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THE GEOLOGY OF THE RABBIT MOUNTAIN AREA, COLORADO

This Thesis for the M. S. degree, by

Louis Otto Quam

not proof Louis Otto Quam, B. A., for the

University of Colorado, 1931.

Geology

By

W. G. Page  
H. Worcester

Date June 2, 1932.

A Thesis Submitted to the Faculty of the Graduate  
School of the University of Colorado in Partial Fulfill-  
ment of the Requirements for the Degree Master of Science.

Department of Geology

1932

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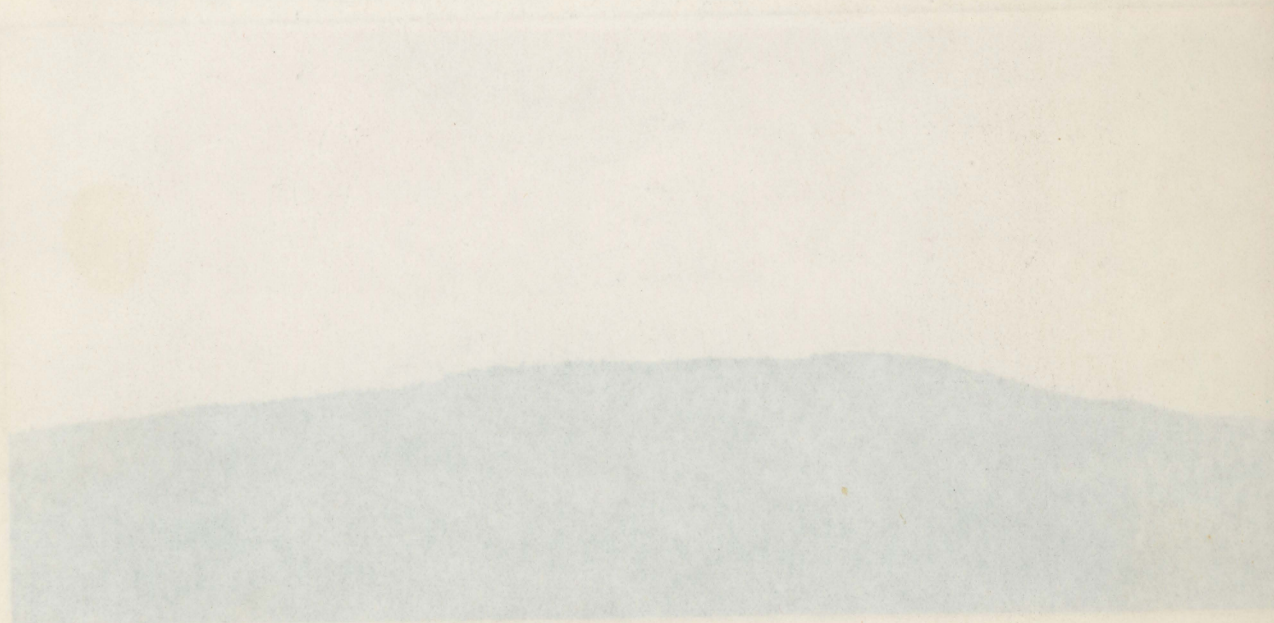
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A. View of Rabbit Mountain and Dell Flats from the south.



B. View of Rabbit Mountain from the east.

Plate V.

Introduction.



A. View of Rabbit Mountain and Dell Flats from the south.



B. View of Rabbit Mountain from the east.

the structural features, especially the fault in Little Thompson Canyon, were questioned by some members of the geology faculty of Introduction. of Colorado. Consequently, it seems desirable to prepare a detailed structure map and present a complete description of the geology of the area.

#### Location.

The Rabbit Mountain area, as mapped and described in this report, includes twenty-four square miles of territory four miles east of Lyons and two miles north of Hygiene, Colorado. It is on the boundary line between Boulder and Larimer counties, and includes the northwest quarter of township three north and the southeast quarter of township four north in range seventy west of the sixth principal meridian. The area is readily accessible, since it is bounded on the south by the Lyons-Longmont highway and the Lyons branch of the Burlington railroad, and on the east by the main highway north from Hygiene. Farmers in the area have constructed roads which make it possible to drive an automobile through the area. Most of the points of interest can be seen without walking far from the car. The area is within twenty miles of the State University at Boulder, and is an excellent field example for geological study.

#### Field and Office Work.

During August 1930, J.E. Simmons and the writer prepared a reconnaissance map of the area using a Brunton compass and pace traverse. The interpretation of some of

the structural features, especially the fault in Little Thompson Canyon, <sup>was</sup> questioned by some members of the geology faculty of the University of Colorado. Consequently, it seems desirable to prepare a detailed structure map and present a complete discussion of the geology of the area.

The field work on which this report is based was done during September 1931 and on Saturdays and holidays during the school year 1931-32. The maps were drafted and the text written during the Spring quarter of the same school year at the University of Colorado. The mapping was done on a scale of one inch to one thousand feet. A plane table and telescopic alidade were used in the mapping. A triangulation net was established for control, three-point method of location was used, and the contacts of the rock formations were mapped by linear traverse. The Niwot and Loveland quadrangle topographic sheets of the United States Geological Survey were used as base maps.

#### Acknowledgment.

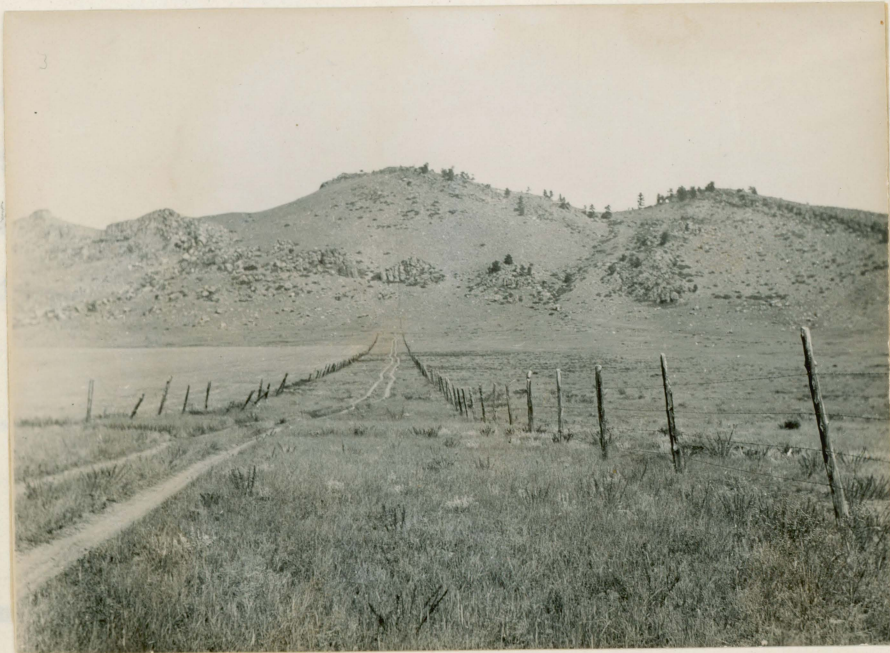
Mr. Howard Stagner acted as instrument man in surveying the area, and much credit is due him for his faithful assistance. The writer also wishes to acknowledge his indebtedness to Mr. J.E. Simmons and Professor W.O. Thompson who helped with the reconnoissance work done in 1930, and to the members of the Geology Department

at the University of Colorado for their helpful criticisms  
and suggestions.

Plate VI.



A. View of Dowe Pass anticline from the north. Note the Dakota ridge encircling the eroded anticline.



B. View of Dowe Pass anticline from Dell Flats. Note the duplicated Dakota on the east limb.

at the University of Colorado for their helpful criticisms and suggestions.

Dakota sandstones now outcrop around an elliptical anticline of Morrison, and form a cliff along the east side of the mountain.

#### GEOGRAPHY.

Topography is a broad synclinal valley called Bell Flats. This valley is about 2 miles

The area is in the foothills zone on the east side of the Front Range of the Rocky Mountains, where the mountains rise abruptly above the plains in roughly north-south-trending ranges. Along the front of the mountain range the sedimentary rocks are tilted and dip eastward at high angles. Erosion has developed a series of longitudinal valleys along the strike of the less resistant beds, and the resistant rocks of the Fountain-Lyons and Dakota formations form parallel hogback ridges. Within the Rabbit Mountain area the foothills extend nearly three miles east of their normal trend to the south, and are duplicated and curved by folding.

The relief of the area is about one thousand feet. <sup>1000</sup> Rabbit Mountain although not the highest, is the most conspicuous ridge because it is surrounded by low land on three sides. It is an anticlinal ridge joined to the mountains only on its northwest side. Erosion has worn away the overlying formations exposing the resistant Dakota sandstone which forms a gentle dip slope on the west side. On the east side, however, erosion has succeed-

in cutting through this resistant formation where fractures had developed along the crest of the fold. The Dakota sandstones now outcrop around an elliptical inlier of Morrison, and form a cliff along the east side of the mountain.

West of Rabbit Mountain is a broad synclinal valley called Dell Flats. This valley is about a mile and a half wide and is surrounded on the west, north, and east side by ridges about six hundred feet high. The valley is open to the south and merges into the plains. It will be noticed that both the ridge and valley described above are determined directly by the structure. That is, the ridge is anticlinal and the valley is synclinal.

To the north is another anticline called Dowe Pass. This fold has been eroded to a considerable extent. The resistant Dakota formation forms a high ridge encircling the fold except on the north. The less resistant Morrison and Lykins beds have been eroded out, forming a horseshoe-shaped valley encircling an elliptical (shaped) hill. This hill is the core of the anticline, and is composed of the Lyons sandstone which, because of its greater resistance to erosion, has not been worn out.

The hogback ridge along the western border of the map curves to the northwest and becomes higher and wider. This change in strike and increase in size is due to a small anticline and syncline which will be re-

As a rule along the Front Range the Lyons-Fountain hog-

ferred to as the "Ridge folds." /

Little Thompson River enters the map area in the northwest corner and follows a southeast course which is determined in a large part by the structure of the underlying rocks. From the place the stream enters the map area its course is deflected to the south east along a fault trace. Farther south along its course the stream follows the trough of a syncline formed by the upturning of the beds along the fault. Where the fault plays out into an anticline in section 34 the stream has eroded its valley through the fold, and finally has cut the Dakota hogback ridge. The valley of this stream is wide where it crosses the longitudinal valleys, but is quite narrow where it cuts through the hogback ridges.

Throughout the area there is a very close relationship between topography and structure, and many examples of erosional adjustment to the structure of the underlying sediments are evident.

Relics of older topographic surfaces are also present. A conspicuous feature along the Front Range is the accordance of the summits of the ridges. In the map area the ridges are approximately 6000 feet in elevation. The western ridges are slightly higher than those farther east; so that a plane connecting the tops of the ridges would slope eastward. This slope is seen to be independent of the type of rock that makes up the ridge. As a rule along the Front Range the Lyons-Fountain hog-

back is the westernmost ridge and is the highest; but here it can be shown that where the Dakota ridge is duplicated with one ridge west of Lyons-Fountain ridge and another east of it, the westernmost ridge is still the highest, and the most easterly ridge is the lowest. The ridges are also lower near the main streams; so that they seem to constitute remnants of a former rather-level surface on which the present east-west drainage lines were established.

This ancient plain has been recognized along the entire Southern Rockies, and is called the Rocky Mountain Peneplain. The highest ridges in the area mapped are probably parts of this great peneplain.

Along the eastern edge of the area are high flat-topped mesa-terraces that extend eastward for many miles. The highest of these terraces is well developed northeast of Rabbit Mountain on the south side of Little Thompson creek. The 5400-foot contour (line) outlines a rather large flattopped area which extends southeast into section 12, and is separated from its former extension - Table Mountain, - by an old stream channel through which the highway now passes. The little circular flattopped hill north of Little Thompson creek is also a part of the same surface. A lower level of terraces, which are much more extensive though not as conspicuous, have a general elevation of 5200 feet near the mountains. These terraces slope eastward at nearly a three-percent grade, and also

slope toward the major streams. They are covered with debris brought from the mountains by erosion, and represent former floodplain levels.<sup>1</sup>

Drainage.

*Climate and Vegetation.*

The area is drained by two main streams - Little Thompson creek and the St. Vrain River. These streams rise in the mountains to the west and flow eastward into the South Platte River. They established their courses on the peneplain surface; and have retained their eastward direction, cutting through the hogback ridges which are along the front of the mountains. These streams are, therefore, superimposed on the present topography of the foothills.

Nearly all the other streams are intermittent. They are mainly gullies that contain water only during periods of melting snow or downpour of rain. Most of the erosion, except in Little Thompson Canyon, is due to these intermittent streams. They have worn out the soft beds and have left the resistant sandstones which form the present topographic features.

---

1. Fenneman, N.M., Geology of the Boulder District, Colorado. U.S.G.S.Bull. 265, pp.13-16(1904)

Lee, W.T., The Origin of the Debris Covered Mesas of Boulder, Colorado. Jour. Geol. vol.8, p.504

The drainage from Dell Flats and Rabbit Mountain flows to the St. Vrain River.

On the steep, eroded slopes of these ridges back brush and other herbaceous growth are the dominant vegetation. The meadows formed in the longitudinal valleys are cultivated in many places, but grasses are the main natural vegetation.

#### Climate and Vegetation.

The climate of the area is semi-arid and particularly dry because the altitude is not high enough to receive the increased precipitation of the mountains; (and) because of its location, the area receives little water from the mountain drainage. Irrigation is impossible, for the area is above the level of the mountain streams. The annual variation of rainfall is considerable. In general, April and May are the months of greatest precipitation. Generally, the summers are very dry, because the increased insolation has a parching effect, and the evaporating power of the air is great.

The vegetation is sparse and open. It consists principally of coarse grasses, herbaceous growths, and trees typical of the dry coarse soil of the foothills belt. A distinct relationship between the vegetation and the underlying rock can be noted. On the dip slopes of the hog-back ridges, the thin sandy soil derived from sandstone favors the growth of rock pine. Primitive bunch grass,

spiny shrubs, and cacti form the ground cover of these pine-sprinkled slopes. On the eroded slopes of these ridges buck brush and (other) herbaceous growth are the dominant vegetation. The meadows formed in the longitudinal valleys are cultivated in many places, but grasses are the main natural vegetation. Poplars and willows grow along the sides of the stream in Little Thompson canyon and along the irrigation ditches. The narrow-leaved cottonwood is the largest and most common tree.

The farmers raise small crops of corn, wheat, and vegetables. Most of the area is used as pasture (land) for cattle and sheep.

Lower Cretaceous?	Morrison (may include Sundance)	333
		351
Permian?	Lynns	333
Pennsylvanian	Lynns (may include Ingle side)	333
	Fountain	333
Pre-Cambrian	Idaho Springs?	?

The generalized columnar section (Plates IV) briefly summarizes the character of the rocks and their most common topographic expression.

## The DESCRIPTIVE GEOLOGY.

### Stratigraphy.

The oldest rocks exposed in the area are a series of gneisses, schists, and quartzites which have been in-

truded by red granite and numerous pegmatite dikes. These of late Paleozoic and Mesozoic sediments. The following table gives a summary of the succession of formations:

	Pierre (Interval to Hygiene 2678)	5000
	Niobrara Mountain. The series	335
Upper	Benton	538
Cretaceous	Dakota Brown quartzite, dark gray	438
	black coarse-grained quartz bitite schist, and a very	
	dark, nearly black, quartzite. The dark color of the	
Lower	Morrison (may include Sundance)	332
Cretaceous?		35'
	Permian ? Lykins probably of sedimentary	568
Pennsylvanian	Lyons (may include Ingleside)	235
	Fountain	860

Pre-Cambrian Idaho Springs ? similar to section ? of

the Idaho Springs formation that are exposed at the base of the Fountain formation in Coal Creek Canyon. They are briefly summarized the character of the rocks and their

which are highly metamorphosed and apparently older than most common topographic expression. a series of quartzite and quartzite-conglomerate of Coal Creek and South Boulder which Van Hise and others provisionally classed as Algonkian.

1. Van Hise, C.H., and Leith, C.S., "Pre-Cambrian Geology of North America." U.S. Geol. Survey Bull. 380, p. 327 (1909)

## THE CARBONIFEROUS SYSTEM.

## The Fountain Formation.

## The Pre-Cambrian Rocks.

The oldest rocks exposed in the area are a series of gneisses, schists, and <sup>amphibolites</sup> (quartzites) which have been intruded by red granite and numerous pegmatite dikes. These rocks are exposed by a fault along Little Thompson creek in sections 28, T. 3 N., R. 70 W, and form a large mountain to the northwest called Blue Mountain. The series consists of a light pinkish-brown quartzite, dark gray to black coarse-grained quartz biotite schist, and a very dark, nearly black, <sup>amphibolite</sup> (quartzite). The dark color of the quartzite is due to a high content of biotite and probably some hornblende.

These rocks are probably of <sup>igneous</sup> sedimentary origin. They show very definitely the structure of bedding planes which dip eastward at about forty-five degrees.

The metamorphic rocks are similar to members of the Idaho Springs formation that are exposed at the base of the Fountain formation in Coal Creek Canyon. They are much more highly metamorphosed and apparently older than a series of quartzite and quartzite-conglomerate of Coal Creek and South Boulder which Van Hise<sup>1</sup> and others provisionally classed as Algonkian.

---

1. Van Hise, C.R., and Leith, C.K., "Pre-Cambrian Geology of North America." U.S. Geol. Survey Bull. 360, p. 327 (1909)

THE CARBONIFEROUS SYSTEM.

The Fountain Formation.

Plate VII.

*an unconformity*

Overlying the metamorphic rocks with *an angular unconformity*, is the Fountain formation, which extends from Pueblo to the southern part of Wyoming. It was named by Whitman Cross from Fountain creek near Colorado Springs. The Fountain of this area is equivalent to only the upper part of the Fountain as named by Cross.

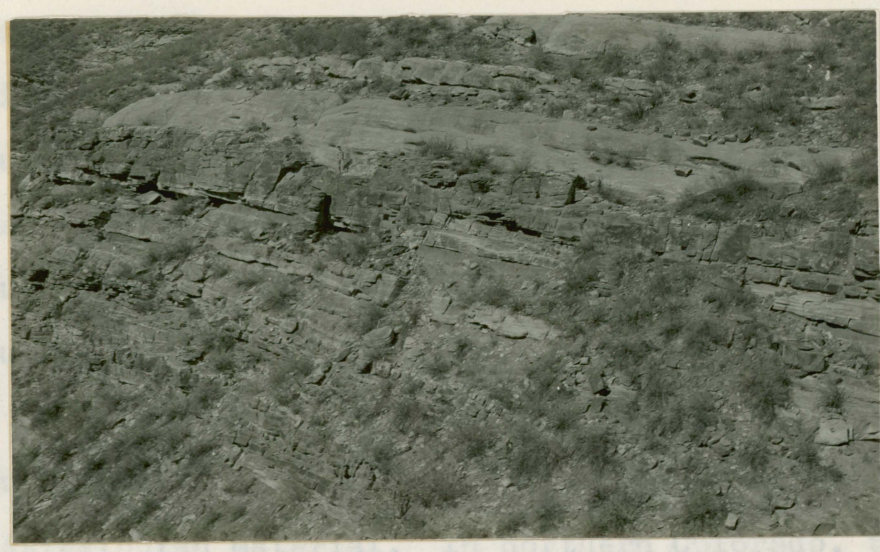
The formation consists of coarse-grained crumbly grits, arkosic sandstones, and conglomerates. It is dominantly red, mottled with greenish-gray and purple. It is irregularly bedded, and is composed of beds of arkosic coarse-grained sandstone, unsorted pebbles of quartzite, and eroded fragments of older rock, with occasional zones of finely bedded red shale. The material is very poorly sorted. The small fragments are rather angular, but the large pebbles show considerable rounding. Torrential cross-bedding is common. In many places there are examples of channels three to five feet deep, in a sandstone zone, which are filled with coarse conglomerate. This characteristic is referred to as cut-and-fill structure. Plate VI shows two such channels. The formation is very variable both vertically and laterally; its nature suggests, as Tiejé<sup>1</sup> has pointed out, a flood-plain deposit.

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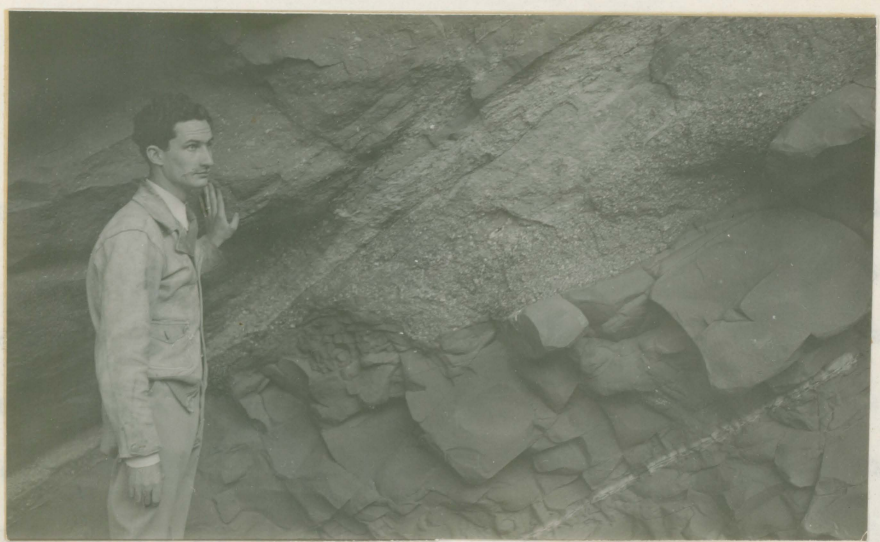
1. Tiejé, A.J., "The Red Beds of Colorado." Jour. of Geol. vol. 31, pp. 192-207 (1923)

The Fountain formation was grouped with the

Plate VII.



A. Cut and fill channels in the Fountain formation.



B. Close-up view of the channeling. Note that the channel truncates the bedding planes of the sandstone zone, and the conglomerate becomes finer grained and grades into sandstone above.

The Rocky Mountains in Colorado. Geol. Surv. Bull. 5, pt. 2, pp. 33-34 (1862)

The Fountain formation was grouped with the other red beds of the Front Range by the early workers under the name, Wyoming Formation, and was considered Triassic in age. The present Fountain is approximately equivalent to the Lower Wyoming of Emmons and Eldridge. The formation is now known to be of Pennsylvanian age, because Pennsylvanian fossils have been reported from the Fountain in several localities<sup>1</sup>, and some pebbles found in the conglomerate contain fossils of Mississippian Age, showing that the Fountain is in part made up of reworked Mississippian material. In northern Colorado, the Fountain is overlain by younger beds of the Ingleside formation which also contain a distinct Pennsylvanian fauna.

#### The Fountain-Lyons Transition.

Between the typical Fountain arkose and the Lyons sandstone there is a massive sandstone zone which is similar to the Lyons, except that it is not so highly cross-bedded. This zone has been shifted between the Fountain and Lyons formations by workers in adjacent areas. Some geologists include it with the Fountain, some regard it as basal Lyons, and still others have designated it as a distinct formation. Butters<sup>2</sup> de-

1. Henderson, Junius. Colo. Geol. Sur. Bull. 19, pp. 84-74.

2. Butters, R.M., "Permian or Permo-Carboniferous of the Eastern Foothills of the Rocky Mountains in Colorado." Colo. Geol. Sur. Bull. 5, pt. 2, pp. 66-94 (1913)

defined the Ingleside formation near the Colorado-Wyoming line as, "a sandstone-limestone series extending geographically from beyond the state line to the north, to a point a little way north of Lyons." Lee<sup>1</sup> extended the Ingleside to Morrison, Colorado, and regarded the transitional zone between the Lyons and Fountain as belonging to this formation.

In August 1930, it was the writer's privilege to work with Professor W.O. Thompson on the Lyons problem. Several sections along the foothills from Box Elder creek to Lyons were measured and the Lyons Fountain contact was carefully studied. The lithological character of the contact zone south of Stout does not justify extending the Ingleside formation farther in that direction. The Ingleside formation consists of several limestone beds separated by sandstones, and overlies the Fountain formation. The limestone beds pinch out to the south, and the sandstones seem to merge with the Fountain and Lyons formations.

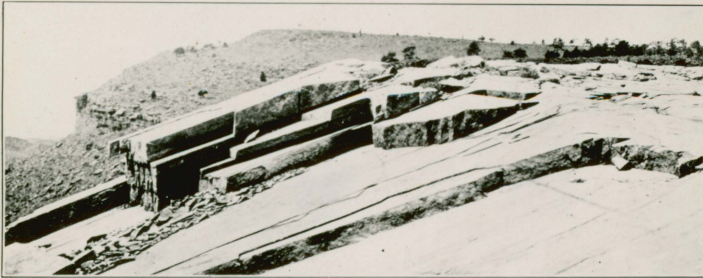
#### THE LYONS SANDSTONE.

Overlying the Fountain, and separated from it by the transitional zone described above, is a series of cross-bedded, fine-grained red sandstones called the Lyons Formation. At the type location, the thickness from the uppermost arkose bed of the transitional zone to the Lyons-Lykins contact is 235 feet. Two rather distinct zones can be identified in the formation. The basal half is more

Plate VIII.

U. S. GEOLOGICAL SURVEY

PROFESSIONAL PAPER 149 PLATE 17



LYONS SANDSTONE AT LYONS, COLO.

In *A* the cross-bedding extends from the top nearly to the bottom of the formation, and the trees stand on the slightly eroded upper surface, or bedding plane. In *B* the eastward-sloping upper surface appears at the sky line and the westward-sloping faces of the laminae exposed in the quarry appear in the foreground. In *C* the face shows sharp boundaries between groups of the cross-bedded layers and the truncation of the older layers before the younger ones were laid down, thus forming an angular unconformity in miniature.

massive with beds from six inches to two feet in thickness, but the upper part is relatively thin-bedded. Both are cross-bedded. The lower zone usually has regular and continuous cross-beds which dip south-east and are not curved. In this zone, the cross-bedding goes only part-way through and is truncated by a younger set of beds. This gives rise to smooth-faced wedge-shaped beds. The upper zone of the formation is characterized by thinner beds which are extremely cross-bedded. The laminae are so smooth-faced and regular in thickness that they make excellent flagstones and building stone.

The sandstones are like the sandstones of the transitional zone in composition and consist of pure quartz grains, well-sorted and cemented with silica. Iron oxide forms a film around the grains and gives the rock a pink to red color. Locally, small concretions about 1/8 inch in diameter are found in the sandstone. These concretions consist of ferruginous soft-lumps of sandy iron oxide. Leaching of these has produced rings, bands, and dendrite figures.

No fossils have been found in the Lyons except amphibian tracks which Henderson<sup>1</sup> identified as *Limnopus ? coloradensis* (Henderson), but which Lee<sup>2</sup> says Gilmore

---

1. Henderson, Junius "Footprints in Pennsylvanian Sandstone of Colorado" Jour. of Geol. Vol. 32, pp. 226-229 (1924).

2. Lee, W.T., Op. cit. p. 12.

has re-identified as *Laoporus coloradensis* (Henderson).

Gilmore also thinks that *L. coloradoensis* may be synonymous with *L. schucherti* from the Coconino sandstone of the Grand Canyon. On this meager evidence, Lee regards the Lyons as Permian in age.

Section On North Bank of Little Thompson Creek

Near Center of Sec. 28, T 4 N, R 70 W.

Strike N 1° E Dip 19° E.

Character	Thickness in Feet	
Sandstone, even bedded, hard and red (transitional to Lyons)	78	
Conglomerate and arkose, pink, friable	53	131
Sandstone, red and hard, crossbedded	20	151
Conglomerate, arkosic, massive, reddish Contain many quartz pebbles well rounded about 1" in diameter.	98	249
Conglomerate, arkosic, light gray to pink mottled and leached	37	286
Sandstone, mottled red and green, massive contains quartz, pink orthoclase and muscovite flakes	52	338
Conglomerate, coarse, dark red to greenish gray, including boulders and pebbles in lenses of coarse conglomerate. Pockets or thin beds of dark red shale.	179	517
Covered	243	760

THE LYKINS FORMATION.

The Lykins formation which overlies the Lyons with apparent conformity is very different lithologically. It consists of rather non-resistant sandstones, shales, and sandy shales which are quite calcareous and gypsiferous at the base. As a whole, this series is thin-bedded, rather friable, and deep brick-red in color. It weathers more easily than the underlying beds, and with the overlying Morrison formation forms a longitudinal valley between the Lyons and Dakota hogbacks. About 40 feet above the base of the Lykins is a persistent, very calcareous sandstone zone about twenty feet thick, which Fenneman<sup>1</sup> called the "crinkled sandstone." It is very finely laminated in red and pinkish-white bands which are twisted, broken, and brecciated. The lower part of this zone is a more massive limestone which is folded and somewhat brecciated and contains calcite veins. The top of the Lykins formation is marked by a slabby, dark red, fine-grained, ripple-marked, sandstone.

Butters<sup>2</sup> found several fossils in the Lykins formation which Girty refers to the Pennsylvanian and Permian. Butters considered the portion above the

---

1. Fenneman, N.M., "Geology of the Boulder District, Colorado. U.S.G.S. Bull. 265, pp. 24-26 (1904)

2. Butters, R.M., Op. cit. p. 71.

been quarried for building stone under the trade name of "crinkled sandstone" as Permian in age, and correlated it with the Cutler formation of the San Juan region.

Rabbit Mountain. It is slightly cross-bedded, and shows curved and irregular bedding. It is named by many geologists to represent the Permian.

#### THE LOWER CRETACEOUS OR JURASSIC.

##### The Morrison Formation.

A thin white limestone bed overlies this sandstone in the ... All the beds between the dark red sandstone at the top of the Lykins formation and the heavy conglomerate bed of basal Dakota are grouped in the Morrison formation. This division follows the original description by Eldridge<sup>1</sup> from the type locality at Morrison, Colorado. The contact of the Lykins and Morrison is marked by a distinct color change and a disconformity which represents a long interval of time. Most of the Triassic and Jurassic periods are not represented in the stratigraphy of the Colorado Front Range. The basal bed of this group is a massive salmon-colored sandstone which Lee<sup>2</sup> called basal Sundance, and which Henderson<sup>3</sup> thinks may be placed in either the Sundance or Morrison formations, or be considered as a distinct formation. In the Boulder district<sup>4</sup> to the South there is a white sandstone at the base of the Morrison formation which has

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1. Eldridge, Geo. H., "Geology of Denver Basin". U.S.G.S. Mon. Vol. 27, p. 60 (1896).

2. Lee, W.T., Op. Cit. p. 16.

3. Henderson, Junius Colo. Geol. Sur. Bull. 5, p. 71 (note)

4. Fenneman, N.M., Op. Cit. p. 26.

been quarried for building stone under the trade name of "Doctor Bond Sandstone." Lithologically, this sandstone is exactly like the salmon-colored member at Lyons and Rabbit Mountain. It is slightly cross-bedded, and shows curved and truncated laminae,<sup>16</sup> and is thought by many geologists to represent an eolian deposit.

A thin white limestone bed overlies this sandstone in the Rabbit Mountain area, and above this are varicolored shales and clays which grade again into a thin white sandstone. Overlying this second sandstone is a gray compact limestone member which weathers brown. The next prominent bed is the "Saurian sandstone," described by Eldridge, which overlies a series of clays and shales which he called the "Atlantosaurus clays." This sandstone is generally gray in color and shows specks of blue and brown. It weathers white, and is calcareous enough to react with acid. Above this bed is a series of blue shales and a brown limy sandstone which are overlain by the conglomerate bed of the Dakota Group.

The age of the Morrison formation has caused much dispute. The fossils, although abundant, are of a provincial type not common in other formations. G.C. Simpson<sup>1</sup> has summarized the present evidence and believes

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1. Simpson, G.C., "The Age of the Morrison Formation." Amer. Jour. Sci., 5th. ser., Vol. 12, pp. 198-215 (1926)

that the available evidence is much stronger in favor of upper Jurassic age than of lower Cretaceous. Knowlton<sup>1</sup> believes the dicotyledonous flora collected by Lee from a sandstone about fifteen feet from the top of the formation near Morrison, Colorado, finds its closest affinity with the so-called Dakota flora and is lower Cretaceous in age. T.W. Stanton<sup>2</sup> states that "so far as stratigraphy and invertebrate faunas are concerned, the Morrison is somewhat more likely to belong to the Jurassic, than to the Cretaceous; but their evidence is not conclusive on this point." The United States Geological Survey has followed Lee's suggestion and tentatively called the Morrison Lower Cretaceous, but the recent tendency is to consider it Jurassic. W.C. Toepelman discussed the problem with John B. Reeside Jr., and they are agreed that the entire formation should be considered Jurassic. Reeside says that the members of the United States Geological Survey will hereafter follow this classification.<sup>3</sup>

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1. Knowlton, F.H., "A Dicotyledonous Flora in a Section of the Morrison Formation." Amer. Jour. Sci., 4th. ser., Vol. 49, pp. 189-194 (1920)
  2. Stanton, T.W., "Invertebrate Fauna of the Morrison" Bull. Geol. Soc. Amer. Vol. 26, pp. 343-348 (1915)
  3. Toepelman, W.C., & Reeside, John B. Jr., Personal communication.

## UPPER CRETACEOUS SYSTEM.

## Section Southwest of Dove Pass

Dakota Group.

Sec. 4, T. 3 N., R. 70 W

Strike N.35° W Dip 85° W

The name Dakota has been applied to a group of

beds along the Colorado Front Range, but it is doubtful if

Basal Dakota so named are equivalent to the typical Dakota

Conglomerate, massive, brown, contains  
sandstone of chert pebbles and quartz grains

Unconformity ? change in lithology

Morrison Formation: Thickness in Feet

an upper Sandstone, brown calcareous	4	
Shale, blue	10	14
Limestone, massive gray,		
The Basal weathers white and brown	38	52
Shale, variegated	163	215
Sandstone white to gray shows specks of blue and brown	15	230
Shale, variegated-red, gray green, blue, purple	60	290
Limestone gray weathers white	7	297
Sandstone (Sundance?) white to salmon colored, friable, cross-bedded	35	332

Unconformity abrupt change in color

Lykins formation

Sandstone, red	64	
Shale, sandy and red	439	503
Limestone and sandstone, crinkled and brecciated, contains much calcite	23	526
Sandstone, red	42	568

relatively thin conglomerate is very firmly cemented with

silica cement which often is harder than the pebbles.

890

When the rock is unweathered, fractures pass through the

pebbles rather than breaking around them. The coarse-grained

sandstone zone is very massive and not as firmly cemented

UPPER CRETACEOUS SYSTEM.

Dakota Group.

The name Dakota has been applied to a group of beds along the Colorado Front Range, but it is doubtful if all the beds so named are equivalent to the typical Dakota sandstone of eastern Nebraska. In the Rabbit Mountain area this group is composed of three parts; a basal sandstone and conglomerate zone, a medial black shale zone, and an upper sandstone.

The Basal Conglomerate.

The basal member consists of a massive bed of conglomerate and sandstone. The pebbles of the conglomerate are well rounded and are usually from a quarter to a half-inch in diameter. They generally consist of chert, flint, jasper, quartzite or fragments of granite, and are mixed with finer-grained material. The conglomerate zone varies in thickness; it is in many places lense like and is in some places entirely absent. The coarse-grained sandy material which is present with the pebbles becomes the constituent material of the rock above the base. The relatively thin conglomerate is very firmly cemented with silica cement which often is harder than the pebbles. When the rock is unweathered, fractures pass through the pebbles rather than breaking around them. The coarse-grained sandstone zone is very massive and not as firmly cemented as the conglomerate. Jointing is very distinct in this

sandstone. On the top of Rabbit Mountain and on other ridges where erosion has exposed the surface of this sandstone as a dip slope, weathering has been more rapid along the joint cracks, and polygonal blocks stand out in a form resembling rough pavement blocks. The sandstone is rather massive, slightly cross-bedded, and <sup>shows</sup> considerable variation (can be seen); (but no one bed seems to have a constant position in the column. The upper surface of this sandstone is slightly finer-grained and more firmly cemented than the lower part. It weathers to a brownish-red, and is beautifully ripple-marked in some places.

The Medial Shale.

Overlying the ripple-marked upper surface of the basal sandstone is a rather thick series of black shales with sandstone stringers and thin layers of platy limestone. Near the top this shale zone is distinctly sandy, and is rusty-brown. There is a good exposure of these shales along the south bank of Little Thompson canyon in the northwest quarter of section 2, T. 3 N., R. 70 W.; <sup>these</sup> but are very highly contorted, and do not represent the true thickness of the members (See plate X). T.W. Stanton has collected the following fauna from this locality:

*Inoceramus cornucopianus* Cragin  
*Inoceramus bellvurensis* Reeside  
*Ostrea noctuensis* Reeside

The fauna of the Dakota group has recently been worked by Reeside<sup>1</sup> of the United States Geological Survey.  
 1. Reeside, John B. Jr., U.S.G.S. Prof. Paper 131, pp. 199-208 (1923)

and he believes (that) the fossils of the medial shale (are) <sup>to be</sup> of the same age as the Purgatoire fauna of Comanchean age. This relationship was suggested by Henderson<sup>1</sup> and confirmed by Lee<sup>2</sup>, who also believes that this shale is the same as the shale member of the Purgatoire formation of southeastern Colorado.

#### The Upper Sandstone.

The uppermost bed of the Dakota group is a rather thin quartzose sandstone (which) <sup>of</sup> (is) variable (in) thickness. It seems to be especially thin in the region of Rabbit Mountain, being thicker both north and south of this area. The sandstone is composed of quartz grains, cemented with silica and is brownish in color. Iron oxide is also present in the rock, occurring in small light-brown spherical specks which weather out, giving the rock a vesicular appearance. This upper bed is generally reddish in color, is very resistant and contains crystalline quartz grains. It often resembles quartzite because of its hardness and the shiny reflection from the quartz grains.

Reeside reports finding an ammonite, *Pachydiscus* ? sp., in this sandstone, which suggests its marine origin. He states that the specimen might belong to the Washita fauna or to a later one.

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1. Henderson, Junius, Colo. Geol. Sur. First Report, p. 175 (1903)

2. Lee, W.F., U.S. Geol. Sur. Prof. Paper 149, pp. 17-23 (1927)

THE COLORADO GROUP

The Benton Formation.

Dakota Section on west side of Dell Flats

Along section line between 16 & 9 T.3 sand-

stone of the Dakota N., R. 70, W. section consists of black shale and inter-bedded thin limestones. Toward the top the color becomes lighter. Between the dark shales of Benton black shales massive basal limestones of the Niobrara Dakota formation. Limestone bed which is top over ten feet

thick Sandstone, brown quartzose	27	
place Sandstone and shale, light brown, friable, thinly bedded at base but more massive at top	102	129
Benton Formation consisting of the lower sandy shales, the shale, dark	127	256
Sandstone calcareous, black	5	261
Crane Shale black with thin white sandstone	110	371
Sandstone, massive slightly cross-bedded, iron stained	52	423
Conglomerate	8	431

371

Morrison variegated shales section consists of three well defined massive limestone beds separated by rather thick beds of light-colored platy shales. The gray limestones are fine grained and very compact. The limestone weathers to a light gray color, and stands as a ridge which is easily distinguished from the black shales

of the Pierre formation. The middle limestone bed is usually the thick THE COLORADO GROUP marker bed.

The Benton Formation. formation are usually calcareous and platy. They are generally dark gray

The Benton formation overlies the upper sandstone of the Dakota group. This formation consists of black shale and inter-bedded thin limestone. Toward the top the color becomes lighter. Between the dark shales of the Benton and the massive basal limestone of the Niobrara formation is a sandstone bed which is not over ten feet thick but is very persistent. It was found to occur <sup>whenever</sup> (every)

(place where) the contact of these two formations is exposed.

As Henderson<sup>1</sup> pointed out, the three-fold division of the Benton formation (consisting of the lower sandy shales, the medial shales containing black hard limestone, and the upper sandy shales) seem to represent equivalents of the Graneros shale, Greenhorn limestone, and Carlile shale and sandstone of the Pueblo Quadrangle.

ickness of about 5000 feet. The interval below the Ogallala sandstone marker measured 8478 The Niobrara Formation. This portion of the formation consists of dark brown to gray-

The Niobrara formation consists of three well defined massive limestone beds separated by rather thick beds of light-colored platy shales. The gray limestones are fine-grained and very compact. The limestone weathers to a light-gray color, and stands as a ridge which is easily distinguished from the black shales

1. Henderson, Junius Opt. Cit. p.85

of the Pierre formation. The middle limestone bed is usually the thickest and forms a good marker bed.

The shales of the Niobrara formation are usually calcareous and platy. They are generally dark-gray but weather to a light-gray color. Near the top of the formation, the shales become more sandy, and grade into the darker buff weathering shales of the Pierre formation. Numerous fossils are found in this formation. *Inoceramus deformis*, and *Ostrea congesta* are the most common forms.

#### THE MONTANA GROUP

##### The Pierre Formation.

The youngest rocks exposed in the area belong to the Pierre Formation. This formation lies conformably on the Niobrara, and has an average thickness of about 5000 feet. The interval below the Hygiene sandstone member measured 2478 feet east of Rabbit Mountain. This portion of the formation consists of dark-brown to gray-black shales at the base, which are rather sandy and weather to a buff color. Approximately two thousand feet above the base is a lime concretionary zone about one hundred feet thick. These concretions are quite ferruginous, and, although they are dark-gray when freshly broken, are generally dark-brown on the weathered surface. They occur in zones along the bedding of the shale. Above the

concretionary zone are greenish-gray sandy shales which grade into the gray sandstones of the Hygiene member.

Section on north bank of Little Thompson Creek from Upper Dakota to Hygiene.

S.E. 1, Sec. 35, T. 4, N., R. 70 W.

	Thickness in feet	
	Top	
Pierre formation - interval below		
Sandstone, gray (Hygiene)	217	417
Shale, greenish gray, sandy	250	467
Shale, containing limestone concretions ferruginous	100	567
Shale, black to gray, weathers buff	2128	7794
		2675
Niobrara formation:		
Limestone, massive, gray and black shale	22	
Limestone, dark gray, shaly Ostrea congoensis	43	65
Shale, white platy	39	103
Limestone, dark gray, massive weathers buff	18	121
Shale, platy, light gray	200	321
Limestone, massive, dark gray weathers white	14	335
Benton formations:		
Sandstone, gray fine grained	15	
Shales, dark with thin sandstones	123	138
Limestone fossiliferous Inoceramus labiatus	2	136
Shale, dark nearly black	225	361
Sandstone thinly bedded	14	377
Shales, black thin beds of sandstone	161	538
Delata		
Sandstone quartzose, brown	37	

Section on north bank of Little Thompson  
Creek from Upper Dakota to Hygiene.  
S.E.  $\frac{1}{4}$ , Sec. 35, T. 4, N., R. 70 W.

	Thickness in Feet	
Pierre formation - interval below	Top	
Sandstone, gray (Hygiene)	217	3280
Shale, greenish gray, sandy	250	467
Shale, containing limestone concretions ferruginous	100	567
Shale, black to gray, weathers buff	2188	576
		2704
		2695
Niobrara formation:		
Limestone, massive, gray and black shale	22	
Limestone, dark gray, shaly Ostrea congesta	43	65
Shale, white platy	38	103
Limestone, dark gray, massive weathers white	18	121
Shale, platy, light gray	200	321
Limestone, massive, dark gray weathers white	14	335
Benton formation:		
Sandstone, gray fine grained	13	
Shales, dark with thin sandstones	123	136
Limestone fossiliferous Inoceramus labiatus	2	138
Shale, dark nearly black.	225	363
Sandstone thinly bedded	14	377
Shales, black thin beds of sandstone	161	538
Dakota		
Sandstone quartzose, brown	27	

STRUCTURAL GEOLOGY.

Regional.

The area mapped is in the foothills zone of the Front Range of Colorado. This range is essentially a great anticlinal uplift with local faulting and subordinate folding. The range has been greatly eroded, with the result that the sedimentary rocks which probably once arched over the entire range have been entirely removed over the crest of the range, thus exposing the Pre-Cambrian crystalline rocks. The normal appearance of the foothills is that of a mountain mass of igneous and metamorphic rocks fringed by upturned sedimentary beds. Differential erosion of these sedimentary beds has resulted in hogback ridges and longitudinal valleys paralleling the mountain trend. The dip of the sediments along the foothills is on the average about 35 to 50 degrees east. Locally, as at Boulder, Golden, and Castle Rock, the dip is very steep, sometimes vertical and even overturned. In other places as at Lyons, the dip may be as low as 15 degrees. These east-dipping beds along the east side of the Front Range have been referred to by Fenneman, Ziegler and others as the "normal monocline" and the "master structure" of the Foothills region.

FOLDS EN E'CHELON.

In addition to the "normal monocline" there

are many folds that form successive offsets along the face of the range. Because of this arrangement, they were named "folds en echelon" by Dr. F.V.Hayden<sup>1</sup>. These folds are generally spoken of as minor wrinkles, but they are perhaps more important in the structure of the southern Rocky Mountains than is generally believed. Many notable examples of echelon folds along the Front Range may be pointed out, as for example: at Box Elder creek, Fort Collins, Big Thompson river, Arkins, Rabbit Mountain South Boulder, Canyon City, Huerfano Park, and many other smaller folds. It has been pointed out by R.T.Chamberlin<sup>2</sup> that in the Southern Rockies echelon arrangement is distinctly a major feature. Many of the major ranges are in an echelon arrangement. The Front Range dies out to the south in the vicinity of Canyon City, and is separated from the Wet Mountains by a broad southeast-plunging syncline. The Wet Mountains are again separated from the southern Sangre de Cristo or Culebra Range by the Huerfano Park syncline. It is also significant that many of the ranges and most of the major faults have a northwest-southeast trend, nearly parallel to the trend of the echelon folds of the Front Range.

#### Local Structure.

Structurally the Rabbit Mountain Area consists

1. Hayden, F.V., Geol. Surv. of Terr. for 1869, p.127.
2. Chamberlin, R.T., "The Building of the Rocky Mountains". Jour. of Geol. Vol. 27, p.146 (1919)

of a series of anticlines and synclines trending north-west-southeast. A glance at the structure contour map (Plate III) reveals at once the echelon relationship of the folds. The axis of the folds deviate about thirty degrees from the trend of the main axis of the Front Range. The anticlines are open to the northwest, but plunge steeply to the southeast and die out in a short distance. The synclines also plunge to the southeast, opening up and disappearing. All the anticlines are asymmetrical; some have their steep-dipping limb on the east and others have a steep dip on the west side. As a general rule, the west limb of the folds along the Front Range is the steeper, and is often overturned. Ziegler<sup>1</sup> states that every echelon fold he has seen has a fault on the west limb of the anticline. Marvine<sup>2</sup> worked along the Front Range from the Big Thompson to the South Platte River, and makes the following statement about the echelon folds:

"The most interesting feature of these folds, next to their general echelon arrangement, is the fact that in the anticlinal the western side of the fold is always more abrupt than the eastern side, and may become a fault, the downthrow being on the western side. That

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1. Ziegler, Victor. "Foothills Structure in Northern Colorado." Colo. School of Mines Quart. Vol. 12, p. 31 (1917)
  2. Marvine, Arch. R. U.S. Geol. Surv. of Terr. Vol. p. 132 (1873)

is to say, the tendency has been either an abrupt downward bend on the west side, or a direct downward faulting of the west side, or both combined".

Rabbit Mountain and the long anticline to the north, the southern nose of which was mapped, seem to be exceptions to the rule so far as the dip on the west limb is concerned, but both pass into a fault to the northwest. The Rabbit Mountain anticline is peculiarly different from the other nearby anticlines. The east limb is much steeper than the west limb, but on its west side, separated from it by a very narrow syncline, is a small narrow anticline which is both overturned and faulted on the west side. As the structure contour map shows, the axis of Rabbit Mountain anticline is forked; the short axis trends nearly north-south, but the west line trends about 45 degrees west of north, and is in a direct line with the fault in Little Thompson canyon. The other folds have rather straight axis, and as a rule are steeper on the west side.

A structure section map has been prepared to show cross sections of the structure along certain lines. Sections A-A' shows the structure along a line through Dell Flats and the center of Rabbit Mountain. The Dakota

is on the west side of Dell Flats is the west limb of this anticline. However, since this anticline has Lyons Sandstone on its crest, and the Dakota is not duplicated farther west we may speak of this structure as the "normal" Dakota on back.

hogback of the normal monocline<sup>1</sup> forms the west limb of a wide shallow syncline which is responsible for Dell Flats. The east limb of this syncline is overturned and faulted. East of the fault the beds are arched into a small anticline and syncline, and flatten out as they arch upward to make the low-dipping west limb of Rabbit Mountain anticline. The strata are sharply folded on the east side of this large fold, and dip eastward at about seventy degrees. The cross-section B-B' is drawn to include the south end of the Dove Pass and the north end of the Rabbit Mountain anticlines. Here the western monocline is wrinkled into a small anticline and syncline, which die out to the south, but become more pronounced to the north. In this paper these folds are referred to as the "Ridge Folds." Dove Pass anticline, the main fold in this cross-section, is an echelon with Rabbit Mountain anticline. The axis of this fold trends about north thirty degrees west, and curves slightly eastward as it pitches to the south. The west limb of the fold is much steeper than the east. The fault referred to above cuts the east limb, and causes a duplication of the basal conglomerate

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1. There is a broad anticline west of Dell Flats and east of Lyons, Colorado that was not mapped. Hence, the Dakota ridge on the west side of Dell Flats is the east limb of this anticline. However, since this anticline has Lyons sandstone on its crest, and the Dakota is not duplicated farther west we may speak of this ridge as the "normal" Dakota hogback.

bed of the Dakota on the surface. As shown in the cross-section, the throw of the fault is very slight, and it dies out a short distance north of this line. In section 3 there is a flattening of the dip which forms a terrace. This terrace occurs in a saddle where the Rabbit Mountain anticline is separated from the Dowe Pass anticline by a shallow syncline.

Cross-section C-C' is drawn through the center of Dowe Pass anticline, and shows the fault in Little Thompson canyon. This fault is a high-angle thrust fault which has the appearance of an attenuated fold. The beds are dragged up along the fault plane in such a manner that the Lyons and Lykins formations are in nearly vertical position along the face of a steep escarpment of Fountain beds.

Along the northern part of the map, where section D-D' is drawn, the fault cuts across the axis of Dowe Pass anticline. The east limb of the fold is faulted and eroded so that west-dipping Fountain beds are in contact with pre-Cambrian schists and quartzites. In the northeast corner of the map this cross-section crosses the southern end of another large anticline that is en echelon to Rabbit Mountain, and extends northward for nearly four miles beyond the border of this map.

#### Drag Folds

In Little Thompson canyon on the southwest side of the fault the Lyons sandstone is upturned to a vertical

Plate IX.



A.

11



B.

Drag folding along the fault in Little Thompson.



C

- A. Shows the Lyons and Lykins beds dragged upward against the Fountain
- B. Shows a closer view of the down drag of the Fountain.
- C.. View looking northwest along the fault escarpment.

drag folding along the fault plane.

Plate X.



A. View showing the fault in Little Thompson at its southeast end where the fault dies out.



B. View showing the fault greatly increased. Note the drag folding along the fault plane.

position due to drag by the fault. ~~Plate~~ <sup>t</sup> ~~X~~ shows the Lyons sandstone standing on end and abutting against the fault. The question naturally arises whether the folding is all due to drag along the fault, or whether the fault is due to fracturing along the steep limb of an attenuated fold. It is very probable that the beds first folded, but there can be no doubt that the present position of the beds is largely due to drag. The fact that the fault cuts across Dowe Pass anticline shows that when the fracture occurred it was not entirely controlled by the folding. Also, beds of the Fountain formation in the hanging wall of the fault are not all affected to the same extent by the drag folding. Some beds seem to be nearly straight, and others are bent downward several feet along the fault plane. This relation is shown in plate VII. At its southern extension, in the southwest quarter of section 34, the fault plays out into an attenuated fold which seems to be nearly on the same axis as the west fork of Rabbit Mountain anticline.

Reverse Faults.

The fault in Little Thompson canyon, which has been referred to many times, starts in the southwest quarter of section 34 and strikes about north 40 degrees west. At its southeastern end the fault dies out into an at-

tenuated anticline, but the throw increases to the northwest. In section 28 where the cross-section D-D' is drawn, the throw of the fault is nearly 1400 feet, and farther on, the increasing fault can be traced into the more <sup>less</sup> structureless pre-Cambrian rocks. Northwest of the map area, <sup>the</sup> great ridge of pre-Cambrian metamorphic rocks forms <sup>the</sup> Blue Mountain (which) has a northwest trend, and is apparently in line with this fault. The fault can be traced along the southwest side of Blue Mountain for several thousand feet, where the sedimentary rocks abut against the metamorphics and are dragged up against <sup>the</sup> fault plane.

This type of fault is often called a hinge or scissor fault. It is most likely due to displacement along the zone of maximum shear resulting from rotational stress in the horizontal plane. It is a high-angle thrust fault, and its strike of the sedimentary rocks. Following the standard nomenclature of faults<sup>1</sup>, this fault is a dip slip, oblique, reverse fault. The up-throw side is to the northeast, and the fault hades slightly in this direction, but in most places appears to be nearly vertical.

The hinge-like movement along the fault has resulted in slightly steepening the dip and elevating

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1. Reid, H.F., & others. Report of the Commission on the Nomenclature of Faults. Bull. Geol. Soc. Amer., Vol. 24, pp. 163-185, 1913.

the sediments on the north side of the fault. Erosion has caused a shifting of the outcrops toward the direction of dip. Hence, there is an apparent displacement of half a mile toward the east on the north side of the fault. This offset is caused by nearly vertical elevation and erosion of east-dipping beds, and not <sup>by</sup> ~~to~~ horizontal movement along the fault. This apparent displacement is most noticeable in the Dakota ridge which nearly parallels the section line between sections 3 and 4 on the south side of the fault, but is a half mile east of this section line on the north side. This offset is due to erosion, and not to horizontal movement along the fault surface. After the faulting occurred the block on the northeast side of the fault stood higher than the land on the southwest side, but when erosion wore the area down the outcrops of the formations were naturally shifted toward the down-dip side. This might have occurred during the formation of the Rocky Mountain peneplain, and since this peneplain has been uplifted, <sup>g</sup> erosion has worn out the less resistant beds leaving the resistant rocks as the present ridges.

On the west side of Rabbit Mountain is another high-angle reverse fault. The east side is the upthrow side, but the displacement is slight. The fault can be traced along the west side of the small overturned anticline from the southern border of section 10 to the northwest quarter of section 3. The fault is not evident on the surface. The west limb of the small anticline is

by erosion of the Platte formation.

Plate XI.



A. View showing the Dakota hogback ridge north of the Little Thompson canyon as seen from the south side of the canyon. Note the steepened dip on the north side due to the hinge fault..



B. View of hogback ridges and the strike valley formed by erosion of the Niobrara formation.

strongly overturned, and seems to disappear to the south. It was found that between the Dakota sandstone and the Niobrara limestone there is not room enough for the full thickness of Benton shales. It was thus inferred that the west limb of the anticline is probably faulted. Good evidence of the fault was found in the northwest quarter of section 10, where a horizontal offset of 360 feet was found in the upper sandstone of the Dakota group. Farther north, on the southeast side of Dowe Pass anticline, the basal Dakota conglomerate bed is duplicated, and a displacement of about fifty feet was measured. This fault is undoubtedly due to great compression and sharp folding which stretched the beds beyond their tensile strength on the limbs of the folds.

#### The local Normal Faults. Rabbit Mountain Area

Only one normal fault was mapped. It is about half a mile south of the county line along the section line between sections 2 and 3. The fault strikes eastward and is traceable for only a short distance. The exact displacement of the fault is very hard to determine, but it is approximately fifty feet. The north side is the down-throw side. This fault is probably due to settling and adjustment after the period of deformation.

#### ANALYSIS OF THE FORCES.

Any statement regarding the direction of the

forces that produced the folds of this area must take into consideration not only the other folds of the foothills area, but also the entire Front Range, if not the entire Southern Rockies. It seems logical to believe that the forces involved came from the west, probably from the Pacific Ocean. This idea is supported both by (the) theoretical reasoning and <sup>by</sup> deductions from field observation. A great number of the writers on mountain structure and mountain building believe the ocean basins are the ultimate source of the force.<sup>1</sup> Also, a study of the structure of the Rocky Mountains and the history of their development tends to show that movement occurred earliest in the western part of the Rocky Mountain area, and most of the great overthrusts of the Rocky Mountains are thrusts from the west.

The local structure of the Rabbit Mountain Area seems to indicate that the forces which produced the folds acted in an east-west direction, and the fault in Little Thompson creek is due to shear. Rabbit Mountain strongly suggests a force active from the west, because the steep limb of the fold is on the east side. Bailey Willis<sup>2</sup> in his experiments on Appalachian structure, obtained

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1. Hobbs, W.H., "Mechanics of the Formation of Arcuate Mountains" Jour. Geol. Vol. 22, pp.71-90; 166-188; 193-208 (1914)  
 Chamberlain, F.T., "The Wedge Theory of Diastrophism" Jour. Geol. Vol. 33, pp.155-191 (1925)  
 Link, Theo. A. "En Echelon Folds and Arcuate Mountains " Jour. Geol. Vol. 36, pp.526-538 (1928)

2. Willis, Bailey. "Mechanics of Appalachian Structure" U.S. Geol. Surv. 13th. Ann. Rept. pp.217-283 (1893)

some results that nearly duplicate the folding in Rabbit Mountain. (See figure 1). In this experiment the small fold on the limb nearest the applied force, is a carinate fold, and it is very likely that the small fold on the west side of Rabbit Mountain is also shallow. Dove Pass fold, on the other hand, suggests that the active force was from the east. The steep limb of this anticline is on the west side, and drag folding, developed in the "medial shales" of the Dakota group on the east limb of this fold, suggests differential movement of the competent sandstones so that the upper sandstones move west with respect to the lower bed. (Plate X). This also suggests a force from the east. Finally, the thrust fault in Little Thompson creek, unless it is regarded as underthrusting, must have been produced by a force from the east.

The en echelon folds are believed to be due to a lateral variation of tangential forces, which amounts to rotational compression in the horizontal plane. There are many ways in which this variation may be accomplished. Fenneman<sup>1</sup> regarded echelon folds as indicating " that there was a north-south pressure in addition to the dominant east-west pressure." Recent experiments show that such a complex set of forces is not necessary to explain

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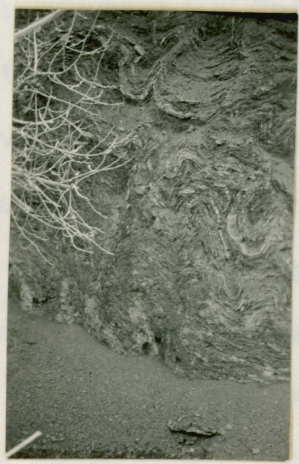
1. Fenneman, N.M., Opt. Cit. p.

echelon folds.

If we assume that the heavy faulting here produced by lateral compression.

### Plate XII

Views showing drag folding in the medial shale zone of the Dakota group.



echelon folds.<sup>1</sup>

If we assume that the Rocky Mountains were produced by lateral compression mainly from the west, we must assume that locally, at least, forces from an easterly direction were also active elements. Link<sup>1</sup> shows by laboratory experiment how a variation of competency in the beds along the strike of the folds may develop differential transmission<sup>55</sup> of stress. In this manner rotational stresses may be set up in a horizontal plane, although the forces in themselves are non-rotational. In an area as limited as the one considered in this report, (the evidence)<sup>it</sup> is not clear whether rotational or non-rotational forces were involved. Differential transmission of stress is suggested along the Front Range. The regions at Boulder and Golden, with the steep and overturned beds, form indentations along the front of the range where deformation did not extend as far eastward. This may be due to local resistance to deformation in this part of the Denver basin. The stress may not have been transmitted as readily in the local strata, or there may have been a release of stress due to faulting. It is also suggestive that a force from the east might have been dominant at these places. If this were the case, rotational force might have been the cause of the echelon folds north of Boulder. Experiments in echelon folding

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1. Link, Theo. Ben Echelon Folds And. Arcuate Mountains  
 Jour. Geol. Vol. 36, pp.526-533 (1928)

performed by S. Tokuda, and discussed by Bailey Willis<sup>1</sup> shows results strikingly similar to the folds north of Boulder. Whatever the nature or direction of the forces has been, the ultimate result has been the development of rotational stress. The fault in Little Thompson canyon represents a displacement along the plane of maximum unit shearing stress. This fracturing should make an angle of 45 degrees with the direction of the initial pressure, provided the material is normally rigid.<sup>2</sup>



Fig. 1.

1. Willis, Bailey Op. Cit. p.495.

2. Willis, Bailey

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