GEOLOGY OF THE BASALT AREA, EAGLE AND PITKIN COUNTIES, COLORADO

by

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This Thesis for the M.S. degree, by George Edward Welder has been approved for the Department of Geology

by

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Welder, George Edward (M.S. Geology) Geology of the Basalt Area, Eagle and Pitkin Counties, Colorado Thesis directed by Assistant Professor John Chronic

Sedimentary formations outcropping near Basalt, Colorado, are the Pennsylvanian Minturn formation (approx. 6000 ft.); Pennsylvanian, Permian, and Triassic (?) Maroon formation (6000-8000 ft.); Jurassic Entrada (35-181 ft.) and Morrison formations (326-411 ft.); and Cretaceous Burro Canyon (?) (0-70 ft.), Dakota (108-185 ft.), Benton (approx. 500 ft.), and Niobrara (160 ft. plus), formations. Breaks in sedimentation occur at the tops of the Maroon, Entrada, and Morrison.

The Basalt area lies in the center of the Permo-Pennsylvanian trough of west-central Colorado. Accumulation of Minturn evaporites in restricted portions of the trough was followed by withdrawal of the sea and piedmont cyclic deposition of the Maroon red beds. Continental deposition prevailed during Entrada, Morrison, Burro Canyon (?), and part of Dakota time, but the whole region was inundated during Niobrara and Benton time.

Conglomerate and sandy shale below the Dakota are probably equivalent to the Lower Cretaceous Burro Canyon formation found to the west, while limestone and shale overlying the Dakota are correlated with the Benton and Niobrara formations of eastern Colorado. Microfossils in the lower Niobrara indicate that the Fort Hays and Smoky Hill faunal

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zones of Kansas are present in the Basalt area.

Early Laramide movement compressed the Permo-Pennsylvanian trough and resulted in northwest trending structures such as the Elk Mountain fault-fold, Castle Creek fault, Capitol Creek syncline, Basalt Mountain syncline, and Red Table Mountain anticline. A later movement resulted in truncation of these structures by the El Jebel and West Basalt Mountain faults.

Extrusion of Miocene (?) lavas was followed by minor reactivation of the older faults, which cut the lava in the Basalt area. In Pleistocene time isolated valley glaciers occupied the northeast and west end of Red Table Mountain.

This abstract of about 250 words is approved as to form and content. I recommend its publication.

Signed John Chronic Instructor in charge of dissertation.

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INTRODUCTION

Purpose of Investigation

Interest in the Basalt area was originally stimulated by a desire to learn more about the Mesozoic stratigraphy of western Colorado and its relation to that in eastern Colorado. Reconnaissance work in the area revealed the possibilities of gaining structural data that would add to the regional picture as well as stratigraphic information concerning sediments from Pennsylvanian to Upper Cretaceous in age.

A geologic investigation of the Basalt area was undertaken for the following reasons: first, to break down the Cretaceous rocks, where possible, into units that are recognizable in surrounding areas; second, to present information concerning the Minturn and Maroon formations and their relation to deposition in the old Permo-Pennsylvanian trough in west-central Colorado; third, to study the local structure in an effort to better understand the regional structure, of which little is known; and fourth, to make a geologic map of the area and to describe stratigraphic sections in detail.

Location of Area

The Basalt area, which includes about 115 square miles, occupies parts of Tps. 6, 7, and 8 S., Rs. 86 and 87 W. in Eagle and Pitkin Counties, Colorado (fig. 1).



Fig. 1 Location of the Basalt area.

The town of Basalt is in the southern part of the area and is 193 road-miles west of Denver, 24 miles southeast of Glenwood Springs, and 18 miles northwest of Aspen. State highways 82, 104, and 107, and the Denver and Rio Grande Western Railroad serve the region.

Topography and Drainage

The topography of the Basalt area is characterized by broad, rounded summits that exceed 10,000 feet in elevation, wide valleys with relatively steep sides, elongate ridges with rounded or flat tops, and vast, gently undulating lava fields.

The highest elevations in the area are on the tops of Red Table and Basalt Mountains, which are 11,600 and 10,600 feet respectively, while in the valley of the Roaring Fork River, the lowest elevation in approximately 6200 feet. The ridges southeast and southwest of Basalt and the lava field north of Missouri Heights reservoir lie between 8000 and 9000 feet.

A diverse topography, ranging in age from late youth to late maturity, has resulted from differential erosion of lava, evaporites, and clastics which vary considerably in resistance.

Methods of Investigation

Field geology of the area northeast of the Roaring Fork River was accomplished from base camps at Cattle Creek

and Toner Creek during the summer of 1953, but several return trips in the spring of 1954 were necessary to finish the area to the southwest.

Aerial photographs made by the U. S. Geological Survey in 1951 and printed at a scale of 1/37,400 were used to plot geologic field data and sections corners. Geology, drainage, and culture were then transferred from the aerial photographs by means of a radial line plotter and a sketchmaster to a base map constructed from land survey plats and information obtained from the U. S. Forest Service.

Instruments used in measuring stratigraphic sections were the Brunton compass, hand level, steel tape, and geology hammer. Rock samples were examined with a binocular microscope and colors were based on the National Research Council color chart.

The geologic cross sections are largely diagrammatic, but some control was afforded by a bench mark in the Roaring Fork Valley and the Mt. Jackson quadrangle.

Previous Work

The Basalt area was included in the general reconnaissance mapping of Hayden (1881), Campbell (1922), and Lovering (1935). A three mile strip along the eastern border of the area is part of the Mt. Jackson quadrangle which was surveyed by the U. S. Geological Survey in 1907-1909.

No detailed geologic work has been done in the area

with the exception of the measuring of stratigraphic sections along Seven Castles Creek by Baker, Dane, and Reeside (1936) and Brill (1944).

Acknowledgements

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Plate 1. Composite stratigraphic section of the Basalt area.

STRATIGRAPHY

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General Statement

Approximately 14,000 feet of sedimentary rocks, ranging in age from lower Pennsylvanian to upper Cretaceous, outcrop in the Basalt area.

Pennsylvanian Series

Minturn Formation

Most of the lava-capped area west of Basalt Mountain is underlain by interbedded red clastics and gray micaceous sandstones, yellowish calcareous siltstones and sandstones, thin dark gray limestones, and shales, and thick contorted beds of gray anhydrite which weather to a light yellowishgray gypsum. The stratigraphic relationship between these varied types of lithology is not clearly shown in the scattered outcrops which are poorly exposed in the map area.

These beds are equivalent to the Minturn formation of the Pando area (Tweto, 1949), the McCoy formation of the McCoy area as redefined by Murray (1950), and the Gothic formation of the Crested Butte area (Langenheim, 1952). At the type section Tweto (1949) applied the name Minturn to 6000 feet of clastics and minor limestones which lie between the Belden and Maroon formations.

About 300 feet of the upper part of the Minturn is exposed on a hill one mile southwest of Basalt. Red sandstone, conglomerate, and siltstone of the Marcon formation grade downward into buff, yellow, pink, and gray sandstone, siltstone, shale, and limy anhydrite which are faulted against Upper Cretaceous shale. The Jacque Mountain limestone, designated by Tweto (1949) as the top of the Minturn formation, is not present; however, it may be present below the 300 foot zone cut off by the fault. It seems best to use the color change (Langenheim, 1952) which is prominent at this exposure as the top of the Minturn. The basal contact of the Minturn formation is not exposed in the map area.

The lithology of the Minturn near Basalt differs from that of the type Minturn in having a gypsum-anhydrite facies which may be as thick as 1000 feet. Evaporites were deposited in the middle and western side of the Permo-Pennsylvanian trough (Brill, 1952) which was restricted at this time. The gypsum evidently thins out between Basalt and Aspen because no gypsum is recorded (Spurr, 1898) in the sections of the Aspen district, but thick deposits of gypsum and anhydrite are found at Ruedi and Gypsum Creek east of the map area, near Cotton wood Pass north of the map area, and in the Roaring Fork River Valley west of the area. The probable extent of the evaporite facies is outlined in plate II.

The distance of the evaporite horizon below the top of the Minturn varies locally. Along the Roaring Fork River the gypsum probably is not more than 500 feet below the base of the Maroon; but along the fault zone, near Cattle Creek, extensive deposits of red clastics interbedded with buff siltstones and gray limestones lie between the gypsum and the



in central Colorado

Maroon formation.

Brill (1952) and Tweto (1949) conclude on the basis of fossil evidence that the Minturn, for the most part, is Desmoinesian in age. No fossils were found in the Minturn of the map area.

Upper Pennsylvanian, Permian, Triassic (?) Series

Maroon Formation

Reddish-brown conglomerates, sandstones, siltstones, and shales of the Marcon formation lie above the Minturn formation and below the Entrada sandstone in the Basalt area.

The name Maroon was originally proposed for Permo-Pennsylvanian beds which underlie the Gunnison or Entrada sandstone on Maroon Creek northeast of Crested Butte, Colorado (Emmons, 1894). Langenheim (1952) has recently recognized the Gothic formation, or Minturn equivalent, in the lower part of Emmon's section. North of the Basalt area Brill (1952) redefined the Maroon formation as those strata which overlie the Jacque Mountain limestone or its equivalents and underlie the Schoolhouse tongue of the Weber formation or strata younger than the Schoolhouse.

Maroon conglomerates are composed of rounded pebbles and cobbles of granite, schist, quartz, and feldspar that are often as much as 6 inches in diameter in the southwestern part of the map area. The sandstones are usually arkosic, while the siltstones and shales are micaceous and slightly calcareous.



Fig. 2. Maroon red beds overlain by the Entrada, Morrison, Burro Canyon (?), and Dakota formations in the "Amphitheater" at the head of Seven Castles Creek. The Minturn-Maroon contact is gradational and arbitrarily based upon the change from vari-colored to predominantly red sediments, but the upper contact is well-defined where light colored Entrada sandstone overlies red beds. In the "amphitheater" at the head of Castle Creek, red beds appear to be gradually pinching out to the southwest beneath Entrada sandstone at an angle of less than 10°. Near Yule Creek, 23 miles south of Basalt, the angle of discordance is from 20° to 28° (Vanderwilt, 1937). Evidently the Maroon was tilted and eroded between late Pennsylvanian and late Jurassic time.

Although complete sections are not exposed in the Basalt area, the thickness of the Maroon can be estimated from aerial photographs and formation dips. In the southwest corner of the area, the Maroon is about 6000 feet thick; while in the area between Basalt and Ruedi, the Maroon is approximately 8000 feet thick.

Rapid lithologic changes, mud-cracks, red coloration, and absence of fossils indicate a fluvial type of deposition. The Uncompany and Front Range Highlands (see plate II) still supplied sediments to the intervening trough and resulted in the piedmont type of cyclothem with coarse material on the margins of the trough and finer material in the center (Brill, 1952). In the Basalt area coarse clastic material grades into finer clastic material from southwest to northeast.

The Permian School house tongue, the State Bridge formation of Permo-Triassic (?) age, and the Shinarump and Chinle formations of late Triassic age are found above the Maroon and below the Entrada north and west of the map area; but these units are not recognizable in the Basalt region. The equivalents of these units either are present in the Basalt area and are not distinguishable, or were present and have been eroded away. If lithologic time equivalents of these units exist in the Basalt area, then the upper part of the Maroon is in part Permian and Triassic in age. In areas where the Schoolhouse tongue is present the "restricted" Maroon is probably of late Pennsylvanian or Wolfcampian age (Brill, 1952).

Upper Jurassic Series

Entrada Sandstone

At the type locality in the northern part of the San Rafael Swell, Utah, the Entrada formation consists of 312 feet of reddish earthy sandstones and subordinate shales (Gilluly and Reeside, 1928). Gilluly believes that these horizontally bedded, unfossiliferous strata are probably marine because of their association with marine beds above and below. In western Colorado, the Entrada is typically a light colored, cross-bedded, clean, quartz sandstone which was obviously deposited under fluvial and aeolian conditions.

The Entrada extends from northern New Mexico and Arizona to southern Wyoming and from eastern Utah to eastern Colorado (Imlay, 1952).



Fig. 3. Massive, colitic, basal Morrison limestone overlying Entrada Sandstone, three miles northeast of Basalt. In the Basalt area the Entrada is composed of a gray to pinkish colored, clean, calcareous, quartz sandstone that varies in thickness from 35 to 181 feet. Two distinct grain sizes which average .1 and from .5 to 1 mm. in size are typical of the formation. The larger grains are rounded, frosted, and pitted while the smaller grains are subangular. The outcrops west of Toner Creek are thinnest and are characterized by the two grain sizes; but outcrops at the head of Seven Castles Creek and northeast of Cattle Creek are thicker and are characterized by fine grained, pinkish sandstone having thin to massive beds and tangential cross-bedding. In the thicker sections the upper part of the Entrada is softer and lighter in color than the lower part of the formation.

At most exposures the Entrada-Maroon contact is fairly smooth and red shale pebbles are sometimes incorporated in the base of the Entrada.

Southwest of Basalt the massive Entrada is overlain by sandy shale of the Morrison formation and worm burrows are present at the contact. East of Basalt the contact is well defined by thick, massive, freshwater limestones of the Morrison which directly overlie the Entrada sandstone (fig. 3)

The Curtis formation which overlies the Entrada in the Burns, Colorado, area is not present in the Basalt region.

The Callovian or late Jurassic age of the Entrada is based upon its association with marine beds above and below in Utah (Imlay, 1952).

Morrison Formation

The Morrison formation was named by Emmons, Cross, and Eldridge (1896) for a 200 foot series of freshwater marls, sandstones, and limestones which are exposed near Morrison, Colorado. This widespread formation extends from New Mexico to Canada, and from Utah to Kansas (Imlay, 1952).

The thickness of the Morrison varies from 326 feet in the southwestern part of the map area to 411 feet in the east-central part of the area. In the "amphitheater" at the head of Seven Castles Creek the Morrison outcrop contains approximately 9% limestone, 15% sandstone, and 76% shale and siliceous mudstone. The limestone is confined to the lower 110 feet of the formation and practically no sandstone is found more than 200 feet above the base. Shale and siliceous mudstones occur throughout the formation.

The massively bedded limestone is medium dark gray in color and has an oolitic to dense and noncrystalline texture. It contains scattered quartz grains which stand out on the weathered surface, fossil fragments of plants and mollusks, and charophytes and ostracods. The massive basal limestone overlying the Entrada in the eastern part of the area varies from 5 to 30 feet in thickness (fig. 3).

The sandstones are white to light greenish-gray, fine to medium grained, well-sorted, subangular, quartzitic, calcareous, thin to massively bedded, sometimes cross-bedded, and ripple marked.

The shales are varicolored with light gray, greenish-

gray, and reddish to grayish-brown colors predominating. In the lower part of the formation nodular, calcareous, sandy shales sometimes contain poorly preserved clams. These shales are always indurated and weather into small blocks. In the upper part of the formation the shales are softer and break down into much smaller pieces when soaked in water, and appear to be partly bentonitic in composition. The mudstone layers interbedded with the shale have about the same color, but are much harder and more siliceous. Alternating hard and soft layers are typical of the upper Morrison throughout the map area (fig. 4).

Black chert lenses up to 4 inches thick and several feet long were found in limestones 75 to 100 feet above the base of the Morrison in the "southwest" and "amphitheater" sections (see detailed sections, Appendix). Ten feet below the black chert zone in the "amphitheater" section, fragments of dinosaur bones were found imbedded in a two-foot sandstone bed. Ostracods and charophytes were found in the shales and limestones in the lower 177 feet of the "amphitheater" section.

In general, the upper part of the Morrison in the Basalt area contains shales and mudstones that are non-calcareous, bentonitic, and unfossiliferous; while the lower Morrison contains calcareous sandstones and limestones along with the shales, and is fossiliferous.

The upper Morrison contact is somewhat undulating but well-defined, especially in the "amphitheater" section where



Fig. 4. Typical alternating shales and siliceous mudstones of the upper-middle Morrison formation, two miles south of El Jebel.

thick massive Burro Canyon (?) conglomerate overlies the soft, green and reddish, Morrison shales. The lower contact is also well-defined.

The character and fossils of the Morrison beds suggests deposition over a lowland area that was crowded with streams and freshwater lakes. Occasionally high areas were reworked by wind and aeolian deposits accumulated. Limestones were secreted by small bushy plants called Charophyta that lived in quiet, clear, freshwater bodies (Peck, 1948).

Recent studies show that the molluscan fauna of the Morrison is older than that of the upper-most Jurassic of England; and Imlay (1952) regards the Morrison as being mostly Kimmeridgian, or lower Upper Jurassic, in age.

Burro Canyon (?) Formation

In the Basalt area, the interval between the Morrison and Dakota formations consists of a resistant conglomerate and sandstone unit overlain by a soft sandstone and shale unit. These beds are best developed in the "amphitheater" section where the conglomerate is 32 feet thick and the upper sandstone and shale unit is 38 feet thick.

The conglomerate is composed of pink, yellow, white, and brown quartz, quartzite, and chert pebbles which range from $\frac{1}{2}$ to 1 inch in diameter and grade upward into a clean, white, medium-grained sandstone. A noncalcareous, bentonitic, clay-like material cements the pebbles together.

The upper soft unit is composed of noncalcareous, reddish-brown shaly sandstone that grades upward into light greenish-gray sandy shale.

These strata are believed to be equivalent to the Burro Canyon formation and are tentatively named Burro Canyon (?) until more definite evidence regarding their age is discovered.

The type section of the Burro Canyon is located in the southwest corner of San Miguel County, Colorado, about 9 miles north of Egnar post office (Stokes, 1948). A series of conglomerates, sandstones, shales, limestones, and cherts from 150 to 260 feet in thickness make up the Burro Canyon formation. These beds overlie the Brushy Creek member of the Morrison and underlie the Dakota formation. They were formerly called post-McElmo and are equivalent to the Buckhorn conglomerate and Cedar Mountain shale found west of the Colorado River in Utah (Stokes, 1952, p. 1774). Nonmarine microfossils, plants, and mollusks, recently found in the Burro Canyon and Cedar Mountain formations, indicate an Early Cretaceous age (Brown, 1950, p. 50; Katick, 1951). No fossils were found in the Basalt area, but an intensive search was not made.

The conglomerate and shaly units are not very well developed in the "southwest" outcrop and were not recognized on Yeoman Creek; but rapid variation in thickness and scattered outcrops seem to be in accord with the nature of the formation (Stokes, 1952).

The reasons for assigning these beds to the Burro Canyon (?) are stratigraphic position, lithologic similarity, proximity to known outcrops, fully developed sections of adjacent formations, and the absence of a pronounced unconformity that would represent very much of Early Cretaceous time.

It is hoped that the tentative assignment of these beds to the Burro Canyon (?) will instigate a re-examination of nearby sections and eventually lead to more conclusive evidence regarding the presence of lower Cretaceous rocks in Central Colorado.

Dakota Formation

In the Basalt area, the rocks between the Burro Canyon (?) formation and the Benton shale are equivalent to the Dakota formation of eastern Colorado. The recent fossil discoveries from western Colorado and eastern Utah by Brown (1950), Katich (1951), and Stokes (1952) indicate that Lower Cretaceous rocks are present. Upper Cretaceous plants (Brown, 1950) and marine fossils (Erdmann, 1934) also found in western Colorado indicate that at least the upper part of the Dakota is Late Cretaceous in age.

The Dakota formation, of the type section in Dakota County, Kansas, was originally believed to be of Late Cretaceous age (Meek and Hayden, 1896). Cobban and Reeside (1952) now consider these beds to be equivalent to the Purgatoire formation of southeastern Colorado and of Early Cretaceous age. The Dakota and equivalents of Wyoming underlie the Mowry shale which has recently yielded Lower Cretaceous ammonites (Cobban and Reeside, 1951).

It is doubtful whether all of the "so-called "Dakota" beds, in various parts of Colorado and adjacent states, everywhere represent the same time interval. It appears that the lower beds, in most places, are Early Cretaceous in age, whereas the upper beds may represent Late Cretaceous time in some localities and Early Cretaceous time in others.

The thickness of the Dakota in the map area varies from 108 to 180 feet. At most outcrops the formation contains two prominent, cliff-forming sandstone-conglomerate units that are separated by a softer shale-sandstone unit.

At the head of Seven Castles Creek the middle unit is 115 feet thick and contains a series of carbonaceous sands which form a third prominent cliff-forming sandstone at this particular locality. The shales which lie above and below the sands are reddish-brown, yellowish-gray, and dark gray in color.

The basal sandstone unit is yellowish-gray to white in color; massively bedded and vertically jointed; and fine to medium grained with scattered chert pebbles in the lower part and well-sorted, clean, quartz sand grains in the upper part.

The upper yellowish-gray sandstone unit is composed of rounded quartz grains which are cemented together by a white, non-calcareous material. The grains are coarse in the base and finer near the top. Massive and indistinct bedding with occasional cross-bedding is characteristic. (Fig. 5.)

It is difficult to recognize specific lithologic features with respect to the top or bottom of the Dakota because of the nature of the individual beds which change rapidly within short distances. This is especially true of the middle part of the formation. The tripartite character of the Dakota is drawn rather arbitrarily where the upper and lower resistant units become soft toward the center of the formation. Certain general features, however, can almost always be associated with the beds as a whole. Clean, white



Fig. 5. Massive cross-bedding in upper Dakota sandstone unit, on West Sopris Creek two miles southwest of Emma.

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sandstones with scattered conglomerate lenses form prominent cliffs that contain pronounced vertical jointing. Yellow, brown, and blue-black iron stains discolor the sands and shales and form the nuclei of odd-shaped nodules. Brown and black fragments of plants and trees seem to be typical of the upper 2/3 of the formation. Massive crossbedding was often seen in the coarse sandstones and conglomerates.

The depositional environment of the Dakota formation, which is considered to be littoral, lagoonal, and paludal, is conducive to the formation of the above features. It is logical to assume that these beds are the result of a shallow transgressing sea that began its inundation of the Western Interior in Lower Cretaceous time.

The lower Dakota contact is not well exposed in the Basalt area, but it is probably gradational because the upper Burro Canyon (?) shales become sandier near the basal Dakota sandstone unit. The upper contact with the Benton shale is also gradational, but can be located within a few feet at the place where the upper resistant sandstone of the Dakota becomes shaly, darker in color, and blocky.

Upper Cretaceous Series

Upper Cretaceous beds which lie between the Dakota and Mesaverde formations have been referred to as Mancos in, and adjacent to, the Basalt area (Lovering, 1935). These beds consist of 4,000 to 6,000 feet of dark shale with minor amounts of sandstone and limestone. On the basis of lithology and fossils the Mancos can be separated into the Benton, Niobrara, and Pierre formations (Wanek, 1953). Only the Benton and Niobrara were observed at outcrops in the map area, but the Pierre is probably present beneath the lava cap of Basalt Mountain (see crosssections, Plate IV).

Benton Shale

Dark Upper Cretaceous shales outcrop in the Cattle Creek Valley north of Basalt Mountain, along the Aspen highway west of Basalt, and near East and West Sopris Creeks in the southwest part of the map area. The Benton shale and lower Niobrara limestone and shale are best exposed just north of West Sopris Creek. At this locality the Benton is approximately 500 feet thick, but varies from 200 to 500 feet in adjacent areas (Vanderwilt, 1937). Spurr (1898) estimated the thickness of the Benton to be about 350 feet near Red Butte, one mile north of Aspen. In the Wolcott area, 30 miles northeast of Basalt, the Benton is 400 feet thick (Wanek, 1953).

On West Sopris Creek the lower Benton contains a 30 to 40 foot zone of black to dark yellowish-brown, indurated, noncalcareous, siliceous shale which breaks into 2 by 3 inch blocks. Yellowish and reddish-brown iron stains coat the jointed surfaces of the blocks. This zone grades upward into about 400 feet of black, bentonite-layered shale which makes up the main body of the Benton formation and is topped with a 30 foot interval of dark shale and sandy, fetid limestone. The upper limestone, which is about 2 feet in thickness, forms a conspicuous ledge (fig. 6) that marks the top of the Benton formation. <u>Prionocyclus wyomingensis</u>, <u>Mortoniceras cf. shoshonense</u>, <u>Scaphites whitfieldi</u>, <u>Inoceramus labiatus</u>, <u>Ostrea lugubris</u>, and <u>Gryphaea sp</u>. were found in this limestone.

The Benton formation was named for Fort Benton, Montana, but the stratigraphic limits of the formation are based largely on sections along the Missouri River in northern Nebraska (Meek and Hayden, 1862). In 1896 Gilbert divided the Benton formation of the Arkansas Valley, Colorado, area into the Graneros shale at the base, the Greenhorn limestone, and the Carlile shale at the top. Bass (1926) applied the name, Codell sandstone bed, to the sandy unit at the top of the Carlile in central Kansas. Dane, Pierce, and Reeside (1937) note that a widespread sandy horizon at the top of the Carlile shale of the Great Plains is characterized by <u>Prionocyclus wyomingensis, Scaphites warreni</u>, and <u>Inoceramus</u> <u>fragilis</u>. This sandy horizon is equivalent to the Codell



Fig. 6. Upper Codell sandstone unit of the Benton formation overlain by the Fort Hays and Smoky Hill members of the Niobrara formation, 1000 feet north of West Sopris Creek and three miles southwest of Emma.

sandstone and Niobenton of the Boulder, Colorado region. The above fauna is also found in the Laramie Basin of Wyoming at the top of the Frontier formation (Thomas, 1936).

A sandy facies at this same stratigraphic level in the Wolcott (Wanek, 1953) and Carbondale (Poole, 1954) areas, as well as the Basalt area, is believe to be equivalent to the Codell sandstone bed. But Cross (1899) states that no limestone or sandstone beds are persistent enough to be traced very far at the type section of the Mancos in southwestern Colorado.

To summarize, the upper 30 foot zone of sandy limestones and shales found at the top of the Benton on West Sopris Creek is equivalent to the Codell sandstone bed of the Great Plains and the upper part of the Frontier formation of Wyoming. This correlation is borne out by stratigraphic position and fossils, some of which are diagnostic of this horizon. The sandy facies probably "shales out" between the map area and the type section of the Mancos in southwestern Colorado. The Graneros, Greenhorn, and Carlile members of the Benton cannot be distinguished in the Basalt area.

The Benton formation represents a deepening of the Early Upper Cretaceous sea after the transgressive deposition of the Dakota sandstone. The waters must have been fairly quiet and no prominent highlands were close by. Near the end of Benton time the sea became shallower and sandy limestones were deposited.
Niobrara formation

The Niobrara formation was named for exposures along the Missouri River near the mouth of the Niobrara River in Knox County, Nebraska (Meek and Hayden, 1862). The formation is recognized in northeastern New Mexico, eastern Colorado, Kansas, Nebraska, eastern Wyoming, southeastern Montana, South Dakota, and North Dakota; and a similar microfauna infers correlation with the Selma chalk of Tennessee, the Austin chalk of Texas, and the Marlbrook marl of Arkansas (Fischer, 1953).

Gilbert (1896) divided the Niobrara into the Timpas limestone and Apishapa shale members in the Pueblo-Walsenburg, Colorado, area. Fischer (1953) recommends that these names be dropped and replaced by the Fort Hays and Smoky Hill which were first used in Kansas by Williston (1893) and Cragin (1896). Lithologic and faunal equivalents of the Niobrara were not recognized at the type section of the Mancos formation in southwestern Colorado by Cross (1899), but they are distinguishable in the Basalt area and can be divided into the Fort Hays and Smoky Hill members (fig. 6).

In the Basalt area a lower 35 foot shale unit, a 60 foot limestone and shale unit, and an upper platy to fissile shale unit of undetermined thickness comprise the Niobrara formation.

The lower few feet of the shale in the basal unit is black and similar to the Benton shale, but it becomes gray

and calcareous upward.

The middle unit is characterized by a persistent 8 to 10 foot series of massive, medium-gray limestone which weathers to a whitish-gray color. The limestones become wider spaced toward the top of the unit and give way to shales which are thin bedded and darker in color, but still very limy. A few <u>Inoceramus</u> fragments, fish scales, and teeth were found in the limestones.

The upper unit is reported to be about 760 feet thick east of Wolcott (Wanek, 1953), but only the lower 75 feet are present at West Sopris Creek. Here, the platy to fissile shales are soft, but form steep slopes. A few 1 to 2 inch bentonite layers and occasional oyster clusters and Inoceramus prisms were found.

Two samples were collected from the upper Benton and eight samples from the lower Niobrara at the West Sopris Creek outcrop for the purpose of micropaleontological examination. The results of this study are as follows:

- 1. The Codell sandy beds at the top of the Benton yielded only <u>Globigerina cretacea</u> and a few <u>Gumbelina sp</u>.
- 2. The basal 35 foot shale unit of the Niobrara contains a few small <u>Gumbelinas</u> and <u>Globigerinas</u> that become larger and more numerous near the top of the unit where the shale becomes more calcareous.
- 3. The upper five feet of the basal shale unit contains a relatively varied and healthy fauna which consists of <u>Gumbelina globulosa</u>, <u>Gumbelina sp.</u>, <u>Globigerina creta-cea</u>, <u>Globotruncana arca</u>, <u>Globorotalia cushmani</u>, <u>Lentic-ulina sp.</u>, and <u>Planulina kansasensis</u>.
- 4. The middle 60 foot limestone-shale unit contains large and fairly well-developed species. The most varied fauna

was found 88 feet above the Codell and consists of the following species:

Gumbelina globulosa Ehrenberg G. reussi Cushman G. moremani Cushman G. globocarinata Cushman ? Loxostomum sp., cf. L. plaitum Carsey Gaudryina sp., cf. G. bentonensis Cushman Dentalina lorneiana D'Orbigny D. reflexa Morrow Vaginulina sp. Palmula sp. cf. P. rugosa D'Orbigny Globigerina cretacea D'Orbigny Globotruncana arca Cushman Globorotalia umbilicata Loetterle Lenticulina kansasensis Morrow L. sublaevis Morrow Planulina austinana Cushman Gyroidina depressa Cushman and Church Valvulineria plummerae Loetterle

- 5. A species very similar to <u>Eouvigerina genae</u> Morrow was found 74 feet above the Codell. Fischer (1953) regards this species and <u>Planulina austinana</u> Cushman as index species for the Fort Hays member of the Niobrara.
- 6. The highest sample was collected 140 feet above the Codell and 45 feet above the base of the platy-fissile shale unit. Only <u>Gumbelina sp</u>. and <u>Globigerina sp</u>. were found.

In conclusion, the fauna and lithology of the Niobrara formation of the Basalt area warrant the division of the formation into the Fort Hays and Smoky Hill members. The Fort Hays includes a basal 35 foot shale unit and an upper 60 foot limestone-shale unit; the Smoky Hill includes a platy to fissile shale unit which may be as much as 760 feet thick.

The Benton-Niobrara contact is placed at the top of the highest fossiliferous, fetid, sandy limestone ledge which is 35 feet below the massive, whitish-gray weathering limestone of the Niobrara. The shale unit between these two below included in the Niobrara because it becomes more calcareous and fossiliferous upward and grades into the overlying massive limestones.

The even-bedded limestones and shales indicate quiet conditions of deposition throughout Niobrara time.

STRUCTURE

Regional Structure

The present structural features in and adjacent to the Basalt area are the result of Laramide movements that began in Late Cretaceous time and continued through the Tertiary.

Plate III outlines the regional structural trends; the most pertinent of which are the Sawatch Range, the Elk Mountains, the Grand Hogback, and the White River Plateau. The Sawatch Range is a north-trending domal uplift with inclined sediments on either side. It merges with the Sangre de Cristo Mountains to the south and ends in the north just west of the Gore Range and southeast of the White River Plateau. Southwest of the Sawatch Range the Elk Mountains form a fault-fold which continues north as the Grand Hogback Monocline opposite the White River Plateau. The Castle Creek fault of the Aspen district flanks the northeast limb of the Capitol Creek syncline and dies out in the Basalt area.

Whether or not these features were controlled by pre-Cambrian zones of folding and schistosity (Stark, 1934 and Macquown, 1945) is questionable. The old Uncompany and Front Range elements (plate II) were covered during Laramide time, but they very likely were instrumental in the formation and orientation of the Laramide structures which developed in the intervening trough (Burbank, 1933).



Plate III. Structural trends of west-central Colorado

The maximum uplift of the "Ancestral Rockies" in late Pennsylvanian and early Permian time (Brill, 1952) was followed by a period of tectonic inactivity that lasted until the Laramide orogeny began. A minor interruption occurred when Maroon beds were tilted prior to Entrada deposition (see page 12). Miocene (?) lavas which transgress the older folded and faulted sedimentary rocks were intruded after the major Laramide movements, but later movements of a lesser magnitude reactivated the old faults causing them to cut through the lavas in the Basalt area.

Local Structure

Important geologic structures occurring within or partly within the Basalt area are Red Table Mountain anticline, Basalt Mountain syncline, Capitol Creek syncline, Castle Creek fault, West Basalt Mountain fault, and El Jebel fault. (See geologic map, Plate IV, in rear envelope.)

Folds

Red Table Mountain Anticline

Red Table Mountain is a conspicuous topographic feature that extends from Cottonwood Pass across the northeast corner of the map area to the vicinity of Mount Thomas just north of Meredith, Colorado. Maroon strata have been folded into an asymmetrical anticline that is concave to the northeast. The dip of the southwest limb is 70° near the anticlinal axis, but Mesozoic beds lower down on the

limb only dip 30°. Red beds in the glaciated area on the northeast limb dip 12°.

Basalt Mountain Syncline

Folded Mesozoic beds clearly outline the Basalt Mountain syncline which is part of a broad structure that plunges to the northwest where it is truncated by West Basalt Mountain fault. The northeast limb dips 30°, while the southern limb dips 8° near Toner Creek and locally 55° where cut by Castle Creek fault.

Capitol Creek Syncline

The southwest corner of the map area is crossed by the Capitol Creek syncline which is a northwest trending structure that extends from Aspen for 19 miles to a point about 5 miles southeast of Carbondale where it is truncated by the El Jebel fault (Plate IV). Capitol Creek bisects the syncline at its greatest width of nine miles, southwest of the town of Snowmass. This structure separates the northern part of the Elk Mountains from the Basalt area and the Castle Creek fault zone.

Mesozoic beds forming the northeast limb dip 25° in the map area; but at Red Butte Mountain, near Aspen, the Mesozoic beds have been overturned to the southwest by the Castle Creek fault. Between West Sopris Creek and El Jebel fault, the northeast limb has been folded into a minor west plunging syncline.

Anticline Southeast of Basalt

In the southeast part of the map area the Maroon beds between Basalt Mountain syncline and Castle Creek fault form a broad anticlinal nose that plunges to the northwest. Erratic dips of the red beds indicate that the structure has been greatly disturbed and possibly broken by minor faults that cannot be seen in the field.

Minturn-Maroon Structures West of Basalt Mountain

Most of the western part of the map area is covered by lava and the structure of the underlying beds is difficult to interpret. Minturn and Maroon beds were broken and tilted by West Basalt Mountain and El Jebel faults; and where these faults cross Cattle Creek, beds dip from 9° to 55° in every direction. South of East Coulter Creek, in the northwest part of the map area, erosion has cut through the lava and exposed Minturn and Maroon beds that dip between 12° and 25° to the north. Vertical Minturn strata can be seen in the Roaring Fork River bed near Emma. North of El Jebel Minturn strata exposed in the road-cut dip north 20°, but adjacent exposures along the same roadcut show highly contorted gypsum beds. West of El Jebel fault and south of the Roaring Fork River the Minturn is covered with gravel and soil and the underlying structure is unknown.

Because of the soft and yielding nature of the Minturn strata there is a tendency for structures in which the Minturn formation is involved to be localized and haphazard rather than extensive and well-defined. The Basalt Mountain synclinal structure which is clearly outlined by folded Mesozoic beds is not recognizable in the deeper Paleozoic beds that have been uplifted west of West Basalt Mountain fault. Minturn and Maroon formations exposed near East Coulter Creek would dip to the south instead of the north if the synclinal structure still existed.

Faults

At no place in the map area were fault planes clearly exposed, with the exception of a small fault which cuts Mesozoic beds below the south face of Basalt Mountain (fig. 7). At several places, fragments of mineralized slickensides, fault gouge, springs, and travertine deposits were found; but offset beds and trends shown on the aerial photographs were the main basis for mapping of faults.

The main movement along the faults came before the lava extrusion, but trends that clearly cut the lava can only be explained by post-lava movements along the faults.

Castle Creek Fault

The Castle Creek fault is a high angle, east dipping, reverse fault that trends northwest from near Ashcroft for a distance of about 30 miles through Aspen to the Basalt area. The maximum throw is about 9,000 feet in Keno Gulch near Aspen (Spurr, 1898) where pre-Cambrian rocks on the east have been upthrown into contact with upper Maroon beds



Fig. 7. High angle normal fault cutting Morrison and Entrada formations three miles northeast of Basalt. The throw is 19 feet. on the west. The fault plane dips from 45° to 50° in Keno Gulch but becomes steeper toward the northern and southern extremities of the fault. Beds along the downthrown side of the fault are overturned to the west at Red Butte Mountain and other places in the Aspen district.

The Elk Mountain fault-fold which parallels the Castle Creek fault 15 miles to the west is also a steep angle, east dipping, reverse fault; and Vanderwilt (1935) states that both faults merge to the northwest with monoclinal structures that join just south of Glenwood Springs. Although the Elk Mountain fault-fold does merge with the Grand Hogback Monocline, evidence indicates that the Castle Creek fault dies out in the Basalt area where northwest trending structures are truncated by West Basalt Mountain and El Jebel faults.

Just south of Basalt the wide alluvial valley of the Roaring Fork River is bounded on the west by the West Basalt Mountain fault and on the east by the Castle Creek fault. Two remnants of tilted Dakota (?), Morrison, and Entrada beds, which were part of the southeast limb of the Basalt Mountain syncline, are present along the west side of Castle Creek fault at the edge of the valley. Maroon beds are upthrown on the east side of the fault which branches and crosses the Frying Pan River near the Basalt Ranger Station. The right branch cuts only Maroon beds and dies out just north of the Frying Pan River, while the left branch crosses the southeast limb of Basalt Mountain

syncline and continues with diminishing throw to the northwest where it is probably truncated by the West Basalt Mountain fault.

Dakota (?) beds outcropping north of the Frying Pan River have been upthrown less than 1000 feet above the tilted Dakota (?) remnant south of the Frying Pan. This difference in throw represents a decrease of more than 8000 feet from the maximum of 9000 feet near Aspen and indicates that the Castle Creek fault dies out, or nearly dies out, near the West Basalt Mountain fault. Whether or not this later fault cuts the former is not definitely known; but if the Castle Creek fault was formed contemporaneously with the northwest trending folds of the region, then it must have been truncated along with the folds.

West Basalt Mountain Fault

In the southern part of the map area the West Basalt Mountain fault describes a wide curve that is concave eastward, while in the northern part of the area the fault runs due north. The pronounced northerly trend indicates that the fault may continue northward and become lost in the thick evaporite deposits of the Dotsero-Gypsum area instead of curving sharply eastward toward Brush Creek as shown on the State Geologic map (1935). South of Basalt the fault decreases in throw and runs into the Castle Creek fault zone.

Aerial photographs show a smooth straight trend over

rugged topography that is characteristic of a steeply dipping fault. The direction of dip of the fault plane cannot be definitely determined in the field, but steeply dipping strata on the upthrown side of the fault can be explained better by a west dipping fault than an east dipping one. (See cross section AA', Plate IV.)

Just north of Emma upper Minturn beds have been faulted into contact with the Niobrara shale and the throw of the fault is approximately 7500 feet. A throw of equal magnitude exists just north of Cattle Creek where deformed Minturn limestones lie at the same level with dark Upper Cretaceous shales. Near the railroad crossing of the Aspen highway, 1½ miles south of Basalt, highly deformed Mesozoic beds are in contact with Maroon red beds and the throw is probably much less than the thickness of the Maroon formation.

It is difficult to explain why the southern extremity of the West Basalt Mountain fault curves to the southwest away from the comtemporaneously formed El Jebel fault. One possible explanation is that the older Castle Creek fault zone of weakness encouraged a break in that direction.

El Jebel Fault

The El Jebel fault has a straight line trend from Cottonwood Creek southwest through El Jebel and across the Roaring Fork River Valley. South of the Roaring Fork the fault truncates the northeast limb of the Capitol Creek

syncline and then swings sharply to the southwest beneath a cover of lava and gravel. Evidence of this sudden westerly change in direction is the presence of Upper Cretaceous shales that outcrop southwest of the map area and west of the extended straight line fault trend. (Plate IV).

The direction of dip of the fault plane is unknown, but it is probably about the same as that of the West Basalt Mountain fault which is believed to be steep, and to the west (see cross section BB').

South of the Roaring Fork Valley the Maroon formation has been faulted out and Minturn beds to the west are at the same level with Mesozoic beds to the east. The throw at this point must be at least 6000 feet, but north of the Roaring Fork the throw decreases rapidly because Minturn beds lie on either side of the fault.

Bowers Gulch Fault

The presence of a fault is indicated by the pronounced north-south alignment of Cottonwood Creek, Bowers Gulch, a south tributary to Cattle Creek, and a scarp still further south. In the north this inferred fault trend appears to merge with the El Jebel fault and continue northward parallel to the West Basalt Mountain fault, while in the south it merges with the Basalt Mountain fault.

If this fault exists, the throw is less than the thickness of the Minturn formation which is found on both sides. Poor exposures prevent definite confirmation of the presence of this fault.

SUMMARY

Highlands bordering the Permo-Pennsylvanian trough (Plate II) reached their maximum height before the end of the Permian period, but an ensuing uplift that occurred sometime before late Jurassic time tilted the Maroon beds slightly. Conformable Jurassic and Cretaceous sediments indicate that the Nevadan orogeny of the far west did not reach as far east as the Basalt area and that a time of tectonic inactivity prevailed in the area until the beginning of the Laramide orogeny in late Cretaceous time.

The first movements resulted in northwest trending structures such as the Elk Mountain fault-fold, the Castle Creek fault, the Capitol Creek syncline, the Basalt Mountain syncline, the Red Table Mountain anticline, and the Burns-Wolcott syncline (Plate III); all of which can be explained by early Laramide movements in the old Uncompany and Front Range elements that resulted in compression of the intervening sediments.

The northwest orientation of the above structures, which trend into the Sawatch Range, very likely was not caused by the rise of the Sawatch Range. An early uplift in the Sawatch area would facilitate underthrusting of the sediments from west to east, or overthrusting from east to west, when compressional movements began, and help explain the development of the Elk Mountain and Castle Creek reverse faults which dip to the east. A second major movement with a greater vertical than lateral component produced steep-angled faults such as the El Jebel and West Basalt Mountain faults which truncate the Capitol Creek syncline, the Basalt Mountain syncline, and possibly the Castle Creek fault in the Basalt area (Plate IV). This movement was probably contemporaneous with the uplift of the White River Plateau and the formation of the Grand Hogback monocline in late Eocene time (Macquown, 1945).

After the extrusion of Miocene (?) lava still later, but relatively minor, movements reactivated the older faults causing them to cut across the lava flows in the western part of the map area.

IGNEOUS ROCKS

Extrusive Igneous Rocks

Basalt

Basalt Mountain and the region to the west are capped by thick lava flows that extend northwest to Glenwood Canyon over a 150 square mile area.

The lava is composed of olivine basalt which is typically dense, moderately vesicular, and dark gray in color; but is sometimes light, highly vesicular, and reddish-brown in color.

Within the map area the thickness of the lava varies from less than 100 feet just north of El Jebel to more than 500 feet on Basalt Mountain. A difference in elevation of more than 2000 feet between the last named places infers that there may have been considerable relief when the lava was extruded; but post-lava faulting and erosion, and possibly sagging over incompetent Minturn beds could have accounted for some of the elevation difference.

At exposures near the Castle Creek and West Basalt Mountain faults, huge masses of black, non-vesicular, basalt occurring below the main lava bodies indicate that the faults may have served as fissures for the molten lava.

In the roadcut exposure, 3/4 miles north of El Jebel, a sandy soil cover at the top of the Minturn formation underlies the lava (fig. 8) and rounded basalt cobbles in the soil



Fig. 8. Basalt overlying sandy soil cover of Minturn formation, in roadcut 3/4 miles north of El Jebel. Basalt cobbles in soil were derived from an older lava flow.



must have been derived from an older lava flow. A series of flows appear to be present on Basalt Mountain, although contacts are not well defined (fig. 9).

The lava of the Basalt area cannot be dated accurately but lava of a similar nature overlies the Ruby formation of early Eocene age west of Carbondale (Poole, 1954). Basaltic lava in the White River Plateau is believed by Macquown (1945 to be Miocene or Pliocene in age. South of State Bridge a dog of lower Miocene affinities was found in the tuff between basaltic lava flows (Wilson, 1939).

Felsite

One hundred to two hundred feet of white to brown-weathering felsite caps part of the ridge between West Sopris Creek and the Roaring Fork River in the southwest corner of the map area.

The felsite contains euhedral crystals of quartz and biotite that are embedded in a fine, noncrystalline matrix. At one locality, near El Jebel fault, a dark colored breccia of quartzitic fragments is present at the base of the flow.

Faulted Minturn and Niobrara beds are transgressed by the felsite, which lies at the same elevation with basalt flows to the north and the west. The nearest igneous rock of this type known to the writer is the Grizzly Mountain rhyolite of the Independence Pass area in the Sawatch Mountains (Howell, 1919).

GLACIATION

The former existence of valley glaciers on the northeast side of Red Table Mountain is verified by broad, steepwalled cirques and wide, U-shaped valleys which drain into Gypsum Creek just northeast of the map area (fig. 10).

Ice was maintained in the protected cirques at elevations between 10,500 and 11,000 feet, but a widespread ice cap probably did not cover the west end of Red Table Mountain because no glacial debris is present on the top of Red Table Mountain or in the Cattle Creek Valley to the southwest. Erratic boulders of granite, pegmatite, and quartzite found near the head of Gypsum Creek indicate that glaciation may have been more widespread at the higher elevations to the east and that foreign material was carried westward from the Sawatch Range.

Glaciation in the Basalt area is probably contemporaneous with the Hunter Creek and upper Roaring Fork Valley glaciation of the Aspen district (Spurr, 1898). Evidence for the definite dating of these glaciers is lacking, but a Wisconsin age is inferred by glaciation at this time in the San Juan region (Atwood and Mather, 1932), the Front Range (Jones and Quam, 1944), and other places in the Rocky Mountains.



Fig. 10. Glacial cirque lake and trough in red beds on northeast side of Red Table Mountain. Glacial valley drains into Gypsum Creek where Minturn evaporites are exposed.

STREAM DEPOSITS

Basalt, granite, and sandstone boulders were found in a few isolated gravel beds at various elevations above the present stream levels (Plate IV). The two most outstanding of these deposits vary from 20 to 50 feet in thickness and are located just north of Missouri Heights Reservoir and on the ridge southeast of Emma.

Recent stream terraces were deposited in the Roaring Fork Valley west of Basalt, but the lack of depositional features in the narrow Frying Pan Valley indicates that down-cutting is dominant cast of Basalt.

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APPENDIX

Detailed Sections

Section 1. - "Amphitheater" at head of Seven Castles Creek.

(Five miles east of Basalt on state highway 104 and 2 miles north of Frying Pan River up to head of Seven Castles Creek.)

Top of hill. Benton formation removed by erosion.

Dakota formation

Bed N

5.

4.

3.

2.

1.

No.	Feet
Sandstone, yellowish-gray (5 Y 8/1), coarse in base to fine at top, rounded quartz grains, in- distinct bedding, sometimes cross-bedded, white noncalcareous cement, forms steep cliff	14
Partly covered. Shale, sandy, red to light gray, with thin (6"-1') brown sandstone beds	42
 d.) <u>Sandstone</u>, similar to a.), but mottled red and brown at top. c.) <u>Sandstone</u>, similar to a.), but more massive and very few wood impressions b.) <u>Sandstone</u>, similar to a.), with wood impres- sions, and streaks and lenses of quartzite. a.) <u>Sandstone</u>, yellowish-gray (5 Y 8/1), medium to coarse grained with occasional pebbles (4 mm.) well sorted and rounded quartz grains, white calcareous cement, slightly friable, porous, cross-bedded 	6 22 10 5
 Shale, grayish-yellow (5 Y 8/1), sandy, with occasional beds (6" thick) of moderate yellowish- brown (10 YR 5/4) sandstone with fine rounded grains, often iron stained	30
 clean quartz grains, white slightly calcareous cement, sugary appearance, steep cliff-former, pronounced vertical joints, light banding, streaks of quartzite in upper part	<u>56</u>
	10)

Burro Canyon (?) formation

Bed No.

Total thickness . . 70'

Morrison formation

Bed No.

- 14. Shale and mudstone, alternating. Shale, greenish-gray (5 GY 8/1) to pale green (5 G 7/2) in upper part of unit and grayish-orange pink (5 YR 7/2) to light greenish-gray (5 G 8/1) in lower part, soft in upper part to moderately indurated below, slightly calcareous and siliceous in lower part of unit becoming noncalcareous and pure in upper part, breaks into small irregular blocks. <u>Mudstone</u>, grayish-brown (5 YR 3/2) to grayishgreen (5 G 5/2), silty, indurated, in beds seldom over a foot thick, massive to blocky, often with pronounced vertical joints. The slope of the unit is uniform and the shale beds are usually covered. No charophytes or ostracods were found 220
- 13. <u>Sandstone</u>, pinkish-gray (5 YR 8/1), clear quartz grains, fine-grained (.25 mm.), subangular to rounded, well sorted, white calcareous cement, slightly cross-bedded, vertical jointing, in beds 6" to 3' thick. A thin siliceous shale in the middle of unit. No fossils were found 14
- 12. <u>Shale</u>, medium gray (N 4) to grayish-red (10 R 4/2), sometimes mottled gray and red, moderately indurated, weathers in tiny chips and blocks, bedding indistinct, calcareous. This unit forms an uninterrupted slope

Feet

except for several one foot mudstone layers. A few charophytes and ostracods were found in the gray shale

- 11. <u>Limestone</u>, medium dark gray (N 4), subcrystalline, dense, in beds 6" to 2' thick, contains black chert lenses and nodules as much as 4" thick in lower half of unit. The weathered surface often has odd markings suggestive of organic debris. A few thin greenish-gray shale beds are interbedded with the limestone. Charophytes
- 10. <u>Sandstone and shale</u>, alternating in layers 1' to 3' thick. <u>Shale</u>, greenish-gray (5 GY 6/1) to reddish-brown, calcareous, moderately indurated, breaks into small blocks. Charophytes were found in the greenish shale near the top of the unit; <u>Sandstone</u>, light greenish-gray (5 GY 6/1), fine to medium-grained (.5 mm.), well sorted, rounded. A large dinosaur bone fragment was found 10' below the top of the unit in one of the sandstone beds . . . 42
- 8. <u>Sandstone</u>, similar to unit 5, massive at base to thin-bedded (1/4-1/8") at top where it is finely cross-bedded .

7. Covered. Probably shale 5

- 6. Limestone, medium dark gray (N 4), noncrystalline, very dense, thin-bedded 11
- 5. <u>Sandstone</u>, white to light greenish-gray (5 GY 6/1), fine to medium-grained, subangular to rounded, well sorted, calcareous cement, thin-bedded to massive, moderately indurated to slightly friable 1

68

16

2

8

- Limestone, medium dark gray (N 4), oolitic (1/2-1 mm.), scattered quartz grains, fossil fragments, ostracods. This unit is flat on top but has an undulating base which causes a variation in thickness of 5 to 25'. The contact with the Entrada sandstone below is well defined and disconformable 5

Total thickness. . . . 411'

Entrada sandstone

Bed No.

Total thickness. . . . 181'

Maroon formation

Bed No.

6. <u>Shale and siltstone</u>, pale to dark reddish-brown (10 R 3/4), sometimes mottled gray, calcareous. Shale, thin-bedded but not fissile, breaks into small pieces. Siltstone, massive beds 5 to 10 feet thick. Mud cracks, ripple marks, white calcite veins (1/8"), and poorly preserved plant

- A series of almost white to pale reddish-brown (10 R 3/4) conglomerates, sandstones, siltstones, and shales.
 - Sandstone, indurated, massive, quartzose, streaked with pebbles up to ½", grading up into mottled silty shale

62.

1

Feet

Feet

m.) <u>Sandstone</u>, coarse, indurated, quartzose. . . 5 1.) Shale, red, white, and purplish, mottled, alternating in hard and soft layers. Layers of white and yellow chert in middle . . . 70 k.) Shale and siltstone, sandy in base 22 2 34 h.) Shale and conglomerate, alternating. Shale, red. Conglomerate, fine; upper conglomerate 32 g.) <u>Conglomerate</u>, very coarse, up to 6", rounded pebbles of quartz, schist, granite etc. Sandy 7 11.5 e.) Conglomerate, arkosic. 2.5 d.) <u>Siltstone</u>, nodular in upper part, sandstone streaks in middle, shale in base 11 c.) <u>Conglomerate</u>, mostly arkose but some red shale pebbles in lower half. Loosely consolidated . 21 b.) Siltstone, thin-bedded $(\frac{1}{4}-\frac{1}{2}")$, cross-bedded in lower part and sandier. Reworked shale pebbles near base 15 a.) Conglomerate, pebbles $(\frac{1}{2})$, with shale and siltstone in middle and sandstone in base . . 59' Estimated thicknesses. 5. Shale, dark reddish-brown, almost fissile, a few thin massive siltstone beds in upper part . . . 100 4. Siltstone, moderate reddish-orange (10 R 6/6). coarse (1/16 - 1/32"), massive, arkosic, calcareous, moderately indurated, cliff-former 350 3. Siltstone and shale, dark reddish-brown, in alternating hard and soft beds, slightly calcareous. A few fine sandstone and thin, red, shalepebble, conglomerate beds. Ripple marks are very common, especially the asymmetrical type which vary from 3/4 to 12 inches between crests. 500 <u>Siltstone</u> and <u>sandstone</u>, massive, thick bedded, pale to reddish-brown. Forms castle-like cliffs 2. at mouth of Seven Castles Creek . . 700 1. Estimate of thickness of this unit based on Brill's (1944) section of partly covered outcrops between Castle Creek and Reudi, eight miles to east. Conglomerates, sandstone, siltstones, and shales,

reddish-brown. The amount of coarse clastic

material		increases.					considerably						in this			part of					
the	secti	on	•	•.	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	5300
										To	ota	a1	tł	ni	ckr	nes	ss				7922'

Evaporites at base of red beds near Reudi are of Minturn age.

Section 2. - "Southwest" section.

(Located on northeast face of hill, 2 miles west-southwest of Emma, in the NE 4, sec. 15, T 8 S, R 87 W.)

Benton shale

Dakota formation

Bed No.

- H.	2	2	-
1.	8	-	1.
	~	-	

4.	 c.) <u>Sandstone</u>, medium gray (N-5), fine-grained, dense, massive, partly quartzitic b.) <u>Shale</u> and <u>sandstone</u>, Carbonaceous a.) <u>Sandstone</u>, massive, medium-grained, slightly carbonaceous 	24 3
3.	Sandstone, very light gray (N 8), medium-grained, white noncalcareous cement, black carbonaceous inclusions and large wood impressions. In part conglomeratic with rounded, dark and light, chert pebbles (1")	4
2.	 d.) <u>Sandstone</u>, white to buff, fine-grained, chalky and gray <u>shale</u>. c.) <u>Sandstone</u>, white at top, gray and carbona- ceous in lower part, massively bedded, weathered surface iron stained. A 4 inch gray 	8
	<pre>shale break in lower part . b.) <u>Shale</u>, gray, with limonite a.) <u>Sand</u>, soft, yellow, silty and <u>shale</u> with gray shale breaks</pre>	97 6
1.	Sandstone, white to gray, fine to medium-grained, indurated, massive, heavily iron stained	10
	Total thickness 10	8
Bur	ro Canyon (?) formation	
Bed	No. Fe	et
2.	Covered. Shale, sandy 1	5
1.	<u>Conglomerate</u> , rounded chert pebbles, white to black up to t inch, cemented with fine gray sandstone. Poorly exposed. Fairly abrupt contact with Morri- son shales below	6

Total thickness . . . 21
Morrison formation

Bed No.

Ded	NO.	Feet
12.	Partly covered. Shale, reddish-brown to buff	24
11.	Shale, green and maroon, increasingly maroon in color upward, a few indurated mudstone layers	130
10.	Sandstone, yellowish-gray, medium-grained, massive- ly bedded, slightly calcareous	8
9.	Shale, greenish-gray to reddish-brown, with indura- ted siliceous mudstone layers. Soft in general	53
8.	Sandstone, light gray, fine-grained, indurated, calcareous cement, cross-bedded, iron stains	9
7.	Shale, gray and reddish-brown, with a few hard layers of gray limestone	25
6.	Limestone, medium dark gray, dense, massive, fossil fragments, 2 inch horizontal lenses of black chert in upper 1.5'. Probably correlates with bed no. 11 in "amphitheater" section	7
5.	Shale, buff to gray, and limy gray siltstone	31
4.	Limestone, medium dark gray, dense, 2' thick; with fine grained, massive, limy gray <u>sandstone</u> above .	8
3.	Shale, buff to gray, a few 6" layers of limestone and silstone near base	11
2.	Sandstone, buff to gray, fine grained, massive, calcareous	10
1.	Shale, light gray, soft, with 1' layer of gray, non-crystalline limestone 3' above base. Contact with the Entrada sandstone below is distinct; worm burrows were found in shaly sand at contact	10
	, Total thickness 3	326

Entrada sandstone

Bed No.

Feet

Sandstone, medium light gray (N 6), massive, cross-bedded, calcareous. Two distinct grain sizes of quartz. The smaller grains are subangular and .1 mm. in diameter. The larger grains are rounded, pitted 1.

Total thickness . . . 35

Maroon formation

Bed No.

15.	Conglomerate and sandstone, light reddish-brown,
-	poorly exposed
14.	Sandstone, thin-bedded. Partly covered 32
13.	Shale, red. Partly covered 14
12.	Sandstone and conglomerate, light reddish-brown, pebbles of quartz up to 3 inches in diameter 32
11.	Sandstone, coarse, arkosic, poorly consolidated, but ledge-former
10.	Sandstones and conglomerates, reddish, massive in upper 20' with finer sandstones, shales and silt- stones below
9.	Sandstone, thin-bedded and soft, red shale above with 5' of light, coarse sandstone below 21
8.	<u>Shale</u> , red, soft
7.	Sandstone, reddish-brown, massive
6.	Sandstone, coarse, conglomeratic at base, thin- bedded sandstone, shale, and siltstone at top 47
5.	Siltstone and shale with 1' of gray, impure limestone at base
4.	Sandstone, coarse, arkosic, silty at top 24
3.	Siltstone and shale, limy in lower part above basal 8' shaly sandstone
2.	Sandstones and conglomerates, reddish-brown, a few pebbles up to 2" in diameter 61
1.	Sandstone, red, very shaly and limy arkosic 25

Feet

Base of exposure.

Total thickness . 620'

Section 3. - Yeoman Creek

(Located north of Basalt Mountain and Cattle Creek in sec. 3, T 7 S, R 86 W).

Thicknesses of this section are inaccurate because of great variation in dip and topographic expression.

Top of hill. Benton shale removed by erosion.

Dakota formation

Bed No.

3.	Sandstone, light gray to white, medium grained, cross-bedded, ripple marked, wood impressions in lower part	47
2.	Partly covered. Shale, gray, sandy, and shaly sandstone	47
1.	Sandstone, white to gray, medium-grained, massive. Conglomerate in base	42
	Total thickness	136

Burro Canyon (?) formation

Not recognized at this locality. Possibly some of the basal Dakota is equivalent to the Burro Canyon (?).

Morrison formation

unit above . .

Bed No.

Feet

16

Feet

10.	Partly covered. Shale, reddish-brown to gray, with siliceous mudstone layers	
9.	Shale and <u>mudstones</u> , alternating, indurated, blocky, greenish-gray below and tan above	
8.	Partly covered. Shale, gray 13	
7.	Shale and <u>mudstones</u> , alternating, very indurated, blocky, tan to greenish-gray, indistinct bedding, pronounced vertical jointing	
6.	Shale and siliceous <u>mudstones</u> , green to brown, more resistant than unit below and less resistant than	

68.

		69.
5.	. Shale, light gray to tan	52
4.	Limestone, medium dark gray, dense, massive, fine crystals, veins of white calcite	37
3.	Limestone and shale, greenish-gray, thin-bedded.	32
2.	Sandstone, very light gray, medium-grained, cal- careous	10
1.	Party covered. Shale, light gray, with thin beds of <u>limestone</u> , light gray	f
	Total thickness	360
Ent	rada sandstone	
Bed	No.	Feet
1.	Sandstone, grayish-orange pink (5 YR 7/2), fine, subrounded quartz grains, well sorted, cross-bedded calcareous especially in top	1.50
	Total thickness	150
Mar	oon formation	
Bed	No.	Feet
12.	Siltstone, bright reddish-brown, shaly at top. Upper contact with Entrada is disconformable, well define	er 60
11.	Partly covered. Shale, red	26
10.	<u>Siltstone</u> , red, arkosic, limy, irregular beds $(1\frac{1}{2}")$	8
9.	Shale and limy siltstone, red	400
8.	Conglomerate, limy shale pebbles, poorly bedded .	21
7.	Partly covered. Red shale and siltstone	86
6.	<u>Conglomerate</u> , reddish-brown with white splotches; pebbles of quartz, quartzite, schist, red shale and sandstone, and feldspar, up to 1" in diameter. Mass ive above, thin bedded in lower 3'	- 8
5.	Shale, red, blocky	4
4.	Sandstone, fine to medium-grained, light reddish- brown, similar to Unit 2.	2

3.	Partly covered. Siltstone and shale, red 375
2.	Sandstone, light reddish-brown, coarse, grades upward into conglomerate with 1/2" pebbles of quartz
1.	Partly covered. <u>Siltstone</u> and fine <u>sandstone</u> , red, limy
	Total thickness 1070
	Red beds of the Maroon formation. Poorly exposed.

•

Section 4. - West Sopris Creek

(Located 400 yards north of West Sopris Creek and 2 miles west of the junction of West and East Sopris Creeks.)

Upper Niobrara removed by erosion.

Lower Niobrara formation

Smoky Hill member

Bed No.

Feet

Feet

8

Fort Hays member

Bed No.

- Limestone, light gray (N 7), weathering very light gray, dense, noncrystalline, massive beds ½ to 2' thick, a few thin shale breaks, secondary calcite crystals, Inoceramus labiatus.
- <u>Shale</u>, black in base to medium dark gray (N 6) near top, thin bedded, relatively indurated, becomes increasingly calcareous upward <u>35</u>
 - Total thickness . 95

Benton formation

Bed No.

Feet

30

3. <u>Limestone</u> and <u>shale</u>, alternating! Limestone, medium dark gray (N 4) to brownish gray (5 Y 4/1), very sandy, fine crystalline, thin irregular beds, sometimes breaks in slabs, fetid odor, upper sandy layer 2' thick, lower bed about 10' thick, intervening layers 2' thick, very fossiliferous in top, shales, black, thin-bedded . . . 71.

Total thickness . . 460

72.