foreign material, as they undoubtedly would if formed where they are now found. If not formed in place, the question immediately arises, Where were they formed? A study of the Millsap at Perry Park shows a soft, shaly formation, with a hard band or bands of chert. On slight exposure to the elements, the soft shale would be easily eroded, without leaving any evidence of its presence; but the chert boulders would remain practically unaltered. Had there been such a formation at the Wyoming line before the Fountain was laid down, and it had been exposed to erosion, as would not be impossible when we remember that the basal Fountain is a very shallow water deposit, the chert boulders would have been left as boulders along the shore. The location of the chert boulders is such as to suggest that they were deposited in the low places of the slightly undulating sea-floor, probably by the action of the tides, waves and shore currents. The red iron cement may have been derived from the granites direct, or from the shale of the older formations, or both.

These chert boulders in the base of the Fountain seem to be more prominent near the Wyoming line, but in many places the actual contact with the granite is not exposed. Possibly, if the granite contact could be found in other places, remnants of such a formation might be found. Farther north, in Wyoming, would probably be the better place to look for such remnants, as all the formations seem to be better developed northward than southward; but, unfortunately, for the first few miles north of the Colorado-Wyoming line the contact with the granite is not exposed any better than in Colorado.

This band is exposed in only a few places, and in these very poorly. It is probably less than 20 feet in thickness. Above this horizon the Fountain consists of a series of alternating bands of conglomerate, arkose, limestone, sandstone and shale, all more or less calcareous. There are several bands containing fossils of early Pennsylvanian age. Near the top of the ridge the arkose and conglomerate become less and less important, and limestones and sandstone cap the ridge. These limestones have been called "Lyons," and they are probably equivalent to the Tensleep of Darton (9). They are equivalent to the upper part of the Casper formation of Darton. I have called them the

Ingleside formation. The contact between the Ingleside and the Fountain is hard to place, but it appears to be at the top of the last prominent band of arkose conglomerate, though there are bands of sandstone in the Fountain similar to those in the Ingleside. The fossils of the Ingleside are Pennsylvanian, and of practically the same species as those of the Fountain. The basal Ingleside is a light-colored sandstone, somewhat harder than the rest. Above the Ingleside occur the characteristic Lykins red shales and shaly sandstones. The dips in this region are from 10° to 30°, except where increased by local folding. At this point there is, if anywhere in the state, continuous deposition from the Fountain to the end of the Lykins period.

Section of Lykins and Sundance at Heygood Canyon (Sand Creek).—At the contact with the Lykins the Ingleside is a creamy sandstone, with but little calcium carbonate. The dip is 9° southeast.

	Feet
Sundance:	
Sandstone—yellow, thick-bedded, soft, to basal Morrison	25
Lykins:	
Sandstone—light pink, possibly, Sundance	100
Sandstone—thin-bedded; would make fair flagstones	15
Shale—soft, flaky and clayey sandstones, with one white, quite thin, limy band	240
Covered portion—partly thin, flaky, red shales	20
Shales and shaly sandstones—red, with a few bands of limestone 10 to 12 inches thick	90
Shales—mottled, red, with bands of white limestone from 2 to 6 feet	50
Shales—soft, red, sandy; almost a sandstone in places, with several white, limy bands up to one foot in thickness	40
Sandstone—light pink; intercalated with grayish, sandy limestone, 2 to 8 feet thick, with a band of impure red limestone, which grades into a shaly sandstone near the top; this weathers away, leaving the limestone capping the ridge; fossiliferous	16
Sandstone—red, massive, thick-bedded, quite soft; intercalated with bands of dark-red clay shale, 3 inches to 2 feet thick	135

Lykins—Continued	Feet
Sandstone—basal Lykins; a soft, pink, rather friable sandstone, intercalated with a dark-red shale and several bands of light-colored, strongly calcareous sandstone	85
Total	791

This is the most complete exposure of the Lykins to be found in Colorado, so far as I know. The fossils are few and scattering. *Bellerophon crassus* and *Myalina subquadrata* have been identified from the fossiliferous horizon about 200 feet from the base.

Lykins at Box Elder Canyon and South Table Mountain.—The lower part of the Lykins here is about the same as it was in Heygood Canyon. The fossiliferous band is thinner, more sandy, contains more crystallized calcite, and the fossils are in poorer condition than they were in Heygood Canyon. The white, limy series which was found above the fossil horizon at Heygood Canyon is either missing or represented by a few thin, light-colored bands of sandstone and a thin bed of gypsum of limited area. There is another bed of gypsum at the same horizon outcropping, in the road north of Table Mountain, not over a mile distant from the mouth of Box Elder Canyon.

The fold on the north slope of Table Mountain exposes the fossiliferous band found in Heygood Canyon. Above this horizon there is a bed of gypsum, which outcrops in the wagon-road, and above the gypsum there is a limy series very similar to the limy series above the fossiliferous horizon at Heygood Canyon. This is probably the horizon of the "crinkled sandstone" at Boulder. The gypsum is in several bands, from 2 to 12 feet thick, separated by thin, red shales, the upper bands being about 12 feet thick. Above the gypsum there is a shaly limestone series, some bands of which are quite calcareous. About 25 feet above the top of the gypsum bed, in the limestone shales, fossils were found, a list of which is inserted on a later page. The upper portion of the Lykins is practically all covered, but the band of yellow Sundance sandstone is exposed in one area at an elevation of between 400 feet and 500 feet above the fossil horizon.

Owl Canyon.—At this point it is very difficult to separate the Ingleside from the Fountain. A coarse sandstone, which grades into a fine, red sandstone, seems to mark the base of the Ingleside. Conformably below this, at the top of the Fountain, is

a brick-red sandstone, grading into a shale toward the top. Next below this is a band of arkose. Perhaps the top of the Fountain should have been placed at the top of this arkose, but the intervening sandstone is soft, while the band now regarded as the base of the Ingleside is very hard, almost a quartzite. No matter where the line is put, there will be lithologically similar bands both above and below it, as there is no abrupt change, but rather a gradual transition from the one formation to the other.

Section of Ingleside Formation at Owl Canyon.—

	Feet
Limestone—pinkish, white, to base of Lykins shale	15
Sandstone—soft, poorly cemented	12
Sandstone—pink, thin-bedded, somewhat limy	12—14
Limestone—mottled, pink and gray	4
Sandstone—limy, pink	10—12
Sandstone—soft, massive	12—14
Sandstone—gray, limy	2
Sandstone—soft, massive, red	12—14
Limestone—lighter-colored, sandy, thin-bedded	4
Sandstone—basal Ingleside formation; hard, thick-bedded, limy near the top	25—30

This upper band of limestone burns to a white lime, and is quarried at Ingleside by the Great Western Sugar Company for use in its factories in northern Colorado. Fossils of Pennsylvanian age were found about 4 feet from the base of this upper band. The dip varies from 10° to 12°, and is nearly due east.

On following southward, the upper four-foot band of limestone thickens rapidly to about 12 feet, and thins down again as rapidly to about 4 feet. This lens-like form is characteristic of the limestones. The sandstone bands retain about the same thickness. At Ingleside there are three bands of limestone, each from 10 to 14 feet thick. The lowest one is quite sandy, but the uppermost is said to be 99½ per cent pure calcium carbonate. Farther south the two lower bands have a tendency to become sandy, and sandstone layers become interbedded with them to such extent that the pure limestone is reduced to a thickness of about two feet. Just south of Ingleside the lower band wedges out entirely, but the other two, although getting much thinner, may be traced continuously to within a quarter of a mile of the Cache la Poudre River. At this point the ridge is low and makes an abrupt turn

to the west. From Ingleside southward the Lykins outcrops in a low ridge of very much crossbedded sandstone, which will be referred to in the following pages as the "Crossbedded sandstone." It looks very much like the Lyons of Boulder, and it is separated from the Ingleside by shales that are identical in character with those of the Lykins. On this ground, both the sandstone and the shales below have been included in the Lykins formation. Just north of the Poudre River the ridge turns west for about a quarter of a mile, and then turns again as abruptly and resumes its old course, a little east of south. In this bend the Ingleside shows practically no limestone, and the ridge it forms is no more prominent than that of the Crossbedded sandstone. Above the Crossbedded sandstone the Lykins is not well exposed, and only the red shales are visible; probably the upper red sandstone is absent at this point.

Bellvue, North of the Cache la Poudre River.—The Fountain formation is a series of alternating arkose, arkose conglomerates, and dark-red, clayey sandstones. The basal Ingleside is a hard, thick-bedded, creamy sandstone, with thinner beds near the top. It contains one band of sandy limestone, 6 feet to 8 feet thick. The uppermost member of the formation is a heavy-bedded sandstone. Between the Ingleside ridge and the Crossbedded sandstone ridge a valley has been cut in the Lykins red shale. The Crossbedded sandstone is 15 to 20 feet thick. Above this in one place, and separated from it by a few feet of shales, is a small bed of gypsum. Above this gypsum there are 3 to 4 feet of limestone. This sequence of beds suggests the section north of Table Mountain, but the strata at this point are non-fossiliferous. A few cherty concretions occur in one layer nearer the base.

Bellvue, South of the Cache la Poudre River.—The Ingleside is about the same as it was north of the river, but is perhaps somewhat darker in color and contains two narrow bands of white, sandy limestone. Above the Ingleside are the red shales and the Crossbedded sandstone of the Lykins. The latter forms a ridge fully as prominent as that of the Ingleside. Above the Crossbedded sandstone the red shales contain one limestone band. At this place most of the quarries are in the Ingleside, but there is one in the Crossbedded sandstone of the Lykins. Most of the rock is not well cemented and is too soft for a good building stone. It is also quite likely to be irregular in hardness.

South of Bellvue the Crossbedded sandstone approaches nearer and nearer to the Ingleside, the shales between become

more and more sandy, and in places true sandstone occurs in narrow bands, which resemble both the Ingleside below and the Crossbedded above. About ten miles south of Bellvue one of these sandstone bands becomes so prominent as to form a small ridge between the Ingleside and the Crossbedded sandstone. The upper portion of the Lykins is red shales and sandstone, and the uppermost band grades from red through pink to yellow and white. The upper yellow to white sandstone at this point may represent Sundance, but the correlation is uncertain, and the exposure so limited in thickness and extent that it is considered Lykins. Through this area there is usually no limestone, but due west of Fort Collins the Ingleside contains two lens-like bands of limestone. The Crossbedded sandstone at this point looks more like the Boulder Lyons than does the Ingleside. South of this point all the quarries are in the Crossbedded sandstone, as the Ingleside is in thin, irregular bands.

Stout.—The Fountain is a series of arkose, conglomerates, dark-red shales, and sandstones. The Ingleside is somewhat thinner and contains no limestone bands. The Crossbedded Lykins is closer to the Ingleside. North of Stout there is a series of calcareous strata in the Lykins, separated from the Crossbedded sandstone by from 30 to 40 feet of shales. These bands, which make a slight ridge, are in about the same horizon as the Crinkled sandstone of Boulder, and consist of about 50 to 60 feet of thin limestones, shales and sandstones. And in the basal member, which is an impure limestone, fossils are found. This series appears to be a local development, as it extends but a short distance north and south. Some of the bands of limestone in this series reach a thickness of 3 feet, but no fossils were found above the basal member. All the Ingleside stone is clayey, and chert occurs in one band.

The Crossbedded sandstone is about 50 feet thick, and all except the upper 10 or 12 feet is rather heavy-bedded, and crossbedding is prominent throughout. Below the Crossbedded sandstone there are about 100 feet of alternating sandstones and shales, with sandstones predominating. At the base there is a very persistent band of red shale, which makes it possible to separate the Lykins from the Ingleside. In the Ingleside the two calcareous bands are still present, but they would be more suitably described as calcareous sandstones. Dr. G. H. Girty identified *Myalina wyomingensis* and *Myalina perattenuata* from the fossiliferous horizon in the fossil beds in the Lykins from Stout.

South of Stout the calcareous shales are present above the Crossbedded sandstone, but contain no fossils. A small bed of gypsum was noticed in one place. The limestone has been burned for lime, but must have made a poor lime on account of the high content of clayey material. This limy series is undoubtedly the Crinkled sandstone horizon of the Boulder quadrangle. The Ingleside and the Crossbedded sandstone of the Lykins may be traced continuously as distinct formations as far south as the Big Fold west of Loveland. In this Big Fold the Lykins contains good gypsum in a bed 25 to 30 feet thick.

Masonville.—At Masonville the Fountain is very similar to the Boulder Fountain, and consists of a series of arkose, conglomerates, micaceous sandstones, and shales. The Ingleside is less than 100 feet thick and consists of rather hard, thin, crossbedded, pink-to-red sandstone. It becomes more and more like the Lykins below the Crossbedded sandstone, which is here about 80 feet thick. The basal Lykins is the dark, brick-red shale which has been so persistent. At this point it is from 3 to 10 feet in thickness, and considerably harder than it was at Owl Canyon. This is probably due to the metamorphism caused by the folding. The Crossbedded sandstone is about 50 feet thick, forms a more prominent ridge than the Ingleside, and contains all the quarries. Above the Crossbedded sandstone the Lykins shales are not well exposed.

Arkins.—The quarries at Arkins are in a ridge of the Crossbedded Lykins, while that portion of the formation below the quarry ridge forms a slope into a shallow gulch. Just a little north of the Big Thompson River there are three low ridges. From west to east the first one is the Ingleside ridge, the third one is the Crossbedded sandstone ridge, while the one between is in the Lykins below the Crossbedded sandstone. Just north of the Estes Park stage-road occurs the first Crinkled sandstone which shows the characteristic crinkling. It is very calcareous, and contains a band of good limestone, from 2 to 8 feet thick. There are 30 feet of red shales separating it from the Crossbedded sandstone, which is cream-colored and from 30 to 40 feet thick. The Ingleside is about 60 feet thick and harder, better cemented and thicker than it has been, more nearly resembling the Boulder Lyons.

Cottonwood Creek.—The Fountain is about the same as at Masonville, and near the top there is a band of limestone. The Ingleside is about 60 feet thick, and is a thin, crossbedded, light-

pink sandstone. The material is so different from that of the Fountain that the point of contact is easy to determine. Above the Ingleside there are from 25 to 30 feet of alternating shales and sandstones, of the lower portion of the Lykins. The shales are mottled red and white, and there is a thin band of mottled shale just below the Crossbedded sandstone. The Crossbedded is from 30 to 40 feet thick. Above it the Lykins is covered.

Carter Lake.—A cross-section shows two ridges, one capped with the Crossbedded sandstone, the other by sandstone of the lower portion of the Lykins. The top of the Fountain is a heavy-bedded arkose, which is followed by about 12 feet of thin-bedded, pink, very much crossbedded sandstone. This is all that is left of the Ingleside, as above it there is the band of red shale which has been found so persistently at the base of the Lykins. Above this band is a series of sandstones, with a few thin shale bands near the base, some of the sandstone containing a little feldspar and mica. The Crossbedded sandstone is very hard and varies from creamy white to a yellowish brown on the weathered surface. This is undoubtedly the horizon that is quarried at Lyons. In no place are there quarries in a horizon as low as the Ingleside. Above the Crossbedded Lykins from 30 to 40 feet is the Crinkled sandstone, which is quite limy, one bed of from 2 to 3 feet being a good limestone. One noticeable thing about this section is the thinning-out of the Ingleside from 60 feet at Cottonwood Creek down to 12 feet here; but it was noticed in following down that the Ingleside rapidly gets thinner, while the lower Lykins holds its thickness and becomes relatively more important.

Town of Lyons.—The Fountain is thicker than at points farther north, with increased hardness, due probably to the movement and pressure of folding. Some bands of sandstone in the Fountain look very much like bands in the Ingleside. The top of the Fountain is a variegated red and white, fine-grained arkose, below which there is a band of limestone 1 to 1½ feet thick. This contains cavities filled with calcite crystals, which may possibly result from replacement of fossils. The lower portion of the Ingleside is a hard, thin-bedded, creamy sandstone. Following this is thin-bedded sandstone, which is being quarried for flagstone. It is practically impossible to separate the Ingleside, if present, from the Crossbedded sandstone and the lower portion of the Lykins below the Crossbedded, because of the change, due to pressure and movement of folding. Probably, if Ingleside is present here at all, it is represented by the

lower 6 to 8 feet, and the remainder is in the same horizon as the lower portion of the Lykins. The quarries here at Lyons are undoubtedly in the horizon of the Crossbedded Lykins, with perhaps one or two in that portion of the Lykins below the Crossbedded sandstone. From this point southward this whole series will be called the Lyons; that is, the Ingleside, if present, and the Crossbedded sandstone, taken together; thus following Fenneman's nomenclature.

Lefthand Creek.—At this point there is a band of hard, red sandstone from 6 to 8 feet thick at the base of the Lyons, followed upward by from 8 to 12 feet of sandstone, which contains so much feldspar that it approaches a fine-grained arkose in character. Above this there are 60 to 70 feet of massive, creamy sandstone, having a pink tinge in places. Above this and below the Crinkled sandstone there is an intrusion of mica dacite into the shales. Possibly the two lower members which were put into the Lyons should have been placed in the Fountain, but at Lyons there are similar bands having the same rough, irregular manner of weathering and the same crossbedding, and there they belong to the base of the Lyons.

Bear Canyon (Near Boulder).—The Fountain is a thick and hard, high, jagged ridge, including the "Flatirons." In contact with the arkose of the Fountain are more than 100 feet of rather heavy-bedded, creamy sandstone. This represents all the sediments from the top of the Crossbedded Lykins to the top of the Fountain, and since it is impossible to make any subdivisions, it will all be regarded as Lyons. There are about 30 feet of soft, red shales above the Lyons, and then follow 12 to 15 feet of Crinkled sandstone. Above this the Lykins formation is covered with wash.

Ralston Creek.—The Fountain formation is very thick north of Ralston Creek, Ralston Peak being practically all Fountain, while south of the creek it is quite thin. The Fountain is considerably altered here and much resembles granite, and, were it not for large, rounded pebbles, particularly pebbles of white quartz, it might easily be mistaken for granite. The Lyons is quite thick, pink in color, and is capped with a band of thin, Crossbedded sandstone. It is hard to determine the contact between Fountain and Lyons, but probably it should be placed at the top of the last band of arkose. The Lykins is exposed in only a few small patches, and is recognized by the Crinkled sandstone horizon.

Morrison.—The Fountain, known locally as the "Old Red Rocks," is at least 500 feet thick, and is characterized by a jagged ridge, in which occur several triangular blocks of strata, known as "Flatirons." The Lyons is represented by about 200 feet of light, yellowish-gray, rather soft sandstone, of which the upper 20 to 30 feet show considerable crossbedding. Above this are 30 to 40 feet of soft, red Lykins shales; then 8 to 10 feet of rather limy, Crinkled sandstone, in places showing 2 feet of good limestone. No fossils were found, but there is much calcite in small cavities, which may be the remains of fossils. Above the Crinkled sandstone there are 150 to 200 feet of soft, red shales. The contact with the Morrison is not exposed.

Turkey Creek.—Turkey Creek is a few miles south of Morrison. The formations are about the same, but the Fountain and Lyons are thinner and do not make such a prominent ridge. The Lykins shales are a little thinner below the Crinkled sandstone, which occurs in two bands, separated by from 12 to 15 feet of red shale. The lower band is about 3 feet thick, and the upper 8 to 10 feet. There are less than 100 feet of Lykins shales to the base of the Morrison. Near the top of the Lykins there is locally a bed of yellow sandstone, not unlike that in northern Larimer County. The Morrison is fairly well exposed, and consists of a shale series, interrupted by hard bands of limestone and sandstone. A thin bed of gypsum occurs toward the top of these shales.

Deer Creek.—Conditions are similar to those at Turkey Creek. The Fountain is thicker but softer, and the Lyons is the ridge-maker. The Crinkled sandstone of the Lykins is in two bands, separated by 12 to 14 feet of shales. The lower half of the upper band is a fairly good limestone, but the upper half is a calcareous shale.

Indian Creek.—The Fountain is quite thick, and is exposed in several saw-toothed ridges. The Lyons is about 75 feet thick, and about 30 feet of shales intervene between it and the Crinkled sandstone, which is in two bands—the lower 3 to 5 feet thick, and the upper 8 to 10 feet. No fossils were found, but small cavities filled with calcite suggest that possibly fossils were once present. All higher formations up to the Dakota are covered by alluvium.

Perry Park.—The Fountain is thick, and consists of alternating hard and soft bands, which result in the formation of saw-tooth ridges and intervening valleys. The Lyons is also quite thick, and varies in color from red to white, but is usually cream-colored. The exact contact of the Lyons with the Foun-

tain is hard to determine. Above the Lyons are from 20 to 30 feet of soft, red shales, followed by the Crinkled sandstone in two bands, of which the lower is calcareous. About one-quarter of a mile south of the lake in Perry Park fossils were found in a band about 6 inches thick near the base of the Crinkled sandstone. In the upper portion of the Lykins there is a bed of gypsum, 40 to 50 feet thick, which is overlain by limestone resembling the Morrison. The following fossils, identified by Dr. G. H. Girty, were found in this fossiliferous horizon:

Myalina wyomingensis.
Myalina perattenuata.
Alula squamulifera.
Alula gilberti (?)
Pleurophorus sp.

Colorado Springs between Fountain Creek and Bear Creek.—The basal sedimentaries are covered. The lowest member exposed is the red conglomerate, followed by a brick-red sandstone in alternating hard and soft bands. Above this is a pink, cross-bedded sandstone, undoubtedly Lyons, but it is difficult to set it off definitely from the Fountain. This is followed by 30 to 50 feet of soft, red Lykins shales, containing the Crinkled sandstone near the top. The Crinkled sandstone here is from 8 to 10 feet thick. The lower half is a good limestone, but the upper half is clayey. The Morrison is not well exposed.

Between the Arkansas River and the New Mexico Line.—There is no exposure which can be assigned to the Lykins, unless it is the upper part of Hills' Badito formation in Red Canyon, just north of Badito. These sediments are lithologically similar to the Lykins shales, but there is no Crinkled sandstone horizon. They are finer-grained than the lower part of the Badito formation, but much brighter red in color than the rest of the Badito, or any other formation along the entire Front Range. No fossils were found in the formation.

The slopes of the Sangre de Cristo Mountains on the western side of Huerfano Park were not studied. In many places south of the Arkansas River the Dakota sediments lap over onto the granite. The larger portion of the country is rather heavily timbered and deeply covered with wash, and is hard to work.

Red Canyon North of Badito.—The base of the Badito formation is not exposed, but there are 300 to 400 feet of arkose and conglomerates which are identical in appearance with the Fountain. As the area is so isolated from the known Fountain areas,

positive correlation was not attempted. There are no sediments corresponding in lithological character to the Lyons, and if that formation is represented, it is by sediments of a different character. Above the upper band of arkose there are about 75 feet of bright-red shales and clayey sandstones, resting apparently conformably upon the arkose. Following this are 15 to 20 feet of a lighter-colored sandstone, similar to one in the northern part of Larimer County in the Lykins formation. Following this are 40 to 50 feet of red sandstone, some bands of which are quite hard. The red shales become mottled near the top. Above this there are bands of purple, shaly sandstone, alternating with layers of calcite from 1 to 6 inches thick. At the top there are 12 to 15 feet of soft, yellowish sandstone. The dip is about 36° east. If this series represents the Lykins, it is much thicker than is usual in central Colorado, and is comparable to the Ingleside and Lykins of Northern Larimer County. It very much resembles the Ingleside of Larimer County.

Six Miles Northwest of Badito.—This exposure is on the western side of the ridge, 2 or 3 miles due west of Red Canyon. The conditions are similar to those in Red Canyon. The Lykins (?) is all red shales and sandstone, with no light-colored bands. It is much harder to separate it from the rest of the Badito formation than it was in Red Canyon. The base of the Badito is exposed, and the lower part consists of 400 to 500 feet of sediments. The lowest member is a very coarse conglomerate, containing gneissoid and granitic boulders up to 2 feet in diameter and not well cemented together. It lies with angular unconformity upon the pre-Cambrian rocks. Above the conglomerates are arkose and other bands of conglomerate, not nearly so coarse and much better cemented than the basal band. Following this are the red shales and sandstones of the Lykins (?). The pre-Cambrian rocks show their sedimentary origin much better than usual.

AGE AND CORRELATION OF THE LYKINS

Age.—The "Red Beds" in northern Larimer County are very thick, and probably present quite the most complete record to be found on the eastern slope in Colorado. The Mississippian period is represented by a thin band of chert in a dark-red shale formation in Perry Park. Overlying the Mississippian or older formations is the Fountain series, considered equivalent to the Hermosa formation, containing a Pennsylvania fauna. Overlying

the Fountain in the northern part of the state is a series of limestones and sandstones (the Ingleside), which Professor Henderson in his report correlates provisionally with the Lyons of Fenneman; but the present work has shown that the series at Box Elder Creek represents at best only the horizon of the lower part of Fenneman's Lyons, and is possibly entirely below it. This series contains Pennsylvania fossils at several horizons. One such horizon is at the very top. Professor Henderson is now inclined to the view that the Ingleside is below the Lyons. Overlying this is the Lykins formation, and at one horizon about 200 feet from the base, at Heygood and Box Elder Canyons, *Bellerophon crassus* and *Myalina subquadrata* were found. The same species are found in the Fountain and Ingleside below. On this evidence, together with the fact that there is no angular unconformity, and no marked difference of lithological character, this basal portion of the Lykins is assigned to the Pennsylvanian period. On the northern slope of Table Mountain, Larimer County, 40 to 50 feet higher than the lower fossiliferous stratum, and separated from it by a gypsiferous series, another fossiliferous stratum occurs. This is probably more than 300 feet from the top of the Lykins formation, and seems to be in the same stratigraphic position as the fossiliferous beds near Stout, and also those in the Crinkled sandstone near Perry Park. At Stout, and also at Table Mountain, the "crinkly" structure is not present. From this horizon Dr. G. H. Girty identified the following fossils:

From Table Mountain:

Myalina wyomingensis
Myalina perattenuata
Alula squamulifera
Murchisonia buttersi

From Stout:

Myalina wyomingensis
Myalina perattenuata

From Perry Park:

Myalina wyomingensis
Myalina perattenuata
Alula squamulifera
Alula gilberti (?)
Pleurophorus sp.

This fauna has been recently discussed, *Alula squamulifera* and *Murchisonia buttersi* described as new, and *Allerisma (Pleu-*

rophorella?) gilberti removed to the new genus *Alula,* by Dr. Girty (18a).

It will be seen that the faunas are essentially the same, and while some of the species are new, the number of known forms is such that Dr. G. H. Girty believes a tentative correlation with the Rico formation of the San Juan region is justifiable. The Hermosa is Pennsylvanian, while the Rico is considered, tentatively, Permian. This leaves 100 to 400 feet of shales to represent the Permian or the remainder of the Permian, the Triassic, and all the Jurassic up to the Morrison. These sediments are usually a soft, red shale or shaly sandstone, and the conditions of deposition were apparently unfavorable for the preservation of fossil evidence.

There seems to be no angular unconformity between Lykins and Sundance, or between Sundance and Morrison, or between Lykins and Morrison where the Sundance is absent. The character of the Lykins is such that erosional unconformity would be very difficult to detect, but the Sundance should show erosion, if it occurred. Of course, it is quite possible that the Sundance is rather local and never occurred where it is not now found.

There seem to be more sediments above the Crinkled sandstone in the northern part of the state than there are in the central and southern parts. In fact, the best section of the Lykins in the state is found in northern Larimer County, and it is possible that over the line in Wyoming an even more complete section might be found. Triassic vertebrate remains are reported by Williston about 200 feet from the top of the "Red Beds" from the Popo Agie River, which is east of Lander (31). If these "Red Beds" can be correlated with those of Colorado, and the identification is correct, possibly the Triassic may be represented in northern Larimer County. The conditions seem to show that, from the Wyoming line south, there was either less and less deposition, or more and more subsequent erosion. It seems probable that, if it is possible to work out the age of the upper part of the Lykins, it must be done in Wyoming.

Correlations.—The correlation of the Fountain, Ingleside, Lyons and Lykins along the foothills from the Wyoming line to Colorado Springs is a question of recognizing the same formation under different names. This has been discussed under the paragraphs headed "Formation Names." Thus the Fountain of Fenneman in the Boulder quadrangle is equivalent to the lower part of the Fountain of Cross in the Pikes Peak area. The

Fountain, Ingleside and Lyons together are equivalent to the Lower Wyoming of the Denver Basin area. The Lykins is equivalent to the Chugwater of Darton and the Upper Wyoming of Emmons. The upper portion of the Fountain and the Ingleside together are equivalent to Darton's Casper formation. The Lyons is equivalent to the Creamy sandstone of the Denver Basin area, but Darton's Tensleep is not the equivalent of the Lyons and the Creamy sandstone. It is a lower horizon, and can be correlated only with the lower portion of the Lyons, and also the Ingleside. An explanation of this requires a description of conditions in northern Colorado. This has been made under "Formation Names." Darton's Tensleep in Colorado is probably in part equivalent to the sandstone-limestone series; that is, the Ingleside formation.

Owing to the absence of fossil evidence in the Badito formation, and from the fact that it is separated so widely from any recognized Fountain exposures, it has not been definitely correlated with the Fountain. Lithologically they are very similar, and the Badito overlies pre-Cambrian rocks unconformably, bearing about the same relation to overlying formations as does the Fountain. On these grounds they are at least approximately in the same horizon.

The Cutler formation is defined as that portion of the "Red Beds" lying above the Rico, where that is present, or otherwise as succeeding the Hermosa, and below the Dolores. The Cutler is assigned to the Permian purely on stratigraphic grounds, and is separated from the Rico by a purely arbitrary line. There seems to be as good ground for assigning the Lykins, above the Crinkled sandstone, or at least the lower portion of it, to the Permian, and thus correlating it with the Cutler.

Above the Cutler formation in the San Juan region is a series of sandstones, sandy shales and conglomerates which vary in thickness from 800 to 400 feet, and from that down to 30 feet at the San Miguel River, disappearing entirely north of this river. These shales and sandstones are a bright vermilion in color, and are known as the Dolores formation. They are assigned to the Triassic age because of scanty, but wide-spread, vertebrate, invertebrate and plant remains. The extreme upper portion of the Lykins in Larimer County may be equivalent to the Dolores, and thus be Triassic. If so, it is impossible to draw a line between the Permian and Triassic in eastern Colorado.

Dr. Girty, in Professional Paper No. 16, in his correlation says that "the evidence seems to show that the lower Pennsylvanian deposits of the San Juan, Crested Butte and Leadville areas are essentially synchronous."

There seems to be sufficient evidence for the belief that the Fountain also was laid down at this time.

The following is a partial list of fossils identified from the "Red Beds" of the Front Range:

From the Fountain:

Manitou region:

Orbiculoidea manhattanensis
Marginifera ingrata

Livermore quadrangle:

Chaetetes milliporaceous
Derbya n. sp.
Meekella striaticostata
Productus nebraskensis
Spirifer rockymountanus
Squamularia perplexa
Ambocoelia sp.
Composita subtilita
Myalina swallowi
Myalina subquadrata
Bellerophon crassus
Nautilus sp.
Phillipsia aff. major

From the Ingleside (Lyons of Professor Henderson):

Livermore quadrangle:

Myalina subquadrata
Myalina aviculoides
Bellerophon crassus
Meekella striaticostata
Productus cora
Loxonema sp.

From the Lykins:

Lower horizon:

Myalina subquadrata
Bellerophon crassus

Upper horizon, identified by Dr. G. H. Girty:

Myalina wyomingensis
Myalina perattenuata
Alula squamulifera
Alula gilberti (?)
Pleurophorus sp.
Murchisonia

Of the Lykins fossils all except *Alula squamulifera* and *Murchisonia buttersi,* which are new species, and *Alula gilberti (?)* are found in the Rico formation of the San Juan region. Girty reports about thirty-seven species from the Rico. Of these, *Bellerophon crassus* and *Myalina subquadrata,* and others, also occur in the Hermosa. It will be noticed by the list of the Lykins fossils that these two occur at a different and lower horizon in the Lykins than the remainder. This rather strengthens the correlation of the Lykins with the Rico. *Bellerophon crassus* and *Myalina subquadrata* are found in the Hermosæ and other Pennsylvanian horizons lower than the Rico. *Pleurophorus subcostatus* and *Pleurophorus occidentalis* occur in several localities, but it is by no means certain that the *Pleurophorous* of the Lykins belongs to either one of these species. A doubtful identification of *Myalina wyomingensis* has been made from Leadville. With these possible exceptions, none of the Lykins fossils have been reported by Girty from any formations in Colorado other than the Rico. In summarizing, it will be seen that there is fairly good evidence for correlating the Lykins with the Rico, and no evidence for correlating it with any other horizon. The Lykins fossils were collected from localities a long distance apart—from the extreme northern part of Larimer County in the north, to Perry Park in El Paso County in central Colorado—so that the Lykins appears to be more widely distributed than the Rico.

On comparing the Fountain fauna with that of the Ingleside formation in the northern part of the state, it will be seen that, with one or two exceptions, all the fossils reported in the Ingleside are reported from the Fountain, so that they will be considered together, thus treating this series as if it were merely the upper portion of the Fountain, which in reality it is, as it is exceedingly difficult to draw a line between them in many places, on either lithological or structural grounds. *Myalina subquadrata* and *Bellerophon crassus*—species common to both this series and the Fountain—are also found in the lower part of the Lykins formation in northern Larimer County.

On examination of the fossils in the various localities, it will be noticed that those in common are the ones that are most frequently met with in the Fountain, and those which differ are those which are not so frequently met with, or are in such poor condition that genera only could be determined. When it is remembered that many of the localities were on opposite sides of the then existing land area, and hence were more or less isolated

from one another, the correlation becomes more noteworthy. There seems to be enough evidence to correlate the Fountain, Ingleside and Lyons with the Hermosa. If this correlation is accepted, the correlation of the Fountain with the Maroon of Crested Butte and the Weber of Leadville follows from Dr. Girty's correlation (15).

Section No. I is just north of Table Mountain, in northern Larimer County. This section shows the Fountain comparatively thin, being only about 500 feet, but probably complete, as a good deal of the formation is finer-grained sandstone, sandy limestone, and shale in contact with the coarser arkose and conglomerates which represent a greater part of the formation in those places farther south where it is thicker. In this section the Fountain shows conglomerates containing chert and other boulders at the base, and arkose higher up. Nearly all the strata, even the conglomerates and arkose, carry lime in varying quantities. The Ingleside consists of about 125 feet of fine-grained limestone. There appears to have been continuous, or nearly continuous, deposition from the basal Fountain to the top of the Ingleside, and it is difficult to separate the two formations. The Lykins is 791 feet thick, and shows the most complete section of this formation to be found in Colorado. It is composed of fine, brick-red shales and shaly sandstones, with a few bands of sandy or shaly limestones, some of which contain fossils. The lower fossiliferous band is about 200 feet from the base. The upper is from 75 to 100 feet higher, and is separated from the lower by the characteristic red shales and a thin bed of gypsum. The top of the Lykins is a massive, red sandstone, containing more or less clay in the lower part. It varies in color from brick-red to pink, to the yellow of the Sundance.

Geologists who have worked in this region have regarded the gray strata as the basal part of the Morrison, but a study of the section shows no evidence of an unconformity, and as there is no fossil evidence to aid in placing the contact, one naturally looks for the most important lithological change as the most natural place for the contact of the two formations. This is the change from the massive, white-to-yellow sandstone of the Sundance, to the fine, gray-to-drab, flaky shales. There are, however, thin bands of similar white sandstone at various horizons in the shales. It is possible that farther south one of these bands may thicken and form the basal member of the Morrison as it occurs at Boulder. If it is assumed that the basal part of the Morrison

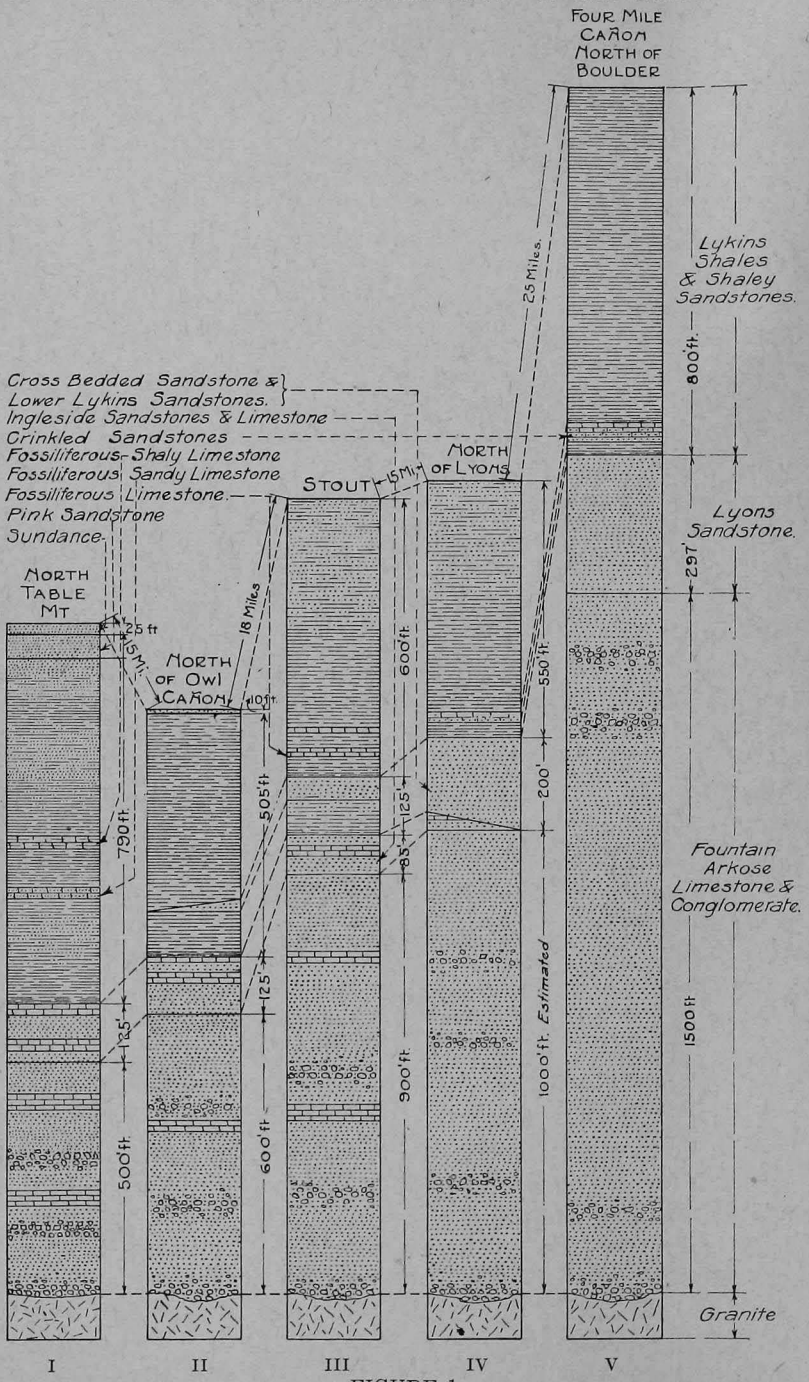

FIGURE 1

Sections Showing Relationship of Lykins, Fountain, and Ingleside Formations, North of Boulder, Colorado.

in northern Larimer County is the massive, white-to-gray sandstone, it is extremely difficult to fix upon the contact between this formation and the Sundance.

Section No. II is north of Owl Canyon and about 15 miles south of Section No. I. In this section the Fountain is a little thicker and contains less lime in the lower part. The Ingleside is of about the same character and maintains a thickness of about 125 feet. The calcareous bands of the Lykins are thinner and more clayey, and no fossils were found in them. The Sundance is thinner, from 10 to 15 feet, and often absent. About 100 feet above the top of the Ingleside an inconspicuous band of light-colored, much Crossbedded sandstone appears in the shale, and thickens southward to about 6 feet, forming a low ridge. From this point south it gradually attains a maximum thickness of about 70 feet. This band can be traced continuously to Lyons, where it forms the top of the Lyons formation. The Lykins below this band becomes more and more sandy toward the south, and at Lyons it has become so much like the Crossbedded sandstone that it is practically impossible to separate the two. The Lykins at this point is about 525 feet thick.

Section No. III is at Stout, about 18 miles south of Section No. II. In this section the Fountain has thickened to about 900 feet, and there is more arkose and conglomerate and less limestone. The Ingleside is thinner and contains less lime, the thinning-out being due apparently to the wedging-out of the limestone members, as the sandstone maintains about its normal thickness. The Lykins also is somewhat thinner. The Crossbedded sandstone is about 50 feet thick. I have discontinued the line separating the Crossbedded sandstone from the lower Lykins sandstone between Sections Nos. III and IV, because at Section No. IV there is no way of distinguishing the contact; all that can be said of Section No. IV is that the upper portion is Crossbedded sandstone. Otherwise they are lithologically alike. From 30 to 40 feet above the Crossbedded sandstone, at Stout, there is a limy series 50 to 60 feet thick, consisting of sandy or clayey limestone bands, with shale between. Fossils were found at the base of the lower limestone band.

Section No. IV is a few miles north of Lyons. The formation is about the same as at Stout. The Ingleside wedges out. At this point it is no longer possible to separate the Crossbedded sandstone from the lower Lykins sandstone. This may be in part due to the sharp folding, which seems to have somewhat modified

the lithological character of the formation. About 30 feet above the Crossbedded sandstone there are calcareous beds, 20 to 30 feet thick, consisting of sandy limestone and shale. The sandy limestone members show that peculiar wavy lamination which characterizes Fenneman's Crinkled sandstone of the Boulder area.

Section No. V is at Four Mile Canyon, about 3½ miles north of Boulder. The thickness of the Fountain, 1,500 feet, is greater than at any point in the northern part of the state. The thickness which the Lyons has attained at this point, 297 feet, is exceeded only at the town of Lyons, where the compression accompanying folding may have thickened the beds. At the point where this section is taken the formation is of coarse texture and more sandy. The measurements in this section are taken from Bulletin No. 265, United States Geological Survey.

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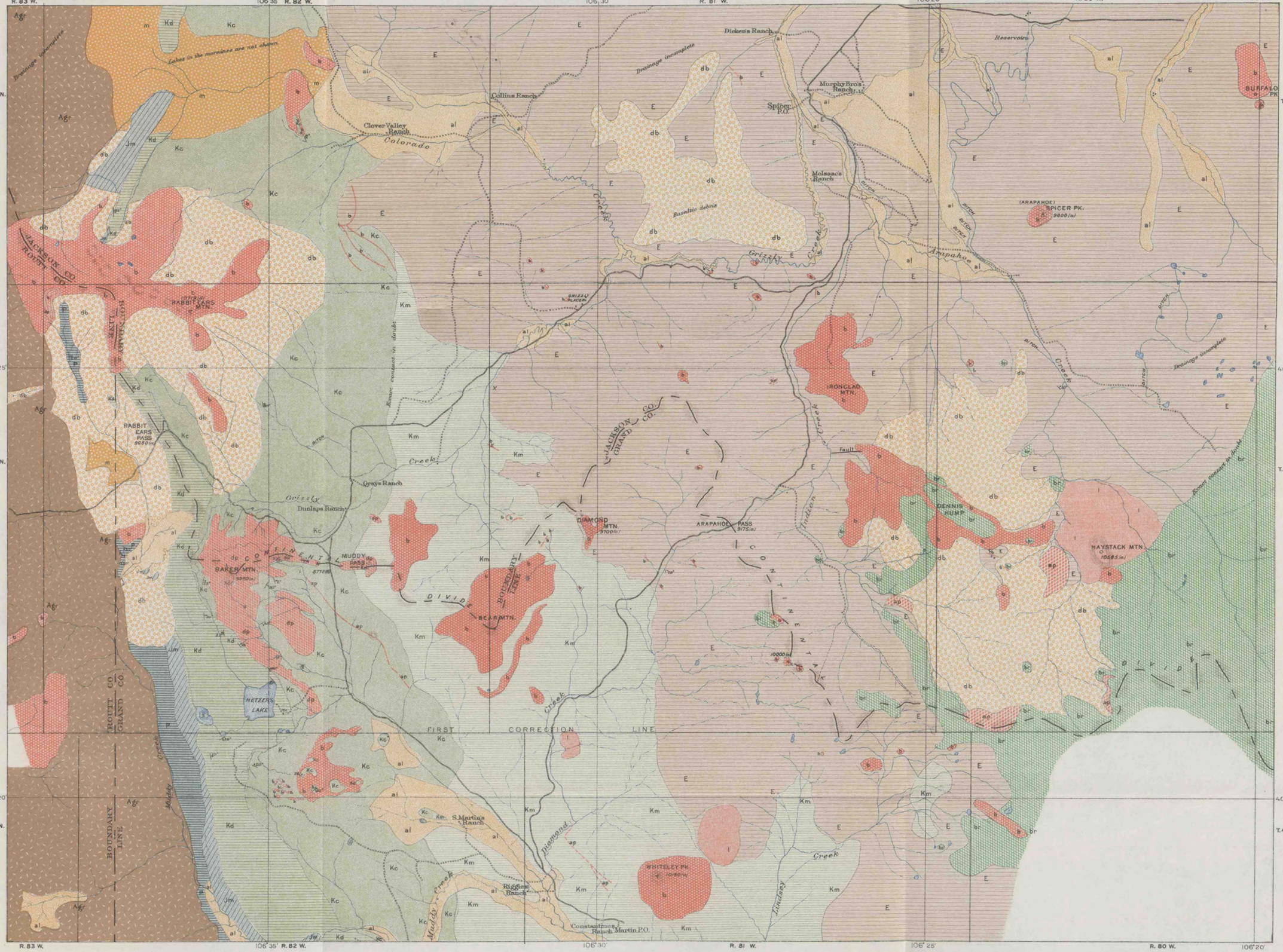
COLORADO STATE GEOLOGICAL SURVEY
R. D. GEORGE, DIRECTOR



LEGEND

SEDIMENTARY ROCKS

QUATERNARY

- al — Alluvium
- db — Debris *Granitic and basaltic*
- m — Moraines

TERTIARY

- E — Eocene ?

CRETACEOUS

- Km — Montana
- Kc — Colorado
- Kd — Dakota

JURASSIC

- Jm — Morrison

PERMIAN

- P — Permian ?

IGNEOUS ROCKS

- br — Breccia *Ash and scoria, etc., with interlaid lava beds*
- b — Basalt
- ap — Andesite Porphyry
- dp — Dacite Porphyry
- l — Quartz Latite

Surface flows — *Intrusives*

TERTIARY — Possibly both pre- and post-Eocene

ARCHEAN

- Agr — Archean *Granites and schists*
- dp / ap / b — Dikes
- × — Prospect shaft or tunnel
- Dip and strike

Primary control taken from the Hayden survey.

Elevations are from the Hayden survey and from Aneroid readings.

Surveyed in 1911 By P. G. Worcester, F. F. Grout and J. Henderson, assisted by A. C. Smith and N. E. Hinds.

GEOLOGIC MAP RECONNAISSANCE SURVEY ALONG THE RABBIT EARS RANGE

ROUTT, GRAND AND JACKSON COUNTIES, COLORADO

Scale 63360

1 ½ 0 1 2 Miles