GEOLOGY OF THE NORTHERN PORTION OF THE
FISH LAKE PLATEAU, UTAH

DISSERTATION
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INTRODUCTION

The northern portion of the Fish Lake Plateau includes the area of sedimentary rock exposures south from the Wasatch Plateau and east from Sevier Valley to the lava fields that cover the southern High Plateaus. Structurally and stratigraphically this area is transitional between the Colorado Plateau province on the east and the Basin and Range province on the west. The major tectonic features include the southern end of the Wasatch monocline, the Gates Creek monocline, and the southern parts of two of the prominent fault zones of the High Plateaus, the Water Hollow graben and the Musinia fault zone.

The exposed sedimentary sequence includes 19 formations of Jurassic through early Tertiary age and a number of deposits that are related to the late Cenozoic geomorphic development. The early Tertiary Crazy Hollow and Gray Gulch formations are more completely exposed here than anywhere else in central Utah. Because of the general completeness of the section, this study has allowed the accurate dating of a number of Tertiary orogenic events.
**Location and Accessibility**

The northern portion of the Fish Lake Plateau is in Sevier County, approximately 150 miles south of Salt Lake City. It is 3 miles southeast of Salina, Utah and 15 miles southwest of Emery, Utah. The area has an irregular outline within the rectangle bounded by 38° 30' and 39° 00' North Latitude and 111° 15' and 112° 00' West Longitude.

The northern portion of the Fish Lake Plateau is in the central part of the High Plateaus of Utah and is bounded on the north by the Wasatch Plateau (see Figs. 1 and 2); on the east by the Colorado Plateau; on the south by Thousand Lake Mountain, the balance of the Fish Lake Plateau province, and the Sevier Plateau; and on the west by the Arapien Hills of Sevier Valley.

Utah state highway 10 crosses the northern edge of the area, highway 72 the eastern edge, and highway 24 the southwest edge. From these highways a number of county and Forest Service roads cross the area in various directions as shown on Plate I. These roads plus access trails that have been constructed by shepherders make about four-fifths of the region readily accessible by jeep with relatively little walking. The eastern one-fifth has no passable roads, even by jeep, and there travel must be either on horseback or on foot. The roads and trails at elevations above 9,000 feet are not open for travel until about July 1
Figure 1. Index map of part of Utah showing location of Northern Portion of the Fish Lake Plateau (inside heavy line).
Figure 2. Index map of central Utah physiographic subdivisions (modified after Woolley, 1947, pl. 4). Hatchured area is High Plateau province.
and remain open only until about October 1. Water from streams or springs is available almost everywhere.

**Physical Features**

The general picture of the physiography as shown on Figure 1, is that of northwest, north and northeast slopes away from the lava-covered highlands of the Fishlake Plateau (11,613 feet), Mount Marvine (11,599 feet), and Hilgard Mountain (11,527 feet, Pl. 2). The eastern and southern quarter of the area is drained by streams which are tributary to Fremont River and thence to the Colorado River. The rest of the area is drained by streams tributary to Sevier River, which terminates in the interior drainage of Sevier Lake. Thus the drainage divide between the Colorado River basin and the interior drainage of Sevier Lake in the Basin and Range province lies diagonally across the area from northeast to southwest. Most of the streams that head at high elevations are perennial as they are fed by meltwater, rainfall, or springs and some have been dammed in order to insure a steady flow.

The north-central part of the area is characterized by fairly flat interstream areas and deep canyons that have been cut by Salina Creek and its tributaries (Pl. 2, Fig. 2 and Pl. 4, Fig. 2). Elsewhere the drainage divides are more rounded and the topographic relief less (Pl. 3, Fig. 1). The only areas of badland topography are along
Plate 2.

Figure 1. Hilgard Mountain
Looking west at headwaters of Clear Creek. Slides cover slope south of creek, Price River sandstones are exposed north of creek.

Figure 2. Musinia Graben and South End of Wasatch Plateau
Looking north from E¼ sec. 28, T. 23 S., R. 3 E.
Plate 3.

Figure 1. Gooseberry Creek Drainage

Looking north-northwest from SW¼ sec. 27, T. 23 S., R. 2 E.

Figure 2. Gray Gulch Exposures along Lost Creek

Looking north from sec. 12, T. 23 S., R. 1 W. Trees in foreground conceal badland topography. Fault separates lavas from Gray Gulch beds. Tgg - Gray Gulch; Tbc - Bullion Canyon series (restricted); Tv - Bullion Canyon series, lava flows.
Lost Creek where the Gray Gulch is exposed (Pl. 3, Fig. 2) and along the western edge of the area where badlands are developed in outcrops of Arapien shale.

Total relief in the northern portion of the Fish Lake Plateau between the lowest elevations along Salina Creek in the northwestern part and the highlands along the southern boundary is about 6,300 feet.

**Previous Work**

The entire area of the northern portion of the Fish Lake Plateau has been included only on one geologic map, that of C.E. Dutton (1880, Atlas Sheet no 2). Dutton’s work was a reconnaissance geologic study of the High Plateaus of central and southern Utah. Since his major efforts were focused on the thick succession of lava flows to the south, the northern portion of the Fish Lake Plateau was largely ignored. Dutton (1880, Pl. 3, p. 160-168) included a stratigraphic discussion and a number of sections by E.E. Howell that were compiled from traverses of this area during 1873 and 1874. The generally correct stratigraphic and structural interpretations by Howell show that he spent considerable time in the region and had an exceptionally acute power of observation.

The reconnaissance groundwater studies of Richardson (1906) and the surface water resources studies by Woolley (1947) in the Sevier and Sanpete Valleys included part of
this area but not bedrock information. Lupton (1916) traversed parts of the Last Chance Creek and Ivie Creek drainages while making a reconnaissance study of the coal reserves of Castle Valley. Some of his interpretations were later corrected by Spieker (1931) during the detailed mapping of the coal resources of the east front of the Wasatch Plateau. Spieker (1931, Pl. 33) extended his work south from the Wasatch Plateau to include the southernmost exposures of coal-bearing beds along Last Chance Creek.

The whole of the Wasatch Plateau and adjacent areas has been the subject of an extended study by E.M. Spieker. Spieker has studied the area north of Salina Canyon, but his only work south of Salina Canyon was that with Baker (Spieker and Baker, 1928), while outlining the coal resources of the Salina Canyon district. The southern half of the area mapped by Spieker and Baker was remapped and included on Plate 1, with very little change of the previous interpretation. The geology of the Wasatch Plateau was summarized by Spieker (1949b) in his discussion of the transition between the Colorado Plateau and the Great Basin. This work is accompanied by a map of the area north of Salina Creek. The Jurassic and Cretaceous rocks that are exposed near the mouth of Salina Canyon are described in Spieker's "Late Mesozoic and Early Cenozoic History of Central Utah" (1946).
Papers on stratigraphy and structure of the Jurassic rocks that are exposed along the west edge of Plate 1 have been published by Hardy (1949 and 1952).

The geomorphic studies in this area include those of Dutton (1880) and more recently the discussion by Hardy and Muessig (1952) of the glaciation and drainage changes of the area immediately to the south.

Field Work and the Geologic Map

The field work for this study was done during the summer season of 1957. The investigation was limited to areas where the stratigraphy and structure had not been studied in detail. Duplication of previous work was restricted to that necessary for accurate connection. Geologic data were plotted on aerial photographs obtained from the Soil Conservation Department and the Forest Service.

The base map for all of the area east of the Salt Lake Meridian is taken directly from a photogrammetric map constructed by the Forest Service using surveyed ground control points for accurately locating the land net. The base for the area west of the Salt Lake Meridian was taken directly from General Land Office plats that had been constructed at a scale of 2 inches to the mile. A photogrammetric map of the area west of the Salt Lake Meridian was constructed from the Soil Conservation Department
photos. Geologic and geographic information was plotted on this map and then reduced to the scale of the final map. For the rest of the area, the geologic information was transferred directly from the photographs to Forest Service maps, which had ample geographic control, and then was copied for the final map.

Acknowledgments

This investigation has profited from the help, suggestions, and assistance of many persons, too numerous to allow individual mention, but to whom the writer extends sincere thanks. Edmund M. Spieker proposed the problem, gave aid and counsel during the field work, and gave many suggestions and much effort to the preparation of this report; the writer has greatly appreciated this supervision and the opportunity to take part in Spieker's central Utah studies.

The Texas Company encouraged the completion of the problem, gave financial assistance toward the field work, and allowed complete access to their files.

Richard A. Young of the U.S. Geological Survey, Richfield, Utah, discussed many features with the writer and contributed valuable information on surrounding areas. J. Hoover Mackin aided in solving the stratigraphy of the Bullion Canyon series of this area. William C. Hill,
District Forest Ranger, and Merle Gee, Forest Supervisor, gave all the geographical assistance that was needed.

Paleontologic determinations have been made as follows: A. LaRocque identified the mollusks; R.E. Peck, the charophytes; J.M. Schopf, the plant fossils; and F.M. Swain, the ostracodes.

Financial aid during the writing and compilation of this manuscript was granted by the Department of Geology of The Ohio State University from the Bownocker Fellowship funds.

Finally the writer takes occasion to thank his wife, Doris, for proofreading and typing the manuscript.
STRATIGRAPHY

General Features

The rocks exposed in the northern portion of the Fish Lake Plateau include sediments ranging from Jurassic to Quaternary age, and igneous rocks of middle and late Tertiary age. The rock column is divisible into three major groups: (1) bedded rock units of Jurassic to middle (?) Tertiary age; (2) igneous rocks; and (3) late Cenozoic unconsolidated sediments. The igneous rocks are discussed under a separate heading.

At least 17,000 feet of bedrock is exposed, which is subdivided into 20 formations. Jurassic rocks are more than 4,000 feet thick, Cretaceous rocks almost 10,000 feet thick, and early Tertiary over 3,000 feet thick. As the rocks of the Jurassic and most of the Cretaceous section have been studied previously in this or adjacent areas, the present study has been limited to obtaining information on the late Cretaceous and Tertiary rocks. The following discussion of the stratigraphy, therefore, includes a summary of previous work on the older part of the section, and a detailed treatment of the younger bedded rocks (Late Cretaceous and early Tertiary).

The Jurassic and most of the Cretaceous sediments are marine. The Cretaceous shoreline fluctuated back and forth across this area, and finally withdrew to the east in the
Late Cretaceous. Sedimentation was nearly continuous even after the withdrawal of the sea. The part of the section that is discussed in detail includes deposits from streams that headed in the orogenic belt to the west and deposits from the lakes that covered much of central and eastern Utah in the Paleocene and Eocene. In the late early Tertiary conditions changed abruptly when the lakes withdrew and volcanoes to the south and southwest became the source of sediments.

The late Cenozoic sediments that followed the major volcanic activity include coarse and fine clastics that were deposited as valley fill, gravel cover over pediment surfaces, gravity slides and local glacial deposits.

**Jurassic System**

The Jurassic rocks exposed in the northwestern part of the area mapped were not studied in detail. The following information on these exposures is a summary of that obtainable by reference to the listed papers.

**Arapien Shale**

The exposures of Arapien shale in eastern Sevier Valley define the northwestern edge of the area studied. This formation and the overlying Twist Gulch formation were the subject of a detailed study by C.T. Hardy (1949 and 1952), who mapped the following five lithologic units of the Arapien:
Unit E. Salt-bearing brick-red silty shale

Unit D. Interbedded bluish gray and red gypsiferous shale

Unit C. Bluish gray calcareous shale with gray thin-bedded calcareous sandstones and massive lenses of gypsum

Unit B. Bluish gray and red gypsiferous shale

Unit A. Gray thin-bedded argillaceous limestone with massive lenses of gypsum

Hardy (1952, p. 16-17) estimated the thickness of exposed Arapien shale to be 2,700 feet and a total thickness for the formation, including unexposed rock, of 3,000 feet. Standard of California Company has since drilled a deep test well in sec. 32, T. 22 S., R. 1 W., that started near the base of Unit A and penetrated 8,997 feet of twisted and contorted Arapien beds before reaching the top of the Navajo sandstone. The section is so disturbed that there is no way of telling how much is repeated. The minimum dips of this section, 10° to 15°, are recorded from cores taken just above the Navajo. The amount of section exposed plus the amount penetrated by the drill, suggests a total thickness for the Arapien of 7,000 to 10,000 feet.

The comparison of lithologies and contained fossils has established that the Arapien is of late Middle or early Late Jurassic age and correlative with the Carmel formation of the San Rafael Swell on the east and the Twin Creek limestone on the north. The interbedded green shale and
gray limestone at the base of the Arapien in the Standard of California Company well closely resemble those of the Twin Creek.

**Twist Gulch Formation**

The section overlying the Arapien shale and under­lying the Morrison (?) formation was defined by Spieker (1946, p. 124) as the Twist Gulch member of the Arapien shale. Detailed work by Hardy (1952, p. 22) showed the regional significance of this section and caused him to redefine the Twist Gulch as a formation. The type section for the formation is in sec. 21, T. 21 S., R. 1 E., on the north side of Salina Canyon, just east of Twist Gulch. At this locality 1,910 feet of a section that may total 3,000 feet in thickness is exposed between a fault on the west and the Morrison (?) formation on the east. There are no Twist Gulch exposures in the area of Plate 1.

Hardy (1952, p. 22-23) lists the lithologies of the Twist Gulch formation as largely red siltstone and reddish gray sandstone, but including a sequence of olive green shale near the top that contains gray sandstone, grit, and bluish gray shale. Fossils in the olive green shale unit enabled Hardy (1952, p. 27-28) to correlate the Twist Gulch formation with the Entrada, Curtis, and Summerville formations of the San Rafael group, the Curtis correlating with the fossiliferous unit.
Morrison (?) Formation

A 1,300-foot succession of variegated shale, brown to white sandstone, and chert and quartzite pebble conglomerate is exposed on the north side of Salina Canyon above the Twist Gulch formation and beneath the Sanpete formation of the Indianola group. Part of this section is exposed also on the south side of the canyon. Spieker (1946, p. 125-126) studied this section and found it to be unfossiliferous. The lithologies appear to be gradational both downward into the Twist Gulch and upward into the Sanpete formation. On the basis of the stratigraphic position and the general Morrison-like character, Spieker and Reeside (1926, p. 432) suggested a correlation of these beds with the Morrison formation. Further study of the chert pebbles supported this correlation, as similar cherts are found in the Morrison of the northern San Rafael Swell (Spieker, 1946, p. 125). Other lithologies, such as the ochre sandstone and variegated beds, are common both to the Morrison and the overlying fossil-bearing Indianola beds. The unfossiliferous section, therefore, has been designated as Morrison (?).

Spieker (1949b, p. 19) later stated:

If the beds are really Morrison in age, the basal gradation is no problem, rather an interesting contribution to Morrison stratigraphy, but the upper one is most puzzling; the whole lower Cretaceous should be missing and so far no one of several
competent geologists has been able to recognize any sign of a break. In fact, were I not familiar myself with so many other instances of baffling concealment of actual gaps I should consider seriously the possibility that the whole Lower Cretaceous and part of the late Jurassic are represented in the formation, and for that matter, to theorize one bit further, evidence of major boundaries obscurely situated in gradational and intertonguing strata is now sufficiently abundant in the Cordilleran region to give the idea some flavor of validity. Against it, however, is the fact that the Morrison (?) sediments are mainly of types that normally accumulate somewhat rapidly.

Spieker now thinks (personal communication) on the basis of studies by Bayley that the Morrison (?) formation must contain a more or less unbroken record of the late Jurassic and the whole Lower Cretaceous.

**Cretaceous System**

**General Character and Distribution**

Sedimentary rocks of Cretaceous age are exposed in most of the eastern two-thirds of the area mapped and in a small area near the mouth of Salina Canyon. Lithologic contrasts between units allow positive identification of exposed formations even though actual tracing is not everywhere possible because of faulting and surficial cover. The deposits are mainly shales and sandstones, with only minor amounts of coal and limestone.

The Cretaceous rocks are divisible into two major groups, which are separated by the erosional unconformity that was caused by early Laramide uplift and folding. The
lower group includes the conformable sequence of Mancos shale, Star Point sandstone, and Blackhawk formation that is exposed over the eastern part of the area, and the members of the Indianola group that are exposed near the mouth of Salina Canyon. The eastern section includes marine beds at the base, two littoral sandstone tongues, and grades upward through littoral to continental beds. Characteristic colors are dark gray to gray for the shale and gray to white for the sandstone. The western section, which is incompletely exposed, includes fluvial sandstone and conglomerate, marine shale and littoral sandstone.

The upper group of Cretaceous rocks includes the Castlegate and the "upper" members of the Price River formation and approximately the lower two-thirds of the North Horn formation. These rocks are exclusively continental in origin and are brown to white massive locally conglomeratic sandstone in the lower part and varicolored beds in the upper part.

Indianola Group

In the area mapped, the clastics of the Indianola group crop out only in a narrow belt along the south wall of the western part of Salina Canyon. The exposures are incomplete and difficult to reach. A more complete section that is excellently exposed on the north side of the canyon has been studied by Spieker (1946, p. 126-128) and
correlated with similar exposures to the north. He lists the following information for the Indianola group along the west side of the Wasatch Plateau, and probable correlations with members of the Mancos shale (from top):

**Indianola group**

**Sixmile Canyon formation (not exposed in Salina Canyon)** includes three members in Sixmile Canyon

3. Conglomerate and conglomeratic sandstone 425+'
2. Gray to white, mainly fine sandstone, gray to white shale, carbonaceous shale and coal 300'
1. Gray conglomeratic sandstone; contains plants and mollusks of Colorado age 2000'

This formation is correlated with a part of the Blue Gate (Middle Mancos) shale of Niobrara age.

**Funk Valley formation (basal 600 feet exposed in Salina Canyon)**. Type area in Funk Valley (secs. 34 and 35, T. 18 S., R. 2 E.) has three members.

3. White to brown sandstone 700'
2. Gray marine shale 650'
1. White to brown sandstone 900'

Fossil control indicates a correlation with lower portion of Blue Gate shale.

**Allen Valley shale (850 feet thick in Salina Canyon)**

Evenly bedded gray marine shale, sandy in part, with thin layers of bentonite, siltstone, very fine sandstone, and limestone.

Spieker (1956, p. 1786) correlates this unit with a part of the Tununk (Lower Mancos) shale.
Sanpete formation (about 1350 feet thick in Salina Canyon). Contact with Morrison (?) formation is difficult to pick because of similar lithologies.

Brown, ochre, buff, and gray sandstone; gray to ochre shale, mainly sandy; and gray conglomerate. Conglomerate is abundant in lower part but absent in upper part. Fossils indicate correlation with lower portion of Tununk shale.

The Indianola group is estimated to be about 7,000 feet thick in Salina Canyon.

The Indianola beds in Salina Canyon are vertical in the western part, with gradually lessening dip eastward and are inclined at 24°SE (strike N. 38° E.) where they are overlapped by upper North Horn shales.

The Indianola group is not exposed anywhere to the south or west of Salina Canyon. Forty miles north, in the Gunnison Plateau and Cedar Hills, the group is composed of 8,000 to 15,000 feet of conglomerate and sandstone and interbedded variegated continental beds. The coarseness and thickness of the clastics to the north indicate orogenic activity to the west or northwest of the Gunnison Plateau during early Colorado time. A change in the lithologies of individual conglomerate fragments of the upper part of the Indianola in the Gunnison Plateau area probably resulted from renewed orogenic activity in the west during late Colorado or early Montana time (Spieker, 1949b, p. 79).
Mancos Shale

Along the east front of the Wasatch Plateau, the members of the Mancos shale are well exposed in the belt of westward sloping cuestas and intervening valleys between the Dakota (?) sandstone cuesta on the east and the Star Point cliffs on the west. The strata dip away from the San Rafael Swell. The upper part of the Mancos has been discussed by Spieker (1931, p. 18-21) and the lower two-thirds has been discussed by Katich (1951).

The Mancos section in the Ivie Creek - Last Chance Creek area is as follows (after Spieker, 1931, p. 19):

Mancos shale  

Masuk shale - bluish black to gray shale  

Emery sandstone - buff, massive to thin-bedded sandstone  

Blue Gate shale - bluish gray shale  

Ferron sandstone - sandstone, sandy shale, and coal  

Tununk shale - bluish gray shale

<table>
<thead>
<tr>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>600'</td>
</tr>
<tr>
<td>800'</td>
</tr>
<tr>
<td>1650'</td>
</tr>
<tr>
<td>500'</td>
</tr>
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<td>600'</td>
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</tbody>
</table>

Total 4150+'

The upper four members of this section crop out over the easternmost part of the area mapped. The exposures of individual members are usually incomplete and discontinuous because of Cenozoic faulting and the gravel cover over the pediment surfaces that have been developed in this area. The four members, however, are easily identified by their lithology or stratigraphic position.
Fossils have been found in the Ferron sandstone and Emery sandstone of the Mancos group. Using the paleontologic evidence, Katich (1951, p. 98) has assigned the Ferron an upper Carlile age (see reference sequence for the Western Interior, Cobban and Reeside, 1952, chart 10b), and Spieker (1951, p. 20) has assigned the Emery an Eagle age.

Star Point Sandstone

The Star Point sandstone was named by Spieker and Reeside (1925, p. 442-443) and designated as the basal formation of the Mesaverde group in the Wasatch Plateau. The other members of this group in central Utah are the Blackhawk and Price River formations. The name of the formation was derived from Star Point, a striking headland on the east side of the Wasatch Plateau, southwest of Price, Utah. The sandstone and included marine shale tongues total about 500 feet in thickness in the type area. Southward along the east front of the Wasatch Plateau the formation thins by loss of the shale and by lateral facies change of the basal littoral sand to marine sandy shale. Spieker (1931, p. 21-27, Fls. 32-33) mapped the exposures of the Star Point along the eastern front of the Wasatch Plateau and traced it as far south as possible (sec. 4, T. 25 S., R. 4 E.), while mapping the Hiawatha and Ivie coals of the basal part of the overlying Blackhawk formation.
The Star Point sandstone exposed along Ivie and Last Chance Creeks is a buff to white massive cliff-forming fine to medium sandstone that is about 230 feet thick. The base is difficult to pick as there is a complete gradation from marine Mancos shale through sandy shale to littoral sandstone. The top is a sharp and distinct break (Pl. 4, Fig. 1) from the cliff-forming sandstone of the Star Point to the gray shale, sandstone and coals of the basal part of the Blackhawk formation. The Star Point, therefore, serves as an excellent marker wherever it is exposed.

Shelter caves are formed locally in the massive sandstone by differential weathering. Along Clear Creek and Ivie Creek the roofs of some of the larger caves have apparent smoke stains that suggest previous occupancy.

Blackhawk Formation

**Definition, lithology, and extent.** The Blackhawk formation consists of the rocks between the top of the Star Point sandstone and the base of the Castlegate sandstone member of the Price River formation. The type locality is at the Blackhawk mine (King No. 1), sec. 34, T. 15 S., R. 8 E., on the east front of the Wasatch Plateau near Hiawatha (Spieker and Reeside, 1925, p. 443-445). The usual topographic expression of the Blackhawk is a rounded or step-like slope between cliff-forming sandstones. The exposures of this formation in Salina Canyon were studied and reported
on by Spieker and Baker (1928, p. 137-139) and those along Ivie and Last Chance Creeks were reported on by Spieker (1931, p. 27-39).

The Blackhawk is the coal-bearing formation exposed in the lower slopes of the upper part of Salina Canyon and includes the oldest outcrops of that area. The oldest rocks exposed are near the east gate of the canyon, where a 537 foot section of medium to fine buff sandstone and gray shale crops out on the north wall (Spieker and Baker, 1928, p. 138). Downstream and along the tributaries the Blackhawk section is in most places covered by vegetation and soil.

East of the Musinia fault zone, the upper part of the Blackhawk is continuously exposed along Meadow Creek. Just east of the Meadow Creek - Ivie Creek divide the complete section crops out. The most extensive exposures of the Blackhawk within the area mapped are over a shallow westward plunging syncline in T. 24 S., R. 4 E. There are no known outcrops of Blackhawk beds in the High Plateaus south of sec. 5, T. 25 S., R. 4 E. The Blackhawk formation east of the Meadow Creek - Ivie Creek divide includes the following elements (Spieker, 1931, p. 35):

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper massive sandstone, little or no coal</td>
<td>280'</td>
</tr>
<tr>
<td>Blocky sandstone, shale, and thin coal beds</td>
<td>350'</td>
</tr>
<tr>
<td>Lower massive sandstone and thick coal beds</td>
<td>120'</td>
</tr>
<tr>
<td></td>
<td>750'</td>
</tr>
</tbody>
</table>

The thick coal beds that occur at or near the base of the Blackhawk, the Hiawatha (lower) and the Ivie beds, have
been traced by Spieker (1931, Pls. 30, 32 and 33) over the Ivie Creek - Last Chance Creek areas. These coals are locally eight or more feet in thickness, but have been exploited only in small mines along Ivie Creek.

**Stratigraphic relations.** The base of the Blackhawk is sharply defined by the top of the cliff of the underlying Star Point sandstone. Channelling in the top of the Star Point has been noted to the north, but none within the area mapped. The contact is even, persistent, and easily picked in almost all exposures.

The top of the Blackhawk is drawn at the erosional disconformity at the base of the cliff-forming Castlegate sandstone where this unit is present, and at the base of the equivalent sandstone section where the cliff-forming habit is lacking. The Castlegate sandstone is easily differentiated from sandstone of the Blackhawk formation because it is generally coarser and locally conglomeratic.

**Age.** Fossil plants collected by Spieker (1931, p. 36) indicate a Montana age. Samples of a coal and silicified coniferous wood were collected in T. 24 S., R. 4 E. at and near the top of the Blackhawk formation, respectively. They were examined by J.M. Schopf, but no generic determinations could be made. The coal consists mainly of bundles of coniferous resin filaments with a few conifer spores and one fern spore.
Plate 4.

Figure 1. Clear Creek Valley

Looking northeast towards confluence of Clear Creek and Ivie Creek. Star Point sandstone is ledge-forming unit. Alternating sandstone and shale of Blackhawk forms the slopes.

Figure 2. Price River Exposures on East Side of Browns Hole

Looking northeast from NE\(\frac{1}{4}\) sec. 10, T. 23 S., R. 2 E. at Browns Hole in near distance and southeastern part of Wasatch Plateau in far distance. Kb - Blackhawk formation; Kc - Castlegate sandstone member; Kpr - Price River formation; Tf - Flagstaff.
Price River Formation

Definition, lithology, and extent. The Price River formation was defined by Spieker and Reeside (1925, p. 445) as the succession of predominantly gray medium to coarse sandstone, grit and conglomerate, and a minor amount of shale that is exposed in Price Canyon, above Castlegate, Utah. It is underlain by the Blackhawk formation and overlain by the North Horn formation. The Price River formation includes at the base the Castlegate sandstone member, which is separated from the upper member because it is a prominent cliff-forming massive sandstone. The upper member (unnamed) is generally similar in lithology, but forms a step-like slope. At the type locality the Castlegate sandstone member is 511 feet thick and the upper member 488 feet, making a total thickness of about 1,000 feet.

The Price River formation crops out extensively throughout the Wasatch Plateau, westward in the Pavant Mountains, the northern portion of the Gunnison Plateau, and eastward in the Book Cliffs as far as the Utah-Colorado boundary. In the northern portion of the Fish Lake Plateau the Price River formation is a conspicuous interval because of the thick massive sandstone beds. The sandstones are most spectacularly displayed on the north side of the middle portion of Salina Canyon where they form precipitous walls. The Price River formation is well exposed over the
north-central and eastern parts of the mapped area. Continuous exposures are seen along Utah highway No. 10 from near the mouth of Gooseberry Creek eastward to the Meadow Creek - Ivie Creek divide except for small areas where disrupted by faulting.

The exposures in Salina Canyon have been studied and reported on by Spieker and Baker (1928, p. 139-143). The cliff-forming Castlegate sandstone member here consists of 229 feet of gray to white, medium to coarse sandstone, and a few conglomerate and shale units. In faulted exposures this member is differentiated from the massive sandstone of the underlying Blackhawk formation by the relative coarseness of the grains. The upper member in Salina Canyon is about 800 feet thick. It is also cliff-forming in part, but generally forms step-like slopes. In areas adjacent to Salina Canyon the lower and upper members have almost exactly the same lithologies, with only a few thin gray or varicolored shale breaks characterizing the upper member (Pl. 4, Fig. 2). In the upper member there is a ledge-forming sandstone that contains a prominent band of white sandstone 20 feet thick at about 140 feet above the Castlegate sandstone.

Eastward from Salina Canyon the Castlegate sandstone member becomes less distinctive and entirely loses the cliff-forming habit at the Meadow Creek - Ivie Creek divide.
The member still can be differentiated because beginning in sec. 24, T. 23 S., R. 3 E. a 10 to 40 foot conglomerate of mostly white quartzite pebbles appears at the base of the upper member (Pl. 5, Fig. 1). This conglomerate is persistent over the eastern area and thereby serves to separate the lower member from the upper member. The conglomerate is the source of gravel in the pit one-quarter of a mile south of the Meadow Creek - Ivie Creek divide.

The southernmost complete exposure of the Price River formation is between Red Creek and North Creek in secs. 5, 7 and 8, T. 24 S., R. 4 E. The Castlegate sandstone member here consists of 233 feet of yellowish gray to brown medium sandstone with some interbedded gray shale. The sandstone contains local concentrations of ferruginous material and appears to have a ferruginous cement. The lithologies, bedding, and contained fresh-water mollusks (in place) indicate a fluvial origin for the Castlegate member in this area. There is a change in average grain size from coarse in Salina Canyon to medium in the eastern areas.

The upper member between Red Creek and North Creek consists of 888 feet of yellowish gray predominantly medium frosted friable sandstone and a low proportion of interbedded shale. Toward the top, some of the shale is red. The sandstone is moderately indurated by a ferruginous cement in the lower part and by a siliceous cement in the upper part. Ferruginous concretions are common throughout.
Stratigraphic relations. The beds of the Price River formation are parallel to those of the underlying Blackhawk formation, but separated by a disconformity wherever the contact zone is seen. The abrupt change from a section with shale and coal to massive sandstone with almost no shale makes this contact easy to locate. In the western part of the area, another means of recognizing the contact is the rather abrupt change in the grain size of the sandstone from fine to medium in the Blackhawk to coarse in the Castlegate member. A thin coal bed is present in some exposures in T. 24 S., R. 4 E., at the top of the Blackhawk, but in other exposures the coal appears to have been removed by erosion prior to deposition of the Castlegate sand.

The disconformity at the base of the Price River formation in the Wasatch Plateau region has been traced westward into a major angular unconformity in the folded belt. Spieker (1946, p. 132) uses this relation to establish that the main Laramide orogeny of central Utah occurred during the hiatus between the Blackhawk and Castlegate.

Over most of this area the upper unit of the Price River is a massive sandstone over 100 feet thick, followed conformably by the more shaly North Horn sequence, so that the contact can be determined easily. Locally the contact
Plate 5.

Figure 1. Basal Conglomerate of Upper Member of Price River Formation

View of the outcrop along Red Creek in sec. 8, T. 24 S., R. 4 E.

Figure 2. North Horn Formation East of Gooseberry Creek

Looking west from center of sec. 19, T. 22 S., R. 2 E. at exposures of middle part of North Horn section. Ridge in the far distance on right is capped by Green River limestone.
is more difficult to place for in some areas the massive sandstone interfingers with the varicolored shale of the overlying North Horn formation. Owing to the regionally gradational character, the contact does not have the same time value in different areas.

**Age.** In the eastern part of Utah the Castlegate sandstone member forms a littoral sandstone tongue in the marine Mancos shale. This relationship can be traced in the Book Cliffs. Marine fossils establish a late Montana age for this part of the Mancos (Spieker, 1946, p. 132).

The control on the chronological position of the Price River formation of central Utah has been limited to a few collections of mollusks in the Wasatch Plateau. The mollusks are those characteristic of the late Montana stage in the Upper Cretaceous of the Cordilleran region. A few fossils were collected in the mapped area but none were of any use in age determination.

**Cretaceous and Tertiary Systems**

**North Horn Formation**

**Definition, lithology, and extent.** The lower section of the varicolored fluviatile and lacustrine sandstone and shale that overlies the Price River was originally defined by Spieker and Reeside (1925, p. 448) as the lower member of the Wasatch formation. The upper two members of the
Wasatch formation were the Flagstaff limestone (the middle member) and an upper varicolored shale and sandstone section (later named the Colton formation). Further study and the discovery of vertebrate remains in the lower varicolored member showed a much older age than originally estimated. Spieker (1946, p. 132) redefined the lower member of the Wasatch formation as the North Horn formation, selecting as the type locality the section exposed on North Horn Mountain, Tps. 18-19 S., R. 6 E., on the eastern side of the Wasatch Plateau. In the type area Spieker described four gross units of alternating fluvial and lacustrine environments as follows (from bottom): (1) fluvial gray medium to fine sandstone, gray to varicolored shale, and some conglomerate; (2) mainly lacustrine gray shale, buff fine sandstone, and some limestone; (3) fluvial gray shale and buff sandstone; and (4) lacustrine evenly bedded red and variegated shale, interbedded gray sandstone, and some limestone. Total thickness is 1650 feet.

The North Horn formation crops out widely in the Wasatch Plateau, Gunnison Plateau, Valley Mountains and Pavant Mountains. Spieker (1954, p. 12) suggests that the upper part of the Kaiparowits formation, that crops out south of the volcanic cover, may be equivalent to the North formation because the lithologies are similar and dinosaurian remains in both formations may be coeval.
The North Horn crops out over much of the central part of the area mapped. The best and most complete exposures are in Gooseberry Valley, T. 22 S., Rs. 1-2 E. (Pl. 5, Fig. 2 and Pl. 6, Fig. 1). Elsewhere the sandstone units may crop out, but less resistant units are usually covered by soil or slides.

The measured thickness of about 1200 feet appears to be fairly constant over the area except where the North Horn laps onto a western highland. This highland existed in late North Horn time and possibly was the scene of recurring minor positive movements throughout most of North Horn time. These positive movements may be reflected eastward by some of the abrupt changes in the North Horn section from evenly bedded lacustrine shale to fluvial conglomeratic sandstone. Minor channelling accompanies the changes but there is no evidence of extended periods of erosional truncation. The wedge-out of the North Horn onlap is seen in the north wall of Salina Canyon in sec. 33, T. 21 S., R. 1 E.

The upper lacustrine unit of Spieker is the only subdivision that can be differentiated. It is excellently exposed in Salina Canyon and in the lower part of Gooseberry Valley. This evenly bedded variegated shale and siltstone unit is 350 feet thick and contains a number of fine yellowish gray locally conglomeratic sandstones. The
sandstone may be of either lacustrine or fluvial origin. There are no limestone beds in the North Horn of this area.

The rest of the section can not be subdivided into units according to depositional environments because it includes alternating fluvial and lacustrine beds. The lithologies include evenly or unevenly bedded red, purple, or gray shale that may be mottled, and yellowish gray sandstone that is locally conglomeratic and may show cross-bedding and channelling.

Stratigraphic relations. The North Horn is easily differentiated from the underlying Price River formation in most exposures by the abrupt change in lithology from massive sandstone to gray or varicolored siltstone and shale.

The upper contact is conformable and plainly marked by the abrupt change to the resistant calcareous sediments or light gray or green shale of the Flagstaff formation. In the western regions there is little color change, but eastward the change from variegated beds to light gray or green beds is conspicuous.

Age. The North Horn formation, according to vertebrate and fresh water faunas collected in the Wasatch Plateau (Spieker, 1949b, p. 26-30), includes beds of Late Cretaceous age that contain a Lance type Ceratopsian fauna and beds of Tertiary age that contain a mammalian fauna like that found in the
Paleocene Fort Union group of the Northern Plains. The study of fossils recently collected in the type area (Spieker, personal communication) has established approximately the lower two-thirds of the formation as Cretaceous in age and the upper third as Tertiary.

No fossils were found in the North Horn exposures of the northern portion of the Fish Lake Plateau.

**Tertiary System**

The lower Tertiary rocks of this area record alternating epeirogenic movements that included downwarping sufficient to form shallow lakes, continued gradual downwarping during deposition while layer upon layer of sediment was deposited, stillstand while the lakes filled or were drained and subsequent deposition was fluvial, and uplift that caused the partial or complete removal of formations prior to additional deposition. The middle (?) Tertiary rocks are mudflows, igneous boulder conglomerates, coarse conglomeratic sandstones and thick lavas of intermediate composition. The upper Tertiary is sparsely represented by remnants of former valley fills or by gravel deposits that cap pediments. The late Tertiary was mainly a time of uplift, normal faulting and erosion.
Flagstaff Formation

Definition, lithology, and extent. The first of the major early Tertiary lakes that covered central Utah is recorded by the lacustrine limestones and shales of the Flagstaff formation. This unit was first recognized in the Wasatch Plateau by Spieker and Reeside (1925, p. 448) who proposed the name "Flagstaff member" for the 800 to 1500 foot fresh water limestone section that is consistently present between the upper and lower varicolored parts of what was then called the Wasatch formation. Spieker (1946, p. 135-136) later revised the terminology of the Wasatch formation and elevated the middle member to formational rank as the Flagstaff limestone. Gilliland (1948, p. 50-51), working in the Valley Range and Gunnison Plateau, was forced again to revise the term "limestone" to "formation" to include equivalent red-colored nearshore and offshore facies. In present usage the Flagstaff formation overlies the North Horn formation and underlies the Colton formation.

The Flagstaff formation of the Wasatch Plateau is the most prominent cliff-former and cap rock in that area. On the west side of the plateau the Flagstaff limestones form the great dip slopes on the outer flank of the Wasatch monocline as far south as Sixmile Canyon, and in the central and eastern parts of the plateau they form the white cliffs that surround the high top of the plateau,
Plate 6.

Figure 1. Flagstaff Formation along Gooseberry Creek

Looking west from Gooseberry Creek in center sec. 13, T. 22 S., R. 1 E. Note gradation from North Horn to Flagstaff. KTN - North Horn formation; TF - Flagstaff formation; TC - Colton formation; TG - Green River formation.

Figure 2. Upper Part of Flagstaff Formation along Nioche Creek

View taken in sec. 35, T. 23 S., R. 2 E. Note Brunton compass for scale.
Figure 1

Figure 2
and cap peaks such as Musinia Peak and North Horn Mountain. In contrast, in the northern portion of the Fish Lake Plateau, the Flagstaff formation crops out only in limited, rounded exposures that flank the lava-covered highlands.

Over the area east of Gooseberry Creek the rocks of the Flagstaff formation include white cherty limestone and some interbedded gray and grayish green shale (Pl. 6, Fig. 2). West of Gooseberry Creek and in the lower part of Salina Canyon (Pl. 6, Fig. 1), the formation is represented by red calcareous siltstone, argillaceous limestone, and a few interbedded conglomeratic sandstones of fluvial origin. The Flagstaff thins out westward in Salina Canyon on a topographic high that existed as an island in the Flagstaff lake (see Spieker, 1949b, p. 67). The red-colored section measures over 85 feet thick west of Gooseberry Creek. The section containing white limestone and interbedded shale at higher elevations in the south central part of the area is nowhere completely exposed. The most complete section (Section no. 12 in Appendix) is over 300 feet thick.

**Stratigraphic Relationships.** The red-colored Flagstaff exposed along Gooseberry Creek and Salina Creek is bounded by conformable contacts with lacustrine beds both above and below. In fact the Flagstaff section, as here interpreted, is restricted to the more resistant calcareous beds that form a prominent ledge. The North Horn beds immediately
below and the Colton beds above are evenly bedded vari-
colored shales that are probably lateral equivalents of
portions of the thick Flagstaff sections exposed to the
east and north.

In Salina Canyon the Flagstaff beds overlap the North
Horn beds and lie in angular unconformity over truncated
Indianola group and Morrison (?) beds. The younger
Flagstaff beds transgress farther than the older, and the
overlying Colton shale transgresses even farther.

All of the Flagstaff sections that crop out at
higher elevations east of Gates Creek are exposed incom-
pletely, because the lower contact either is buried or
concealed by soils and the upper contact generally has been
eroded away.

Pre-Flagstaff unconformity. Spieker (1946, p. 136-137)
discussed a pre-Flagstaff angular unconformity along the
western border belt of the Wasatch Plateau that is exposed
in valleys between Salina and Manti. Unconformable
relationships in the Kaiparowits Plateau and on Thousand
Lake Mountain indicate that the major monoclinal folds of
the Colorado Plateau developed at the same time as this
unconformity. From his studies in Sixmile Canyon, east
of Manti, Spieker determined that following deposition
of the North Horn formation, orogenic movements
caused the North Horn beds to be bent upward. The folded beds subsequently were truncated prior to deposition of Flagstaff limestone.

The section exposed in Salina Canyon differs from that of Sixmile Canyon because the Price River formation is missing and pre-Flagstaff folding can not be observed. Any folding or uplift in the Salina area must be dated prior to the deposition of the upper shale section of the North Horn formation that overlies the angular unconformity because there is definitely no angular relationship between this unit and the Flagstaff. Tracing of lithologic units between this area and Sixmile Canyon has shown that the red-colored Flagstaff section of Salina Canyon is younger than the lower part of the Flagstaff formation to the north and that the red shale and siltstone of the North Horn in Salina Canyon is the lateral equivalent of the basal Flagstaff in Sixmile Canyon (Spieker, personal communication).

The designation of the time of folding as post-North Horn, pre-Flagstaff is therefore somewhat misleading because the contact between these two units is not a time line. Actually, to satisfy all relations, Spieker's interpretation need only to be changed slightly to date the movements as having occurred intermittently and locally during the deposition of the North Horn and part of the Flagstaff formations. The island onto which the upper
North Horn, Flagstaff and Colton beds transgress then is interpreted to be a topographic high that initially was elevated by the early Laramide (post-Blackhawk, pre-Price River) orogenic movements and was subsequently re-elevated by positive movements during North Horn time.

Regional relations. Regionally the wide range in thickness and lithology of the Flagstaff formation is even more pronounced than it is in the northern portion of the Fish Lake Plateau. In the Wasatch Plateau the Flagstaff is most commonly 300 to 800 feet thick (Spieker, 1949b, p. 32), but locally it feathers out over a pre-Flagstaff erosion surface, similar to that observable in Salina Canyon. In the eastern part of Sevier Valley, Gilliland (1951, p. 29-30) identified a number of isolated exposures of limestone and conglomerate, some up to 750 feet thick, as Flagstaff. Westward, just across Sevier Valley from the Salina Canyon feather edge, Lautenschlager (1952, p. 54) reported a thickness of over 2,800 feet for the undifferentiated Flagstaff-Colton section in the Pavant Mountains. In the Valley Mountains, Gilliland (1948, p. 25) listed five zones of yellow, gray, and red fossiliferous limestone and gray shale in the northern part that change southward to dominantly red limestone, sandstone, and conglomerate. Thicknesses range from 500 to 1,400 feet. Lautenschlager's section consists mainly of bright-red siltstone, silty
limestone and shale with minor amounts of pure limestone or conglomerate. In both the Valley and Pavant mountains the lacustrine origin of the Flagstaff is evinced by the bedding and included fresh water gastropods, pelecypods, and ostracodes.

South of the northern portion of the Fish Lake Plateau there are no exposures of Flagstaff-equivalent beds for approximately 45 miles. In Cleaves Gulch (T. 32 S., R. 1 W.) on the west side of Aquarius Plateau, Gregory (1944, p. 590) reports 70+ feet of "Wasatch" beds (sometimes called the Bryce Canyon formation). This section of pink limestone, with lenticular conglomerates at or near the base, thickens southward to 1,800 feet at Bryce Canyon (T. 37 S., R. 3 W.) where it overlies the Wahweap sandstone. Around Canaan Peak (T. 37 S., R. 1 E.) on the Kaiparowits Plateau, the beds of the "Wasatch" overlie the truncated strata of the Kaiparowits formation (Late Cretaceous). Gregory (1951, p. 52) believes the "Wasatch" beds of the Paunsaugunt and Aquarius regions to be Eocene on the basis of the gastropod fauna. Spieker (1954, p. 10 and personal communication) has made lithologic and tectonic comparisons and believes these beds to be equivalent to the Flagstaff and thus be late Paleocene in part.

The southernmost Flagstaff exposures in the northern portion of the Fish Lake Plateau do not help in
establishing a correlation with the "Wasatch" beds because the section here is white limestone and interbedded gray shale and contains no pink beds.

**Age.** The age of the Flagstaff was first postulated to be late Paleocene by Spieker (1946, p. 136 and 1949b, p. 32) because of its stratigraphic position relative to the Wasatch formation of northeastern Utah, and based on a preliminary study of the molluscan fauna. LaRocque (1956, p. 140-141) after a more detailed study of the mollusks, suggested a late Paleocene age for the lower part of the Flagstaff and an early Eocene age for the upper part.

Ostracodes and fish scales were collected in the northern portion of the Fish Lake Plateau. Three samples of ostracodes from limestone units near the base of the red Flagstaff section along Gooseberry and Salina creeks were studied by F.M. Swain. The species identified included:

- *Heterocypris* sp.
- *Candona* sp., with median node
- *Cyprio* cf. *marginata* (Strauss)
- *Cypris pagei* (Swain)

Swain suggests a correlation on the basis of the ostracodes with the upper Colton or lower Green River formations of the Uinta Basin. This would indicate a late early Eocene or early middle Eocene age for the red Flagstaff beds along Gooseberry and Salina Creeks, but such physical tracing of
the Flagstaff that has been done shows that these beds correlate with the part of the section identified by LaRocque as Paleocene on the basis of the molluscan fauna (Spieker, personal communication).

Colton Formation

**Definition, lithology, and extent.** The varicolored continental beds that were originally classified as the upper member of the Wasatch formation have been redefined by Spieker (1946, p. 139) as the Colton formation. The type section is two miles east of Colton, at the head of Price Canyon and consists of 1,500 feet of irregularly bedded, gray pepper-and-salt sandstone, greenish buff sandstone, and deep red to variegated shale of fluvial origin. The Colton beds of the type area overlie the Flagstaff in sharply defined contact and are in turn conformably overlain by Green River beds. The bright colors of the Colton strata offer a striking contrast to the light gray to green lacustrine beds of the Flagstaff and Green River formations. Spieker (1946, p. 139) states that the stratigraphic limits given for the Colton are valid only locally in central Utah because the fluvial strata intertongue extensively with lacustrine beds, and in places the entire formation grades westward into the Green River formation.
The Colton is exposed at numerous places along the western edge of the Wasatch Plateau where the Flagstaff, Colton, and Green River beds form the strata in the Wasatch monocline, westward in the Gunnison Plateau, in the Valley Mountains, and probably in the Pavant Mountains.

In the northern portion of the Fish Lake Plateau, the Colton is exposed in Salina Canyon and in continuous outcrops in a north-south belt along the west side of Gooseberry Valley north of Gates Creek. The small occurrences in Tps. 23 and 24 S., R. 2 E. are identified on the basis of stratigraphic position and red soils because no bedrock is exposed. The well-exposed Colton section west of Gooseberry Creek includes evenly bedded brownish red shale and siltstone that is generally mottled with gray, and a few thin purplish gray shales. There is one 4 foot bed of ostracode-bearing bentonite near the base. In contrast to the type area, there are no channel sandstones or irregularly bedded units that would suggest a fluvial origin for any of the beds. The evenly bedded character of the shale and the ostracode-bearing bentonite suggest a lacustrine origin.

The Colton is 531 feet thick along Gooseberry Creek and thins out to the west. The lithologies of the Colton remain remarkably constant, even where the formation unconformably overlies vertical beds of the Morrison (?) and Twist Gulch formations.
There is no evidence of any pause in sedimentation either before or after Colton sedimentation, for the Flagstaff is gradational upward into the Colton and, though there is an abrupt change of color, there is likewise no evidence of any break between the Colton and Green River (Pl. 7, Fig. 2).

Regional relations. The Colton is known to grade laterally in central Utah from fluvial deposits, to variegated lacustrine shale, and into shale and limestone of the Green River formation. In Twelvemile Canyon (Johnson, 1949, p. 40) the Colton contains beds that can be attributed to all three environments because the section includes irregularly bedded sandstone and conglomerate; red blocky calcareous shale; and thin white limestone. On the west, lacustrine conditions in the Pavant Mountains were such that Lautenschlager (1952, p. 44-58) included the section of evenly bedded varicolored shale and interbedded limestone and sandstone that appears to be equivalent to the Colton, as an undifferentiated part of the upper Flagstaff.

The only known occurrence of beds which may be equivalent to the Colton in the southern part of the High Plateaus is the upper part of the "Wasatch" formation of the Paunsaugunt region.
Age. The age of the Colton has been adequately discussed by Spieker (1946, p. 137-138), who noted that molluscan faunas of the Colton contain none of the species found in the North Horn and Flagstaff that suggested a pre-Eocene age for these units. Spieker correlates the Colton with the traditional Wasatch (Lower Eocene = Sparnacian of the European scale) with the reservation that because of lack of vertebrate remains in the Colton, the equivalency is not supported by fossil evidence.

A bentonite bed 13 feet above the base of the Colton contains abundant ostracodes that were identified by Swain as:

- Heterocypris sp.
- Cypris pagei (Swain)
- Cyprosis sp.

Swain (1949, p. 175 and 1956, p. 135) has studied the ostracode faunas of Uinta Basin and surrounding areas and suggests a correlation with the lower Green River or uppermost Colton formation of the Uinta Basin. This indicates an early middle or late early Eocene age for this part of the Colton formation.

Green River Formation

Definition and extent, Hayden (1869, p. 89-92) proposed the name "Green River shales" for a group of thinly laminated, chalky shales of fresh water origin that are exposed along
Plate 7.

Figure 1. Green River Limestone in Soldier Canyon

View of massive and thin-bedded limestone of upper part of Green River formation in sec. 4, T. 22 S., R. 1 E.

Figure 2. Contact of Colton and Green River Formations West of Gooseberry Creek

Looking north-northwest in sec. 25, T. 22 S., R. 1 E.
the Green River near Rock Springs, Wyoming. Equivalent Eocene lake sediments were soon recognized in the Uinta Basin and in discontinuous exposures to the south. Dutton (1880, p. 166-167) lists two sections measured by E.E. Howell in the southwestern portion of the Wasatch Plateau that Howell provisionally assigned to the "Lower Green River" epoch, but could not demonstrate their correlation. Concerning the distribution of these beds Dutton says (p. 167):

The beds in question are found only in the Sevier and San Pete valleys, in the uplift between them, and extending a short distance up the great monocline flanking the west side of the Wasatch Plateau. That they formerly extended over that plateau, and for an indefinite distance eastward, is very probable.

Cope (1880, p. 303-304) proposed the name "Manti beds" for the strata in the cuestas of San Pete Valley that, as he suspected, belong in the Green River formation. Generally, workers in central Utah have followed the suggestion of Spieker and Reeside (1925, p. 451) and mapped these beds as the Green River formation.

In addition to the mentioned exposures in central Utah, the Green River formation has been mapped in the Pavant and Valley Mountains, Long Ridge, and the Gunnison Plateau.

The Green River limestones form the high walls of Soldier Canyon (Pl. 7, Fig. 1), and the lower portion of
Salina Canyon and the west wall of Gooseberry Valley. The formation thins southward along a band of outcrops in the Gates Creek monocline to the most southerly exposure in sec. 20, T. 24 S., R. 2 E. Westward from the monocline, the Green River is buried and eastward it has been removed by erosion. The excellently exposed section in Soldier Canyon is one of the thickest in central Utah. The only other Green River section to compare in thickness is that described by Gilliland (1951, p. 37-40) in the southern part of the Valley Mountains.

**Lithologies.** The Green River formation in the northern portion of the Fish Lake Plateau consists of two members; a lower green to grayish green shale 430 feet thick and an upper white to yellowish gray limestone with a maximum measured thickness of 709 feet. The formation thins south and southeastward by pre-Crazy Hollow erosional truncation. The lithology of the Green River formation shows considerable variation laterally, but the two members maintain their identities (see Fig. 3). In most places in the Gates Creek monocline the green shale is covered.

The lower member includes with the green shale, thin lenses and layers of sandstone and various types of limestone. At approximately 160 feet above the base is an olive gray paper thin-bedded calcareous shale that contains impressions and carbonaceous films of dismembered insects.
As seen in Figure 3, this is the only marker unit that can be traced laterally. There are no tuffs in the green shale member of the types described to the north by Johnson (1949, p. 46-60) and Faulk (1948, p. 34), or to the west by Gilliland (1948, p. 76). The limestones in the green shale member are thin-bedded and only minor ledge formers. Towards the top of the member there is a greater frequency of thin fine-grained sandstone beds and interfingering with massive limestone.

The overlying limestone member is characterized by two types of limestone; thin-bedded platy limestone and massive dense limestone that locally is oolitic. It is believed that two facies of limestone deposition are reflected by the relative thickness of individual beds; deposition in deep water (more than 15 feet) for the thin-bedded limestone and deposition in shallow water (less than 15 feet deep) for the massive limestone. The light gray to white thin-bedded platy dense limestone is the more common in the northern portion of the Fish Lake Plateau. Practically all the exposed limestone that crops out along the Gates Creek monocline is of this type. Individual beds are 1/8 to 1 inch thick. Small amounts of interbedded gray chert, that is believed primary, are found throughout. The thin-bedded limestone of the Soldier Canyon and Salina Canyon areas is siliceous where interbedded massive
Figure 3. Comparison of measured Green River sections.
limestone units have been partly replaced by silica. The added cement makes the thin-bedded sections more resistant and gives them a characteristic brittle, china-like clink when walked on or struck by a hammer.

In Soldier and Salina canyons thick sections of massive yellowish gray limestone alternate with sections of thin-bedded limestone. The massive units are locally oolitic and many contain biostromal algal growths. The alga, according to the description of Bradley (1923, p. 207-218, is *Chlorellopsis coloniata* Reis. Bradley (1923, p. 223) states that this alga indicates water depths of less than 15 feet. The lack of this alga in the thin-bedded limestones suggests that they were formed under deeper water conditions.

The massive limestone units are the major cliff-formers in Soldier and Salina canyons. Here they are especially resistant because of partial or complete replacement by silica. Similar silicified limestone has been reported (Fig. 4) northward along the west side of the Wasatch Plateau (Johnson, 1949, p. 46-60), in the Gunnison Plateau, and in the Valley Mountains (Gilliland, 1948, p. 160-175). In these areas the massive limestone generally is limited to the upper 150 feet or so of the Green River formation. The accompanying thin-bedded
limestone is siliceous in all areas where the massive limestone has been partly replaced.

Most of the hand specimens of the partly replaced massive limestone have a brecciated appearance. The cause of the brecciation is not tectonic. The strata have been folded but neither the adjacent unreplaced massive limestone nor the thin-bedded limestone is brecciated. A few thin sections were made to study the apparent brecciation and the type of replacement. In thin section the apparent brecciation of the limestone is seen to have resulted from solution of up to 50 percent of the original material. This formation of vugular porosity was followed by, or partly concomitant with, the partial or complete replacement of the remaining limestone and the partial or complete filling of the vugs. The replacement generally appears to have taken place in waves, with each successive wave causing the formation of larger crystals. Oolitic limestone is generally more thoroughly replaced than adjacent dense structureless limestone. The first mineral formed by the replacing silica more commonly is finely crystalline chalcedony, but finely crystalline normal quartz also is seen. The mineral of the outer layers precipitated in the vugs is chalcedony. The mineral that is precipitated in the inner parts of the vugs is either normal quartz, or pods of chalcedony (see Pl. 8).
Figure 4. Green River formation exposures in central Utah. Limestones partially replaced by silica indicated by solid black. Sources: 1, Lautenschlager (1952); 2, Gilliland (1948); 3, Hunt (1949); 4, Faulk (1949); 5, Johnson (1949); 6, Spieker (1949); 7, Hardy (1949); 8, Nussig (1951); 9, Hardy (1948); 10, Zeller (1949); 11, this paper.
Photomicrograph of Replaced Green River Limestone

Crossed nicols. Dense material is unreplaced limestone. Note chalcedony pods and normal quartz in some vugs.
The dating of the major part of the replacement is pre-Crazy Hollow and would logically be contemporaneous with the erosion of Green River beds during post-Green River, pre-Crazy Hollow time. The source of the silica is unknown.

**Stratigraphic relations.** The Green River formation overlies the strata of the Colton conformably. The change of color is striking but otherwise the change in lithology is only minor.

The contact with the overlying Crazy Hollow beds is exposed at many places along the outcrop belt. An irregular surface was developed in the upper beds of the Green River formation by pre-Crazy Hollow erosion. The thickness of section removed by this erosion increases to the south. The top of the Green River has a maximum local relief of about 50 feet. A broad valley was cut into the Green River in the southern half of T. 22 S., R. 1 E., and later filled with Crazy Hollow sediments.

The gradual thinning of the Green River formation to the south apparently is the result of differential uplift that inaugurated or accompanied the post-Green River, pre-Crazy Hollow erosion. The southwestern wedge-out of the Green River is reported by Lautenschlager (1952, p. 62) to be 3 miles west of Richfield in T. 23 S., R. 3 W. In the northern portion of the Fish Lake Plateau, the thin-out
appears to be along a north-south line through T. 23 S., R. 2 E., because the formation is not present in the south central part of this township.

**Age.** Fossils collected from the Green River formation in the northern portion of the Fish Lake Plateau include fragments of insects, wood, and gastropods; algal growths; and ostracodes. The ostracodes were obtained from limestones in the upper member at three localities. Those from limestones of the top 350 feet in the Soldier Canyon area are identified by Swain as

- *Heterocypris sp.*
- *Cyprois cf. marginata* (Strauss)
- *Cypris pagei* (Swain)

These occurrences indicate to Swain a correlation with the "Cyprois marginata zone" and the "Lower Heterocypris zone" in the middle portion of the Green River formation of the Uinta Basin (Swain, 1956, Pl. 1).

From an oolitic limestone at the top of the eroded Green River sequence in sec. 7, T. 24 S., R. 2 E., Swain identified

- *Cyprois n. sp.*
- *Heterocypris sp.*

This unit correlates with Swain's "Cyprois n. sp. zone" (1956, Pl. 1) of the lower Green River formation of the Uinta Basin, thus supporting the above statement that the upper part of the section has been removed in the southern areas.
On the basis of this information and the conformable stratigraphic position of the Green River above the lower Eocene Colton formation, the Green River in this area is believed to be of middle Eocene age. An unanswerable problem remaining is the question of the duration of the succeeding erosional interval.

Crazy Hollow Formation

Definition, lithology, and extent. Spieker (1949b, p. 36) proposed that a body of varicolored clastic rocks that overlies the Green River formation and underlies the Gray Gulch formation in the Sevier Valley area be designated by the provisional name "Crazy Hollow formation." As a type area, he selected the canyon south of Salina Creek (secs. 5 and 8, T. 22 S., R. 1 E.), next west of the mouth of Soldier Canyon, giving the name Crazy Hollow to this canyon in view of the complex faulting displayed. The formation consists of red and orange sandstone, siltstone and shale, light gray sandstone, and pepper-and-salt sandstone. Section No. 6 of the Appendix is the first measured section to be published for the type area.

The Crazy Hollow formation occurs in the foothills immediately west of the Wasatch Plateau, in Sanpete Valley, on the west side of the Gunnison Plateau, and in the Valley and Pavant Mountains. The formation is exposed in the northern portion of the Fish Lake Plateau along a somewhat
sinuous belt south from the type area to the head waters of Lost Creek. There are small areas of exposure in the lower portion of Lost Creek valley and in a faulted area south of the Gooseberry Ranger Station.

The lithology in the different outcrop areas varies, but characteristically the formation consists of evenly bedded red or orange siltstone and shale, pepper-and-salt sandstone, and locally may include broad thick lenticular conglomerate. The lenticular nature of the sandstone and conglomerate, uneven bedding, and the variety of composition indicate a fluvial origin for the Crazy Hollow strata. The section generally becomes less sandy south of the type area except in sec. 22, T. 22 S., R. 1 E., where gravel was deposited in a shallow valley cut into the Green River formation. The gravel (see Unit 8, Section No. 5) is dark colored because of the high percentage of black chert pebbles, otherwise it is very similar to the North Horn gravel in sec. 10, T. 23 S., R. 2 E. The Crazy Hollow chert was probably derived from erosion of the upper layers of the Green River formation.

Muessig (1951, p. 105-106) believed that extrusive activity was extensive during the late middle Eocene and suspected that the black grains of the Crazy Hollow pepper-and-salt sandstones may be fragments of igneous rock. A check of the black sand grains was made with a petrographic microscope and nearly all were seen to be composed of
microcrystalline quartz and chalcedony and no grains were seen that could be attributed directly to extrusive activity.

The formation is 918 feet thick near the type area. It gradually thins to the south and is approximately 300 feet thick in exposures west of Lost Creek in T. 24 S., R. 2 E. Lautenschlager (1952, p. 64) reports a maximum thickness in the Pavant Mountains of 366 feet.

Stratigraphic relations. The Crazy Hollow formation is seen to overlie the Green River formation disconformably wherever the base is exposed. In sec. 27, T. 23 S., R. 2 E., the Crazy Hollow may overlie the Colton with no intervening Green River. The maximum relief on the underlying erosion surface noted in any one exposure is about fifty feet. The contact between the Crazy Hollow and the overlying Bald Knoll member of the Gray Gulch formation is exposed in the type area and along Lost Creek. In both areas the color change from the brownish red shale and siltstone of the Crazy Hollow beds to the light gray of the Gray Gulch formation is abrupt but with no evidence of a sedimentary break. The first sign of volcanic activity that is recorded in the post-Green River strata of this area is in the Gray Gulch bentonitic shale that immediately overlies the Crazy Hollow formation.
Age and correlation No fossils were found in the Crazy Hollow formation. It is separated from the middle Eocene Green River formation by an erosional disconformity of considerable duration. In turn, the Crazy Hollow beds are immediately overlain by conformable bentonitic shale that contains charophytes which have been estimated by R.E. Peck (personal communication) to be of a late Eocene or Oligocene age. According to these limiting factors the Crazy Hollow is most likely late Eocene in age.

The Crazy Hollow formation probably correlates with the upper part of the Green River or Uinta formations that occur in the Uinta Basin, but such a correlation can not be established without paleontologic control because there is no continuity of upper Eocene exposures between central Utah and the Uinta Basin.

Gray Gulch Formation

Definition. The term "Gray Gulch formation" was provisionally applied by Spieker (1949b, p. 37-38) to the pyroclastic beds above the Crazy Hollow formation and beneath the lavas in the Salina District. Spieker did not designate any type section, but had in mind the section exposed in Gray Gulch in the W½ sec. 32, T. 21 S., R. 1 E. (Spieker, personal communication).

The writer has found from his investigations in the Salina District that the Gray Gulch formation as designated
by Spieker includes strata equivalent to the Bald Knoll formation of Gilliland (1948, p. 87) and parts of the Bullion Canyon volcanics of Callaghan (1939, p. 441) as well as a previously unnamed interval that was mapped as the Gray Gulch (?) formation by Lautenschlager (1952, p. 72).

The following discussion will propose that (1) the term "Gray Gulch formation" be retained; (2) the formation be subdivided to include two members; (3) the Bald Knoll formation be redefined as the lower member of the Gray Gulch formation; (4) the name "Dipping Vat member" be applied to the upper member of the Gray Gulch formation; and (5) the beds equivalent to the Bullion Canyon volcanics be included in the Bullion Canyon series (restricted).

Bald Knoll Member

Definition, lithology, and extent. Gilliland (1951, p. 43) used the term "Bald Knoll formation" to denote a 601 foot thick section of light-colored clay, siltstone, sandstone, and limestone that is typically exposed at the mouth of Bald Knoll Canyon in the Valley Mountains (T. 21 S., R. 1 W.). Lautenschlager (1952, p. 70) reported that subsequent to the original definition, pyroclastic beds were found in the middle and top of the formation at the type locality. The Bald Knoll strata generally are composed of soft fine clastics that are very susceptible
to erosion. The outcrop areas are characteristically of the badland type, have very little grass, and support a relatively sparse juniper cover. The evenly bedded, well-sorted clastics and the silty limestone, along with the included fresh-water fauna, indicate a lacustrine origin for Bald Knoll member.

The northernmost exposure of the Bald Knoll member in the area under investigation is the section of lacustrine bentonitic shale, evenly bedded shale, and siltstone that crops out in Crazy Hollow (T. 22 S., R. 1 E.). The Bald Knoll member can be followed discontinuously south and southwest from Crazy Hollow to the excellent exposures over the drainage basin of Lost Creek.

In the Lost Creek area the Bald Knoll member is predominantly light gray to white shale, some of which is bentonitic, and includes a few distinctive layers of red to red-orange shale. Interbedded are thin (1 to 6 foot) silty limestone and micaceous sandstone beds. The sandstones contain no volcanic glass near the base, but include increasing percentages towards the top; this suggests an increasing volume of clastics of pyroclastic origin during Gray Gulch sedimentation. Charophytes, replaced reeds, air-breathing gastropods, and small growths of algae found in some beds indicate that for at least part of the time the lake was very shallow. None of the fossil-bearing beds
can be traced far laterally, so the conditions were apparently of a local character. There are no beds that would suggest a shore line or indications of subaerial exposure. It is concluded that the area remained covered throughout Bald Knoll time by a fresh-water lake of varying depth.

The complete section of the Bald Knoll member exposed along Lost Creek totals 1042 feet.

**Stratigraphic relations.** The contact between the Bald Knoll member and the underlying Crazy Hollow formation is conformable. The change in lithologies is sharp, with no evidence of either gradation or a long lapse of sedimentation. Spieker (1949b, p. 65), describing exposures in Twist Gulch, secs. 32 and 33, T. 21 S., R. 1 E., suggested a possible angular unconformity between the Crazy Hollow formation and the Gray Gulch formation and that the flexing of the Wasatch monocline may have taken place prior to Gray Gulch sedimentation. In all the areas south of Salina Canyon, the Bald Knoll beds are parallel with those of the Crazy Hollow and, with the Crazy Hollow beds, were bent by the folding of the Wasatch monocline. Thus the date of folding is definitely later than the deposition of the Bald Knoll member.

The contact with the Dipping Vat member of the Gray Gulch formation is likewise conformable and distinct on the
basis of lithology, but not on the basis of color. There is an abrupt change from light gray to white shale to light gray to white coarse tuffaceous sandstone. Both sequences appear to be lacustrine with no break in sedimentation. It is conceivable that this contact may be gradational elsewhere.

Age and correlation. Charophyte oogonia and Planorbid gastropods were collected from a bentonic shale near the base of the member in sec. 8, T. 22 N., R. 1 E. The charophytes were submitted for examination to R.E. Peck who made the following comments (personal communication):

I regret to state that I do not have anything in my collection that compares closely with your material and I have been unable to arrive at a very firm identification from the literature. I believe the gyrogonites belong to genus Chara... Your material compares most closely with specimens from the Aquitanian of France and from the Frio of the Gulf Coast. Unfortunately so little is known concerning the North American Tertiary charophytes that it is difficult to use them stratigraphically. If I were pressed for a date on the material you submitted I would have to call it late Eocene or Oligocene.

The only suggestion of an age for the Bald Knoll beds is the one provided by the charophyte oogonia, and in view of the fact that Peck's very tentative suggestion does not conflict with the dating of any adjacent beds in the local section, it may be accepted as the best estimate now available.
Table 2.-Correlation of Post-Crazy Hollo* Early Tertiary Formations,
Northern por^larysvale Upper Seviex
Salina
Parent
Cedar Hills valley
liver Valley
tion, Fish
District
Mountains
Mountains
Lake Plateai
Gregory
Kerr et al
Spieker
IAPG Guide Schoff,1951 Gilliland Lauten­
schlager,
1919b
1957
19M
1952
Book,1957 Cooper,1956
ulnta
Basin

1952
Plova in these areas are
believed younger
Duchesne
River
fi.

Bullion
Canyon
series
(restricted)

Moroni
fa.

Bullion
Canyon
aeries

Gray
igneous
congloaerate
member

-o
Ul
Pyroclastic
Gray Gulch
(?)
fm.

Dipping

Gulch
member

Green
River
fa.

Knoll
fa.

Hollow

Crazy
Hollow
fa.

Knoll
member

Hollow

Crazy
Hollow
fm.

Z

Table 2

Hollow

Bala
Knoll
fa.

white
member


Plate 9.

Figure 1. Bald Knoll Member East of Lost Creek

Looking north-northwest from northwest corner sec. 7, T. 23 S., R. 1 E. at fault zone east of Lost Creek.

Figure 2. Dipping Vat Member in Dipping Vat Canyon

Evenly bedded coarse tuffaceous sandstone exposed near mouth of Dipping Vat Creek. Boy is $3\frac{1}{2}$ feet tall.
Table 2 illustrates the relations between the different lithologic units that crop out here and in surrounding areas. Because of (1) the presence of similar lithologies in the Bald Knoll formation and the basal member of the Gray Gulch formation and (2) the priority of the term "Gray Gulch formation" over "Bald Knoll formation" (in published form), it is here proposed that the term "Gray Gulch" be retained for the formation and that the term "Bald Knoll formation" be changed to "Bald Knoll member of the Gray Gulch formation."

Dipping Vat Member

**Definition, lithology, and extent.** The term "Dipping Vat member of the Gray Gulch formation" is here proposed for the light gray to white coarse tuffaceous sandstone which rests conformably on, and possibly is gradational with, beds of the Bald Knoll member of the Gray Gulch formation and is overlain disconformably by the Bullion Canyon series. The type measured section for this unit is at an outcrop west of Lost Creek in secs. 1, 11 and 12, T. 23 S., R. 1 W., where the member is 208 feet thick. The name, "Dipping Vat member," was selected because of the excellent exposures of this unit in the canyon of Dipping Vat Creek just above the confluence with Little Lost Creek, in sec. 30, T. 23 S., R. 1 E. (See Pl. 9, Fig. 2).
The Dipping Vat member includes evenly bedded tuffaceous sandstone that contains varying amounts of glass and other pyroclastic fragments and some interbedded white clay and silty limestone. The Dipping Vat member is somewhat more resistant than the underlying Bald Knoll member so that it tends to form cliff-walled canyons rather than the badland topography typically developed in Bald Knoll exposures.

The increased coarseness of the clastics plus the increased percentage of volcanic glass in the Dipping Vat member indicate one or more of the following: (1) nearer source for pyroclastics (would result in more glass and coarser clastics); (2) increased volcanic activity at source (more glass, possibly an increase of coarse clastics); (3) increase competence of the medium transporting clastics into lake (uplift or climatic change, either would explain coarser deposits); or (4) shallower conditions (coarser deposits would be beach sand). Since the lake apparently was fairly shallow throughout its history, and there is no increase in fragments derived from older beds, the latter two explanations are less probable. The general change is probably due to one or both of the first two reasons. The direction or distance to the source has not been ascertained from the outcrop evidence.
The Dipping Vat member is exposed in the northern portion of the Fish Lake Plateau along Lost Creek on either side of the valley, in the fault block exposures in sec. 21, T. 23 S., R. 1 W., and near Farnsworth Reservoir in secs. 27 and 34, T. 23 S., R. 2 E. The writer found rocks with lithologies like those of the Dipping Vat member along Utah highway number 72 in a slide that covers a fault zone in sec. 33, T. 25 S., R. 4 E., but the rocks could not be traced to any bedrock exposures.

**Stratigraphic relations.** The lower contact of the Dipping Vat member is sharp and conformable.

The Dipping Vat member is set off sharply from the overlying mudflows and conglomeratic sandstone of the Bullion Canyon series (restricted) by an erosional disconformity of considerable relief. There is likewise an abrupt color change from the light gray of the Dipping Vat member to the medium gray of the Bullion Canyon series (restricted) and a change from the evenly bedded lacustrine sediments to unevenly bedded fluvial sandstones and unbedded mudflows. The beds above and below the contact are essentially parallel. Where the Bullion Canyon series (restricted) beds have been eroded and the Dipping Vat member is overlain by lava flows, the relationship is angular.
**Age and correlation.** The gastropods of the family Lymnaeidae and genus *Gyraulus*, the ostracode *Heterocypris* ? sp., and poorly preserved charophyte oogonia were collected from a silty limestone in the Dipping Vat member in secs. 27 and 34, T. 23 S., R. 2 E. Swain believes the ostracodes may indicate a correlation with the uppermost Green River or Uinta formations of the Uinta Basin ("Upper Heterocypris zone?").

The Dipping Vat member is correlated with the Gray Gulch (?) formation of the Pavant Mountains (Lautenschlager, 1952, p. 72), tentatively correlated with the lower part of the pyroclastic section in the Redmond Hills (Gilliland, 1951, p. 47-50), and is believed to correlate with part of the white member of the Brian Head formation south of the volcanic cover (Gregory, 1944, p. 591-597). The relation to the Moroni formation of the Cedar Hills is not known.

The only other complete section of Eocene and possibly Oligocene deposits in Utah is in the Uinta Basin. Stratigraphically it appears that the Gray Gulch formation may be equivalent to the uppermost Green River or Uinta formations that are of late Eocene age (Kay, 1957, p. 112).

The fresh water sediments of the Bald Knoll and Dipping Vat members of the Gray Gulch formation represent the last known deposits of the early Tertiary lakes that covered parts of central Utah. Only during the post-Green River, pre-Crazy Hollow hiatus and during the deposition of
the Crazy Hollow sediments was there any considerable change from lacustrine conditions in the northern portion of the Fish Lake Plateau. The completeness of the early Tertiary section in this area - total thickness of the Flagstaff through Gray Gulch section is more than 4150 feet - suggests that early Tertiary history of central Utah, through the Eocene, will be more completely known if sufficient paleontologic control can be obtained.

The extent of the lake in which the Gray Gulch beds were deposited may have been more limited than that of the Flagstaff-Green River lake. This point can not be debated as the section equivalent to the Gray Gulch is not preserved elsewhere in Utah beyond the exposures in Sanpete and Sevier counties and south in Garfield and Iron counties.

Bullion Canyon Series

Definition and regional distribution. Callaghan (1939, p. 441-442) used the term "Bullion Canyon volcanics" in the Marysvale region for a series of widely exposed "Early Tertiary" tuffs, volcanic breccias, and latite flows that are intruded by a quartz monzonite and a latite. The type section is in Bullion Canyon on the east side of the Tushar Mountains. The proportion of flows to pyroclastics varies greatly, as does the type of rock. The total thickness in the Marysvale region is over 5,000 feet (Callaghan, p. 441).
In the type area the Bullion Canyon volcanics overlie pre-Cretaceous sedimentary rocks and are overlain, following an erosion interval, by the Roger Park volcanic breccia or the Mount Belknap rhyolite.

In a recent study of the Marysvale Canyon region by Kerr et al. (1957) the term "Bullion Canyon series" is used for a series of 12 members with a total thickness of 3,170 to 4,000 feet.

The term "Bullion Canyon series" is also used by the writer but with some reservation because of the inherent ambiguities. The following is from the American Commission on Stratigraphic Nomenclature, Report 4 (1956, p. 2006)

Although the term "series" has been applied, in a group sense, to rocks resulting from a succession of extensive eruptions or intrusions, along with an adjective term like "eruptive", "intrusive", or "volcanic", indicative of the origin of the group, it is desirable in formal nomenclature to restrict the term "series" to its time-stratigraphic meaning.

The writer is nevertheless retaining the usage of series in a group sense for these reasons: (1) it has already been used in the region; (2) the rocks designated are believed to be equivalent to those of the type area; (3) the sequence in the northern portion of the Fish Lake Plateau includes two thick members, a lower sedimentary unit and an upper succession of lava flows; and (4) not enough is known about this section to justify the introduction of new stratigraphic terms. When more is known
the redesignation of these rocks as formations or groups may be necessary.

The Tertiary volcanic sequence in the Marysvale area is as follows (Kerr et al., 1957, Pl. 12 and p. 14-36, from top):

Basalt
Joe Lott tuff
Mount Belknap series (mainly west of Sevier River)
Gray rhyolite phase (flow)
Ardosic sandstone
Red rhyolite phase (flows and tuffs)
Gray rhyolite porphyry phase
Glass
Dry Hollow series
Latite and quartz latite, 400-750', reddish brown
Post-intrusive conglomerate (local only)
Unconformity
Intrusive series
Granite, quartz monzonite and monzonite
Bullion Canyon series
Crystal tuff, 150', flow texture, welded
Pyroxene andesite (2), 200-1,000, reddish brown to greenish gray
Gray latite porphyry, 350'
Tuff (2), 30-400', bedded, white to buff, with reddish brown beds, vesicular, contains quartz, andesine, sanidine, glass, and rock fragments, partly water laid
Pyroxene andesite (1), less than 450', same description as (2)
Tuff (1), less than 800', same description as (2)
Biotite latite porphyry, 10-1,000'
Hornblende andesite, less than 20', reddish brown
Rock Candy latite, 50-500', red-brown, mottled with green
Rock Candy agglomerate, 660', light green and red latite in a purple latite groundmass
Green-brown latite, less than 50'
Green latite porphyry, 1,000-', green to purple with white phenocrysts, agglomeratic in part
Unconformity
Sedimentary rocks
Rocks correlatable with the Bullion Canyon series and the youngest of the sequence, the basalt, occur in the northern portion of the Fish Lake Plateau.

The Bullion Canyon series has been traced to the north and south from Marysvale over a wide area of central Utah. Lautenschlager (1952, p. 86) mapped andesite flows in the southern portion of the Pavant Mountains that appear to correlate with the pyroxene andesite flows of Kerr. Callaghan (1939, p. 443) made the following observations on the Bullion Canyon series in the Sevier Plateau:

In the Sevier Plateau east of the Sevier fault, the earlier Tertiary rocks consist of a thick series of latitic breccias and thin flows at the base, a succession of latite-flows with almost no intervening volcanic breccia, and more calcic latite at the top. No exact correlation between the members in the Tushar Mountains and those in the Sevier Plateau is possible. Probably the lower breccias correspond to the lower part in the Tushar Mountains, and the remainder correspond to the upper part; the base is not exposed. The total thickness is over 5,000 feet.

The same section appears to continue north through the Monroe amphitheater area of the Sevier Plateau into the northern portion of the Fish Lake Plateau. North of the Monroe district the Bullion Canyon series consists of a thick basal member of conglomeratic tuffaceous sandstone and mudflows and an equally thick upper member of gray to brown to reddish brown lava flows. Because these two members in the northern portion of the Fish Lake Plateau are easily differentiated and are almost everywhere
separated by a disconformity or angular unconformity, the sedimentary section has been mapped as the "Bullion Canyon series (restricted)" and the extrusive rocks have been mapped as the "Bullion Canyon series, lava flows."

Bullion Canyon Series (Restricted)

Definition, lithology, and extent. The term "Bullion Canyon series (restricted)" is here used for the sequence of mudflows, conglomeratic tuffaceous sandstone and tuff that disconformably overlies the Gray Gulch formation in the Lost Creek and Peterson Creek drainage basins. The exposures of the Bullion Canyon series (restricted) for the most part are continuous.

The Bullion Canyon series (restricted) section that crops out along Lost Creek and Little Lost Creek is divisible into three distinct units. The basal unit in northern exposures is a conglomerate containing pebbles and cobbles of lava, tuffs, and older sedimentary units. The correlative basal unit in southern regions is composed of mudflows that fill valleys cut into the underlying Dipping Vat member of the Gray Gulch formation (Pl. 10, Fig. 1). The boulders and cobbles of the mudflows are angular to subrounded and consist of fresh gray igneous rock and weathered indurated red tuff. The phenocrysts indicate that the igneous rocks are probably latites and
Plate 10.

Figure 1. Gray Gulch - Bullion Canyon Series (Restricted) Contact along Little Lost Creek

Note channeling in top of Dipping Vat member prior to mudflow deposition. Location: sec. 30, T. 23 S., R. 1 E.

Figure 2. Channel-Filling Mudflow Deposit near Base of Bullion Canyon Series (Restricted)

Location: sec. 30, T. 23 S., R. 1 E.
Plate 11.

**Figure 1. Tilted Conglomeratic Sandstone of Bullion Canyon Series (Restricted)**

Exposure in Little Lost Creek Canyon (sec. 31, T. 23 S., R. 1 E.) Dip is 46° to northeast. Note rounded cobbles, channeling and cross-bedding.

**Figure 2. Vertical Beds of the Bullion Canyon Series (Restricted) in Little Lost Creek Canyon**

Looking east at beds of middle unit of Bullion Canyon series (restricted) that have been folded, truncated, and then overlain by beds of the same lithology. Dark beds at skyline are mudflow deposits of upper unit. Location: sec. 31, T. 23 S., R. 1 E.
andesites. The matrix of either the conglomerates or the mudflows is coarse tuffaceous sand that contains relatively little glass, as compared with the underlying Dipping Vat member or the overlying unit. The measured thickness of the basal unit along Little Lost Creek, 130 feet, appears to be representative.

The middle unit of the Bullion Canyon series (restricted) is a sequence, more than 1690 feet thick, of irregularly interbedded coarse conglomeratic tuffaceous sandstone and tuff (Pl. 11). The pebbles and cobbles are well rounded and are of intermediate igneous rocks that appear, from hand sample examinations, to be mainly andesite porphyry with lesser quantities of hornblende andesite porphyry, dacite (?) porphyry, and weathered indurated gray tuff. The lavas are relatively fresh. This middle unit is notable for the spectacular angular unconformities that are found within it in secs. 22 and 23, T. 23 S., R. 1 W., and sec. 31, T. 23 S., R. 1 E. In both of these areas, the beds of the middle unit only are complexly folded and faulted within fault-bounded areas, and were truncated by erosion so that the overlying beds of the middle unit were deposited on a nearly flat surface. The only marker bed in the entire Bullion Canyon series (restricted) is a distinctive biotite-hornblende crystal tuff that crops out near, or at, the top of the middle unit. Because of its
importance as a stratigraphic and structural marker, the biotite-hornblende tuff is described under a separate heading below.

The upper unit of the Bullion Canyon series (restricted) is composed mainly of mudflows with some intercalated conglomeratic tuffaceous sandstone near the base (Pl. 12, Fig. 1). The upper unit is only locally preserved in the southern part of the area as elsewhere it either was not deposited or was removed by subsequent erosion. The contact of the upper unit with the overlying lava is nowhere exposed because of talus cover. The sandstone and the matrix of the mudflows are of approximately the same composition. The sandstone contains almost no glass fragments; it is mostly fragments of plagioclase with small amounts of quartz, biotite, and other minerals. The lava fragments in the mudflows, where sampled, are angular and composed of reddish gray to light medium gray aphanitic lavas that contain scattered small phenocrysts of plagioclase and amphibole. The upper unit is 690 feet thick along Little Lost Creek.

The almost complete absence of lapilli or bombs in either the mudflow or fluvial deposits is notable. The only deposit of scoriaceous material found was a lens about 15 feet thick and 150 feet long exposed high on the east wall of Little Lost Creek Canyon in the center, W1/2 sec. 6, T. 24 S., R. 1 E.
Plate 12.

Figure 1. Bullion Canyon Series (Restricted) Mudflow Deposits

Mudflows of upper part of Bullion Canyon series (restricted) in Little Lost Creek Canyon. Note irregularly intercalated sandstones. Location: sec. 7, T. 24 S., R. 1 W.

Figure 2. Closeup of Mudflow Deposit in Bullion Canyon Series (Restricted)
The thickest exposed section of the Bullion Canyon series (restricted) is that of about 2500 feet measured along Little Lost Creek. Northward the formation thins to a few hundred feet along Lost Creek and eastward it is lost under the lavas. The thinning is mainly the result of erosional truncation prior to the extrusion of the overlying lava, but may also reflect conditions of deposition since the source was to the south.

Biotite-hornblende tuff. A distinctive crystal tuff is found in some of the Bullion Canyon series (restricted) sections at or near the top of the middle unit. The tuff is easily recognized by its grayish pink color and the prominence of biotite and hornblende fragments. Mackin (1957 and 1958, personal communication) describes this tuff as an ignimbrite, whose source was probably just south of Clear Creek Canyon in the northern part of the Tushar Mountains (30 miles southwest of Lost Creek). The ignimbrite is over 1,000 feet thick in Clear Creek Canyon. As indicated by the outcrops of this tuff in Tps. 22 and 23 S., R. 1 W. (see Pl. 1), this member has an irregular distribution in the mapped area, apparently for two reasons: (1) this area is near the edge of the nüe ardente sheet and (2) erosion following deposition removed an unknown amount of material. In this area the tuff is thickest in sec. 24, T. 23 S., R. 1 W., where it is 145 feet.
Mackin (1958, personal communication) says the following about current interpretations of the significance and distribution of the biotite-hornblende tuff:

In a paper now nearly completed the biotite-hornblende tuff is called the Needles formation, with the type locally on the east side of the Needles Range in southwestern Utah. There are three members, each a separate ignimbrite. In some places these are separated by lava flows or volcanic sediments, and in some places one or another of the units is missing. All are crystal tuffs, with 15-35 percent crystals, of which 60-70 percent is plagioclase; 20-35 percent biotite and hornblende; 5 to 15 percent quartz; 0-5 percent potash feldspar. The Needles formation rests of the Claron formation (Pink Cliffs-Wasatch) or on older volcanics of local origin - or in western Utah on Paleozoic or Mesozoic rocks. It is commonly overlain by what I call the Isom formation, which consists chiefly of porphyry of the Dry Hollow type.

The family resemblance between the members of the Needles formation is strong, and I'm not sure which of the members is in your area...the Needles formation is definitely equal in part to the Bullion Canyon, and the Isom is equivalent in part of the Dry Hollow latite.

The biotite-hornblende tuff in the northern portion of the Fish Lake Plateau is characterized by a grayish pink color, conspicuous biotite and hornblende grains, and a strong subparallel orientation of platy and elongate mineral grains (Pl. 13). Generally the biotite-hornblende tuff is well indurated and either caps ridges or is a prominent ledge-former, but the basal part of the tuff may be friable and non-resistant. Section No. 1 of the Appendix contains a detailed description of the lithologies. An erosional disconformity near the middle of the tuff in most
Photomicrograph of Biotite-Hornblende Tuff

Plane-polarized light. Typical crystal tuff development of upper part of biotite-hornblende tuff of Bullion Canyon series (restricted). a-andesine; b-biotite; h-hornblende; q-quartz
exposures indicates at least two periods of deposition separated by a hiatus.

Stratigraphic relations. The Bullion Canyon series (restricted) overlies the Gray Gulch formation with disconformity. There is an abrupt change in lithology from the lacustrine light gray tuffaceous sandstone of the Dipping Vat member, to the gray conglomeratic sandstone or dark gray mudflows of the basal unit of the Bullion Canyon series (restricted). The duration of the time break represented by the erosional disconformity is not known, but it is believed to be slight because the thickness of the Dipping Vat member appears constant. The writer's interpretation is that the Gray Gulch lake was drained, or at least withdrew from this area and that the first mudflows and fluvial conglomeratic sandstone of the Bullion Canyon series (restricted) were deposited shortly after the establishment of fluvial conditions.

The Bullion Canyon series (restricted) is preserved only in the western portion of the area and generally is above a complete section of Gray Gulch. The only exception to the latter statement is found in the thin sections of Bullion Canyon series (restricted) that unconformably overlie the Arapien shale in the western part of the area mapped. These relations can be seen along either Peterson Creek or Lost Creek. The angular unconformity between the
Bullion Canyon series (restricted) and the Arapien shales is like that exposed in Salina Canyon where North Horn, Flagstaff, and Colton beds, respectively, transgress from east to west onto a topographic high.

The Bullion Canyon series (restricted) of the northern portion of the Fish Lake Plateau area represents the last sediments of a period of deposition that was continuous, except for just a few hiatuses, from Late Triassic to early Tertiary and possibly middle Tertiary time. The sedimentary succession was terminated at some time following the deposition of the Bullion Canyon series (restricted) by regional uplift that was accompanied by monoclinal folding (Wasatch and Gates Creek monoclines, especially) and some faulting. The uplift apparently was greater in areas to the east than in the eastern Sevier Valley area. This is evinced by the preservation of Bullion Canyon series (restricted) only in areas that were structurally low following the uplift, and, as mentioned above, Bullion Canyon series (restricted) sediments overlie the Arapien shales of the eastern Sevier Valley area.

The erosion that accompanied and followed the uplift removed considerable thickness of rock from the structurally higher areas and lesser amounts from the structurally low areas. The duration of this erosion interval between the deposition of the Bullion Canyon series (restricted) and the
extrusion of the overlying lavas was apparently long because the lavas lie with angular unconformity over all units from the middle unit of the Bullion Canyon series (restricted) down to the North Horn formation. In the structurally low areas along Little Lost Creek the lavas appear to conformably overlie the mudflows of the upper unit of the Bullion Canyon series (restricted).

**Origin and correlation.** Certain aspects of the origin of the Bullion Canyon series (restricted) have been mentioned in the above discussion. These include (1) the restricted area of exposure; (2) the development above complete sections of Gray Gulch; (3) change from lacustrine conditions of Gray Gulch sedimentation to fluvial conditions during the deposition of Bullion Canyon series (restricted); (4) composition of mudflows, tuff, tuffaceous sandstone and igneous rock conglomerate; and (5) southward increase in thickness and frequency of mudflows in the lower and upper units and general southward increase in thickness for the whole series.

The origin of the biotite-hornblende tuff as an ignimbrite whose source was in the northern portion of the Tushar Mountains has been fairly well established by Mackin (personal communication).

The location of the topographic high off which the mudflows originated was probably 3 to 24 miles south, in
the Sevier Plateau area. Recent mudflows from volcanoes to
distances of over 23 km (Mason and Foster, 1956, p. 74) and
20 miles (Crandell and Waldron, 1956, p. 349) have been
reported. The individual mudflows of the lower unit are
comparatively small (see Pl. 10), indicating a not-too­
distant source. Those of the upper unit are mainly sheet­
like masses that could have traveled over long distances.

That the fluvial deposits and tuffs of the middle
unit came primarily from extrusive vents and volcanoes in
the general area to the south is indicated by correlation
of equivalent units to the south of the volcanic cover.

Dutton (1880, p. 39, 69-79, 178, 214, 233-238, 275,
295) paid particular attention to the igneous rock con­
glomerate section that underlies the lava flows. He makes
the following general statement concerning their signifi­
cance and distribution (p. 69-70):

...some of the most interesting lithological prob­
lems presented by the volcanic products of the
high plateaus are those relating to the origin
and development of what may be termed the clastic
igneous rocks, or rocks apparently composed of
fragmental materials of igneous or volcanic
origin, but now stratified either as so-called
tufaceous deposits or as conglomerates...They
cover nearly 2,000 square miles of area, and their
thickness ranges from a few hundred feet to nearly
2,500 feet, the average being probably more than
1,200 feet. Lavas are frequently intercalated,
but much more frequently no intercalary lavas are
seen, and in general, they seldom form any large
proportion of the entire bulk when they occur in
conjunction with the clastic masses. The grander
displays of these fragmental accumulations are
seen in the central and southern portions of the
district, though a few important ones are found in the northern part of the field. The great western wall of the Awapa, the central and southern mass of the Sevier Plateau, the southern Tushar and northern Markagunt, are composed chiefly of such formations. The grand escarpments which wall the imposing fronts of these plateaus are conglomerates, sometimes capped with lava, sometimes intercalated, and more frequently without them. Near the center of Grass Valley we have, on the east, bounding the western verge of the Awapa, a wall of conglomerate which is more than 2,500 feet thick; and directly opposite, to the west, forming the eastern front of the Sevier Plateau, is an exposure of very nearly equal magnitude, both stretching southward for 25 miles without interruption...diminishing in thickness. From a point a few miles southeast of Marysvale the western front of the Sevier Plateau exhibits a wall of similar nature, extending south a distance of more than 40 miles to the terminus of the plateau, with only two brief interruptions...The East Fork Canon is cut transversely through the narrowest part of the Sevier Plateau, and exhibits on either side a series of terraces rising 3,500 to 4,000 feet above the bed of the stream. The lower 600 to 800 feet consist of tufaceous sandstones, and above them are more than 2,500 feet of coarse conglomerate, with a few massive sheets of intercalary lava...

Dutton reports the conglomerate to be absent eastward in the Awapa Plateau (p. 275) and to the southwest near Panguitch Lake (p. 199).

Gregory (1944 and 1945) includes the conglomerates of the southern part of the High Plateaus as the upper member of the Brian Head formation. Neither he nor Dutton reports any mudflow deposits. Dutton (1880, p. 233-235) located three very old centers of eruption in the northern, central and southern parts of the Sevier Plateau, away from which the conglomeratic masses appear to attenuate. Dutton
Table 3.—Correlation of Post-Gray Gulch Middle Tertiary Deposits

<table>
<thead>
<tr>
<th>Proterozoic (this paper)</th>
<th>Upper Sevier River Valley</th>
<th>Marysvale Area</th>
<th>Northern Portion, Fish Lake Plateau</th>
<th>Pavant Mountains</th>
<th>Ceder Hills</th>
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</thead>
<tbody>
<tr>
<td>Miocene</td>
<td></td>
<td></td>
<td>Mt. Belknap series</td>
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<td>Schoff, 1951</td>
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<td>Dry Hollow Latite ser.</td>
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<td>Cooper, 1956</td>
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<tr>
<td>Oligocene</td>
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<td>Bullion Canyon series</td>
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<td>Bullion Canyon series, lava flows</td>
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<td></td>
<td>Bullion Canyon series (restricted)</td>
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<tr>
<td></td>
<td>Gray igneous conglomerate member</td>
<td>Brian Head</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eocene</td>
<td>White member</td>
<td></td>
<td>Dipping Vat Creek member</td>
<td>Gray Gulch (? fms.</td>
<td></td>
</tr>
</tbody>
</table>

103
repeatedly mentions that near these centers the conglomerates are commonly intercalated with sheets of trachytic lava.

The biotite-hornblende tuff that is a prominent marker bed to the north also is present in the conglomerate section on Mount Dutton of the southern part of the Sevier Plateau (Mackin, 1957, personal communication).

The above information gives a generalized picture of a probable correlation of the Bullion Canyon series (restricted) clastics with the tuffaceous sandstone and conglomerate south of the volcanic cover. A more exact correlation will have to await a petrographic study of the succession of eruptions in the High Plateaus.

Igneous rock conglomerates at the top of the Tertiary sedimentary sequence have been reported elsewhere in central Utah. At Long Ridge, near Nephi, Utah, Muessig (1951, p. 89-108) applied the name "Golden's Ranch formation" to a succession of volcanic conglomerate, tuff, and sandstone with three intercalated aphanitic andesite flows. There is also one interbedded limestone (Sage Valley limestone member) that appears at varying stratigraphic positions above the top of the Green River formation. The Golden's Ranch lithologies interfinger with upper Green River limestone. This interfingering plus the fact that the Sage Valley limestone member contains a middle Eocene flora,
indicates a middle Eocene age for most of the Golden's Ranch formation. The igneous activity in the Long Ridge area, therefore, is earlier and unrelated to the Bullion Canyon series.

Schoff (1937 and 1951) and Cooper (1956) have described the Moroni formation of the Cedar Hills as a sequence of pyroclastics, water-laid sandstone, shales, and volcanic conglomerate in the lower part and a sequence of ignimbrites in the upper part. The Moroni formation like the Bullion Canyon series (restricted) is at the top of the Tertiary sedimentary section. The Moroni formation disconformably overlies the Crazy Hollow formation (Cooper, 1956, p. 18). The source and the age of the Moroni pyroclastics and conglomerate are not known. It may be wholly or partly contemporaneous with the Bullion Canyon series (restricted), but undoubtedly had a different source.

Age. No fossils have been reported from the Bullion Canyon series (restricted) or equivalent sections to the south. The Brian Head formation has been tentatively assigned by Gregory (1945, p. 110) to the Miocene, but he found the assignment far from satisfactory. His only control is the stratigraphic position above Eocene beds and below lavas that underlie the Sevier River formation, which is Pliocene (?). For the time being, an early middle Tertiary
age designation for the Bullion Canyon series (restricted) most clearly states what is known.

**Tertiary and Quaternary Systems**

**Pediment Gravels**

Pediments are prominent in the central and eastern part of the area, especially in the Last Chance Creek drainage area. They are cut at various levels in sedimentary beds of Late Cretaceous and early Tertiary age. The inclination of the pediment surfaces ranges from 4° to 10°. No continuous surface can be followed for more than a few miles because of the faulting that took place during and following the erosion of the pediments.

Most of the pediments are covered by a veneer of gravel that is locally partly consolidated. The gravels contain angular boulders of lava in a matrix of rounded sedimentary-derived pebbles that are less than 4 inches in diameter. The thickness of the gravel cover generally is 10 to 20 feet, but may be more locally.

The formation of the pediment surfaces probably began after the middle Tertiary extrusions of lava and prior to the major faulting; it has continued to the present. The pediment gravel deposits between Yogo and Niotche creeks in the west half of T. 23 S., R. 3 E., are on a perched pediment surface west of the Musinia fault zone and indicate a
pre-faulting origin for that pediment surface. Pediments in the south half of T. 24 S., R. 4 E. are developed across older fault zones, and the associated pediment gravels have been displaced by recent minor faulting. The most extensive pediment development apparently was during the middle or late Tertiary, prior to the deposition of the valley-filling gravel deposits that are discussed below.

The area covered by pediment gravels is being reduced by headward stream erosion or valley widening as the result of slide movement.

**Gravel Deposits**

Most of the gravel deposits indicated as "QTg" on Plate 1 are isolated remnants of previously more extensive valley fill deposits. A few of the areas at high elevations that are included under this designation, especially where bedrock is not exposed as in the Sheep Valley area, may actually be thick gravel covers over faulted pediment surfaces that could not be differentiated. Most of the gravel deposits are at lower elevations in valleys that postdate the major pedimentation.

The lithology of the gravel deposits varies according to the area drained. Generally the deposits contain rounded boulders of lava, sandstone, and limestone in a matrix of chert and quartzite pebbles and coarse sand. Matched terraces of gravel on either side of a valley are
found only in one area; in sec. 36, T. 23 S., R. 1 E.,
along Lost Creek. In all other areas erosion has since
removed most of the gravel and left only isolated remnants.

The gravel deposits that occupy a former shallow
valley just north of Yogo Creek in sec. 3, T. 23 S.,
R. 3 E., have clearly been truncated on the west by a fault.
This is the only place where post-gravel faulting can be
demonstrated.

The gravel deposition postdates pediment cutting and
is believed to predate glaciation. Some of these gravels
may represent units that are correlatable with the late
Pliocene or early Pleistocene Axtell gravels of the Gunnison
quadrangle and Pavant Mountains (Gilliland, 1948, p. 11;
Spieker, 1949b, p. 38; and Lautenschlager, 1952, p. 76-82),
but lacking paleontologic control, the gravel deposits can
only be dated as post-lava and pre-Quaternary alluvium.

Quaternary System

Glacial Deposits

Distribution and lithologies. Glacial deposits are limited
to certain stream valleys at altitudes generally above 9,000
feet. Generally the valleys that have been glaciated are on
the north or east side of highlands and are headed by
imperfectly developed cirques. The zone of accumulation and
ablation was usually on the flanks of lava-covered
mountains and as a result, the till is made up of the waste products of lavas and includes angular to subangular blocks of lava up to two feet or more in diameter. The till in the left fork of UM Creek moraines also contains limestone blocks derived from the Flagstaff formation, which crops out along one side of the valley.

Ground and end moraines of two glaciations are readily distinguished in the field or on photographs. The older moraines stratigraphically underlie and usually are more extensive than the younger in that they are wider and extend to lower elevations. The surfaces of the older moraines have considerably less relief than the younger, are characterized by smooth hummocks, are better drained and are devoid of ponds. Where the older moraines have been breached, as in sec. 21, T. 24 S., R. 2 E., a relatively broad channel has formed (Pl. 14, Fig. 1). Channels through the younger moraines, as in secs. 32 and 33, T. 24 S., R. 3 E., are deep and youthful (Pl. 14, Fig. 2). The weathering rims on the included coarse-grained flow rocks are likewise distinctive between the two moraines (Hardy and Muessig, 1952, p. 1113). If a still older glaciation took place in this area, it has not been recognized. No clearly defined recessional moraines have been found for either glaciation. No outwash gravels have been found down stream from the moraines.
Plate 14.

Figure 1. Stereopair Showing Deposits of Earlier Glaciation

Lost Creek reservoir was formed by damming the stream that breaches the terminal moraine.

Figure 2. Stereopair Showing Deposits of the Later Glaciation

Terminal deposits of glacier that occupied the valley of the left fork of UM Creek.
Age and correlation. The conditions observed indicated to Hardy and Muessig (1952, p. 1113) that the time between glaciations was relatively slight. The writer on the other hand, has been impressed by the fact that the time between glaciations appears to have been considerably longer than the time since the last glaciation. The duality of the glaciations corresponds very closely to the two distinct glaciations discovered by Atwood (1909, p. 92) in both the Uinta and Wasatch Mountains. The earlier glacial moraines, while subdued and weathered, according to Hardy and Muessig do not have the aspects that would be associated with a glacial deposit as old as Illinoian. Conversely, because of the considerable separation in time of the two glaciations and the lack of knowledge on the rates of erosion at these high altitudes, an attempt at long range correlation with glaciation elsewhere in the Cordillera is hazardous at best. Table 4 is an attempt to show where the two glaciations of the Fish Lake Plateau appear to belong in the general Pleistocene stratigraphy as currently interpreted in the Wasatch Mountains - Lake Bonneville area, based on the relative amounts of dissection of the moraines in both areas. This table likewise illustrates the confusion that still exists in the attempts to correlate this region with the standard section of the Mississippi Valley region. Because of this confusion, age assignments have not been made on the table for pre-Farmdale events.
<table>
<thead>
<tr>
<th>Time control</th>
<th>Lake Bonneville</th>
<th>Little Cottonwood Canyon, Wasatch Mtns.</th>
<th>Wasatch Mtns.</th>
<th>Northern portion, Fish Lake Plateau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horberg 1955</td>
<td>Borberg 1955</td>
<td>Eardley et al. 1957</td>
<td>Ives 1950</td>
<td>Atwood 1909 (Ives' correlations)</td>
</tr>
<tr>
<td></td>
<td>Borberg 1955</td>
<td>Eardley et al. 1957</td>
<td>Ives 1950</td>
<td>Atwood 1909 (Ives' correlations)</td>
</tr>
</tbody>
</table>

**Table 4.-Late Pleistocene Correlations**

- **Great Salt Lake**
  - Gilbert stage
  - Stansbury stage
  - Provo stage
  - Bonneville stage

- **Alluvial cover**
  - Little Cottonwood "A" moraine
  - Protalus ramparts

- **Later Glacial epoch**
  - Interglacial epoch
  - Erosion

- **White marls of early Bonneville stage**
  - Bell Canyon old moraine series
  - Earlier Glacial epoch

- **Graniteville erratics**
  - Bonneville yellow clay (pre-Bonneville shoreline)

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Slide Deposits

Classification, location, and lithologies involved. The slide deposits indicated on Plate 1 by the designation "Qs" are the result of these types of mass movement, following the classification proposed by Sharpe (1938, p. 96):

1. Slump
2. Earth-flow
3. Rock slide
4. Rock glacier

Slopes which show soil creep are not included.

Slides of varying size are present on almost all slopes of more than 500 feet per mile. The slides have considerably modified both slopes and valleys. By far the more common type of mass movement begins with slump at higher elevations and grades downslope into earth-flow. The landscapes produced are hummocky, usually becoming less irregular toward the terminal portions. Ponds are developed where the slump blocks have undergone a toreva-block rotation. Sheep men have enlarged some of these ponds (such as Farnsworth Reservoir, sec. 27, T. 23 S., R. 2 E.) by damming the spill point.

The slides may begin at, or at some distance below, the top of steep slopes (Pl. 15). The headward origin may be a rounded surface or a near-vertical cliff. Slides are found at elevations of from 5,400 to over 11,000 feet, but
the larger slides are at elevations of over 8,000 feet.
The size of individual slides ranges from a minimum of a few acres to a slope with an area of over 13 square miles (8,320+ acres), such as the westward sloping slide area in the northwestern part of T. 32 S., R. 2 E.

The bedrock on which the slides take place includes practically all units of the stratigraphic section, but the areas underlain by the North Horn formation or other formations containing high percentages of shale are the more favorable. Likewise the type of material involved in, and deposited by, the slides ranges from soil, sand, and shale to limestone and lava talus, depending on the underlying bedrock units.

Rock slides of talus are found at the head of slides that begin at lava cliffs. These cliffs are at elevations greater than 10,000 feet, where frost weathering processes provide the debris. Small protalus ramparts are commonly seen near the base of the cliffs. On steeper slopes, some of the rock slides become rock glaciers.

Age. All rockslide areas, but only limited areas of landslide, are active at the present time. Sheepherders camped near rockslides report occasional rumblings that indicate movement. The slope shown on Plate 15, Figure 1, on the east side of Niotche Creek valley in secs. 35 and 36, T. 23 S., R. 2 E., is covered by an active landslide.
Plate 15.

Figure 1. Stereopair Showing Slides East and West of Niotche Creek

Figure 2. Slide on Slope West of Gates Lake

Looking north-northwest along Gates Creek monocline from S\(\frac{1}{4}\) sec. 33, T. 23 S., R. 2 E. Ktn - North Horn; Tg - Green River; Tch - Crazy Hollow.
The westward movement of this slide has caused the constriction of the Niotche valley and the undercutting of the west slope. Sheepherder trails across this slide are slightly displaced from one summer to the next.

None of the slides appears to be older than late Pleistocene. The main slide activity was probably the result of increased precipitation during late Pleistocene time. Most of the glaciated areas are modified by post-glacial slides, especially by rock slides in the cirques.

**Causes.** The lithologic and topographic conditions in this area that favor development of slides include (1) thick argillaceous sections and (2) slopes of more than 500 feet per mile. When tied with the canyon cutting that preceded Quaternary alluviation, it is apparent that the topography was more rugged and had greater relief prior to sliding.

The initiating causes include both the changes of climate during the Pleistocene and the recurring earthquakes. The two late Pleistocene periods of glaciation and lake formation indicate an increase in precipitation and probably cooler conditions. Any appreciable increase in precipitation would have a widespread effect for even the present precipitation of about 20 inches per year (at higher elevations) is sufficient to keep some slides active. The combination of greater precipitation with the jarring of occasional earthquake would initiate slides. The
Rattlesnake Hill landslide, north side of Salina canyon (sec. 3, T. 22 S., R. 1 E.), was triggered by a quake along the Sevier fault in 1910 (Mrs. Monger, Salina, Utah, personal communication). In the last 100 years alone 236 earthquakes have been recorded in Utah, 62 of which were along nearby fault zones (Bate, 1957).

Alluvium

Virtually all valleys in the northern portion of the Fish Lake Plateau have been partly filled with alluvium. Streams flow on bedrock in only a few places in the mapped area. The alluvial deposits are predominantly laminated sand and silt, but some contain a mixture of coarser material, the composition of which depends on rock exposed in headward areas. Erosional intervals are evinced in some sections by minor channeling.

The writer believes the main alluviation took place during the pluvials of the late Pleistocene. The deposition was probably contemporaneous with the periods of glaciation, the majority of the slump and earth-flow, and the nearby lake formation. Since settlement of this area, a certain amount of alluviation has been associated with heavy rains and spring thaws, but on the whole, it has been a time of erosion of the alluvium, and arroyo cutting.
IGNEOUS ROCKS

Bullion Canyon Series, Lava Flows

Definition, lithology, and extent. The term "Bullion Canyon series, lava flows" is used here for the volcanic sequence that rests disconformably on the sediments of the Bullion Canyon series (restricted) in the western part of the area, and elsewhere rests unconformably on eroded older sedimentary rocks. The lava flows are designated as the upper member of a sequence that is believed equivalent to the Bullion Canyon series as defined at the type area near Marysvale, Utah. Because of the distinct break between the sedimentary deposits and the lava flows of the Bullion Canyon series, the flows are easily differentiated and thus are mapped as a separate unit (see description of sedimentary part of series in the Stratigraphy discussion).

The flows of the Bullion Canyon series are exposed continuously across the southern part of the area mapped and represent the northern edge of a volcanic cover that extends over more than 3,000 square miles of the High Plateaus. The flows of the Fish Lake Plateau area have been studied only by Dutton (1880, Atlas Sheet 2, p. 59-60, 232-242, 258-259, 261, 265-272, 280), who mapped them all as "...a great aggregate thickness of trachytes, alternating with augitic andesites and some dolerites" (p. 265).
No attempt was made to map systematically the succession of flows that is exposed in the northern portion of the Fish Lake Plateau. Such a study would be a major project in itself. A few lava samples were collected and five of the rock samples were sectioned. No chemical analyses were run.

The flow rocks examined, on the basis of the phenocrysts, may be classified as andesites and latites. There may be other lithologies in the flows that were not sampled. Where the base of the lavas can be seen, the basal rock is locally vesicular, with the vesicles elongated in the direction of flow.

The colors of the rocks here classified as andesites vary from grayish red to medium gray. Phenocrysts that are 2 to 3 mm long usually constitute about 10 percent of the rock. Plagioclase that has an average composition of Ab$_{50}$An$_{50}$ is the most abundant phenocryst mineral. Lesser amounts of sanidine, biotite, hornblende, or pigeonite may be present along with traces of quartz and magnetite. The groundmass of the samples examined contained 30 to 50 percent plagioclase microlites and, in some, contained glass.

The rocks that are thought to be latites are medium gray and contain about 10 percent phenocrysts, which include plagioclase (avg. Ab$_{50}$An$_{50}$) and sanidine in about equal amounts, lesser amounts of amphibole, pyroxene and accessory
magnetite. The groundmass contains plagioclase microlites and specks of magnetite.

The lavas are 200 to 700 feet thick in the north and thicken to over 1,000 feet southward. The mapping of the stratigraphic sequence and distribution of the flows will be a somewhat complex problem, but should prove very interesting for some future worker.

Sources. Dutton discovered a number of source areas for the flows of the Fish Lake Plateau area. The flows west of Lost Creek and those that extend northward across Salina Canyon near Salina, probably emanated from vents at Blue Mountain in the north-central portion of the Sevier Plateau (Dutton, 1880, p. 233). Dutton (p. 261, 266-269) believed the flows north of Fish Lake Plateau and those of the Mount Terrel-Mount Marvine-UM Plateau areas originated in the Fish Lake Plateau. He could not isolate any particular area in the Fish Lake Plateau as a focus because there is no evidence of a cone or crater. The eruptions probably came from numerous fissures and orifices.

The flows of the Sheep Valley and Hilgard Mountain areas came from a chain of volcanic vents along a fissure that extends from Hilgard Mountain on the north to Thousand Lake Mountain. The extravasation appears to have taken place along the entire extent of the fissure with the result that no individual peak or cone rises appreciably
above a broad summit platform. The frequency and magnitude of the outpourings appears to increase gradually northward along this chain to the Hilgard Mountain area (Dutton, p. 271).

The writer suspects a small center of emanation in sec. 1, T. 24 S., R. 3 E., but exposures found in the time allotted were not adequate to prove it.

Correlation and age. The Bullion Canyon lava flows appear to correlate with the upper part of the Bullion Canyon series of the Marysvale area as defined by Callaghan (1939) and Kerr et al. (1957). As mentioned in the discussion of stratigraphy the succession of lava emanations is not adequately known and exact correlation will have to await further work. There remains the possibility that the flows of this area may partly or even entirely correlate with the Dry Hollow series of the Marysvale area.

The lavas of the northern portion of the Fish Lake Plateau unconformably overlie late Eocene rocks and predate the main late Tertiary normal faulting. The relations suggest that the flows are of late early or middle Tertiary age.

Callaghan (1951) made a comparison of available information on the extrusive and intrusive succession from New Mexico to the Sierra Nevada and found a recurring pattern. Intermediate extrusive rocks, chiefly andesites
and latites, form an older series which is followed by major granitoid intrusions, mineralization, and subsequent erosion. This sequence is followed by a series of rhyolite, latite and basaltic andesite flows, which are usually not cut by granitoid intrusives and are not associated with mineralization. Both series are older than latest Miocene.

The volcanic activity in some Southwest areas began as early as Early Cretaceous (Callaghan, 1953, p. 144). Post-Miocene volcanic activity is greatly restricted and limited to basaltic andesite, olivine basalt, and rhyolite. The Marysvale Canyon area igneous activity clearly follows the pattern.

Volcanic activity in central Utah apparently began in a small way in late Paleocene and continued into Eocene. This activity is evinced by the ash in the Flagstaff of the Wasatch Plateau (Spieker, 1946, p. 136), bentonite in the Colton of this area, and the tuff of the lower portion of the Green River in the Spring City-Mayfield areas (Faulk, 1948, p. 22). The sources of these pyroclastic deposits are not known.

The first volcanic activity known to originate in central Utah is that in the Tintic volcanic area where the basal Laguna latite flows interfinger with the late middle Eocene sediments of the Golden's Ranch formation (Muessig, 1951, p. 129). Schoff (1937, p. 93-96) reports lava
boulders in a conglomerate in the upper half of the Green River formation in the Cedar Hills that could have been eroded from Laguna latite flows.

The volcanic activity in the southern Wasatch Mountains and Cedar Hills area that contributed the deposits of the Moroni formation may be in part coeval with the upper part of the Laguna latite series of Long Ridge, but such an equivalency has not been demonstrated by fossil or petrographic evidence. The Moroni formation is definitely post-Crazy Hollow in age (Cooper, 1956, p. 18).

The outbreak of extrusive activity that caused deposition of extensive pyroclastics in the northern portion of the Fish Lake Plateau appears to have been concurrent with the inception of the Gray Gulch lacustrine conditions. The pyroclastic rain into the Gray Gulch lake during the deposition of the Bald Knoll member remained fine, but fairly steady, only occasionally being sufficient to cause formation of bentonite beds. The coarse, tuffaceous sandstone of the Dipping Vat member suggests a somewhat abrupt increase in volcanic activity, probably sometime in late Eocene. The Bullion Canyon series represents a culmination of volcanic activity with the flows of the upper part of the series spread in vast fields over much of the southern part of the High Plateaus.
The volcanic activity in the Marysvale area that followed the Bullion Canyon extrusions did not affect the northern portion of the Fish Lake Plateau. The Dry Hollow series is 650 to 700 feet thick in the Marysvale area (Kerr et al., 1957, p. 23) and is preserved as erosion-remnants in the Sevier Plateau (Callaghan, 1939, p. 449). Detailed work will be necessary to determine the extent of the Dry Hollow flows in other areas. The rhyolites of the Mount Belknap series appear to have been largely restricted to the Tushar Mountains and Marysvale regions with only limited extrusion over areas to the east. Dutton (1880, p. 265-266) describes remnants of an acidic flow on the summit of the Fish Lake Plateau that may be part of the Mount Belknap series. A general late Oligocene-early Miocene age for the Mount Belknap series seems reasonable according to stratigraphic relations.

Basalt Dikes and Flows

Basalt occurs in two widely separated areas in the northern portion of the Fish Lake Plateau. Basalt dikes are exposed in the southeastern part and basalt flows cover small areas in the western part.

The small flows in secs. 15 and 16, T. 23 S., R. 1 W. are fairly fresh, usually less than 50 feet thick, and individually cover less than 20 acres. They are intimately
associated with the complex faulting of the area and apparently erupted from fissures.

The flow rock is dark gray and contains about 30 percent vesicles, which are elongated slightly in direction of flow. Study of a single thin section indicates about ten percent of the rock is phenocrysts of olivine, plagioclase (about Ab$_{40}$An$_{60}$) and pyroxene (augite?), generally 2 and 3 mm long. The groundmass is composed of microlites of plagioclase in a subparallel orientation caused by flow, and is abundantly speckled with minute grains of magnetite. The rock shows very little alteration.

Erosion since the extrusion of the basalt flows has removed surrounding materials to levels slightly below the pre-basalt surface. This relationship, coupled with the freshness of the exposures, suggests a late Pliocene or early Pleistocene age for the flows, which corresponds to the Pliocene and Pleistocene age of the extensive basalt flows in the southern parts of the High Plateaus (Dutton, 1880, p. 197-202, 250-256, 276, 295 and Gregory, 1944, p. 603-604; 1945, p. 115; 1951, p. 69-73).

Two basalt dikes, each about 4 feet thick, cut the Blue Gate shale in sec. 25, T. 25 S., R. 4 E. Similar small dikes were noted in the area immediately to the south. The dike rock is dark gray and is speckled by yellowish green phenocrysts. Vesicles constitute about 5 percent of
the rock and are filled or partly filled by either a white, fibrous mineral that has the indices of heulandite, or by a chlorite. Study of two thin sections indicates about 10 percent phenocrysts, with maximum lengths of 1 mm, which include: pyroxene (mainly augite), plagioclase (Ab$_{40}$An$_{60}$), and olivine that has been partly altered to a mineral resembling bowlingite. The groundmass is an indefinite mixture of unoriented plagioclase microlites, zeolites and a pleochroic mineral resembling goethite, and is spotted with minute grains of magnetite.

The age of the dikes is not known other than that they cut Blue Gate shale.
STRUCTURE

General Features

The northern portion of the Fish Lake Plateau lies between the northwest trending asymmetric Last Chance anticline and the simple dome-like uplift of the San Rafael Swell of the Colorado Plateau on the east, and the highly faulted, structurally complex region of the Great Basin on the west. Because of this transitional location between differing structural types, the northern portion of the Fish Lake Plateau contains elements of both. The strata are warped gently into broad swells and depressions, and only locally to dips greater than 10°. Two Colorado Plateau-type monoclinal flexures are developed in the western part of the area, the Gates Creek monocline and the southern terminal part of the Wasatch monocline, and over much of the area the strata are broken by systems of normal faults similar to the types that characterize parts of the Great Basin. Included are several prominent graben that are separated by stretches of unfaulted rocks.

Attitude of the Strata

The strata of the northern portion of the Fish Lake Plateau are for the most part nearly flat or tilted at slight angles except along the monoclinal folds. The prevailing direction of dip is west at about 4° toward the structurally low areas along Little Lost Creek and Peterson
Greek. The northwestward plunging Paradise anticline in the southeastern part of the area and a broad westward trending anticline across the northern edge of the area are the only structures, other than the monoclines and the fault blocks, that cause any variations from the regional dip.

The northern flank of the Paradise anticline in Tps. 24-25 S., R. 4 E., is outlined by the east-west strike and north dip of exposed units. The crest and southern flank are almost completely covered by pediment gravels and slides, so that the axis of this feature can not be located northwest of sec. 22, T. 25 S., R. 4 E. on the basis of surface information. The trend of the Paradise anticline, when compared with the similar trends of the Last Chance, Caineville, and Fruita anticlines (Hager, 1954, Pl. 11) on the east and southeast, suggests that the time of folding was the same as that of the Colorado Plateau structures.

The southern flank of a broad westward plunging anticline, whose surface expression is bisected by Salina Creek, is present across the northern part of the area mapped. This southern flank is not apparent when viewing Plate 1 alone, but is obvious when Plate 1 is combined with Spieker's geologic map (1949b, Pl. 1) of the area on the north. El Paso Natural Gas Company drilled an unsuccessful test for oil to the Morrison (?) formation on a fault
closure on this anticlinal trend. The youngest rocks involved in the arching are the same beds that are involved in the Wasatch monocline folding, thus indicating that the warping postdated their deposition. On the other hand, the way the Wasatch monocline bows around the nose of this feature (see Pl. 16, in pocket) strongly suggests that the east-west fold existed prior to that monoclinal folding.

**Wasatch Monocline**

The Wasatch monocline forms the western front of the Wasatch Plateau between Milburn and Salina Canyon, a distance of about 55 miles. Its outlines are plainly marked by sweeping dip slopes on resistant limestone beds of the Flagstaff formation in the northern part and on the Green River formation in the southern part. Total displacement from the top of the plateau to the places where the Green River beds pass westward beneath the valley alluvium is generally 6,000 to 7,000 feet, gradually diminishing south from Ephraim, Utah.

An abrupt change in the trend of the monocline occurs at Salina Canyon from a N. 20°-40° E. strike to a nearly north-south strike. This change is probably the result of bowing of the monocline around the nose of a broad westward plunging anticline.

South of Salina Creek the Wasatch monocline becomes considerably less pronounced in physiographic expression
because (1) there is progressively less displacement; (2) the less resistant Crazy Hollow and Gray Gulch beds are the main units that crop out at the surface; and (3) there is a progressively greater overlap of folded beds by younger lavas. The monocline can not be identified south of sec. 20, T. 22 S., R. 1 E. The displacement may have been dissipated by early movements on the fault that continues for five miles southwest from this area, but the main movements along this fault displaced the same lavas that unconformably overlie part of the monocline in secs. 5 and 8, T. 22 S., R. 1 E., and thus are younger than the folding (see Pl. 3, Fig. 2).

The units involved in the monoclinal folding south of Salina Canyon include the Green River formation, Crazy Hollow formation, and the Bald Knoll member of the Gray Gulch formation. Spieker's studies (1949b, p. 38, 41, 63-65) of the Wasatch monocline as far south as Salina Canyon show that the monocline is located over a zone that was tectonically active a number of times during the late Mesozoic and early Cenozoic. Because of the recurring tectonic activity, the area of monoclinal folding is critical in determining much of the orogenic chronology of central Utah. Spieker has compiled the following sequence of post-Green River movements from studies in Twist Gulch, just north of Salina Canyon: (1) post-Green River, pre-Crazy
Hollow normal faulting; (2) monoclnal flexing and faulting during post-Crazy Hollow time and probably pre-Gray Gulch time since in the Twist Gulch region the Gray Gulch formation appears to unconformably overlie the Crazy Hollow; (3) strip thrusting and associated folding following the monoclnal flexing and preceding the volcanics; (4) post-Gray Gulch, pre-lava thrusting; (5) post-lava thrusting; (6) late Cenozoic warping; and (7) late normal faulting.

A reverse fault with 30 feet of dip-slip displacement that may be part of the post-Green River, pre-Crazy Hollow movement is exposed in sec. 5, T. 22 S., R. 1 E. The fault cuts only Green River beds and cannot be traced into the Gray Gulch beds west of a younger north-south normal fault. The contact between Green River and Crazy Hollow beds is disconformable, but there is no evidence of an angular relation that would indicate a period of extensive faulting or folding during this erosion interval.

Spieker put the time of monoclnal folding during the post-Crazy Hollow, pre-Gray Gulch interval because of the absence of Gray Gulch beds on east side of Twist Gulch. In doing this he assumed that the Gray Gulch pyroclastics were related to the lavas. Elsewhere (p. 80) he put the time of monoclnal folding during the post-Crazy Hollow, pre-lavas interval, the relation that holds in the northern portion of the Fish Lake Plateau. The writer believes the flexing
of the Wasatch monocline took place later than post-Crazy Hollow, pre-Gray Gulch time. Local evidence of a disconformity between these units has been reported (Spieker, 1949b, p. 37), but south of Salina Canyon there is no indication of a break and definitely no indication of an angular relation. The discussion of the "Time and Origin of Folding" (p. 140 of this report) includes the postulate that the main monoclinal flexing most likely occurred during the erosion interval between the deposition of the Bullion Canyon series (restricted) and the extrusion of the Bullion Canyon lava flows.

Gates Creek Monocline

The Gates Creek monocline appears to be a sister structure of the Wasatch monocline because displacement on it increases as the Wasatch monocline decreases and because it is developed en echelon 5 miles east of the southern termination of the Wasatch monocline. The Gates Creek monocline is a westward dipping, north-south monoclinal fold in Tps. 22-24 S., Rs. 1-2 E., with dips of 4° to 10° above the shoulder, 18° to 41° in the steepest parts, and less than 10° at the toe, and a maximum displacement of about 6,000 feet. As shown on the section along 38° 45' North Latitude (Pl. 17, in pocket) there is evidence that the original fold may have been in part an asymmetric anticline with the Gates Creek monocline as the steeper west flank, but the
combination of subsequent cover by lava flows, faulting, and recent slide activity prevents ascertaining the true relations. In T. 23 S., R. 2 E., where the fold is less pronounced (see section along 38° 50' No., on Pl. 17), there is no evidence of eastward dip.

The monocline dies out at the north end by a progressive flattening into a regional dip that is reflected in the fan-shaped distribution of strike symbols on Plate 1. At the southern end in T. 24 S., R. 2 E., most of the folded bedrock is covered, but the change of strike and dip of the exposed early Tertiary beds indicates the same relations with regional dip.

The diagonal fault in the northwest quarter of T. 23 S., R. 2 E., is not exposed because of valley fill, but is postulated on the bases of the abrupt change of strike, the oblique displacement of the monocline and the amount of stratigraphic displacement that is necessary in cross-sections constructed across this valley. The fault probably formed during the folding and most likely has lateral as well as vertical displacement, but this cannot be demonstrated by existing information because individual beds cannot be traced through.

The north flank of Hoodoo dome (a half-dome closure) is the result of the terminal flattening of the Gates Creek monocline and the south flank was formed by displacement
along the diagonal fault. The half-dome closure is the result of later normal faulting east of Gates Creek monocline (Pl. 18, Fig. 1).

The youngest beds exposed in both the Gates Creek and the Wasatch monoclines are those of the Gray Gulch formation. There is evidence of earlier broad warping in the Gates Creek monocline area during post-Green River, pre-Crazy Hollow time, but most likely the warping was not related to the later monoclinal folding for no angular unconformity is found. The post-Green River, pre-Crazy Hollow movements are indicated by (1) southward thinning of Green River section along the monocline; (2) apparent absence of Green River east of the monocline; and (3) southward thinning of the Crazy Hollow, apparently onto a topographically high area during early Crazy Hollow time.

The main flexing of the Gates Creek monocline (and probably the Wasatch monocline as well) occurred at some time between the deposition of the Gray Gulch lake beds and the extrusion of the Bullion Canyon lava flows since the flows unconformably overlie the tilted lake beds.

The normal faulting east of the monocline is obviously younger than the folding because the lavas are displaced by the faulting. The diagonal fault south of Hoodoo dome is believed to be contemporaneous with the folding, but this can not be proved. Both Hoodoo dome and the part of the
Plate 18.

Figure 1. Displacement of Price River – North Horn Contact on Hoodoo Dome

Location: sec. 4, T. 23 S., R. 2 E. Kpr – Price River formation, KTk – North Horn formation.

Figure 2. M & O Reservoir

Looking northeast from east side of UM Plateau. There is a fault along the base of slope on east side of M & O Reservoir.
Gates Creek structure to the south have structural closure against the post-lava normal faults.

Additional Areas of Folding

The two other areas of moderately steep dip show on Plates 1 and 16 have nearly the same relation to the overlying lavas as the Wasatch and Gates Creek monoclines and probably were formed during the same disturbance. The lineament that extends south-southeastward from sec. 36, T. 22 S., R. 1 W., along the east side of Lost Creek valley, is a fairly complex area that includes a fault zone or single fault on the west side and an eastward inclined flank with dips of 9° to 20°. West of the faults the rocks have a regional west or southwest dip of 4° to 8°. The faults appear to be nearly vertical normal faults with a displacement of 200 or 300 feet, up on the east. The east dip can be traced for only half a mile because of the lava cover.

The general picture is that of a fault zone with displacement that causes a local reversal of the regional dip. The disturbance is dated as post-Bullion Canyon series (restricted) and pre-Bullion Canyon lava flows because of the angular unconformity between these units. The north-south faults that cut the lavas in sec. 7, T. 23 S., R. 1 E., are younger.

The other area of steep dip occurs along a narrow zone on the east side of Peterson Creek valley. Beds of the
Bullion Canyon series (restricted) dip 17° to 20° west-southwest. These folded beds are unconformably overlain by lava flows.

Time and Origin of Folding

The southern end of the Wasatch monocline, the Gates Creek monocline, the fault zone along Lost Creek, and the folding on Pterson Creek have subparallel trends and are all structurally higher on the east side. These four features were developed sometime between the deposition of the Bald Knoll member of the Gray Gulch formation and the extravasation of the Bullion Canyon lava flows. Stratigraphic relations on two of the features indicate the disturbance occurred during post-Bullion Canyon series (restricted), pre-Bullion Canyon lava flows time. The folding is definitely not contemporaneous with or related in any way to the displacements in the fault zones east of the monoclines because the major movements in these zones came considerably later than the extrusion of the Bullion Canyon lava flows.

The Wasatch monocline is considered by Spieker (1949b, p. 48 and personal communication) to have developed as a result of regional uplift of the Wasatch Plateau area and simple subsidence of the Sanpete-Sevier Valley block. The regional effect of the uplift was tensional, similar to that of the uplift that caused the normal fault systems of
the Wasatch Plateau, rather than compressional like that assumed to hold for the Colorado Plateau monoclines because the monocline (1) faces westward instead of eastward, (2) lies in a different kind of structural setting, (3) post-dates the Colorado Plateau folding, and (4) is clearly associated with the normal fault systems, especially the graben. The last point is not supported by information from the northern portion of the Fish Lake Plateau because the graben of this area were formed much later than the monoclines.

No additional evidence on the origin of the Wasatch monoclinal folding can be obtained from the expression south of Salina Canyon because only the shoulder and part of the steep flank are exposed, and the southern termination is somewhat concealed by lava flows. The formation of the Wasatch monocline appears to have been coeval with that of the other three features, but there is no direct evidence.

The Gates Creek, Lost Creek, and Peterson Creek structures differ from the Wasatch monocline in that they have trends that are not aligned parallel with the older trends of the Sevier Valley and areas to the west, but rather are somewhat oblique to them. The Gates Creek and Lost Creek structures appear to have resulted from differential uplift, up on the east, because the relative movements and areal position preclude any regional compression and the rocks west of both features are inclined at
regional dip with no evidence of down-warping that would be expected to accompany any other type of movement. The linearity of the two features suggests possible deep-seated fault control. The Peterson Creek structure is not exposed sufficiently to determine the relative movements.

Intraformational Unconformity in the Bullion Canyon Series (Restricted)

There are three small areas in the western part of the mapped area where angular unconformities involving vertical beds are found within the middle unit of the Bullion Canyon series (restricted). The areas are centered in sec. 11, T. 23 S., R. 1 W., secs. 20 and 21, T. 23 S., R. 1 W., and sec. 31, T. 23 S., R. 1 E. As shown on Plate 19 these areas are extremely disturbed with close vertical folding and both normal and thrust faulting. Wherever the lateral relations are seen, the disturbed areas are separated from relatively undisturbed areas by high-angle faults. The disturbed areas are most likely down-dropped because they are near Gray Gulch outcrops and if upthrown the Gray Gulch beds would be exposed in the folds. Trends are not discernible and nowhere are beds other than those of the middle unit involved. The folded and faulted beds are truncated by erosion nearly to a plane (see Pl. 11, Fig. 2) and are overlain by nearly horizontal beds of the middle unit of the Bullion Canyon series (restricted).
Disturbed Area along Little Lost Creek

Looking west to northwest across Little Lost Creek at complexly folded and faulted beds of middle unit of Bullion Canyon series (restricted). Location: sec. 31, T. 23 S., R. 1 E.
The origin of these features is a complete puzzle to the writer. Their complex folding and faulting suggests a cryptovolcanic origin, but since the beds involved are limited to the middle unit (estimated to be about 1,700 feet thick) of the Bullion Canyon series (restricted) this type of origin is difficult to visualize.

Spieker (personal communication) states that a similar structural feature is developed in the Axtell (?) beds (unconsolidated late Tertiary gravels) on the east side of Gunnison Reservoir, northwest of Sterling, Utah. The loose gravels are locally vertical and are overlain by terrace gravels. He believes this feature is the result of jamming of the Axtell (?) beds by local compression.

Faults

General Nature

The most distinctive features of the northern portion of the Fish Lake Plateau are the north and northeast trending groups of high-angle normal faults. Included are three graben that attain special significance because of the large amounts of displacement and the pronounced physiographic expression. The high-angle normal faults of the High Plateaus have been generally considered as the eastern termination of the Basin and Range faulting, with the Paradise fault the easternmost. Eardley (1951, p. 494-496) includes the late Cenozoic faulting of this area in a
discontinuous belt of graben (trenches) in the Cordilleran region that extends from northern Arizona to the Yukon.

The graben of the Wasatch Plateau trend north-south and have an en echelon arrangement from northeast to southwest (Spieker, 1949b, p. 42-44). Five major graben are developed in the main body of the plateau. Three of these extend as graben or as single faults south into the northern portion of the Fish Lake Plateau. These features are, from east to west, the Paradise fault (a southern extension of the eastern fault of Joes Valley graben), the Musinia graben (actually a fault zone with a number of en echelon graben separated by narrow horsts - see Pl. 16), and the Water Hollow graben.

Except for the pre-Crazy Hollow reverse fault mentioned above, all the faults of the northern portion of the Fish Lake Plateau are believed to be of the normal type. The fault surfaces seen in the field have inclinations of 61° to 90°.

The actual fault surfaces rarely are seen in the High Plateaus. This is especially true in the northern portion of the Fish Lake Plateau because of the area covered by late Cenozoic gravels and slides. On the accompanying geologic map (Pl. 1) the relative surface control on the presence or location of the fault surface is indicated by the length of dash. Short dashes indicate that no evidence could be found
in the field, but that either the trace was projected on the basis of control north and south of the short dash area, or that photogeologic control, such as abrupt topographic changes, soil changes and/or alignment of drainage, indicated the presence of a fault. Long dashes indicate the fault is concealed by soil or surficial cover, but displacement is obvious. Solid lines indicate the fault is exposed.

Paradise Fault

The Paradise fault was selected as the eastern limit of the area to be reported on because it forms a natural structural boundary for any High Plateau study. Spieker (1931, p. 56-58, Pl. 32-33) traced the Paradise fault for 12 miles south-southwest from the southern end of the Joes Valley graben while mapping the Wasatch Plateau coal field. The displacements in the Joes Valley graben north of Emery are generally over 2,000 feet with the downthrown block 1½ to 2½ miles wide. The relative displacement of the higher blocks on either side of the graben appears rather slight. South from Emery the graben displacement gradually lessens. The eastern fault of the graben continues south-southwest from the southern end of the graben as a normal fault that is downthrown on the west. At Ivie Creek this fault has an en echelon relationship with the northern termination of the Paradise fault (the writer's only
difference with Spieker's interpretation). Total displacement across the fault zone at Ivie Creek is approximately 600 feet. At Last Chance Creek, where basal Blue Gate shale is in contact with upper Emery sandstone, the displacement is about 2,000 feet. The displacement decreases southward to about 1,000 feet in Paradise Valley where upper Ferron sandstones are in fault contact with middle Blue Gate shales. The northwest trending fault in the west half of T. 25 S., R. 4 E., is a branch of the Paradise fault zone.

Lupton (1916, p. 42) believed the Paradise fault connects directly with the Thousand Lake fault, west of Thousand Lake Mountain and thus may continue south for another 40 miles. Detailed work never has been published on the area between Thousand Lake Mountain and Paradise Valley so such a connection has not been demonstrated.

Musinia Fault Zone

The relations of the faults within the Musinia fault zone are seen on Plate 16. The overall expression of the Musinia fault zone is that of a number of en echelon graben that are separated by narrow horsts. The best exposure of the Musinia fault zone is in the Salina Creek area where it was first mapped and described by Spieker and Baker (1928, p. 146-148, Pl. 22). At Salina Creek the Musinia fault zone is bounded by two faults of large
displacement and is divided into two sunken blocks by a narrow horst. The sunken blocks are tilted according to the relative displacement along the bounding faults to diverse angles with respect to one another and to the blocks of flat-lying strata east and west of the fault zone. North and south from the Salina Creek area the bounding faults of the zone decrease in throw, and en echelon faults become the bounding faults (see Pl. 16). This causes the offset arrangement and lateral displacement of the zone itself. As an example the east bounding fault is described by Spieker and Baker (1928, p. 146) as having about 1,050 feet of displacement at Spring Canyon (sec. 25, T. 22 S., R. 3 E.). Six miles south at Meadow Creek (sec. 19, T. 23 S., R. 4 E.), the displacement is less than 20 feet. The fault zone, however, extends south for another nine miles along an en echelon fault one mile farther west.

The western bounding fault of the Musinia fault zone has a displacement of around 2,000 feet at Salina Canyon. This displacement decreases southward and the graben loses its identity in T. 24 S., R. 3 E., where the fault dies out.

An interesting sequence of faulting is suggested by the fault relations in the eastern half of T. 23 S., R. 3 E. The trends, relative ages and displacements may be interpreted as shown in Figure 5; however, the relations can not be proved because the critical areas are covered
Musinia Fault Zone

Looking north from SE1/4 sec. 35, T. 23 S., R. 3 E.
Figure 5. Postulated sequence of faulting relative to lava flows. 
A and B, pre-lava fault movements, D, post-lava movements.
by soil or slides. Some of the minor faulting appears to be pre-lava, but the major displacements are post-lava.

**UM Plateau Graben**

The UM Plateau graben is located in the southern part of the horst block between the Musinia and Water Hollow graben, in the west half of T. 24 S., R. 3 E. Total displacement on the bounding faults is not known because the sediments that underlie the lava are not exposed. Recent movement along the normal fault that bounds the UM Plateau graben on the west is indicated by the small lake in sec. 19, T. 23 S., R. 3 E., and by slight displacement of the earlier glacial deposits in sec. 18, T. 24 S., R. 3 E. Along the eastern fault there is drainage alignment in the slide deposits, but no displacement of the later glacial deposits. The recent movements have been slight, generally less than twenty feet.

**Water Hollow Graben**

The Water Hollow graben is separated from the Musinia fault zone in the area north of the UM Plateau graben by an unbroken stretch of rocks about 2½ miles wide. The nature of the downdrop in the Water Hollow graben is entirely different from that of the Musinia fault zone. The southward tracing of the faults shows the overall picture of the Water Hollow graben is that of one main fault on the east side
with three subsidiary faults that appear to be antithetic. The westernmost fault of the three is seen in Salina Canyon to dip 61° to the east. The surface trace of this fault indicates a nearly vertical dip south of Salina Canyon. The displacement along the eastern main fault averages about 1,000 feet with a maximum of about 1,400 feet at Catamount Canyon. The downdropped blocks have a step-like arrangement to the west. The easternmost block was displaced the most and the other two blocks progressively less (Pl. 21). Browns Hole, a topographic basin, is the result of removal by differential erosion of the soft North Horn beds that covered the eastern block.

The Water Hollow graben is difficult to recognize south of Browns Hole as the fault displacements decrease and there is no longer a prominent physiographic expression. The rocks exposed at the surface south of Browns Hole are mainly the soft shales of the North Horn formation which yield their typical smooth-sloped terrain. The fault traces were mapped by photogeologic information and are located at critical places by field data.

**Age of Faulting**

Until recent years the normal faulting was thought to have come rather late in the history of the region, no earlier than the latter part of the Tertiary, and to have continued into the Quaternary as some of the faults show
Browns Hole and Water Hollow Graben
Looking north from N\textsuperscript{\textfrac{1}{2}} sec. 12, T. 23 S., R. 2 E.
clear evidence of recent movement. The earlier views as summarized by Spieker (1954, p. 13) held that all the faulting came after the folding and thrusting had died down in a post-orogenic period of relaxation from compressional stress and as a concomitant of the general uplift that brought the whole region to its present condition. Spieker (1949b, p. 78-81) lists the following Cenozoic history of normal faulting based on extensive studies in the Wasatch Plateau area:

- Paleocene normal faulting (evidence on east front of Gunnison Plateau)
- Post-Colton, pre-Green River normal faulting (on west slope of the Gunnison Plateau)
- Post-Green River, pre-Crazy Hollow normal faulting (in Twist Gulch)
- Flexing and faulting of the Wasatch monocline (Spieker here places these events in the rather long interval between Crazy Hollow time and that of the earliest volcanics, but as mentioned above, present information indicates a post-Bullion Canyon series (restricted), pre-Bullion Canyon lava flows age for the monoclinal flexing)
- Late normal faulting (Pleistocene and Recent movement is demonstrable on some of these faults, but in most cases the age of earlier movements is not known)

The history of normal faulting is fairly long, but examples of individual movements prior to the extrusion of the Bullion Canyon lava flows are obtainable only in limited areas in the more complexly disturbed western part of the transition belt. These movements were all relatively small when compared with post-lava movements. In the northern portion of the Fish Lake Plateau faults that appear
to predate the lava flows can be traced toward the lava cover in three areas, but in the critical zones adjacent to the lavas, the faults either appear to die out, as in sec. 36, T. 22 S., R. 1 W.; are covered by soil as in sec. 9, T. 24 S., R. 1 E.; or are covered by slides as in sec. 35, T. 23 S., R. 3 E. Since the lavas east of Lost Creek overlie beds that are tilted by the faulting along Lost Creek, that faulting must pre-date the lavas.

The main faulting definitely came after the Bullion Canyon lava flows because all of the major faults displace flows and sediments equally. Along many of the faults the physiographic expression is more pronounced in the flow-covered areas than to the north. Two of the highest elevations, Mount Terrel and Hilgard Mountain, are on the upthrown sides of major faults.

The major faulting also followed the main development of pediments in the central part of the area. Evidence of this includes the perched pediment between Yogo and Niotche creeks in T. 23 S., R. 3 E.; faulted pediment gravels in the south half of T. 23 S., R. 3 E.; a tilted pediment surface in sec. 36, T. 23 S., R. 2 E.; etc. The difference in elevation between the perched pediment south of Niotche Creek (secs. 8 and 17, T. 23 S., R. 3 E.) and the pediment in the Musinia fault zone (secs. 16 and 22) is about 1,000 feet, nearly the same as the displacement on the fault -
but it is not known positively whether the two pediments represent a once-continuous surface. A post-pediment date of faulting is suggested also by the antecedent character of the drainage. The way in which streams like Niotche Creek cut diagonally across one or more fault blocks can only mean that the drainage generally is following courses that predate the faulting.

Because the age of the pediment development is not known, other than that it postdates the lavas, a general middle or late Tertiary age is given to the period of major faulting. Additional geomorphic or stratigraphic information will be needed for more accurate dating.

The gravel deposits that partly filled stream valleys in the late Pliocene or early Pleistocene postdate the major faulting since they were deposited following the differential erosion of the fault blocks.

The displacements by the relatively recent faulting are small compared with those of the major late Tertiary stage.

**Cause of Normal Faulting**

The information from this area and the Wasatch Plateau area shows the history of normal faulting to extend from the early Paleocene to the present with a period of major faulting in middle or late Tertiary time. The causes of all of the faulting, with the many orientations and diverse
structural locations, are bound to be complex. The local faulting of early Tertiary time, such as that along Lost Creek, can be ascribed to tensional conditions developed during differential uplift. The northeast trending post-lava faults of Tps. 22-23 S., R. 1 W., present a special problem because they are located in an area that is probably underlain by salt-bearing Arapien shales. The faulting may be related to a plastic flow of the Arapien beds, like that proposed by Walton (1955, p. 405) for normal faults on the Gordon Creek anticline of the northern portion of the Wasatch Plateau, or the faulting may be related to the family of normal faults farther east in the plateau. Surface information is not sufficient to prove anything, one way or the other.

The period of major faulting is separated in time from any compressive activity, even that associated with the crustal shortening during monoclinal folding, by a long erosion interval, a period of extrusive activity, and another long erosion interval. As the result of the major faulting, the northern portion of the Fish Lake Plateau, like the whole of the Wasatch Plateau on the north and the region to the south, is a highly fault-dissected area, especially in relation to the mildness of the folding. The faults or fault zones of the High Plateaus have little or no relationship to the lineation or position of older folds.
This type of normal faulting must have been caused by
tensional conditions because it is developed in nearly
flat-lying strata and most of it is localized in graben-
forming fault zones. The tension may have resulted from
either a stretching of the surficial strata or from the loss
of support because of withdrawal of underlying matter. The
idea of stretching is favored by those who advocate the
theory of relaxation following compression, and by those
who advocate the theory that the faulting accompanied the
late Tertiary general uplift of the region (Spieker, 1954,
p. 13). The loss of support idea has been mentioned by
some when discussing the great quantities of extrusives
piled in the southern portion of the High Plateaus, but
inasmuch as the normal faulting cuts across the volcanic
cover and continues far to the north, this theory never has
received any serious support.

Walton (1955, p. 410-411) postulates a combination of
uplift and subsidence related to movements of the Arapien
salt mass to explain the faulting. His explanation includes
the following steps: (1) downsinking of the Arapien salt
mass in the Sanpete-Sevier Valleys, accompanying tensional
stress in the plateau, and formation of Wasatch monocline,
(2) shoulder faults, and (3) the development of graben-
plastic flowage of the salt away from the fault zone adding
to their large displacement. Walton mentions that since
the faults are part of a regional linear belt and are independent of any of the earlier structures, a strong structural control must have been exerted by the basement rocks, probably the crystalline rocks. Two important points of Walton's theory are open to question: (1) Walton does not treat the monoclinal folding and the faulting as distinctly separated events and (2) the stratigraphic log compiled from tests of Flat Canyon anticline, which lies between Joes Valley and Pleasant Valley graben, records less than 250 feet of evaporites in the Arapien section - under the horst block - certainly insignificant compared to the 3,000 feet of displacement in the adjacent 1½ to 2 miles-wide graben.

The writer does agree with Walton's concept of basement control of the direction of strike of the faults.

Eardley (1951, p. 494-498) associates the normal fault zones from south of the Colorado River in Arizona to at least Yellowstone Park in Wyoming and possibly continuing from western Montana north to the Yukon, as late Cenozoic trenches of the Rocky Mountains. In so doing he implies that the High Plateau faults, which are developed mainly in nearly flat-lying beds, are of the same origin as the normal faulting of the eastern Idaho and western Wyoming disturbed belts, and that of areas west of the disturbed belt in Montana and British Columbia. Eardley
links the faulting of this area with that of eastern Idaho through a Basin and Range type fault, namely, the Wasatch fault that Eardley (p. 479) also included with Basin and Range faulting. A study of the Tectonic Map of the United States (1944) indicates that the normal faulting of the High Plateaus terminates in the Uinta Basin and should not be associated with any faulting further north.

No distinct structural boundary exists between the Basin and Range faulting and the faulting of the High Plateaus; the one is gradational into the other. However, there are appreciable structural differences. Cross-sections of the Wasatch Plateau and the northern portion of the Fish Lake Plateau plainly show that the movements in the graben are those of foundering blocks against one major fault (see discussion of Water Hollow graben) or between major faults; these are conditions that could only be tensional. Any tilting of beds associated with this faulting resulted from differential movement along the faults, and only affects down-dropped blocks. The faulting in the Basin and Range province has been shown by recent authors, especially Nolan (1943, p. 184-185), to involve both compressional and tensional conditions. Faults in the western part of the High Plateaus, such as the Hurricane fault (Koons, 1945, p. 163-166), apparently contain elements of both pure tensional faulting and Basin and Range
type conditions. There appears to be complete overlap of the age of the faulting in both areas. Nolan (quoted in Eardley, 1951, p. 485) believes that the Basin and Range block faulting, as a process, began in early Oligocene time and has been more or less continuous ever since. Certainly there is no doubt that the post-lava faulting of the northern portion of the Fish Lake Plateau is included in this time span.

All of this leaves us with many facts about the normal faulting, but little knowledge of the causes. The conditions that caused the faulting in the High Plateaus caused east-west tension to be developed over a long, somewhat narrow belt from Arizona north to the southwestern part of the Uinta Basin. The general alignment of the fault zones is most likely controlled by movements in the basement rock (broadly, the sial) and some of the faults may even be continuous with basement faults. The exact relation of the High Plateau faulting to the general Basin and Range faulting is not thoroughly known, but it is believed that one grades into the other.
GEOMORPHOLOGY

General Features

The late Cenozoic geomorphic history includes (1) a period of pedimentation during which the drainage pattern was established, (2) two cycles of stream erosion and subsequent valley-filling by clastics, and (3) recent arroyo cutting. Slides of small and large magnitude have been active on valley or mountain slopes during late Pleistocene to present time and small areas at high elevations have been glaciated. The glacial deposits and the nature, distribution, and causes of the slides are described in the discussion of the Stratigraphy.

The streams, as best exemplified by Niotche Creek, are antecedent to the faulting. Locally the valleys are developed in softer units along strike or in graben, but generally the valleys are cut obliquely or directly across structural units such as fault blocks or monoclines. This observation supports Hunt's hypothesis (1956, p. 81) that the drainage of this part of the Colorado Plateau was established by early Miocene, prior to most of the faulting.

The only evidence of stream piracy is in Summit Valley, T. 24 S., R. 2 E. Because of the damming of a former west fork of Seven Mile Creek in the SE1/4 sec. 21 by the earlier glaciation, a part of the drainage apparently was diverted westward into Lost Creek, which then cut
headward into the lavas and captured all the drainage of the northern part of Summit Valley.

The topography of the lava-covered highlands must be considered separately for the drainage texture is coarse and predominantly controlled by faulting. The summits show a certain concordance in that the five highest elevations are between 11,010 and 11,599 feet. The profiles of these peaks vary from that of a broad plateau such as UM Plateau, to a prominent knob such as Hilgard Mountain (Pl. 2, Fig. 1) or Mount Terrel, to a ridge such as Mount Marvine. The mountains are all fault blocks that have had their outlines modified by erosion and slides. Glaciation has had no appreciable effect on the shapes of the mountains.

**Pedimentation**

Pediments are prominent in the central and eastern parts of the area, especially over the Last Chance Creek drainage. They are developed in sedimentary beds of Late Cretaceous and early Tertiary age at elevations between 10,400 and 7,000 feet and have inclinations of 4° to 10°. The pediments of the central area have been truncated by faults of the Musinia and Water Hollow fault zones so that many pediment surfaces now are perched on horst blocks or isolated in the graben. Continuous pediment surfaces can not be followed for more than a few miles because of the faulting.
The pediments generally are covered by a veneer of gravel.

The major formation of the pediment surfaces probably began following the extrusion of the Bullion Canyon lava flows and continued to the epoch of faulting in the central area and to the present in the Last Chance Creek area. The evidence that supports a pre-faulting age for the major development of pediments is discussed in the section on the age of faulting.

The drainage pattern that exists today apparently was established during the major pedimentation. Faulting has had very little effect on the stream courses, for almost all streams cut across fault blocks with no reflection of the faulting or of the relative hardness of rocks on either side of faults.

The area of pediments is being reduced by headward stream erosion or valley widening as the result of slide movement.

**Late Cenozoic Erosion**

The uplift that accompanied the faulting initiated a new cycle of erosion and streams both deepened and widened their valleys while the faulting proceeded. This period of erosion probably ended some time after the positive movements ceased. By then, the valleys were eroded close to their present depths, but had more rounded profiles.
The valleys subsequently were partly filled with coarse detritus.

The valley-filling deposits were removed almost completely during a second late Cenozoic period of erosion, and the valleys were deepened considerably as canyons were cut by most streams. The initiating cause of this second cycle is not known.

Glaciation

Glaciation in the Fish Lake Plateau has been described by Dutton (1880, p. 35, 41-42, 263, 264, 269-270, 279, 285) and by Hardy and Muessig (1952). Two separate glaciations are recognized in the Fish Lake Plateau, the earlier being the more extensive. The glaciated areas are usually small, and the general effect on the topography of the highlands rather slight.

Ice erosion has not been sufficient to form U-shaped valleys. Well-defined cirques are developed only at the head of the left fork of UM Creek (called Moraine Valley by Dutton, 1880, p. 269), west of the Lost Creek Reservoir in sec. 19, T. 24 S., R. 2 E., and on the east side of UM Plateau in sec. 16, T. 24 S., R. 3 E. Small protalus ramparts commonly are formed in the cirques. The sides of the cirques and the glaciated valleys have been modified considerably by post-glacial rock slides and slump.
The following is Dutton's description of one of the larger glaciated areas (1880, p. 269-270):

Before proceeding southward it is desirable to look briefly at Mount Hilgard and at the intervals which separate it from Mounts Terrill and Marvine. From Summit Valley we may easily cross the col which separates the two latter summits, and descending the other side we find ourselves in a broad valley parallel to the one just left. This has been named Moraine Valley, from a rather large and conspicuous relic of glacial times, which could not escape observation because it is so well preserved and tells its story so plainly. It fills a lateral valley, heading near the summit of Mount Terrill and extending eastward into the broader expanse of Moraine Valley. It is covered with pools and lakelets bowered with aspen and spruce, and has the ordinary terminal character where its proper bed opens into Moraine Valley; beyond which no traces of glaciation are recognizable. The altitude of the termination is very nearly 9,000 feet, showing the same general fact which has already been spoken of, that the glaciers did not, in this part of the country descend to low levels, but were confined to the highest parts of the region.

The description, age and correlation of the glacial deposits are discussed in the section on Stratigraphy.

Valley Plain Terraces, Arroyo Cutting

In common with many of the major streams and their tributaries of the Southwest, the valleys of this area show a Quaternary sequence of (1) canyon cutting, (2) partial filling of canyons by alluvium and the development of broad flood plains, and (3) recent arroyo cutting. The resulting matched alluvial terraces have been classified by Cotton (1940, p. 28) as valley plain terraces.
A striking fact that is observed when traversing the valleys is that the streams of this area rarely are flowing on bedrock. Plate 22, Figure 1 illustrates the condition that may be found anywhere along a stream from the headwaters to the confluence with a larger stream. Plate 22, Figure 2 shows an extreme case along Dipping Vat Creek, where an 80 foot straight-walled canyon has been cut into alluvial fill.

The deep dissection that preceded the deposition of alluvium occurred during the second late Cenozoic cycle of stream erosion and ended with the climatic fluctuations of the late Pleistocene in which the humid conditions of the pluvials alternated with periods of relative dryness. The greater rainfall of the pluvials resulted in a denser vegetation, which in turn lessened the rate of erosion and increased alluviation of all streams. Periods of alluvial deposition were followed by erosion intervals, but the cumulative effect was, figuratively, to inundate the valleys with alluvium. The sections of the alluvium show mainly laminated deposits of sand and silt, but also include coarse detritus, depending on the area drained. Erosional intervals are observable in some sections.

The periods of alluviation appear to correspond to other events that took place during the late Pleistocene, such as the periods of glaciation, the majority of the slump and earth-flow, and the formation of Lake Bonneville.
Plate 22.

Figure 1. Arroyo Cutting by a Tributary of Clear Creek

Looking northwest. Location: secs. 19 and 20, T. 24 S., R. 4 E.

Figure 2. Box Canyon Cut by Dipping Vat Creek

An 80 foot canyon cut in light gray to white sandy clays eroded from surrounding outcrops of Gray Gulch beds. Location: sec. 29, T. 23 S., R. 1 E.
Plate 22

Figure 1

Figure 2

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The recent arroyo cutting of the Southwest has been the subject of discussion in many papers. Antevs (1952) summarized these discussions and finally concluded that (p. 384)

The main ultimate causes of arroyo cutting in the Southwest were drought in the past and over-grazing since about 1875.

Overgrazing prior to 1910 in the Fish Lake National Forest area is an established fact. Cottam (1947, p. 21) states that the two decades of the 1880's and 1890's saw an upsurge in sheep population that resulted in the stripping of forage cover from the High Plateaus. This removal of vegetation from the water sheds caused the replacement of large areas of grassland by poor soil-binding plants, such as juniper and scrub oak and was followed by an increase of destructive flash floods and the beginning of arroyo cutting. Some writers think that another more basic factor is involved, namely, that because of the post-Pleistocene dry climate, a change from alluviation to erosion was taking place or about to take place and that (Bryan, 1928, p. 281)

The introduction of livestock and the ensuing over-grazing should be regarded as a mere trigger pull... The rapidity with which the grass areas were invaded by desert shrubs (within 25 years after settlement, Cottam, 1947, p. 19) supports this assumption.
The Civilian Conservation Corps during the 1930's built small dams along Salina, Meadow and Soldier creeks as flood control measures. They were to impede the flow of water and cause the deposition of suspended sediment. The dams were filled to capacity with alluvium in about two years and have had only a local effect on controlling arroyo cutting.

The Forest Service has a program to revegetate those lands that have been denuded of the better soil-binding plants with the best artificial and natural plants that will grow on the site.
The contributions to the geologic history of central Utah that are afforded by studies in the northern portion of the Fish Lake Plateau are mainly those of the Cenozoic history, as the record is more complete here than anywhere else in the region. The total exposed section includes rocks of all periods from Jurassic on. The features of the pre-Jurassic geologic history of this part of central Utah can be obtained by reference to Nolan's work (1943) on the Great Basin, Muessig's study (1951) of Long Ridge, Spieker's late Mesozoic and early Cenozoic history of central Utah (1946), and his (1954) structural history of this area. The following paragraphs summarize the post-Triassic events that are recorded in the rocks of the northern portion of the Fish Lake Plateau and adjacent areas.

In the Early Jurassic continental conditions prevailed over this region while a succession of alternating aeolian and fluvial sediments were deposited. These continental deposits are included in the Glen Canyon group as the aeolian Wingate sandstone, fluvial Kayenta formation and aeolian Navajo sandstone, in ascending order. Stokes and Holmes (1954) indicate that the lower two formations are probably present in the subsurface of the northern portion of the Fish Lake Plateau. The Navajo almost certainly is present because the upper 600 feet were penetrated in the
Standard of California Company well (sec. 32, T. 22 S., R. 1 W.) below the 8,997 foot depth and the formation crops out to the east, in the western border of the San Rafael Swell.

An arm of the late Middle to early Late Jurassic sea advanced into central Utah from northwest to southeast. A lithologic comparison of the Arapien shale of Sevier Valley with the Carmel formation of the San Rafael Swell indicates that the northern portion of the Fish Lake Plateau occupied a position marginal to the sea and that alternating transgressions and regressions caused the formation of local evaporite basins. The greater thickness of the Arapien (7,000 to 10,000 feet) than the Carmel (about 650 feet) resulted from continuous negative movement of the Sevier Valley area during this time. The area apparently was emergent, but probably low in elevation during the Late Jurassic deposition of the red siltstones and reddish gray sandstones of the lower Twist Gulch and Entrada formations and was submerged again during the deposition of the greenish gray clastics of the Curtis formation and the laminated sandstones and mudstones of the Summerville, and the equivalent section in the upper part of the Twist Gulch formation. The similar thicknesses of these intervals in Sevier Valley and over the San Rafael Swell denote stable conditions during the final withdrawal of the Jurassic sea.
Sedimentation was continuous throughout Late Jurassic, Early Cretaceous and on into Late Cretaceous time. Coeval with this continuous deposition were a number of episodic orogenic events in the region to the west. The Late Jurassic and Early Cretaceous conglomerates coarsen westward in the Gunnison Plateau area, suggesting that they were eroded from an uplift not far west of that feature. The northern portion of the Fish Lake Plateau occupied a position east or southeast of the mountains; in this area the coarse clastics of the Morrison (?) formation of the Sevier Valley area grade eastward into a succession of freshwater limestone and an upper unit of variegated shale and mudstone and conglomeratic sandstone of fluvial or lacustrine origin (Morrison and Cedar Mountain formations, respectively, Stokes and Holmes, 1954, p. 39; and Katich, 1954, p. 44).

The Mancos sea gradually transgressed into this area from the east in the late Early Cretaceous (Katich, 1951, p. 18). The shoreline oscillated back and forth throughout Colorado and early Montana time, and never extended much farther west than Sevier Valley (Spieker and Reeside, 1926, p. 436). These conditions are reflected in the sediments by westward gradation of the relatively thin littoral Dakota (?) sands and overlying dark marine Tununk shales of the eastern area into the near-shore zone of dominantly
coarse sediments (Sanpete formation) "intermediate between the open sea to the east and a mountainfront belt of coarse gravel fans to the west" (Spieker, 1946, p. 127). The maximum Cretaceous marine invasion came during the deposition of the Allen Valley shale and the equivalent upper portion of the Tununk shale. A succeeding period of uplift on the west is reflected in this area by a change to alternating marine and fluvial conditions during the deposition of the Funk Valley sands and shales in the western portion, the lower part of which grades eastward into the coal-bearing, but predominantly littoral, deposits of the Ferron sandstone. This sequence of marine invasion and subsequent retreat following renewed uplift was repeated again twice as the Blue Gate shale of late Colorado age and the Emery sandstone, Masuk shale and Star Point sandstone of early Montana age were deposited, each of the thick littoral sand sections forming a tongue eastward into the dark shales of the Mancos as the shoreline retreated in that direction. The records from the El Paso Natural Gas Company well show that the sea inundated the Salina Canyon area for a while after Ferron deposition, and that there was then a period of regression and littoral sand deposition, which was followed by the formation of coal swamps. The Star Point sandstones were deposited following renewed uplift to the west, by streams that drained to the Mancos shoreline that stood along the present eastern front of the High Plateaus.
The Blackhawk sandstone, shale and coal record the fairly quiet, lowland, continental conditions that followed the withdrawal of the Mancos shale from this area.

Renewed orogenic activity in middle Montana time strongly affected this area for a folded belt was formed along the east side of Sevier Valley and the whole region was uplifted temporarily. The folded belt was truncated prior to Price River deposition, but locally it remained as a topographic high, probably reinforced by later minor positive movements, until finally buried in the early Tertiary. The initial orogenic activity was the greatest; it furnished the quantity of coarse sands that forms the great tongue of the Castlegate sandstone east all the way to the Colorado state line. The orogenic activity gradually abated and subsequently the highlands on the west were reduced considerably. Conditions changed from coarse sandstone deposition to the piedmont fluvial and lowland lacustrine environments during the deposition of the North Horn sands and muds. The North Horn sediments were deposited apparently without a break during the latest Cretaceous and early Paleocene time.

The post-North Horn, pre-Flagstaff regional compression that affected the Colorado Plateau and areas to the north along the west front of the Wasatch Plateau is not recorded by any observable relationship in this area, but
the Last Chance and possibly the Paradise folds may have been formed at this time.

Flagstaff Lake, the first of the large lakes that covered most of central Utah during the early Tertiary, covered this area in the middle Paleocene. One of the island areas in this lake was the above-mentioned eastern Sevier Valley highland that resulted from post-Blackhawk and pre-Flagstaff movements. In the early Eocene, stream-carried sand and pebbles from this island interfingered with the calcareous lake sediments during Flagstaff deposition. Conditions changed somewhat during the early Eocene in that the eastern Sevier Valley highland was topographically subdued, but not yet covered by the lake. The lacustrine variegated siltstones and shales of the Colton formation transgressed farther onto this highland and finally the area was inundated completely by the lake during deposition of the Green River formation.

Green River sedimentation was followed by a period of erosion that probably included late middle Eocene and early late Eocene time, during which there was regional upwarping of the eastern area and local faulting, but very little positive movement in the eastern Sevier Valley area. The Green River section was removed completely from areas east of Gates Creek and was eroded deeply except in the structurally low areas.
Streams draining into the former lake basin developed wide valleys and during and following the period of erosion deposited the Crazy Hollow muds and sands and, occasionally, quantities of pebbles. Renewed down-warping in this area or damming of the outlet area in late Eocene time caused a second great lake, the Gray Gulch lake, to form over this region. The Gray Gulch lake is believed to have extended south to the Bryce Canyon area, east to the vicinity of Thousand Lake Mountain, north to the Valley Mountains and west at least to the Pavant Mountain areas. Almost coincident with the beginning of lacustrine sedimentation, volcanic activity began in adjacent areas, probably to the southwest. There was sufficient ash to form a few bentonitic layers in the northern portion of the Fish Lake Plateau and to give much of the Gray Gulch section a white, chalky appearance. The deposition of muds and limestone precipitates in the lake gradually was succeeded by the deposition of coarser, more tuffaceous sands as the nearby extrusive activity increased. The last deposits in this lake, the sands of the Dipping Vat member, contain up to 50 percent glass fragments. The lake withdrew from this area in latest Eocene time, just before the formation of large volcanoes in the Sevier Plateau and Tushar Mountain areas. There was a short period of badland-type erosion into the Gray Gulch beds for the first records of the
existence of volcanoes are the igneous boulder-bearing mudflows that irregularly fill the badland gullies. In the period that followed, streams from the volcanoes carried huge quantities of igneous cobbles and coarse weathering products into the adjoining lowlands on the north, east and south. The area of thickest deposition that is preserved north of the volcanoes is along Little Lost Creek.

During the deposition of mudflows and igneous cobble conglomeratic sandstone a number of local disturbances that appear to be the result of cryptovolcanic activity caused local complex folding and faulting in the Little Lost Creek-Peterson Creek areas. Shortly after the cryptovolcanic(?) activity a series of tremendous gaseous explosions in the northern Tuschar Mountain area spread nuée ardente deposits over much of south-central Utah, with the northeastern limits in the Lost Creek area. This activity was succeeded by a period of volcanic growth during which streams draining north alternately carried coarse weathering products or were overrun by mudflows.

A general uplift of the region, probably during the early Oligocene, included differential forces that caused the folding of the Wasatch and Gates Creek monoclines and the development of other north to north-northwest trending folds and faults. The erosion that accompanied the uplift appears to have been active everywhere except over the
structurally low Little Lost Creek area, which continued to be overrun occasionally by mudflows. After considerable thickness of sediments had been removed from over the eastern regions and a nearly level surface was developed, most of the south half of the northern portion of the Fish Lake Plateau was covered by a series of lava flows from sources in the Sevier Plateau, Fish Lake Plateau and Hilgard Mountain areas. A vast lava field was formed by this extrusive activity that extended south for at least 84 miles and probably over an even greater east-west distance at the latitude of Marysvale. A series of flows filled a wide valley at the base of the Wasatch monocline northward to at least five miles north of the present Salina Canyon.

Exactly what followed this extrusive activity is not known. Volcanic activity continued in the Marysvale region, but there is no record of these events in this area. The succeeding period apparently was one of erosion and pediment development north and east of the lava-covered highlands, and it included the establishment of the present drainage pattern. Sometime after the drainage pattern was well-established, probably in the Miocene, the whole region was uplifted and normal faulting began. Individual fault movements were small, so the drainage pattern was not disturbed appreciably, but the cumulative effect on the later physiographic expression was great (following
differential erosion). The frequency of movements probably began to decrease at some time in the Pliocene because subsequent deposits are disturbed only locally by faulting. Stream erosion had developed considerable relief by late Pliocene or early Pleistocene time when there was a temporary halt of downcutting and the valleys were filled partly with coarse clastics. The coarse clastics of the Sevier River and Axtell formations may have accumulated at the same time, but such a correlation has not been demonstrated. About at this time small quantities of basalt issued along faults near Peterson Creek. The valley-filling coarse clastics subsequently were removed almost completely when base level was lowered again and stream erosion proceeded with renewed vigor.

With the change to humid conditions in the middle or late Pleistocene, precipitation increased, lakes were formed over the wide valleys to the west, slides became common (some of which probably were triggered by the earthquakes that resulted from minor movements along old or new faults) and locally small valley glaciers were formed in the highlands. Two distinct glaciations separated by an erosional interval indicate at least two cycles of humid conditions. The increase of vegetative cover during these pluvial cycles caused the valleys to be partly filled by alluvium.
The Recent events include melting of the glaciers, return to arid conditions with a decrease in slide activity, and the beginning of a new cycle of stream erosion that is causing arroyo cutting into the late Pleistocene alluvium. Most of the present slide activity is limited to the areas bordering the highest elevations, where precipitation and frost action are at a maximum.
Coal, gravel, oil and gas, and water are the products of real or potential economic value in the northern portion of the Fish Lake Plateau. Bentonite beds are present in the Colton and Gray Gulch formation, but none appear to have sufficient thickness to allow economic exploitation. The area has been examined for uranium mineralization and some places along Peterson Creek have been staked, but the writer found only a negligible amount of non-radioactive alteration. The following summary indicates the potential productivity of some of the more important materials.

Coal

The coal deposits of the northern portion of the Fish Lake Plateau that have been worked are in the Blackhawk formation of the Salina Canyon area and along the east front of the plateau. These deposits have been adequately investigated and reported on by Spieker and Baker (1928) and Spieker (1931). During the 1920's a number of small mines along Salina and Ivie Creeks exploited the coals and one, the Sevier Valley mine, sec. 20, T. 22 S., R. 3 E. stayed in operation until around 1940. Currently the only coal mining operations in the vicinity of the area here described are the Sunset mine in Convulsion Canyon, sec. 12, T. 22 S., R. 4 E. which is in a bed about 100 feet above the base.
of the Blackhawk, and the Browning mine, sec. 33, T. 22 S., R. 6 E. which is in a coal bed in the Ferron sandstone. The sample log (from The Texas Company files) of the El Paso Natural Gas Company No. 1 Salina Canyon unit, sec. 15, T. 22 S., R. 2 E. indicates a number of thick coal beds in the interval below the Star Point sandstone. The depths to this part of the section (1,300 to 2,600 feet) are too great to merit economic consideration at the present time.

Gravel

Thick gravel deposits that are moderately well-sorted and have a low clay content are found in the Price River, North Horn and Crazy Hollow formations and in the late Cenozoic gravel deposits. The gravel pits marked on the map are places where these deposits are being or have been worked. The only use to date has been as road metal. This area is assured of an ample supply for the future.

Oil and Gas

Gas is produced from the Ferron sandstone in the Clear Creek and Flat Canyon fields of the northern portion of the Wasatch Plateau and from the Dakota (?) sandstone in the Flat Canyon field (Walton, 1955). The gas has accumulated in structural traps similar to some in the northern portion of the Fish Lake Plateau. Gas also has been discovered in sandstone of the Moenkopi formation and in limestone of the
Sinbad member of the Moenkopi in the North Last Chance and South Last Chance anticlines, but has not been exploited because of lack of a pipeline (Hager, 1954).

Five tests for oil and gas have been drilled in the immediate area (see Pl. 16) but only one, the El Paso Natural Gas Company No. 1 Salina Canyon unit, was located within the area mapped. This well is a test of a 300 foot closure against the west fault of the Water Hollow graben. Since the fault dips away from the well, parts of the closure that structurally are higher could have been tested if the well had been located about a quarter of a mile or more east. The test was completed at 6,117 feet, after penetrating the top of the Morrison (?) formation. Cores were taken in the Ferron, Tununk and Dakota (?)-Cedar Mountain intervals, but no indications of oil or gas were recorded. The hole was plugged back and completed as a flowing water well from sands in the basal Blackhawk and Star Point intervals.

Three large structures in this area, Hoodoo dome, Gates Creek monocline and Paradise anticline have closures of considerable magnitude against east-bounding faults and certainly merit serious consideration for testing. Of the three, only the Paradise anticline needs additional structural data. Because exposures are almost nonexistent on the south flank of this structure, it would pay to make
a seismic investigation to determine the location of the crest.

Walton's study (1955) of the Wasatch Plateau gas fields has indicated to him that the gas accumulation in the Ferron sandstone is the result of a combination of structural and stratigraphic controls. These observations are especially interesting in evaluating stratigraphic conditions in the northern portion of the Fish Lake Plateau when the basal sandstone in the Ferron sections of the El Paso Natural Gas Company and the K.D. Owen (sec. 23, T. 22 S., R. 5 E.) wells is studied (Walton's Fig. 3, p. 400). There is the suggestion of a possible updip stratigraphic trap due to loss of porosity in this basal sand that should be investigated carefully in future tests of the eastern part of the Fish Lake Plateau.

In summary, the northern portion of the Fish Lake Plateau is a virgin territory for oil and gas exploration. Three large structural closures have been mentioned, but there are also other smaller fault traps. Production has already been established for limestones and sandstones of the Moenkopi formation and sandstones of the Dakota (?) and Ferron intervals in nearby areas, and according to available information, there is no reason to doubt their potential in this area. All of these intervals lie within reasonable drilling distances. The exploration for the possible oil or
gas entrapment by updip loss of porosity in the basal Ferron sandstone will have to await additional stratigraphic information that will be gained from testing of the structural traps.

Water

Water at present is the most important single commodity in central Utah. The Forest Service and Soil Conservation Department are constantly trying to improve control over stream runoff and to make better use of the water in the irrigatable areas. The main concern in the Salina area is increasing the flow of Salina Creek to make more water available, and to insure a steady flow during times of drought. The main untapped water sources are the Price River sands in the subsurface west of the area of outcrop. Wells located along the lower part of Gooseberry Creek or adjacent parts of Salina Creek should tap water with a hydrostatic head sufficient to cause a natural water flow. As mentioned above a water supply from the basal Blackhawk and Star Point sands already is being used from the El Paso Natural Gas Company well. Additional wells could be sunk west of this well that would tap the same sources at reasonable depths.
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Section No. 1

Section of biotite-hornblende tuff of Bullion Canyon series (restricted) measured at north end of cliff in NE\(^2\), sec. 15, T. 23 S., R. 1 W.

Bullion Canyon series (restricted)

6. Sandstone, conglomeratic, tuffaceous, light to medium gray. Laterally unit contains mudflows. (Upper part of middle unit) not measured

Disconformity

Biotite-hornblende tuff

5. Crystal tuff, grayish pink, well-indurated, rock consists of about 30 percent euhedral to anhedral minerals in a matrix that is about 70 percent glass. The rest of the groundmass is tuffaceous material. Maximum diameter of mineral grains is 3 mm, average is about 1.5 mm. Subparallel orientation of platy or elongated minerals but not as pronounced as in Unit 4. Rock contains some small lithic inclusions of a tuff of similar composition. Secondary carbonate fills small elongate pore spaces. Minerals: plagioclase (Ab\(^{50}\)An\(^{50}\)), euhedral, 60-70 percent; biotite, 15 percent; quartz, 5-10 percent; hornblende (lamprobolite), 5 percent; magnetite, 1-2 percent; trace of pyroxene. Some of the crystals have an angular broken appearance. Plagioclase grains are fresh and some exhibit zonal growth. Hornblendes are commonly twinned. The composition appears to be that of dacite.

4. Crystal tuff, grayish pink, powdery, weakly indurated, shows a preferred subparallel orientation of platy and acicular mineral grains and inclusions, diameters are usually 1-2 mm. Rock contains approximately 20 percent euhedral to anhedral mineral grains, 15-20 percent angular glass fragments, with the balance a tuffaceous groundmass that includes a large amount of small interlocking glass shards and rounded inclusions of purely
tuffaceous material. The minerals are: plagioclase (Ab$_{50}$An$_{50}$) most of which shows zonal growth, 60-70 percent; biotite, 5-10 percent; hornblende (lamprobolite), 15-20 percent; magnetite, 1 percent; trace of pyroxene.
All minerals have a distinctly fresh, unaltered appearance. The hornblends are commonly twinned. Some of the plagioclase contains minute inclusions of pyroxene, amphibole or glass and spherical bubbles.
The composition appears to be that of andesite.

3. Tuff, light gray, medium to coarse, friable, pronounced flow structure - subparallel alignment of acicular and platy minerals.
Composition: glass fragments and shards, 50 percent; plagioclase, 30 percent; quartz, 5 percent; hornblende, 5 percent; biotite, 4 percent; magnetite, trace; ashy matrix, 5-6 percent; igneous rocks fragments (medium to coarse size), trace

2. Tuff, light gray, very fine, mainly ash, fine glass shards, and minor amounts of (microlite size) twinned plagioclase, quartz, hornblende and biotite; pebbles of intermediate igneous rocks plastered in base, basal surface has little relief

Total Biotite-hornblende tuff

1. Sandstone, tuffaceous, medium to light gray, coarse, irregularly bedded, upper part of middle unit

(not measured)
Section No. 2

Section measured along Little Lost Creek road from sec. 30, T. 23 S., R. 1 E., to sec. 18, T. 24 S., R. 1 E.

Bullion Canyon series, lava flows

5. Lava flow, medium gray, weathers medium gray with local iron stain. Vesicular, with vesicles up to 1 by 4 cm elongated with direction of flow. Rock is aphanitic with less than 10 percent phenocrysts, which are mainly anhedral to subhedral andesine, with lesser amounts of euhedral augite, traces of quartz and accessory magnetite. Neither the plagioclase nor pyroxene is altered. Some of the magnetite is partly altered to hematite. Vesicles are thinly lined with calcite.

Bullion Canyon series (restricted)

Upper unit

4. Mudflows and tuffaceous conglomeratic sandstones intercalated in 20-40 foot intervals. Percentage of mudflow material increases upward, and upper 540 feet of interval is almost entirely mudflow material. Where sampled the mudflows are composed mainly of angular fragments up to boulder size of reddish gray to light medium gray aphanitic lavas that have a few small phenocrysts of plagioclase and amphibole. Conglomerates at base contain cobbles of biotite-hornblende crystal tuff.

Middle unit

3. Sandstone, conglomeratic, tuffaceous, and some interbedded tuff, gray to light gray, massive or irregularly bedded; sandstone shows some cross-bedding; cobbles and pebbles, where sampled, consist mainly of (hand sample identifications) andesite porphyry, lesser quantities of hornblende andesite porphyry, dacite (?) porphyry and weathered gray indurated tuffs. The
cobbles are well rounded and largely unaltered by weathering. Sandstones are poorly sorted, angular, and contain euhedral fragments of clear plagioclase, biotite and hornblende, and high percentages of glass fragments. Massive units exhibit honeycomb weathering.

Lower unit

2. Mudflows, channel-filling, dark gray to medium gray, very irregular in shape, contain angular to subrounded boulders and cobbles of fresh gray latite, weathered indurated red tuff, and lesser amounts of fresh gray andesite (hand sample identifications) in a matrix of tuffaceous sandstone similar to that described above, but without high percentage of euhedral mafic minerals and only about 10 percent glass fragments. The mafic minerals of the lavas are commonly altered to chlorite.

Total Bullion Canyon formation

Dipping Vat member of Gray Gulch formation

1. Sandstone, light to medium gray, coarse, tuffaceous, evenly bedded

Section No. 3

Section of Bald Knoll and Dipping Vat members of Gray Gulch formation measured along a line starting in cutbank on west side of Lost Creek in sec. 1, T. 23 S., R. 1 W. and ending in northeast quarter, sec. 11, T. 23 S., R. 1 W. Section 3 is believed to be approximately the continuation of section 4.

Covered

Bullion Canyon formation
27. Sandstone, conglomeratic in part, tuffaceous, very coarse; quartz, glass, feldspar, biotite, and hornblende grains with trace of magnetite and tourmaline. Laterally contains interbedded mudflows and more tuffaceous units.

Dipping Vat member of Gray Gulch formation

26. Sandstone, tuffaceous, light to medium gray, coarse, evenly bedded; rounded weathering; 50 percent glass grains (n 1.502, – probably latite glass), 30 percent quartz, 10 percent plagioclase, plus biotite, magnetite, fragments of weathered feldspar, and a clay cement

25. Sandstone, tuffaceous, medium gray, massive, medium; contains about 15 percent glass grains. Unit is poorly exposed, covered in part by medium gray soil.

24. Sandstone, light gray to white, medium, angular, quartz with considerable glass, minor amounts of biotite, orthoclase, magnetite, calcite and feldspar grains in white clay cement. Unit is friable and mostly soft with some rounded weathering, ledge-forming intervals.

23. Sandstone, light gray, with tuffaceous appearance, coarse, contains fragments of calcite and clay; with some interbedded soft gray shale and thin-bedded silty limestone. Unit is more resistant than underlying units; has rounded, massive form.

22. Sandstone, white to light gray, coarse, angular, white clay cement; mostly quartz grains with 5 percent fine glass, 5 percent biotite, and traces of orthoclase, plagioclase, muscovite, and magnetite. Unit is soft, friable, and weathers to a rounded outcrop.
20. Shale, silty, reddish orange, soft, weathers to characteristic orange soil

19. Siltstone, calcareous, light gray, thin-bedded

18. Shale, silty, light red, soft. Soil developed over unit is characteristic orange color.

17. Shale, light gray, soft, with a few beds of light gray thin-bedded silty limestone

16. Limestone, silty to sandy, light gray, unevenly bedded; ledge former

15. Siltstone to very fine sandstones, light gray, soft, non-resistant

14. Limestone, silty in part, light gray, unevenly bedded; ledge former

13. Shale, light medium gray, soft, with disseminated mica flakes. In the middle of this thick sequence are a few thin (3 to 12 inch) beds of sandstone, light gray, medium to coarse, mainly quartz, but containing biotite,
feldspar, calcite, chert and magnetite grains; and light gray silty limestones

12. Limestone, silty, light gray; interbedded with mottled reddish orange and light gray shale. Unit weathers with characteristic reddish orange color. Minor ledge former

11. Siltstone, light to medium gray, soft

10. Limestone, silty, light gray, weathers with characteristic orange stain, contains biotite flakes and finely disseminated specks of limonite

9. Interbedded shale, light to medium gray, soft; sandstone, calcareous, medium gray, fine, quartz with some mica flakes, soft, more resistant and thin-bedded where limy; and light gray silty limestone. Whole unit is non-resistant

8. Siltstone, limy in part, light gray, massive, soft

7. Shale, light gray, soft

6. Limestone, light gray, weathers orange, dense, thin-bedded

5. Sandstone, medium gray, very fine to fine, angular, quartz grains with about 10 percent biotite grains and a trace of very fine glass shards, massive

4. Shale, silty, bentonitic, light to medium gray, soft

3. Limestone, light gray to white, massive, partly crystalline; with several 6 to 12 inch beds of soft light gray slightly bentonitic silty shale. Minor ledge-forming unit

2. Shale, light gray, soft; shale, bentonitic, medium gray, soft, sandy in part; and occasional (every 12 feet) 3 to 8 inch beds of light gray to white
thin-bedded limestone. A lenticular limestone bed that caps unit may be up to 6 feet thick.

1. Regularly interbedded sandstone, light gray, somewhat lenticular, fine, angular, containing quartz and minor amounts of chert, jasper, biotite, and feldspar grains and a trace of glass fragments; and soft light gray bentonitic silty shale (6 to 8 foot beds). Shale contains some thin (2 inch) beds of light gray limestone. Whole unit is non-resistant

Lost Creek

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<th>Description</th>
<th>Feet</th>
<th>Inches</th>
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<td>892</td>
<td>11</td>
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<tr>
<td>Total measured Gray Gulch formation</td>
<td>1101</td>
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Section No. 4

Basal section of Bald Knoll member of Gray Gulch formation measured east of Lost Creek in sec. 1, T. 23 S., R. 1 W.

Section starts west of fault in slope above a cut bank.

Fault

Bald Knoll member of Gray Gulch formation

8. Shale, slightly bentonitic, silty, light gray, soft; with several 3 to 12 inch beds of sandstone, medium gray, very fine, soft, lenticular; and hard light gray limestone. Unit is non-resistant. Top is faulted.

7. Sandstone, light gray, lenticular, medium, angular, grains are clear frosted quartz, biotite, gray chert, jasper, and feldspar (no volcanic glass fragments), some cross-bedding; ledge former
6. Shale, bentonitic, light gray; with thin (3 to 6 inch) beds of sandstone, medium gray, fine to medium, thin-bedded; and gray limestone. Whole unit is non-resistant.

Total measured Bald Knoll member

Top of Crazy Hollow formation

5. Sandstone, medium gray, lenticular, very fine, quartz grains with minor amounts of biotite, hematite, and feldspar; massive; minor ledge former

4. Limestone, silty, brownish red mottled with gray; rock is 40 percent very well-sorted angular quartz grains with a trace of feldspar, biotite, and hematite; irregularly thin-bedded; some interbedded soft brownish red shale

3. Sandstone, medium gray, lenticular, thin-bedded, fine, sub-angular, quartz and calcite grains with minor amounts of feldspar (weathered) and mica, calcareous cement; minor ledge former

2. Regularly interbedded (3 to 5 foot beds) shale, limy, mottled brownish red and light gray; sandstone, medium gray, fine to medium, clear quartz grains with traces of chert and biotite; and light gray silty limestone. Limestone and sandstone beds are minor ledge formers.

1. Sandstone, medium gray, lenticular, fine to medium, subangular, poorly sorted, calcareous cement; clear quartz grains with some black, gray, and brownish red chert grains; weathers to rounded forms

Lost Creek

Total exposed Crazy Hollow formation
Section No. 5
Section of basal portion of Crazy Hollow formation measured in SE$^1_4$ sec. 22, T. 22 S., R. 1 E.

### Crazy Hollow formation

<table>
<thead>
<tr>
<th>Covered</th>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. Sandstone, argillaceous, brown, fine to medium, thin-bedded; minor ridge former</td>
<td>6+</td>
<td></td>
</tr>
<tr>
<td>13. Shale, brownish red, soft</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>12. Sandstone, brownish red, fine, concretionary</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11. Sandstone, mottled grayish purple and yellow, fine to medium, friable</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>10. Sandstone, argillaceous, light gray, fine, subangular, friable; non-resistant</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>9. Shale, brownish red, soft; with lenses of mottled brownish red and yellow, medium sandstone</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>8. Conglomerate, in part conglomeratic sandstone, medium gray, pebbles are 40 percent black chert; 30 percent light colored quartz, chert, and quartzite; 20 percent gray, green and red chert; and 10 percent misc. (as, agate, limestone); all are well rounded and have a maximum diameter of 2 1/2 inches; gravel is used for road surfacing</td>
<td>27</td>
<td>5</td>
</tr>
<tr>
<td>7. Shale, brownish red, soft; with thin lenses of very fine orange sandstone</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>6. Shale, silty, reddish orange, soft</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>5. Sandstone, light gray, very fine</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4. Covered, orange soil</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>3. Conglomerate, medium gray, mainly black and gray chert pebbles</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
2. Covered, orange soil

<table>
<thead>
<tr>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44</td>
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</tbody>
</table>

Total measured Crazy Hollow formation

<table>
<thead>
<tr>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>162</td>
<td>8</td>
</tr>
</tbody>
</table>

Disconformity

Top Green River formation

1. Limestone, silty, white, dense, thin-bedded, platy  
   not measured

Section No. 6

Measured section of Green River, Crazy Hollow and basal Gray Gulch beds exposed west of Soldier Canyon in NE^½ sec. 8 and NW^½ sec. 9, T. 22 S., R. 1 E.

Section starts in Bald Knoll member of Gray Gulch formation.

Covered

42. Shale, medium gray; with interbedded gray bentonitic clay  
    not measured

41. Limestone, yellowish gray, crystalline; contains crystalline casts of the small gastropod *Hydrobia*? and unidentifiable pelecypods; minor ledge former  
    5

40. Clay, medium gray, bentonitic; interbedded with dark gray bentonitic shale. Unit contains numerous charophyte oogonia of *Chara* sp., Planorbid gastropods and rare ostracode tests  
    Total measured Bald Knoll member of Gray Gulch  
    50  
    55

Top Crazy Hollow formation

39. Shale, interbedded brownish red and light gray, soft  
    70

38. Sandstone, tan, fine, angular, quartz  
    1
37. Shale, silty, brownish red
36. Sandstone, light gray, fine, quartz; minor ledge former
35. Shale, brownish red; with interbedded siltstone, brownish red to orange; and medium to fine angular light gray sandstone; shales predominating. Sandstones are minor ledge formers.
34. Sandstone, light gray to yellow, soft, friable, medium, frosted
33. Sandstone, light gray, fine to medium, subrounded, in part pepper-and-salt type because of gray chert grains, frosted; varying resistance; minor ledge former; contains a few thin lenses of brownish red shale
32. Sandstone, mottled red and brownish reddish orange, medium, subangular; with lenses of gray coarse subangular pepper-and-salt cross-bedded frosted sandstone, which are more resistant than balance of unit
31. Sandstone, medium gray, coarse, pepper-and-salt, cross-bedded, friable in part; ledge former, very rough weathered surface; chert pebbles (diameters up to 1 inch) near base
30. Sandstone, mottled brownish red and yellow, fine to medium; unit covered in part; may contain lenses of brownish red shale in covered part of slope
29. Sandstone, light gray, coarse, frosted, soft, pepper-and-salt, friable, cross-bedded; rounded weathering
28. Shale, purplish red; with a 5 foot lens of sandstone, as next above, near top
27. Sandstone, tan, medium, soft

Feet Inches
24
4
240
75
148
143
19
15
23
42
15
26. Shale, brownish red to orange, silty in part, with intercalated 3 foot lenses of gray medium friable sandstone

25. Sandstone, gray, medium to coarse, sub-rounded, pepper-and-salt, cross-bedded, friable; channel-filling at base; ridge former; interfingers with brownish red shale to south

24. Covered. Probably brownish red shale

23. Sandstone, medium gray, pepper-and-salt, medium, cross-bedded; irregularly weathering with honey-comb surface

22. Shales, interbedded dark red, medium gray and orange, sandy in part

21. Sandstone, medium gray, pepper-and-salt, medium, 15 percent dark chert grains, some cross-bedding, friable, ledge former

20. Shale, brownish red; with interbedded greenish gray sandy shale

19. Shale, calcareous, light gray

Total Crazy Hollow formation

Erosional disconformity

Top Green River formation

18. Limestone, white to light gray, massive; irregularly replaced by bluish black to medium gray to white silica

17. Limestone, light gray to white, siliceous, thin-bedded, platy; with small amounts of interbedded gray chert. Some beds contain fragments of cylindrical shaped algal (?) growths up to 1 mm long, 1/10 mm in diameter

16. Limestone, white to light gray; average replacement by silica, 25 percent; contains abundant tests of the ostracode _Heterocypris_ sp.
15. Chert, brown; and light gray thin-bedded limestone, partially replaced by silica; algal growths as in unit 17

14. Shale, light brown

13. Limestone, white, approximately 50 percent replaced by silica; contains conspicuous irregular concentric algal growths and abundant tests of the ostracodes *Heterocypris*, *Cyprois* cf. *marginata* (Strauss), and *Cypris pagei* (Swain)

12. Limestone, yellowish gray, partly oolitic, contains scattered very fine angular fragments of quartz; with some interbedded thin sheets of gray chert

11. Limestone, white to yellowish gray, irregularly replaced by blue to gray silica; irregular algal growths locally

10. Shale, grayish green to light gray and irregularly intercalated white limestone; traces of gastropod remains

9. Limestone, white, massive, irregularly replaced by silica

Disconformity

8. Shale, grayish green

7. Limestone, as in Unit 9, 30-60 percent replaced. Replacement is irregular both vertically and laterally

6. Limestone, light gray, massive, dense; with characteristic concoidal weathering habit. Not as resistant as limestone units above and below

5. Shale, grayish green, soft

4. Limestone, white, oolitic in part, massive, up to 80-90 percent replaced by silica; ledge former

3. Chert, mottled medium gray and blue
2. Limestone, white, chalky, oolitic in part, massive

1. Sandstone, calcareous, white to tan, fine, 3 inch ferruginous layer near top. Same bed as unit 16, Section No. 7

Alluvium

Total measured Green River formation

<table>
<thead>
<tr>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>663</td>
<td>8</td>
</tr>
</tbody>
</table>

Section No. 7

Basal section of Green River formation measured on east side of the mouth of Soldier Canyon, NW\(\frac{1}{4}\) sec. 4, T. 22 S., R. 1 E.

Top of canyon wall

Green River formation (not top)

17. Limestone, white, dense, partly replaced by silica (not measured)

16. Sandstone, calcareous, white to tan, fine, 3 inch ferruginous layer near top. Same as unit 1, Section 6

15. Limestone, white, thin-bedded to massive; thin algal growths near top of unit; with interbedded gray dense chert beds (8 inches thick); massive portions are largely replaced by silica

Top of shale sequence

14. Shale, arenaceous, grayish green, thin-bedded, soft

13. Sandstone, light brown, massive, fine, some dark chert grains, some cross-bedding; contains ferruginous concretions

12. Limestone, light gray, very thin-bedded in part; contains lenses of fissil green shale
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Shale, grayish green, grades upward into thin-bedded grayish green limestone</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>Sandstone, calcareous, light brown, medium</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Shale, greenish gray, with interbedded thin (1 foot) intervals of white cherty argillaceous limestone. The latter are ripple-marked and mud-cracked</td>
<td></td>
<td>96</td>
</tr>
<tr>
<td>8</td>
<td>Evenly interbedded limestone, white to light gray; and grayish green shale; unit is ledge former</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td>7</td>
<td>Shale, grayish green; with thin layers of dense platy white limestone</td>
<td></td>
<td>77</td>
</tr>
<tr>
<td>6</td>
<td>Shale, calcareous, light olive gray, paper thin-bedded, non-resistant; contains impressions and carbonaceous films of dismembered insects</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Shale, grayish green, soft; with thin lenses of sandstone, gray, fine, hard and dense thin-bedded white limestone</td>
<td></td>
<td>123</td>
</tr>
<tr>
<td>4</td>
<td>Limestone, white, dense, massive; ledge former; lenticular</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Limestone, light gray, dense, platy</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Shale, silty, grayish green; with intercalated thin beds of fine medium gray sandstone</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total of basal green shale interval</td>
<td>430</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Total measured Green River formation</td>
<td>478</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Total Green River formation, Sections no. 6 and 7</td>
<td>1139</td>
<td>2</td>
</tr>
</tbody>
</table>

Top of Colton formation

1. Shale, brownish red, soft

Alluvium
Section No. 8

Section of Green River formation measured in NE\(^2\) sec. 1, T. 23 S., R. 1 E.

45. Reddish brown soil, no exposures

Top of Green River formation

44. Limestone, light gray, silty, thin-bedded; with interbedded gray chert 16 6

43. Covered, probably limestone 231

42. Limestone, slightly oolitic, light gray to white, thin-bedded, soft, tests of ostracode *Heterocypris* sp. 88

41. Sandstone, brown, medium, soft, friable, irregularly bedded 2 11

40. Limestone, light gray, thin-bedded, platy, non-resistant, ostracode tests (not separable) 26 6

39. Limestone, algal, partly replaced by silica 3

38. Limestone, light gray, thin-bedded, platy in part 5 7

37. Limestone, arenaceous, light greenish gray; poorly exposed 11

36. Sandstone, micaceous, with considerable weathered feldspar, tan, fine; contains abundant fragments of woody material; minor ledge former 3 3

35. Limestone, silty, light gray to white, thin-bedded, non-resistant 3

34. Siltstone, grayish green; minor ledge former 10

33. Chert, mottled grayish green and gray with ferruginous streaks, scattered biotite flakes, brittle 7

32. Limestone, cherty white, silty in part, thin-bedded 20
31. Limestone, algal, light gray, replaced by silica 6
30. Siltstone, grayish green; minor ledge former 3 5
29. Shale, mottled grayish green and brown, soft 7 9
28. Limestone, cherty, pinkish white, dense, massive 6
27. Bentonite, medium gray to grayish green, soft 5
26. Siltstone, light green, massive; ledge former 2 10
25. Shale, grayish green, rare ostracode tests; with interbedded light gray limestone 17
24. Limestone, white to pink, dense, concoidal fracture; and several lenses of green fissil shale; minor ledge former 3 10
23. Shale, silty, calcareous, grayish green, soft 35 6
22. Siltstone, limy, medium gray, with ferruginous specks 6
21. Shale, green, soft 6 3
20. Sandstone, green, fine, massive; ledge former 4 6
19. Shale, grayish green, fissil; with lenses of thin-bedded silty limestone 5
18. Limestone, medium light gray, ferruginous streaks, thin-bedded; minor ledge former 8
17. Shale, green, soft, grades upward into grayish green limy shale 11 6
16. Siltstone, limy, medium gray, thin-bedded, non-resistant, grades upward into unit 17 3
15. Shale, green, soft 3 5
<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.</td>
<td>Sandstone, limy, green, fine to medium; minor ledge former</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>13.</td>
<td>Shale, dark green, soft</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>12.</td>
<td>Limestone, medium gray, thin-bedded</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>11.</td>
<td>Shale, dark green, soft</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>10.</td>
<td>Limestone, as in unit 12</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>9.</td>
<td>Shale, dark green, soft</td>
<td></td>
<td>5 6</td>
</tr>
<tr>
<td>8.</td>
<td>Siltstone, calcareous, greenish gray</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>7.</td>
<td>Shale, green, soft</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>6.</td>
<td>Shale, calcareous, light olive gray, paper thin-bedded, with abundant impressions and carbonaceous films of dismembered insects</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>5.</td>
<td>Shale, green, soft</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>4.</td>
<td>Limestone, silty, light gray, thin-bedded</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>3.</td>
<td>Shale, olive green, soft</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>2.</td>
<td>Limestone, silty, white, thin-bedded, platy, some cross-bedding</td>
<td></td>
<td>6 6</td>
</tr>
<tr>
<td>1.</td>
<td>Shale, grayish green, grades upward to medium gray thin-bedded and minutely cross-bedded medium-grained sandstone</td>
<td></td>
<td>20</td>
</tr>
</tbody>
</table>

**Alluvium. Estimated covered Green River formation**

<table>
<thead>
<tr>
<th>Description</th>
<th>Total measured Green River formation</th>
<th>Estimated total Green River formation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>660 2</td>
<td>760</td>
</tr>
</tbody>
</table>
Section No. 9

Section of Colton formation measured in S\(\frac{1}{2}\) sec. 24, T. 22 S., R. 1 E.

Green River formation

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Shale, grayish green, soft</td>
<td>20</td>
<td>+</td>
</tr>
<tr>
<td>20</td>
<td>Limestone, light gray to white, dense, contains small fragments of green shale</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>19</td>
<td>Shale, green, soft; with a few lenses (not over 6 inches thick) of gray thin-bedded fine-to medium-grained minutely cross-bedded sandstone</td>
<td>11</td>
<td>8</td>
</tr>
</tbody>
</table>

Total measured Green River formation 32

Top of Colton formation

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Shale, brownish red mottled with gray, soft</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Shale, medium gray, mottled with purplish gray, soft</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>Shale, purplish gray, soft</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>Shale, brownish red, mottled with gray in part; with thin (2 to 3 inch) lenses of light gray very fine sandstone; unit weathers with orange soil</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Shale, purplish gray, soft, arenaceous in part</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Shale, brownish red, some layers mottled with medium gray; lenses of gray silty clay; non-resistant</td>
<td>192</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>Siltstone, argillaceous, light gray, soft</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Siltstone, argillaceous, brownish red, slightly mottled with gray, soft</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
10. Limestone, silty, white, dense, concoidal fracture, brittle; prominent ledge former 1 2

9. Shale, silty, brownish red, mottled in part with gray; scattered plant fragments 55

8. Covered, believed to be same as above 159

7. Sandstone, yellowish gray, fine, massive; ledge former 1 5

6. Siltstone, calcareous, light gray, massive, resistant 1

5. Shale, silty, brownish red, mottled with gray and yellow 7 6

4. Bentonite, sandy in part, becomes limy at top, light gray, abundant tests of the ostracodes Cypris pagei (Swain), Heterocypris sp., and Cyprois sp. 4

3. Shale, mottled brownish red and medium gray, soft 11

2. Siltstone, calcareous, contains coarse sand grains, mottled brownish red, gray and yellow; gradational both up and down 2+

Total Colton formation 531 7

Top Flagstaff formation

1. Sandstone, medium gray, fine to coarse, poorly sorted; forms prominent dip slope 10+

Section No. 10

Incomplete section of Flagstaff formation measured in sec. 13, T. 22 S., R. 1 E.

Erosion surface
Flagstaff formation

17. Limestone, light gray to white, dense, massive 8
16. Shale, calcareous, grayish yellow green, soft 1
15. Shale, purple to red, soft, poorly exposed 4 8
14. Shale, reddish brown, soft, poorly exposed 10
13. Sandstone, argillaceous, grayish yellow, fine to medium, poorly sorted, massive 10 2
12. Siltstone, calcareous, mottled light gray, purplish red and yellow, dense 1 6
11. Shale, calcareous, mottled reddish brown and yellow, soft; irregular surface at top 2 10±
10. Limestone, silty, mottled light gray and grayish purple; interbedded with shale, as next above; slope former 6
9. Siltstone, calcareous, arenaceous, mottled yellow and reddish brown, massive 6 2
8. Sandstone, yellow, weathers light gray, fine to medium, massive; contains thin lenses of siltstone, as next above; ledge former 21 10
7. Shale, mottled reddish brown and yellow, soft 6
6. Limestone, silty, light grayish purple mottled with light gray, dense 2
5. Shale, mottled grayish red and yellow, soft 4
4. Siltstone, calcareous, light gray, dense, massive; grades upward 1 8
3. Limestone, shaly, light grayish purple, dense; grades into mottled dark red, yellow and gray limy shale; unit is non-resistant

2. Calcarenite, silty in part, light gray to yellowish gray, massive to thin-bedded, abundant tests of the ostracodes *Heterocypris* sp. and *Cyprosis cf. marginata* (Strauss); concentric weathering habit; ledge former

1. Calcarenite, arenaceous, mottled reddish brown, yellow and light gray, massive; base not exposed

Covered, see section No. 13 for continuation

<table>
<thead>
<tr>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>10</td>
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<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

Total measured Flagstaff formation

Section No. 11

Section measured on north side of Salina Canyon, SW 1/4 sec. 34, T. 21 S., R. 1 E.

Colton formation

17. Shale, brownish red, soft, covered

Flagstaff formation

16. Siltstone, calcareous, mottled brownish red, yellow and light gray; minor ledge former

15. Sandstone, conglomeratic in part, yellowish gray, coarse, subrounded, some cross-bedding, and channeling; laterally at about this horizon, channels up to 47 feet deep are cut into underlying units and filled with conglomeratic sandstones of approximately this description

<table>
<thead>
<tr>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
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<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>14.</td>
<td>Shale, mottled, brownish red and yellow, soft</td>
</tr>
<tr>
<td>13.</td>
<td>Siltstone, calcareous, arenaceous, brownish red</td>
</tr>
<tr>
<td>12.</td>
<td>Sandstone, calcareous, brownish gray, fine, subrounded, massive, hard; cliff former</td>
</tr>
<tr>
<td>11.</td>
<td>Shale, calcareous, mottled grayish red and gray, soft</td>
</tr>
<tr>
<td>10.</td>
<td>Sandstone, calcareous, yellowish gray, fine to medium, massive, hard</td>
</tr>
<tr>
<td>9.</td>
<td>Limestone, silty, grayish red, soft</td>
</tr>
<tr>
<td>8.</td>
<td>Limestone, argillaceous in part, light brownish gray, massive; ledge former, concoidal weathering habit; abundant tests of the ostracodes <em>Heterocypris</em> sp. and <em>Cypris pagei</em> (Swain)</td>
</tr>
</tbody>
</table>

**Total Flagstaff formation**

80 7

**North Horn formation (top is covered)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Covered, probably shale, grayish red to purplish red</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Sandstone, conglomeratic, gray, poorly sorted</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Shale, grayish red, soft; with lenses of yellowish gray siltstone</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>4.</td>
<td>Sandstone and siltstone, yellowish brown; with two thin lenses of light grayish red siltstone</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Siltstone, calcareous, yellowish gray, soft</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>2.</td>
<td>Siltstone, argillaceous, calcareous, grayish brown, thin-bedded; interbedded with mottled grayish red and yellow argillaceous siltstone</td>
<td>10</td>
<td>6</td>
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</tbody>
</table>
1. Sandstone, light gray to yellowish gray, medium to coarse, poorly sorted

<table>
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<th>Inches</th>
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<tbody>
<tr>
<td>1</td>
<td>6</td>
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Total measured North Horn formation 64 8

Unconformity

Indianola group

Section No. 12

Section of Flagstaff formation measured west of Niotche Creek in NE\(\frac{1}{4}\) sec. 35, T. 23 S., R. 2 E.

Flagstaff formation

Top of exposed section is a weathered surface covered with black chert and white quartz pebbles and pieces of chert pebble conglomerate, ferruginous sandstone, algal limestone that has been replaced by silica, oolitic limestone and ostracode limestone that contains fish scales. This material is probably not a remnant of a late Tertiary gravel deposit as no lava pebbles were included.

24. Limestone, white, thin-bedded, reworked in part 1 10

23. Shale, grayish green, soft; scattered ferruginous specks 6

22. Limestone, cherty, white, dense, thin-bedded to massive; contains scattered rhombic fish scales and rare ostracode tests 10

21. Limestone, cherty, white, dense, vertical jointing, evenly bedded, in 3 to 5 foot thick intervals; interbedded with 8 to 12 inch layers of soft light gray calcareous shale; the lithologies are usually gradational from one into the other 49 6

20. Limestone, medium gray, dense, massive, brittle 9
19. **Shale, brown, soft**

18. **Limestone, light brown to medium gray, irregularly bedded; shaly in part; minor ledge former**

17. **Shale, mottled grayish green and brown; with some interbedded light gray dense fractured limestone**

16. **Limestone, light gray, dense, non-resistant because unit is fractured; contains lenses of mottled grayish green and brown shale**

15. **Sandstone, brown to light brown, fine to medium, cross-bedded, non-resistant, massive; rounded outcrop; becomes irregularly intercalated with green siltstone at 20 feet above base; by gradation unit is predominantly green siltstone in upper portion**

14. **Sandstone, argillaceous, yellowish gray, fine to medium, irregularly bedded; minor ledge former**

13. **Shale, mottled grayish green and brown; some portions pure dark green; soft**

12. **Limestone, argillaceous, alternating dark brown and brown layers in pairs 1/10 mm to 2 mm thick, channeling is common, dense, thin-bedded, weathers white; non-resistant**

11. **Shale, dark green, soft, contains scattered plant fragments; mottled with brown towards top of unit**

10. **Clay, grayish green, soft**

9. **Sandstone, calcareous, reddish orange, medium, contains small pieces of wood**

8. **Limestone, silty, light gray, massive; non-resistant**
7. Limestone, light gray, reworked, thin-bedded

6. Limestone, silty, light gray, dense, massive, concoidal fracture; with cigar-shaped grayish brown chert concretions

5. Shale, dark green, soft

4. Limestone, medium gray, dense, massive; ledge former

3. Limestone, light gray, dense, massive; ledge former

2. Limestone, light gray, dense; with some interbedded soft greenish gray shale; sequence is incompletely exposed

1. Limestone, silty, light gray, dense, evenly bedded; base not exposed

Niotche Creek

<table>
<thead>
<tr>
<th>Section measured from NE(\frac{1}{4}) sec. 29, T. 22 S., R. 2 E. to NE(\frac{1}{4}) sec. 24, T. 22 S., R. 1 E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagstaff formation</td>
</tr>
<tr>
<td>65. Siltstone, mottled yellow, brownish red and gray</td>
</tr>
<tr>
<td>64. Limestone, arenaceous, yellowish gray, massive, blocky ledge former, contains tests of the ostracodes Heterocypris sp. and Candona sp.</td>
</tr>
<tr>
<td>63. Siltstone, calcareous, mottled purplish red and light gray, soft</td>
</tr>
</tbody>
</table>
62. Sandstone, limy, mottled yellow and brownish red, unevenly bedded

Total measured Flagstaff formation

North Horn formation

61. Shale, reddish orange; with a lense of light gray fine sandstone

60. Shale, brownish red, mottled with yellowish gray, soft

59. Sandstone, yellowish gray, very fine, well-sorted, cross-bedded, massive; ledge former; with 1 to 3 inch lenses of brownish red shale; percentage of shale increases upward

58. Shale, arenaceous, brownish red mottled with yellowish gray, soft

57. Sandstone, locally conglomeratic with fine-to medium-grained matrix, yellowish gray, channeling into underlying unit, cross-bedded, with pebbles aligned along cross beds

56. Shale, silty, brownish red mottled with medium gray in part, soft; with lenses up to 1 foot thick of yellowish gray medium sandstone

55. Sandstone, yellowish gray, fine to medium, subrounded, evenly bedded, hard; minor ledge former

54. Clay, arenaceous, grayish red, soft

53. Sandstone, yellowish gray, medium, subrounded, evenly bedded; minor ledge former

52. Shale, silty, brownish red with medium gray shale; interbedded in 3 foot beds; with occasional lenses of yellowish gray fine argillaceous sandstone
<table>
<thead>
<tr>
<th>Feet</th>
<th>Inches</th>
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<tbody>
<tr>
<td>51. Sandstone, pale yellowish orange, fine to medium, friable, frosted, rounded; with interbedded lenses and channel-fills of chert and quartzite pebble conglomerate, maximum diameter - 5 inches; unit is prominent ridge former</td>
<td>52</td>
</tr>
<tr>
<td>49. Shale, brownish red, soft; and soft, medium gray shale; interbedded in 4 to 8 foot beds</td>
<td>93 6</td>
</tr>
<tr>
<td>48. Interbedded shale, grayish red, soft; and yellowish gray siltstone</td>
<td>11</td>
</tr>
<tr>
<td>47. Sandstone, yellowish gray, fine to coarse, poorly sorted, friable, but locally well-indurated; massive</td>
<td>2 11</td>
</tr>
<tr>
<td>46. Shale, medium gray, soft; contains beds of brownish red shale near top</td>
<td>35</td>
</tr>
<tr>
<td>45. Shale, silty in part, mottled medium gray and brownish red</td>
<td>11</td>
</tr>
<tr>
<td>44. Sandstone, tan, medium to coarse, poorly sorted, coarse material is subangular; minor ledge former</td>
<td>2 10</td>
</tr>
<tr>
<td>43. Shale, silty, brownish red; with included thin beds of sandstone, light brown, very fine and soft medium gray shale</td>
<td>13 7</td>
</tr>
<tr>
<td>42. Sandstone, conglomeratic, light gray, poorly sorted, cross-bedded; minor ledge former</td>
<td>1 2</td>
</tr>
<tr>
<td>41. Shale, medium gray, soft; with interbedded brownish red arenaceous shale</td>
<td>21 6</td>
</tr>
</tbody>
</table>
40. Sandstone, light gray, coarse, sub-rounded, lenticular; minor ledge former

39. Shale, purple gray, soft; with interbedded layers of fine light gray sandstone

38. Sandstone, conglomeratic, yellowish gray, poorly sorted, friable, channel-filling

37. Shale, purplish gray, soft

36. Interbedded shale, silty, brownish red, soft; chert, light gray; and soft light gray shale

35. Sandstone, yellowish gray, fine

34. Shale and chert as in unit 36

33. Sandstone, tan, medium, rounded, friable; non-resistant

32. Conglomerate, pebbly, sandy in part, light gray, friable, subangular

31. Shale, silty, grayish red, soft

30. Sandstone, tan to yellowish gray, very fine to fine, evenly bedded, soft

29. Shale, reddish brown, soft

28. Sandstone, tan to yellowish gray, medium, friable, some cross-bedding; minor ledge former

27. Shale, purplish gray, soft

26. Sandstone, light brown at base, yellowish gray at top, fine-grained with pebbles, locally lenticular; rounded weathering

25. Siltstone, reddish brown, lenticular

24. Sandstone, conglomeratic at base, yellowish gray, coarse, pebbles up to 1 inch diameter, ferruginous cement locally near top
23. Shale, purplish gray, soft; interbedded with medium gray shale and grades upward into soft fine tan sandstone 16

22. Sandstone, yellowish gray to light brown, fine to medium, cross-bedded, lenticular, varies in hardness 13 6

21. Shale, purplish gray; with interbedded 1 1/2 inch layers of light gray siltstone 10

20. Covered, appears to be fine tan sandstone, and brownish red shale 179

19. Sandstone, light brown to tan, fine, cross-bedded, unevenly bedded, friable; ledge former 20

18. Shale, purplish gray, soft 16 6

17. Sandstone, yellowish gray, fine, irregularly bedded; minor ledge former 5

16. Siltstone, grayish red, grades upward to yellowish gray, soft 11

15. Sandstone, tan, very fine, unevenly bedded; minor ledge former 3

14. Shale, light olive gray, soft 7

13. Shale, silty, mottled purplish gray and light olive gray, soft 3 5

12. Mudstone, silty, yellowish gray, flaky 3

11. Shale, as in unit 13 9

10. Sandstone, yellowish gray, very fine, hard 2 5

9. Sandstone, light brown, very fine, massive, hard; blocky weathering, ledge former 1 6
8. Shale, mottled grayish red and gray, soft  

Feet Inches

3

7. Shale, medium gray, soft  

5

6. Covered, reddish orange soil  

38  6

5. Sandstone, tan, fine, cross-bedded, rounded weathering; minor ledge former  

9

4. Covered, red-orange soil  

49  6

3. Sandstone, light brown, fine to medium, cross-bedded, massive; ledge former  

5

2. Shale, silty, medium gray, soft  

16  6

Total North Horn formation  

1191  7

Price River formation

1. Sandstone, tan, medium, massive; contains scattered kidney-shaped ferruginous concretions; locally conglomeratic in small channels  

110

No exposures

Section No. 14

Section measured from SE¼ sec. 5 to W½ sec. 18, T. 24 S., R. 4 E.

North Horn formation

Covered

57. Shale, mottled grayish red and gray, soft  

20

56. Sandstone, tan, medium, frosted, friable, massive; minor ledge former  

5

55. Covered - reddish brown soil  

22
54. Sandstone, yellowish gray, medium, frosted, soft 4

53. Siltstone, brownish red, soft 1

Total measured North Horn formation 52

Price River formation

52. Sandstone, tan to yellowish gray with local ferruginous layers, medium to coarse, locally conglomeratic near top, friable, cross-bedded in part 220

51. Sandstone, yellowish gray, fine to medium, subrounded, soft, friable, ferruginous at top; minor ledge former 21

50. Sandstone, tan to light gray, fine to coarse, rounded, frosted in part; with interbedded 3 foot beds of soft purplish gray to medium gray shale 23

49. Shale, grayish red, soft 6

48. Shale, light olive gray, soft 5 6

47. Sandstone, tan, fine to medium, soft, friable 17

46. Shale, dark gray to medium gray, soft 7 6

45. Sandstone, yellowish brown, medium, angular in part, ferruginous 36

44. Sandstone, yellowish gray, medium, subrounded, friable, frosted; non-resistant 17

43. Sandstone, brown, medium, subangular, ferruginous, lenticular; minor ledge former 8+

42. Shale, silty, light olive gray, soft 5 6
41. Sandstone, tan to light brown, fine to medium, subrounded, frosted, friable, cross-bedded, rounded weathering; ledge former 16 7

40. Siltstone, light gray, soft 9 6

39. Sandstone, yellowish gray, fine to medium, subrounded, friable, frosted, cross-bedded; prominent ledge former 38

38. Sandstone, brown, medium to coarse, subrounded, friable, frosted, ferruginous, cross-bedded, rounded weathering; ledge former 3 7

37. Sandstone, yellowish gray, medium to coarse, rounded, friable, soft; non-resistant 10

36. Sandstone, locally conglomeratic, yellowish gray, medium, subrounded, frosted; non-resistant 5

35. Interbedded shale, medium gray, soft; and brown locally conglomeratic sandstone 18

34. Sandstone, yellowish gray to tan, fine to medium, subrounded, frosted, massive, cross-bedded; prominent ledge former 21

33. Sandstone, light gray, fine, massive, hard; ledge former 8

32. Shale, brownish red, soft 10

31. Shale, medium gray; interbedded with very fine tan sandstone; unit is soft, non-resistant 26 9

30. Sandstone, yellowish gray, medium, subrounded, frosted, cross-bedded; prominent ledge former 13

29. Sandstone, tan, medium to coarse, subrounded, frosted, ferruginous in part; non-resistant 56
28. Shale, silty, light olive gray, soft
27. Sandstone, as in unit 29
26. Shale, as in unit 28
25. Sandstone, as in unit 29
24. Shale, as in unit 28
23. Sandstone, as in unit 29
22. Sandstone, tan to yellowish gray, fine
   to medium, subrounded, friable, frosted,
   cross-bedded; blocky weathering;
   becomes ferruginous at top
21. Interbedded shale, medium to dark gray,
   soft; and fine tan sandstone
20. Sandstone, tan, fine, soft
19. Shale, medium gray, soft
18. Sandstone, yellowish gray, fine,
   ferruginous in part, cross-bedded,
   thin-bedded where more resistant;
   with interbedded layers of medium
   gray siltstone; unit is minor ledge
   former
17. Sandstone; tan, with ferruginous
   staining, some cross-bedding; soft at
   base, more resistant towards top
16. Shale, medium gray; with lenses of
   sandstone, tan, fine, and ferruginous
   sandstone; non-resistant
15. Sandstone, locally ferruginous, yellowish
   gray, fine, cross-bedded; minor ledge
   former
14. Interbedded shale, silty, medium gray,
   soft; and fine tan to yellowish gray
   sandstone that is ferruginous in part
13. Sandstone, yellowish gray, fine to medium
   with scattered pebbles and occasional
thin conglomeratic beds, cross-bedded, massive, ferruginous in part; ledge former locally

12. Conglomerate, 50 percent white quartzite, 10 percent jasper and 20 percent black chert pebbles up to 3 inch in diameter, average is 3/4 inch; intertongues as channel-fill in sandstone that is light brown, locally ferruginous, medium, subrounded, and cross-bedded; unit is ridge former and is laterally persistent though thickness may vary 33

Total Price River formation excluding Castlegate member 888 1

Castlegate member (Note: This section is carried as a mappable unit, but does not conform strictly to the type Castlegate member because it does not have the cliff-forming habit).

11. Sandstone, yellowish gray to tan, fine, ferruginous in part, massive, weathers yellowish; soft at base, more resistant towards top 12 6

10. Interbedded shale, silty, medium gray, soft and angular fine to medium tan sandstone; poorly exposed 38 7

9. Sandstone, pepper-and-salt, yellowish gray, medium to fine (quartz, feldspar, mica and mafic grains), ferruginous at top, massive; rounded weathering 5 5

8. Shale, silty, medium gray, soft, fissile; with lenses of fine brown sandstone that contains ferruginous concretions; contains pieces of fossilwood 55

7. Sandstone, yellowish gray, fine, irregularly bedded and some cross-bedding, friable, lenticular; contains ferruginous concretion zones 9 6
6. Sandstone, slightly argillaceous, brown, medium, ferruginous in part, more ferruginous and resistant toward top, soft; contains fossil wood; poorly exposed 60+

5. Sandstone, light grayish brown, poorly sorted; contains abundant Viviparous and some Naiad shells; hard but non-resistant 3

4. Sandstone, brown, ferruginous, medium, unevenly bedded, cross-bedded; minor ledge former; thickness varies laterally 495

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>Total Castlegate</td>
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<tr>
<td>Total Price River</td>
<td>1121</td>
<td>6</td>
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<tr>
<td>formation</td>
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</table>

Disconformity

Blackhawk formation

3. Coal; becomes shaly laterally 14±

2. Sandstone, brown, fine to medium, sub-angular, frosted, cross-bedded, massive; contains dark reddish brown ferruginous nodules; ledge former 15

1. Shale, medium gray, fissil; lenses of fine brown ferruginous sandstone; and small brown siderite concretions 40+

Covered

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<td>Blackhawk formation</td>
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AUTOBIOGRAPHY

I, Donald Paul McGookey, was born in Sandusky, Ohio, September 19, 1928. I received my secondary school education in the public schools of Sandusky, Ohio, and my undergraduate training at Bowling Green State University, which granted me the Bachelor of Science degree in 1951. From the University of Wyoming, I received the Master of Arts degree in 1952. While in residence there, I was assistant to Professor Brainerd Mears during the year 1951-52. From 1952-56 I worked as a geologist for The Texas Company in Montana. In September 1956, I was appointed Graduate Assistant at Ohio State University, where I specialized in the Department of Geology. I held this position for one year and then was elected Bownocker Fellow for the year 1957-58. I again was appointed Graduate Assistant during the fall of 1958, at which time I completed the requirements for the degree Doctor of Philosophy.
<table>
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<th>JURASSIC</th>
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<td>10</td>
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Table 1: Generalized section of rocks exposed in the region.