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Geology of the Gunnison Quadrangle, Utah

William N. Gilliland
University of Nebraska - Lincoln

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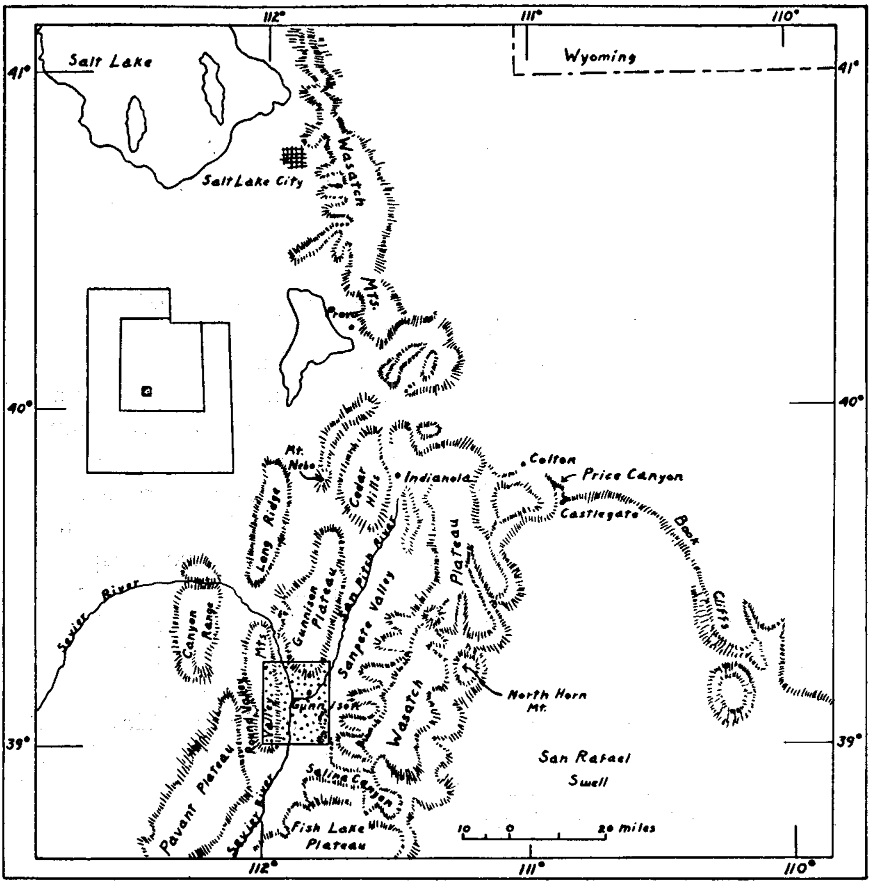


FIGURE 1—Index map of part of Utah showing location of Gunnison Quadrangle (stippled). (Modified after E. M. Spieker, 1946.)

INTRODUCTION

The Gunnison Quadrangle is in central Utah approximately 130 miles south of Salt Lake City at the juncture of the Sevier and Sanpete valleys (see fig. 1). The quadrangle is bounded by 39°00′ and 39°15′N. Lat. and 111°45′ and 112°00′ W. Long. Parts of both Sevier and Sanpete counties are included.

The Gunnison Quadrangle is considered important geologically because it lies athwart the juncture of the Sevier and Sanpete valleys and includes portions of three major structural and physiographic units—the Wasatch Plateau, the Gunnison Plateau, and the Valley Mountains. Two of these, the Gunnison Plateau and the Valley Mountains, were virtually unknown geologically prior to the beginning of this investigation. The present report is a description of the geology of the Gunnison Quadrangle. Wherever possible, an attempt has been made to show relations between these major geologic units and between them and adjacent regions. A minor structural and topographic feature, hereafter referred to as the Redmond Hills, is also included in the quadrangle.

The data in the report pertaining to the Gunnison Quadrangle and adjacent areas to the west were collected by the writer chiefly during the summers of 1946 and 1947. Additional information was obtained during the summers of 1949 and 1950. The field work was supplemented by laboratory work during the academic years of 1946-1947 and 1947-1948.

EARLIER WORK IN THE AREA

Only brief mention of the geology of the Gunnison Quadrangle (Gilliland, 1949) has been made prior to this time. However, considerable information has been reported about central Utah east of Sevier Valley and Sanpete Valley. For many miles west of these valleys, little of the geology—except in widely separated areas—was known at the beginning of this work. Thus the present report represents a westward extension of known geology. The more important earlier workers in central Utah and their publications are listed below.

E. E. Howell (1875) briefly mentioned the geology of the Wasatch Plateau and some of the immediately adjacent areas. Some of his notes and cross-sections made during reconnaissance were incorporated in a publication by C. E. Dutton (1880). This report by Dutton on the High Plateaus was the first organized and somewhat detailed account of the geology of the region.

C. A. White (1886) described some fossils collected at Wales, Utah and at other scattered localities in Sanpete and Sevier valleys.

G. B. Richardson (1907), inspired by the great need for water in the semi-arid Sanpete and central Sevier valleys, described with some detail the ground-water conditions and the potentialities for further development of ground-water. He prepared a generalized geologic map of the region and commented on the stratigraphy and structure of the area.

The stratigraphy of the Wasatch Plateau was summarized in 1925 by E. M. Spieker and J. B. Reeside, Jr. (1925). Three years later Spieker and Baker (1928) described the geology and coal resources in the vicinity of Salina Canyon, Utah. The Wasatch Plateau coal field was discussed in detail by E. M. Spieker (1931). His report of 1946 is a comprehensive treatment of the geology and geologic history of central Utah. Since completion of this work, Spieker has discussed the Cretaceous sedimentation and related diastrophism in Central Utah (1949a) as well as the transition between the Colorado Plateaus and the Great Basin (1949b).

A paper by M. P. Billings (1933) described strip-thrusting of younger rocks over older rocks in the vicinity of Salina, Utah. A portion of this study was made in the southeastern corner of the Gunnison Quadrangle.

Other publications relating to the features of the Gunnison Quadrangle are cited at the proper places in the report.

MAPPING METHODS

Because of small scale all the known maps of the Gunnison Quadrangle are unsuited for use in detailed geologic mapping. The Manti Sheet, a reconnaissance map of the region prepared by the U. S. Geological Survey in 1895, and several U. S. Forest Service maps are satisfactory for reconnaissance. Because an adequate map was lacking, aerial photographs* procured from the U. S. Soil Conservation

* Aerial photographs were secured from the U. S. Soil Conservation Service, Washington 25, D. C.

BPL 6–137 through BPL 6–147
BPL 8– 50 through BPL 8– 61
BPL 8– 68 through BPL 8– 78
BPL 10– 49 through BPL 10– 60
BPL 14– 17 through BPL 14– 28
BPL 14– 80 through BPL 14– 92
BPL 33–131 through BPL 33–145

Service were used by the writer as a base for mapping the quadrangle. Geologic data were transferred from individual photographs to a semi-controlled mosaic also prepared by the Soil Conservation Service. An overlay was then made from the mosaic showing the geology, the main drainage lines, and the principal cultural features. The data for the area south of Willow Creek and east of U. S. Highway 89 was partially taken from E. M. Spieker's map of the Wasatch Plateau, part of which has been published by the U. S. Geological Survey. It was modified in the light of new evidence obtained by the writer. Elevations used in preparing the structure sections were determined by using aerial photographs and an Austin Photo Interpretometer.

GEOMORPHOLOGY AND GEOGRAPHY

GEOMORPHOLOGY

GENERAL SETTING

The Gunnison Quadrange is situated in the north central part of the High Plateaus of Utah—a series of high, deeply dissected plateaus arranged in three rows of two to four plateaus each and separated by two great north-south valleys. This group of plateaus and valleys constitute the High Plateaus of Utah section, which forms the northwestern boundary of the Colorado Plateau province.

The main masses of the plateaus are formed, in general, of flat-lying or gently dipping strata; the margins of many are deformed by great monoclinal flexures or by faults of very great displacement. These structures are reflected in majestic escarpments, which rise abruptly 5000 or 6000 feet above the floors of the adjacent valleys.

The westernmost of the two great longitudinal valleys is occupied throughout most of its length by the north-flowing Sevier River, which is joined near Gunnison, Utah, by the southwest-flowing San Pitch River.* From Gunnison, Utah, the Sevier River flows north and west to emerge from the High Plateaus section and enter the Basin and Range Province, where the river eventually discharges into Sevier Lake. The Wasatch Plaeau, immediately east of the Gunnison Quadrangle, constitutes the divide between the interior drainage of the Basin and Range province and the exterior drainage of the rest of the Colorado Plateaus. The portion of the High Plateaus west of the central Wasatch Plateau is characterized by intensive faulting and steep monoclinal folding. Thus, this area of the High Plateaus, by virtue of the interior drainage and structural complexity, is, in the writer's opinion, more intimately related to the Great Basin than to the Colorado Plateaus, which are characterized essentially by approximate horizontality of the rocks and a few large gentle monoclines. Dutton (1880, p. 7), however, considered the High Plateaus part of the Colorado Plateaus, and Fenneman (1931), with due recognition of the difficulties in drawing physiographic boundaries, placed the boundary separating the Great Basin and the northern part of the High Plateaus on the west side of the Pavant and Gunnison plateaus.

* The names Sanpete and San Pitch have been used interchangebly and inconsistently in the past for both the river and its valley. Current local usage restricts the name San Pitch to the river and Sanpete to the valley.

SEVIER VALLEY

The Sevier Valley, in the center of the Gunnison Quadrangle, is a broad, north-south trending, extensively alluviated valley. It is flanked on the west by the Valley Mountains, on the northeast by the southern part of the Gunnison Plateau, and on the southeast by the low foothills of the Wasatch Plateau. The valley is joined east of the town of Gunnison by Sanpete Valley.

Viewed from near-by high elevations (see pl. 1), the valley floor appears to be flat, though there are long gentle slopes rising persistently from an elevation slightly under 5000 feet at the level of the Sevier River to the base of the bordering highlands. The slopes are most strikingly developed on the west side of the valley, where their surfaces are inclined about 3 or 4 degrees to the east. These slopes are underlain by very coarse, poorly sorted gravel, sands, and silts derived from the Valley Mountains, and deposited as alluvial fans at the foot of the mountains. Three generations of fans, composed chiefly of gravels, may be seen particularly well on aerial photographs.

The oldest and topographically highest gravel deposits, which have been included by the writer in the Axtell formation, occur at the foot of the mountains and overlap the bedrock. These gravels are the only group differentiated on the geologic map; the others are included in the Recent alluvium. The high-level gravels are extensively dissected and possess a topography consisting almost entirely of gentle slopes and low rounded hills. Viewed along an east-west profile, however, the dissection is only slightly noticeable, and the concordant hilltops appear to be a continuous surface. The dissection of the gravels increases westward toward the mountains and is most prominent at the mouths of the main canyons. Near the mouth of Redmond Canyon, the hills have a relief of about 115 feet, measured from the terrace of the drainage to the crest of the gravel hills. Eastward the dissection decreases, and locally this higher unit merges imperceptibly into the two younger generations of alluvial materials.

The next lower and younger unit is represented by the material which forms the narrow terraces bordering the washes near the canyon mouths, and in general consists of finer material than that in the Axtell formation. This intermediate unit has been moderately dissected. It likewise grades imperceptibly into the youngest and topographically lowest unit, which in turn grades into the fine alluvium of the flood plain bordering the Sevier River. All three alluvial units

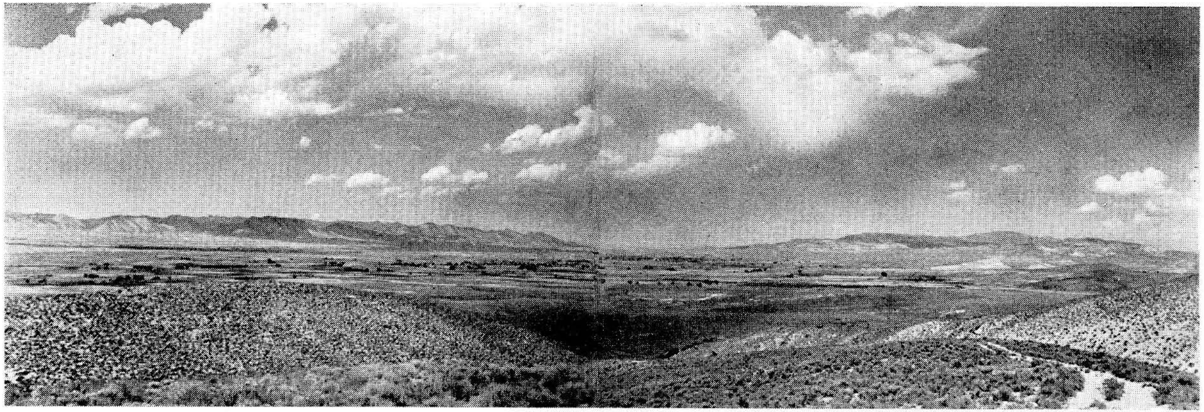


PLATE 1

PANORAMA OF THE GUNNISON QUADRANGLE. View northwest from the Green River hogback north of Willow Creek. Sevier Valley, middle ground; Valley Mountains, left background; Gunnison Plateau, right background.

FIGURE A—PANORAMA OF THE VALLEY MOUNTAINS AND VICINITY. View northeast from the Pavant Plateau. Round Valley, middle foreground; Valley Mountains, center; Sevier Valley and Wasatch Plateau, right background; Gunnison Plateau, middle background; Mount Nebo, extreme left background.

FIGURE B—VERTICAL JURASSIC SALT BEDS. Vertical salt beds overlain by residual clay blanket. Block of white salt in center foreground.

become increasingly finer in texture toward the valley because of decreasing gradient in that direction and a resulting decrease in competency of the transporting streams.

At the south end of the Valley Mountains, about five miles west of Salina and near the mouth of Bald Knoll Canyon, truncated strata of the Bald Knoll formation of late Eocene or Oligocene age are at different places overlain directly by material belonging to each of the three generations. The Bald Knoll beds dip about 15° east, and their upper surface is a continuous slope inclined about 3° to 4° east. It is clear that in this area, and possibly along the entire east front of the Valley Mountains, the gravels were deposited as a veneer upon a pediment.

Generally similar relations are present along the east side of Sevier Valley. West of the hogbacks between Willow Creek and the San Pitch River in the southeastern part of the quadrangle, there are several sloping gravel-covered terraces. The gravel cover is underlain by truncated Tertiary strata and, as in the case of the gravels on the west side of the Sevier Valley, it was deposited upon a pediment. These gravels likewise locally merge into the finer alluvium of the valley.

Recent climatic variations, particularly changes in rate and amount of precipitation, may have been the chief cause of the greater dissection near the mountains and the progressively decreasing amount of dissection toward Sevier Valley. The difference in erosion may also have been induced by a relative rise of the highlands, while the Sevier River, which is the local base level, remained unchanged. This deformation would possibly result in an increasingly steeper gradient toward the upper reaches of the streams and, consequently, greater erosive activity in those areas.

VALLEY MOUNTAINS

The Valley Mountains are an orogenic and physiographic unit consisting, in general, of antithetically faulted, east-dipping Tertiary strata. The range trends north-south and is approximately 25 miles long and 5 to 10 miles wide. The mountains are bounded on the east by Sevier Valley and on the west by Round Valley, which separates the range from the Pavant Plateau (see pl. 2, fig. A). Long gentle slopes rise from the Sevier Valley to the eastern base of the mountains, whereas the western edge of the range rises abruptly from the comparatively level alluvium-covered floor of Round Valley. The highest peaks of the range are between 3000 and 3500 feet above the floor of

Sevier Valley. Stevens Mountain, the highest peak, has an altitude of 8,442 feet and is located just south of South Valley. Only the southeastern portion of the range is included in the Gunnison Quadrangle.

Along the east front of the range, the foothills consist most commonly of cuestas of the Tertiary Green River formation separated from the main mountain mass by north-south valleys eroded in the comparatively nonresistent Colton formation (see pl. 6, fig. A). To the west of these valleys are fault blocks of the more resistent underlying formations that comprise the main mass of the mountains. The original configuration of these fault blocks has been little affected by erosion. In general, each block has a gentle east side developed on the dip slope and a steeper west side which is the fault scarp.

Numerous ephemeral streams have eroded canyons of considerable size, most of which trend roughly east-west. The east-flowing streams discharging down the dip into Sevier Valley are generally longer than those flowing west into Round Valley. Thus, the watershed of the range is west of the north-south geographic axis of the range. The north sides of practically all the canyons have considerably less vegetation and more talus than the south sides. Several hypotheses might be advanced to explain this contrast in the distribution of vegetation and talus. The writer favors the hypothesis that concentration of the sun's rays on the north sides results in a greater diurnal temperature change there, and consequently, more frost action on those sides during the colder seasons. Therefore, mechanical weathering is more effective and gives rise to talus slopes rather than a soil mantle suitable for plant growth. Also the additional heat received by the north sides in comparison with the south sides reduces the amount of moisture available for plant growth.

Two prominent valleys are centrally located in the Valley Mountains along the west boundary of the Gunnison Quadrangle. The name of the mountains was derived, in all probability, from the presence of these valleys. South Valley, the smaller one of the two, is about two miles south of the Lone Cedar Road. It is largely structural in origin and is irregular in shape. Alluvium of unknown thickness covers most of the floor. The entire drainage of the valley is accomplished through Dastrup Canyon. Japs Valley, a graben, extends from about three-fourths of a mile north of Lone Cedar Road to approximately the northern boundary of the quadrangle and averages

between one and one and one half miles in width. The valley floor is largely covered with alluvium and drainage of the valley is through Hayes Canyon. In both south and Japs valleys, dry farming is practiced.

GUNNISON PLATEAU

The southwestern tip of the Gunnison Plateau occupies the northeastern one-quarter of the quadrangle. The plateau extends from the south side of Salt Creek near Nephi, where its elevation is almost 10,000 feet, to the town of Gunnison. There the elevation is about 5000 feet, and the strata underlying the moderately dissected surface disappear beneath the alluvium of Sevier Valley. The western margin is delimited by a highly faulted zone, which begins near Fayette and continues north for several miles. The faulting has exposed massive conglomerate that forms very high, steep, and almost unscalable cliffs.

JURASSIC BADLANDS

Along the southern half of the eastern border of the Gunnison Quadrangle, there is a belt of steeply dipping Jurassic shale and siltstone. These strata are especially susceptible to erosion. Because of this characteristic, a badland-type of topography has developed in the area of outcrop. The entire belt consists of deep, steep-sided gullies and sharp ridges which are almost completely barren of vegetation. Relief of the ridges is generally less than 300 feet.

DRAINAGE

The Gunnison Quadrangle and much of central and southwestern Utah is drained by the Sevier River and its tributaries. The river flows north through the quadrangle at an altitude just under 5000 feet and continues northwest to Parley, Utah, thence southwest to Sevier Lake in western Utah. In the area covered by this report, the Sevier has meandered over its floodplain leaving numerous meander scars and oxbow lakes.

The smaller San Pitch River, likewise meandering over its flood plain, enters the quadrangle due east of Gunnison. It flows southwest and west, joining the Sevier River about three miles west of Gunnison. The only other perennial stream in the area is Willow Creek, which flows west from Willow Creek Canyon in the Wasatch Pleateau and empties into the Sevier River about 2½ miles north of Redmond. In the area under investigation, Willow Creek at one time flowed through the next valley south of its present course; the former Willow Creek valley is now occupied by an intermittent stream. This rather

striking drainage change is in all probability due to damming of the stream near the mouth of Willow Creek Canyon by recent faulting in the Jurassic strata. Insufficient time has prevented a detailed analysis of this problem.

All other drainage of the area is accomplished by the numerous ephemeral streams, which flow only during flash floods. The very swiftly moving flood waters disappear rapidly on the lower gravel-covered slopes bordering the higher areas and seldom flow directly into the permanent streams.

CULTURE

The central part of the Sevier Valley is intensively tilled and the adjacent highlands are used for cattle and sheep ranges. The Sevier River and its tributaries are the chief source of agricultural productiveness in the Sevier and Sanpete valleys. The luxurious grasses in the many poorly drained parts of the flood plain afford excellent pasturage for livestock and give rise to many picturesque scenes remindful of much less arid regions. Water derived from the permanent streams is extensively diverted into numerous irrigation ditches that are responsible for the transformation of the semi-arid, once sage brush-covered Sevier and Sanpete valleys into fertile farmlands, furnishing much of the agricultural produce used in Utah. A minor amount of mining is conducted in the south-central part of the quadrangle.

Gunnison, Redmond, Fayette, Centerfield, and Axtell, the only towns in the Gunnison Quadrangle, are supported chiefly by agricultural activity, but also in part by the mining operations. Gunnison, the largest of the towns and the trading center for much of the region, is north-centrally located in the quadrangle; its population is about 1,100.

A line of the Denver and Rio Grande Western Railroad crosses the eastern part of the quadrangle and affords daily freight connections with Salt Lake City and towns as far south as Marysvale. Several bus lines make daily stops at Gunnison, providing through service between Salt Lake City and points south.

U. S. Highway 89 and Utah Highway 28, both of which are paved, meet at Gunnison. The former connects Salt Lake City and southern Utah through Sanpete and Sevier valleys. Utah Highway 28 follows the west side of the Gunnison Plateau between Gunnison and Levan, where it connects with U. S. Highway 91, forming the most direct route to Salt Lake City. Many secondary roads exist in the Sevier

Valley. One gravel road crosses the Valley Mountains through Lone Cedar Canyon, connecting the Sevier Valley with Round Valley. Branches of this road enter Japs Valley and South Valley. A very poor road follows the bed of the wash in Hayes Canyon, affording the only other entrance into Japs Valley. The mouths of most of the canyons in the Valley Mountains may be reached by trails, and in some canyons, vehicles may be driven a mile or two, but not without difficulty. There is a road in the bed of Mellor Canyon, which leads to the surface of the Gunnison Plateau and continues for some miles north.

STRATIGRAPHY

GENERAL FEATURES

The rocks of the Gunnison Quadrangle briefly described earlier (Gilliland, 1949) are here summarized in Table 1 and discussed at greater length in the succeeding pages of this report. The rocks include sediments ranging from Jurassic to Quaternary in age. A few small outcrops of Tertiary igneous rock are also present.

All the sediments in the Gunnison Quadrangle are deposits of nonmarine origin except the Arapien shale and parts of the Twist Gulch formation. The nonmarine Cretaceous strata present a marked contrast to the very extensive marine Cretaceous formations in most of the Western Interior. The rocks of Tertiary age constitute a lateral continuation of the continental sedimentation so widespread elsewhere in the Western Interior during Tertiary time. Because of the sharply contrasting environments in which Cretaceous sedimentation occurred and because of the nature of continental environments which necessarily involves many lateral changes in deposition, the rocks of Cretaceous and Tertiary age present in the quadrangle and adjacent regions are characterized by numerous, very pronounced facies changes. Furthermore, late Mesozoic and early Tertiary orogenies caused vertical variations and lateral shifting of environments. The result of these effects is a series of stratigraphic units, which represent markedly different and migrating environments, and through which horizons of contemporaneity are difficult, if not impossible, to trace.

JURASSIC SYSTEM

ARAPIEN SHALE AND TWIST GULCH FORMATION, UNDIFFERENTIATED

Type Locality and Distribution

The Arapien shale was named by Spieker (1946, pp. 123-124) from typical exposures on the west side of Arapien Valley, which parallels the base of the Wasatch Plateau about 6 miles southeast of Gunnison, Utah. Spieker described two members of the Arapien; a lower, the Twelvemile Canyon member, which crops out in the valley of Twelvemile Creek west of the Arapien Valley; and an upper, the Twist Gulch member, exposed on the north side of Salina Canyon between the compact, red, salt-bearing shale in Twist Gulch and the diverse strata of the Morrison (?) formation. Subsequently, the term Arapien shale

TABLE 1
FORMATIONS IN THE GUNNISON QUADRANGLE

AGE		FORMATION	DESCRIPTION	THICKNESS
QUATERNARY	Recent	Alluvium	Gravel, sand, silt, and clay.	
QUATERNARY	Pleistocene	Beach Sand	Very well-sorted, fine sand, partially covers low hills east of Fayette.	
QUATERNARY	Pleistocene	Volcanic Gravel	Dark-gray, moderately well-sorted gravel composed of volcanic, chert, limestone, and flint pebbles.	
TERTIARY	? Pliocene	Axtell	Light-gray and orange-brown, very coarse, locally consolidated gravel; orange-brown clays, silts, and sandstones.	
TERTIARY	Oligocene	Pyroclastics and Associated Sediments	Many-colored bentonite and ash interbedded with thin-bedded limestone, shale, and sandstone. Minor amount of Mexican onyx.	
TERTIARY	Oligocene	Bald Knoll	Light-green, light-tan, gray, and white clay, poorly indurated siltstone and sandstone, greenish-gray and white, soft limestone. Lacustrine.	600+
TERTIARY	—?— Eocene	Crazy Hollow	Red, reddish-brown, gray, lavender, and purple shale, brown, red, gray, white, pepper-and-salt sandstone, conglomerate with quartzite and black chert pebbles, dense limestone. Largely fluviatile.	1,000±
TERTIARY	Eocene	Green River	Greenish-gray shale, yellow thinly bedded, in part oolitic limestone, and yellow, buff, and gray massive limestone. Limestone is locally silicified. Many ganoid bone fragments and scales. Lacustrine.	1,150
TERTIARY	Eocene	Colton	Red, green, gray, varigated shale with minor amounts of red sandstone and thin-bedded limestone. Fluvialtile.	410
TERTIARY	—?— Paleocene	Flagstaff	Five zones of yellow, gray, red, fossiliferous limestone and gray shale in northern area, change southward to dominantly red, pure and sandy limestone, sandstone, and conglomerate. Lacustrine.	500 to 1,400
TERTIARY	Paleocene	North Horn	Dominantly brown sandstone with yellowish-brown arenaceous limestone. Minor amount of gray and red shale and conglomerate. Lacustrine and fluviatile.	1,580+
MESOZOIC	—?— Upper Cretaceous	Price River	Very massive gray conglomerate with pebbles of Paleozoic limestone and quartzite up to 10 inches in diameter. (Unconformably overlain by Flagstaff.)	1,315+
MESOZOIC	Jurassic	Arapien Shale and Twist Gulch, Undifferentiated	Dominantly gray and red mottled shale, with small amounts of thin-bedded, gray, limestone, sandstone, and siltstone. Gypsum and salt common. Of marine- and brackish-water origin.	8,000 to 13,000

has been restricted to the former Twelvemile Canyon member and the Twist Gulch member has been elevated to formational rank (Hardy and Spieker, in preparation). The redesignation of the members as formations was done following the field work preceeding this report. The two formations therefore, have not been differentiated on the geologic map (pl. 11).

Strata belonging to these formations are widely exposed in central Utah. They are exposed in a nearly continuous belt along the east side of Sevier Valley extending south from near Gunnison to Richfield; locally along the western base of the Gunnison Plateau; in discontinuous outcrops along the east base of the Gunnison Plateau, and in Salt Creek Canyon at the southern end of the Wasatch Mountains.

In the Gunnison Quadrangle (see pl. 11), the undifferentiated strata of the Arapien and Twist Gulch formations crop out in an area of badland topography along the southern half of the eastern boundary. Exposures have also been recognized by the writer in the Redmond Hills, where salt-bearing beds crop out in an elongate discontinuous band, which extends about 5½ miles north of Redmond. Another exposure is located about 2 miles west of Gunnison. According to well data discussed in later paragraphs concerning the Recent alluvium, red salt-bearing shale of the Arapien may also be below the alluvium at Centerfield.

Lithology and Thickness

Recently five lithologic units have been recognized by Hardy (1949) in the Arapien shale (former Twelvemile Canyon member). These units, from top to bottom, are as follows:

"Unit E:

Brick-red silty shale locally salt-bearing. The salt appears to be stratified and commonly contains a considerable amount of red clay.

"Unit D:

Alternate layers of bluish-gray and red gypsiferous shale. Blotched appearance of the outcrop due to lenticular nature of the beds, facies changes, and complex structure.

"Unit C:

Bluish-gray calcareous shale with gray thin-bedded calcareous sandstone. Several prominent resistent layers of arenaceous limestone with fossils. Massive lenticular beds of gypsum.

"Unit B:

Bluish-gray and red gypsiferous shale. Blotched appearance as Unit D. Red gypsiferous shale in upper part locally salt-bearing.

"Unit A:

Gray shale, gray thin-bedded limestone weathers brown, red shale, gypsum in thin lenticular beds; or gray thin-bedded argillaceous limestone with massive lenticular beds of gypsum."

Compact, red, salt-bearing strata (presumably part of Hardy's Unit E) are present along much of the western edge of the Jurassic badlands; at the south end of the Green River Hogback located immediately south of Willow Creek; and in the Redmond Hills (see pl. 2, fig. B). In the latter two named places, the strata consist largely of rock salt, which contains a minor amount of finely disseminated red clay sufficient to give the salt a brick-red appearance. Occasional layers of nearly pure white salt, generally not exceeding two feet in thickness, alternate with thick red layers. At least 200 feet of salt is exposed in the Redmond Hills. The readily weathered salt beds are covered by a blanket of red residual clay and the actual thickness of salt may be much greater than is exposed. No further attempt has been made during the course of this study to differentiate the lithologic units of the Arapien shale or the Twist Gulch formation.

Structural complexities within the Arapien shale (former Twelvemile Canyon member) render virtually impossible the accurate determination of the thickness. Spieker (1946, p. 125), however, estimated a thickness of between 5000 and 7000 feet based on the possibility that a modified anticlinal structure exists northeast of Salina, where the section was estimated. Previously Eardley, (1933, p. 331) had estimated a thickness between 4,000 and 11,000 feet for the formation in Salt Creek Canyon, east of Nephi, Utah. Hardy (1949) did not give an accumulated thickness for the Arapien but compilation of thicknesses reported by Hardy for the several units seems to indicate a total thickness near 3000 feet but possibly as much as 4000 or 4500 feet.

The Twist Gulch formation, originally defined by Spieker (1946, p. 124) as the upper member of the Arapien shale and later redesignated as a formation by Hardy and Spieker (in preparation), consists largely of red siltstone and reddish-gray sandstone and grit layers. Hardy (1949) reported that at least 1910 feet of Twist Gulch strata are exposed in Salina Canyon where the beds are partly covered and disrupted by a fault. Spieker (1946, p. 125) calculated a maximum thick-

ness of 3000 feet at the same locality, by assuming a regular succession inasmuch as the fault parallels the bedding.

Relation to Adjacent Formations

The base of the Arapien has not been observed to date. However, the wide regional extent of the Navajo sandstone and its equivalent, the Nugget sandstone, and the occurrence of these formations directly below strata presumably correlative with the Arapien suggests to the author the likelihood of similar sandstones underlying the Arapien of this area.

The upper boundary of the Twist Gulch formation is well known in central Utah although the relations, in all instances, are not entirely clear. At many places in central Utah, the next younger beds above the Twist Gulch are lithologically similar to those included in the Indianola group, presumably Colorado in age. No disconformity is apparent between these units though widely separated in age. At still other localities, beds commonly referred to the Morrison (?) formation overlie the Twist Gulch conformably.

At all exposures in the Gunnison Quadrangle and in several nearby localities, however, the Arapien and Twist Gulch beds, according to the writer's observations, are overlain angularly by Tertiary beds. At the north end of the Flagstaff hogback just south of Willow Creek, a vertical angular unconformity separates horizontal Twist Gulch beds and vertical Flagstaff strata. In the Redmond Hills, Oligocene pyroclastics overlie vertical Arapien salt beds with angular discordance. Near the mouth of Salina Canyon, there is a progressive westward overlap of Flagstaff, Colton, and Green River strata over vertical to steeply dipping Arapien, Twist Gulch, Morrison (?), and Indianola (see fig. 3). The lower two Tertiary formations pinch out westward and are absent at the west end of the exposures where Green River beds rest directly on Arapien and Twist Gulch. A similar relationship —Green River resting directly on the Arapien and Twist Gulch— probably existed in the general area of the Jurassic badlands along the southeast boundary of the Gunnison Quadrangle. There, thrust plates of Green River strata have overridden the two Jurassic formations along or near former depositional contacts.

Age and Correlation

Spieker, in his original definition, (1946, pp. 123-125) suggested a generalized correlation of the Arapien shale and the Twist Gulch formation with the San Rafael group of southeastern Utah, the Twin

Creek limestone of northcentral Utah, and, therefore, with the Sundance of the northern Great Plains. An Upper Jurassic age was considered likely for the Arapien and the Twist Gulch. Recently Hardy (1949) confirmed Spieker's generalized correlation and suggested a more detailed correlation of the Jurassic strata in central Utah with the Jurassic strata in adjacent areas.

On the basis of similar lithology, similar sequence, and faunal relations, Hardy (1949) indicated probable equivalence of the Arapien shale, the upper portion of the Twin Creek limestone in the Wasatch Mountains and possibly in Idaho and Wyoming, and the Carmel formation of the San Rafael Swell. He further pointed out, however, that the lower part of the Arapien may be considerably older than the Carmel and that the upper red and bluish-gray gypsiferous shales may be equivalent to the Entrada formation of the San Rafael group. The age of the Arapien is still uncertain, although it seems to be late Middle or early Upper Jurassic or both.

The Twist Gulch formation contains a lithologic sequence which in many respects, is comparable to the Entrada, Curtis, and Summerville sequence of the San Rafael group. Furthermore, the middle lithologic unit in the Twist Gulch formation contains a fauna similar to that found in the Curtis. Therefore Hardy (1949) considered the Twist Gulch approximately equivalent to the Entrada, Curtis, and Summerville. The Twist Gulch and the Preuss formation of north-central Utah and southeastern Idaho also seem to be approximately equivalent, although the relations are not exactly clear. An Upper Jurassic age seems certain for the Twist Gulch.

CRETACEOUS SYSTEM

PRICE RIVER FORMATION

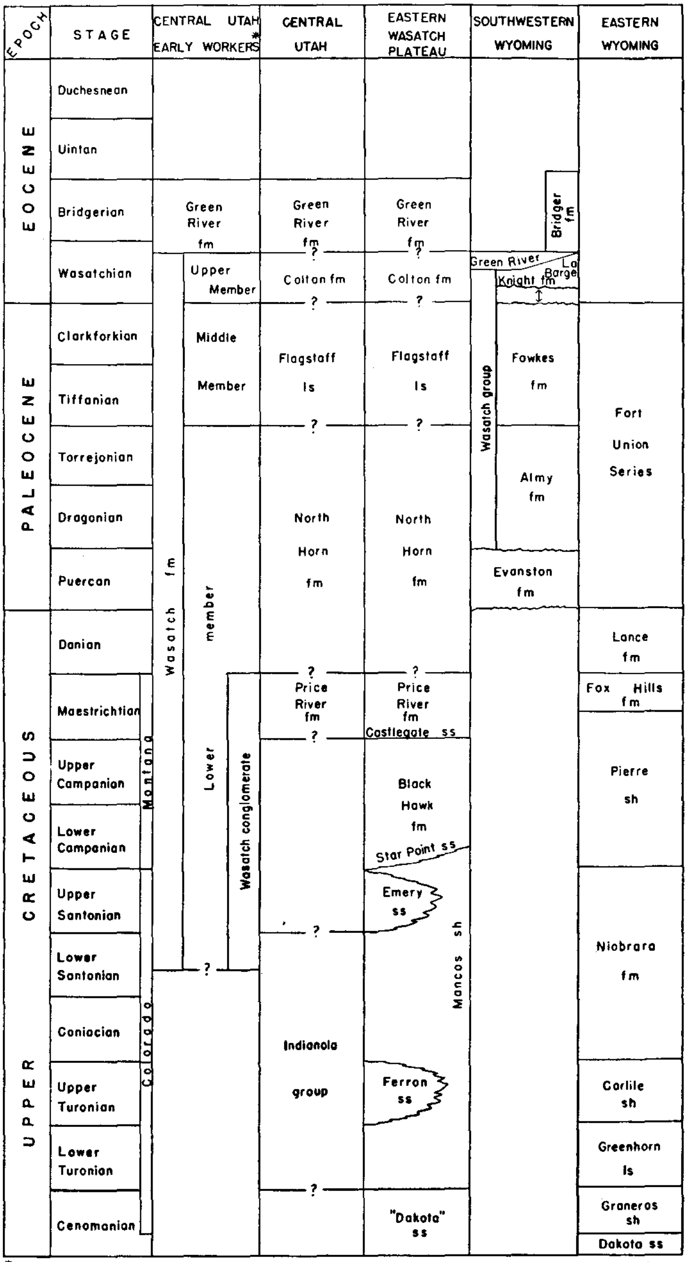
Type Locality and Distribution

The name Price River formation was first applied by Spieker and Reeside (1925, p. 445) to a succession of predominantly gray sandstones, grits, conglomerates, and minor amounts of shale between the Black Hawk formation and the North Horn formation in the canyon of Price River above Castlegate, Utah. The formation at the type locality consists of two members: a basal, cliff-forming unit—the Castlegate member (Clark, 1928, p. 20)—composed of massive, white to brown, medium to coarse sandstone containing lenses of quartz and chert pebbles, and an upper, less massive slope-forming member of similar lithology. The thickness of the Price River formation at the type

TABLE 2

DIAGRAM SHOWING APPROXIMATE CORRELATION OF UPPER CRETACEOUS AND EARLY TERTIARY FORMATIONS OF CENTRAL UTAH WITH THOSE OF WYOMING

(Modified after H. E. Wood et al., 1941, and E. M. Spieker, personal communication, 1946)



* The Wasatch formation was originally thought to be entirely Eocene in age. Conglomeratic facies of the Price River and possibly part of the Indianola were included as the Wasatch conglomerate. This chart shows present known equivalents.

locality is between 900 and 1000 feet. In general the Price River becomes coarser towards the west and finer towards the east.

The several facies of the Price River formation are abundantly exposed in central and eastern Utah. The exposures occur at many localities in the Wasatch Plateau and almost continuously in the Book Cliffs as far east as the Utah-Colorado boundary. The writer has recognized the formation at the south end of the Gunnison Plateau, in Long Ridge west of Nephi, Utah, and at the northern end of the Pavant Plateau.

Outcrops of the Price River formation in the Gunnison Quadrangle (see pl. 11) are limited to the north-central portion of the area where they appear in Mellor Canyon and in several patches south of Mellor Canyon. In these areas and northward along the west front of the Gunnison Plateau, the unit forms high, very steep cliffs.

Lithology and Thickness

The Price River formation exposed in the area of this report belongs to the conglomeratic facies common in the western regions. In the Gunnison Quadrangle the Price River consists almost entirely of light- to dark-gray, massive, firmly cemented conglomerate containing pebbles of quartzite and limestone (see geol. section 8 and pl. 3, fig. A). Fine- to coarse-grained, light-gray sandstone lenses and a few persistent layers of sandstone up to 20 feet thick are interbedded with the conglomerate. The pebbles and cobbles of quartzite are chiefly white, gray, pink and red; some red-banded quartzite pebbles are also present. A smaller number of pebbles and cobbles is made up of limestone, which is either light or dark gray and dense to very finely crystalline. Most of the pebbles and cobbles are well rounded and have an average diameter between 2 and 4 inches, although some cobbles are as large as 10 inches. The matrix is fine- to coarse-grained, locally calcareous, and generally firmly cemented. The quartzites and limestones were derived from Paleozoic strata now exposed a few miles west in the Pavant Plateau.

A thickness of 1314 feet of Price River was measured in Mellor Canyon (see geol. section 8); however, neither the top nor the base of the formation is exposed there. Hardy (1948) measured a thickness of about 1500 feet on the west Gunnison front north of Mellor Canyon and did not observe the base. Richardson (1907, p. 10) reported "at least 2000 feet" of red and buff conglomerate (interpreted by the present writer as part of the Price River formation) on the east front of the Pavant Plateau. In general the conglomeratic facies of the

Price River in central Utah is considerably thicker than the finer facies at the type locality and in eastern Utah.

Relation to Adjacent Formations

The basal contact of the Price River formation reflects the orogenic conditions which gave rise to the formation; on the other hand, the upper contact represents at most places, normal transition from one type of sedimentation to another. Spieker (1949a) has clearly shown the westward change from transition with older strata at the base of the Price River in eastern Utah to erosional unconformity and finally angular unconformity at the base of the formation in central Utah.

Although the base of the Price River is not exposed in the Gunnison Quadrangle, the present writer believes that angular relations separate the Price River and older strata there. The conglomerate in Mellor Canyon belongs to a near-source orogenic facies of the Price River which is distributed in a north-south belt extending at least from the Pavant Plateau to the Southern Wasatch Mountains. The belt is bounded on the west by the folded rocks of the source area. Throughout this belt, the conglomerate of the Price River unconformably overlies older beds ranging in age from Pre-Cambrian to Coloradan. It therefore seems likely that the Price River in the Gunnison Quadrangle also overlies older beds unconformably, but the age of the underlying beds is unknown.

Exposures of the contact of the Price River with the next younger formation, the North Horn, are also lacking in the Gunnison Quadrangle, but Spieker (1946, p. 133) described the contact as transitional at all places where the two formations are known. Hardy (1948) stated that along the west front of the Gunnison Plateau about 8 miles north of the Price River exposures in Mellor Canyon, the conglomeratic Price River grades upward into the finer clastics and limestones of the North Horn. These younger beds pinch out southward and at their terminus, contrary to Spieker's earlier statement, they appear to overlap truncated Price River conglomerate. The present writer (Gilliland, 1949, p. 70) determined that these North Horn beds are missing in Mellor Canyon where the Price River is separated from the still younger Flagstaff by an angular unconformity (see pl. 3 fig. B and pl. 10). The unconformity is rather limited in extent but it does appear again along the southeast margin of the Gunnison Plateau between Christiansburg and the Sterling reservoir. In this area, however, Flagstaff and locally some North Horn strata angularly overlie red conglomerates, shales, and freshwater limestone tentatively identified as

Morrison (?). It is possible that the Price River has been truncated through its entire thickness between the west and east sides of the Plateau, thus causing older beds to be exposed along the east side. Still another possibility is that the conglomerate pinches out from west to east by overlap, and for that reason is missing at the unconformity.

Age and Correlation

No fossils, upon which an age determination can be made, have yet been found in the western conglomeratic facies of the Price River. Thus the age of the Price River in the western areas, including the Gunnison Quadrangle, is dependent on stratigraphic evidence alone. Although Spieker (1946, p. 131) has established the continuity between the western conglomerates and the finer clastics in eastern Utah where the age of the Price River is fixed as late Montanan or Lance, this continuity does not necessarily imply contemporanetity. In fact, considering stratigraphic relations, contemporaneity is not likely. The widespread angular unconformity at the base of the conglomerate facies and its eastward change to disconformity and finally gradation indicates that deposition of the conglomerate must have progressed from east to west. It is certain then, that the Price River in the Gunnison Quadrangle is younger, at least in part and possibly in its entirety, than the Price River in its type locality. But since the amount of temporal transgression by the conglomerate has not been determined, it seems best to tentatively accept for the Price River in this area, the age assigned to it in the type locality, that is late Montanan or Lance.

Regional Relationships

At many places in central Sevier Valley and southern Sanpete Valley the Price River is missing at angular unconformities where older Mesozoic strata are overlain by latest Cretaceous and early Tertiary beds. For reasons presented in detail in the discussion of the Early Laramide orogeny, it was suggested by the writer (Gilliland, 1949, p. 74) that deposition of the Price River did not take place in these areas and that the coarse conglomerate exposed in the Gunnison Quadrangle and in the Pavant Plateau accumulated in a basin, bounded on the west by folded Paleozoic and early Mesozoic strata and on the east by folded Jurassic formations and the Indianola group of Colorado age. Thus, the conglomerate facies in this area and the fine clastics exposed due east in the Wasatch Plateau were probably separated by a positive area composed of Jurassic and Indianola strata.

CRETACEOUS AND TERTIARY SYSTEMS

NORTH HORN FORMATION

Type Locality and Distribution

In the Wasatch Plateau, the portion of the former Wasatch formation above the basal conglomerate (now known to be Price River in age) is divisible into three units, which from base upward are: 1) sandstone, vari-colored shale, conglomerate, and minor amounts of fresh-water limestone; 2) fresh-water limestone; and 3) vari-colored shale and sandstone (Spieker and Reeside, 1925, p. 448). The lowest unit, exclusive of the basal conglomerate, has been named the North Horn formation from typical exposures on North Horn Mountain (Ts. 18 and 19S., R. 6E., Salt Lake Meridian), where four readily recognizable units of alternating fluviatile and lacustrine deposits make up the formation (Spieker, 1946, pp. 132-133).

The North Horn formation is now known to be present throughout the Gunnison Plateau, Wasatch Plateau, and adjacent regions on the northeast. Its presence has been determined by the writer in Long Ridge, the Pavant Plateau, and in the Valley Mountains. Its southern and southwestern extent has not been definitely ascertained.

In the Gunnison Quadrangle, the exposures are limited to the Valley Mountains along the western border of the quadrangle where the formation generally crops out at the base of fault scarps capped by Flagstaff limestone (see pl. 11).

Lithology and Thickness

Over most of its extent the North Horn formation is a variable assemblage of variegated shale, sandstone, conglomerate, and limestone. It is of fresh-water lake and fluviatile origin. In the Valley Mountains the North Horn contains a much greater proportion of coarse clastic material than is typical of the formation in most other areas. In the Valley Mountains the formation consists chiefly of brown, tan, gray, fine to coarse-grained sandstone with a smaller amount of yellow or yellow-brown, sandy limestone (see geol. sections 2, 3, 4). Sandstone beds 2 to 4 feet thick predominate; other beds range in thickness from laminae to 30 feet. Many of the sandstone layers are cross-bedded. Where shale directly underlies the sandstone, the contact is commonly irregular and indicative of channeling by at least moderately strong currents. Small conglomerate lenses with pebbles of limestone derived from underlying beds are present in a few of the sandstones. Minor amounts of red, gray, and purple shale and brown to red conglomerate

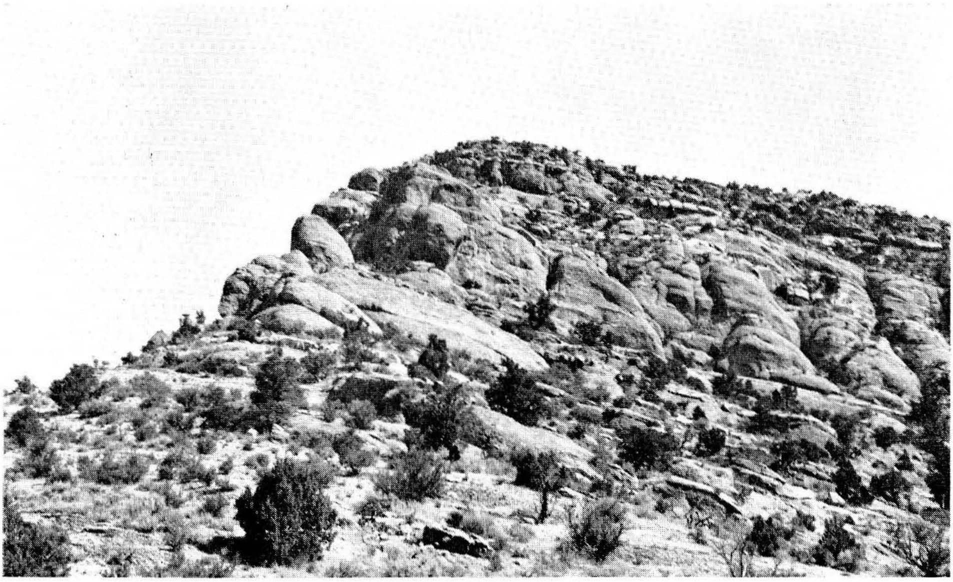


FIGURE A—PRICE RIVER FORMATION IN MELLOR CANYON. View north at mouth of canyon. Exposure of massive conglomerate typical of the Price River in the western district.

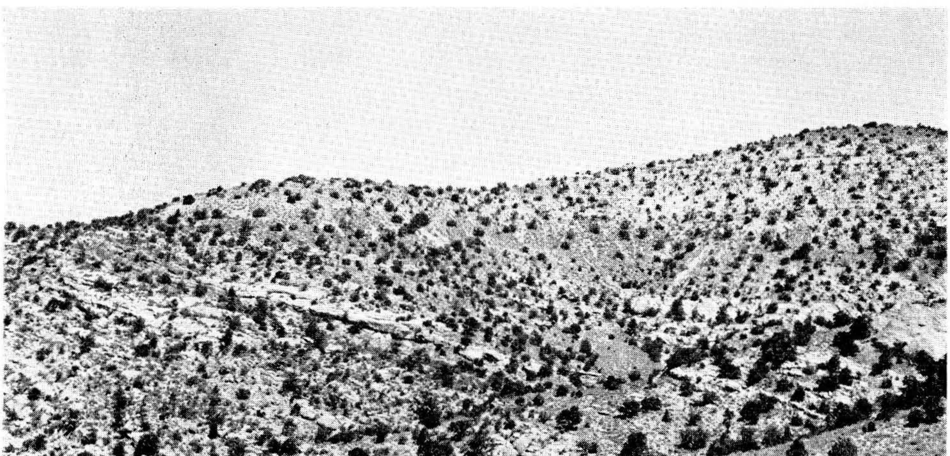


FIGURE B—FLAGSTAFF-PRICE RIVER UNCONFORMITY IN MELLOR CANYON. View north near mouth of canyon. The Flagstaff is at skyline and truncating steeper dipping Price River conglomerate.

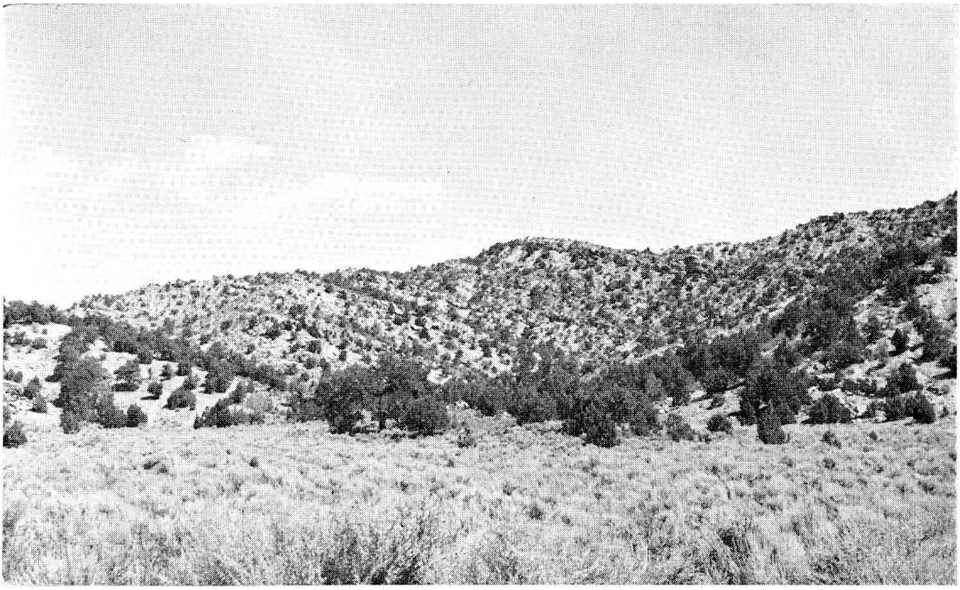


FIGURE A—NORTH HORN FORMATION IN DASTRUP CANYON. View north at head of canyon showing alternating ledges and slopes typical of the North Horn.

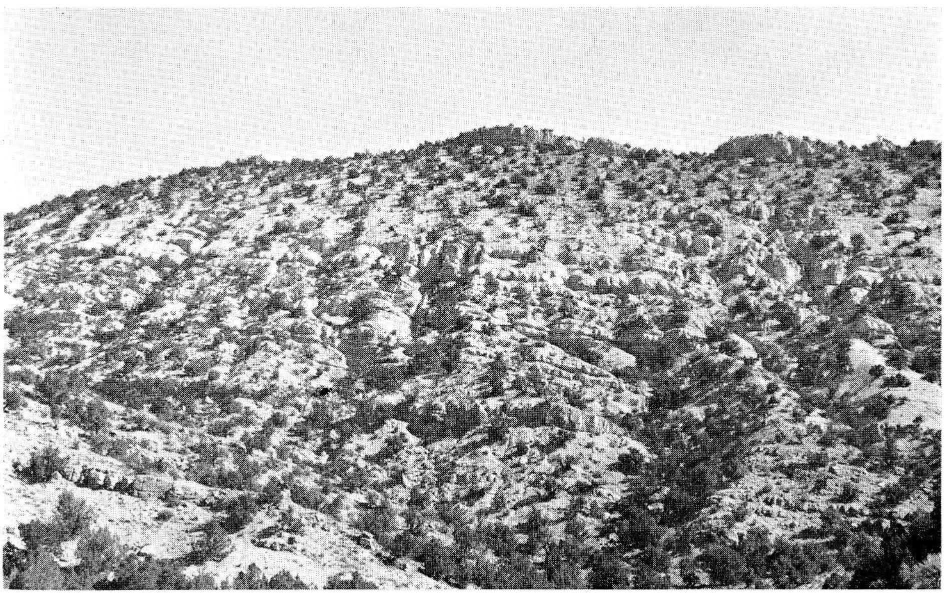


FIGURE B—BASAL UNITS OF THE FLAGSTAFF IN HAYES CANYON. View in Hayes Canyon showing characteristic exposure of unit A (irregular slope) and unit B (cliff at skyline).

are interbedded with the sandstone and limestone. The conglomerates consist of quartzite and gray and blue limestone pebbles. These pebbles are similar to those comprising the Price River and were likewise originally derived from Paleozoic rocks. Grayish-brown algal nodules up to 6 inches in diameter are abundant throughout the formation. At some places beds 2 to 3 feet thick consist entirely of the nodules.

The lithology of the formation is expressed in moderately steep slopes underlain by thin-bedded sandstones, shale, or limestone, alternating with low cliffs of resistant sandstone or conglomerate (see pl. 4, fig. A).

In this area, the North Horn formation possesses the irregular bedding and variety of composition that is commonly considered to be characteristic of channel and flood-plain deposits. The abundant sandy limestone suggests near-shore lacustrine conditions. However, the fourfold alternation of fluviatile and lacustrine deposits that characterize the formation in the type area is not distinguishable in the Valley Mountains.

The base of the North Horn is not exposed in the area under investigation; therefore, the total thickness of the formation is unknown. The maximum thickness observed is at the head of Dastrup Canyon on the east side of South Valley, where a total of 1578 feet were measured (see geol. section 4).

Relation to Adjacent Formations

Since the base of the North Horn formation is not exposed in the Gunnison Quadrangle, the lower contact is unknown here. Elsewhere, except at the earlier cited location north of Mellor Canyon, the lower portion of the formation is gradational with the Price River strata; the boundary is drawn at the line of apparent change from dominantly fluviatile and lacustrine strata of the North Horn to the littoral and conglomeratic sediments of the Price River. The boundary between the North Horn and the overlying lacustrine Flagstaff formation is likewise arbitrary except in Sixmile Canyon near Sterling, Utah, where, according to Spieker (1946, p. 133), units of the North Horn are truncated by the Flagstaff limestone.

In the area of this report, the dominantly clastic North Horn strata pass transitionally upward into the typically non-clastic Flagstaff; the gradation is commonly restricted to a small vertical distance. Limestones, generally sandy, are common in the upper part of the North Horn, and a few thin sandstone lenses are present in the basal Flagstaff

limestones, which are locally sandy. For the purpose of this investigation, the top of the highest, prominent, clastic unit was used arbitrarily as the formational boundary. In the vicinity of Hayes Canyon (see geol. section 2), however, the top of a prominent, red silty limestone seemed to be a more satisfactory boundary because it was more easily recognizable.

Age and Correlation

The age of the North Horn at the type locality has been definitely determined to be transitory between latest Cretaceous and earliest Paleocene (Spieker, 1946, pp. 134-135). This determination was based on the discovery of Cretaceous reptilian remains in the lower 500 feet of the formation and the discovery of Paleocene mammalian remains in the upper part.

Aside from algal nodules, no fossils were found in the North Horn formation during this study. Therefore, evidence bearing on the age of the formation in this area is restricted to stratigraphic relations. The base of the formation is not exposed in the Gunnison Quadrangle, but at many exposures near this area the basal beds pass gradationally into Price River strata tentatively assigned to late Montana or Lance age. The North Horn underlies the Paleocene (?) Flagstaff formation with no apparent break between the two. Because the ages of the adjacent Price River and Flagstaff formations are indefinite, the age of the North Horn exposed in the Valley Mountains is likewise uncertain; however, it is either uppermost Cretaceous or early Paleocene or both. Therefore, the North Horn is probably correlative in part with the Lance and Fort Union of the western Great Plains (see Table 2). It is also correlative with the Torrejon, Puerco, and Ojo Alamo formations of the San Juan Basin.

Regional Relationships

The source mountains which furnished the gravels now comprising the Price River conglomerates remained positive, although with less relief, into North Horn time and furnished much of the material included in the North Horn formation. The remnants of these mountains now mark the westernmost known extent of the North Horn. East of the mountains and in the general vicinity of central Sevier Valley and southern Sanpete Valley, a positive area, postulated by the writer (Gilliland, 1949, p. 74) and mentioned in the discussion of the Price River formation, probably remained positive through North Horn

time. Thus, the North Horn exposed in the Valley mountains and the northern part of the Pavant Plateau apparently was deposited in a basin bounded on the west by the source mountains and on the east by the positive area. It is likely, though, that this basin was connected on the north with other depositional areas. Its southern extent is not known.

The North Horn strata deposited in the partially isolated basin contrasts rather strongly with the more typical North Horn of other areas. In general it lacks the four-fold character so prominent in much of the Wasatch Plateau and also it is composed generally of coarser material than the strata in the Wasatch Plateau. The contrast, however, with the northern equivalents in the Gunnison Plateau and Long Ridge is less pronounced. In those areas the North Horn also lacks the four-fold character and, notwithstanding many facies, it is largely composed of coarse clastics.

TERTIARY SYSTEM

FLAGSTAFF FORMATION

Type Locality and Distribution

The name Flagstaff formation was applied recently (Gilliland, 1949, p. 70) to the western extension of the Paleocene Flagstaff limestone, which was defined and named by Spieker and Reeside (1925, pp. 448-449) from exposures in Flagstaff Peak in the southern Wasatch Plateau. The term Flagstaff limestone was considered by the present writer as inappropriate for the unit in the area west of Sevier Valley, where the formation contains a considerable amount of sandstone and conglomerate.

In the Wasatch Plateau, where the Flagstaff was first recognized, the formation is a lacustrine phase between the flood-plain deposits of the former Wasatch formation and was designated originally as the middle, or Flagstaff limestone member, of the Wasatch. At the type locality and throughout most of its known extent, the Flagstaff formation consists of fresh-water limestone with minor amounts of shale, sandstone, gypsum, and volcanic ash. It ranges considerably in thickness, but has a maximum of roughly 1500 feet.

The Flagstaff formation was previously known to extend throughout the Wasatch Plateau and to the plateaus north of the Book Cliffs. In 1946 the writer recognized its occurence as far west as the Pavant Plateau as well as in the Valley Mountains and at the south end of the Gunnison Plateau. In 1947 the writer also observed the presence

of the Flagstaff in Long Ridge. It is now known that the formation is present throughout much of the Gunnison Plateau and at least at the north end of the Fish Lake Plateau.

In the Gunnison Quadrangle, the formation is present in the Gunnison Plateau east of Fayette, throughout the Valley Mountains, and in the southeast corner just south of Willow Creek. A prominent and easily accessible exposure of the Flagstaff is on the north side of U. S. Highway 89 at the east boundary of the quadrangle.

Lithology and Thickness

The lithology and thickness of the Flagstaff formation ranges widely in the Gunnison Quadrangle. There are four, more or less, distinct facies present in the formation within the area (Gilliland, 1949, p. 70). These facies are: 1) yellow, gray, and red, dense, massive limestone with some shale in the northern Valley Mountains; 2) dominantly red limestone, areanaceous in part, interbedded with considerable amounts of sandstone and conglomerate in the southern Valley Mountains; 3) massive, gray, dense limestone present in the Gunnison Pleateau northeast of Fayette; and 4) a conglomerate and limestone facies exposed south of Willow Creek.

VALLEY MOUNTAIN FACIES: The facies of the Flagstaff in the northern Valley Mountains is divisable into five lithologic units, three of which may be coincident with faunal zones. Four of the five units are traceable into the southern Valley Mountains. The units are lettered A through E from bottom to top (see pl. 9).

In general, the Flagstaff formation in the Valley Mountains grades from dominantly yellow and gray with some red, dense, lacustrine limestone in the northern area to dominantly red and pink, partly arenaceous limestone with some sandstone and conglomerate in the southern area. The southern type of lithology continues into the Pavant Plateau and becomes more clastic. The formation thickens southward from over 1100 feet in Hayes Canyon (see geol. section 2) to about 1400 feet in the southern Valley Mountains. Units A and B tend to thin southward, whereas C and E thicken in the same direction. Unit D is missing in the southern Valley Mountains. All five units are present and clearly exposed in Picket Canyon (see geol. section 3).

Unit A: In the northern Valley Mountains, most of this unit consists of yellow and gray, dense to finely crystalline, massive, fossiliferous limestone with small amounts of arenaceous limestone, a few brown

sandstone lenses in the lower part, and some gray shale (see geol. sections 2, 3, and pl. 4, fig. B). The limestone commonly weathers to sharply angular fragments averaging two to three inches in length, and forms very steep talus-covered slopes. Notwithstanding a considerable proportion of gray limestone, the unit most commonly has an overall yellow appearance, which is perhaps its most distinguishing major characteristic. At Lone Cedar Canyon, a small amount of pink, red, and lavender limestone occurs in unit A. These colors increase southward to Dastrup Canyon (see geol. section 4), where the unit forms a very prominent highly-colored cliff consisting in large part of pink and lavender limestone. Farther south (see geol. section 6), the yellow again becomes dominant, but pink, red, and lavender limestone is also abundant.

There is an overall thinning of the unit from north to south (see geol. sections 2, 3, 4, 5, and pl. 9). A thickness of 457 feet was measured in Hayes Canyon (see geol. section 2), whereas only 337 feet were measured in the southern area (see geol. section 6). The unit has a maximum thickness of 494 feet in Dastrup Canyon (see geol. section 4).

Unit B: Unit B characteristically consists of very light-gray or white, medium-gray to nearly black, massive, extremely dense limestone that is locally fossiliferous (see geol. sections, 2, 3, 6, and pl. 4, fig. B). The limestone typically weathers to rough irregular surfaces, but locally it weathers to very angular blocks and forms prominent cliffs. Small amounts of limestone conglomerate, containing pebbles generally no larger than one-eighth of an inch in diameter, also occur in the unit. In the vicinity of Picket Canyon (see geol. section 3), a very dark-gray to black bituminous limestone bed, 3 feet thick, occurs at the base of the unit. This basal bed consists largely of macerated shell fragments.

Southward, the normally gray limestone becomes so mottled with pink that it assumes an overall pinkish cast; other lithologic characteristics remain constant.

Unit B thins southward. A maximum thickness of 513 feet was observed in Hayes Canyon (see geol. section 2), and a minimum of 296 feet was measured in the southwest part of the quadrangle (see geol. section 6).

Unit C: Unit C in the northern Valley Mountains is dominantly red, pink, lavender—mottled slightly with yellow and gray, dense, massive limestone (see geol. sections 2, 3, and pl. 5, fig. A). It weathers

commonly to variegated slopes. Toward the south, the unit becomes more clastic in composition, but the colors are essentially the same throughout the mountains.

In contrast with the lower two units, unit C thickens appreciably from north to south. Measurements of 142 and 108 feet were made in Hayes and Picket Canyons respectively (see geol. sections 2, 3), and 460 feet was measured in the southern Valley Mountains (see geol. section 6).

Unit D: This unit is thin but persistent throughout the northern Valley Mountains in the Gunnison Quadrangle. It consists of yellow, buff, or tawny colored limestone that contains abundant but unidentified remains of ostracods (see geol. sections 1, 2, 3, and pl. 5, fig. A). The limestone weathers to rounded blocks between 1 and 3 feet square and in many exposures forms a distinct ledge above the slopes of the underlying unit C. Unit D is present in Lone Cedar Canyon but is not found in the next canyon south of Lone Cedar. The thickness of the unit ranges between 3 and 8 feet.

Unit E: In the northern Valley Mountains, unit E, the highest unit of the Flagstaff, consists largely of light-gray with some buff, dense to finely crystalline, massive limestone that locally contains fragmentary gastropod remains (see geol. sections 1, 3). It weathers in part to angular, chip-like fragments and in part to very rough surfaces. The unit is well developed at the north boundary of the quadrangle and in Picket Canyon but is missing at the mouth of Hayes Canyon, where unit D is conformably overlain by red shale of the Colton formation (see geol. sections 1, 2, 3). Absence of unit E at Hayes Canyon may be due to erosion or nondeposition, but in view of the apparent conformity between unit D and the Colton, it is more likely the result of a lateral change from the limestone to the Colton shale. Furthermore, known vertical gradation from typical limestone of unit E to thin-bedded limestone and shale of the Colton makes the latter possibility more plausible.

The unit becomes dominantly red and arenaceous southward (see geol. sections 5, 6, 7). A prominent gray limestone ledge, about 130 feet thick at the top of the zone in the vicinity of Bald Knoll Canyon (see geol. sections 6, 7) contrasts sharply with both the underlying red strata and the Colton formation.

The unit thickens toward the south from Hayes Canyon (see geol. section 2), where the unit is absent, to a maximum of 400 feet in Redmond Canyon (see geol. section 5).

Fayette Facies: The Fayette facies of the Flagstaff consists of light-gray to buff, extremely dense, massive, locally fossiliferous limestone. The basal beds rest directly upon the Price River formation in angular unconformity (see pl. 3, fig. B). The basal limestone is arenaceous and locally red because of sand and oxidized iron probably incorporated during transgression of the Flagstaff waters over the eroded and weathered Price River conglomerate, which is also locally red just below the unconformity.

Hardy (1948) reported a thickness of nearly 500 feet for the Flagstaff on the north side of Mellor Canyon where the unit is particularly well exposed.

The exact correlation of the Fayette facies with the Flagstaff of other areas is not known. Hardy (1948) described a red basal unit of the Flagstaff on the west side of the Gunnison Plateau and stratigraphically below the limestone exposed in Mellor Canyon. This lower limestone is gradational with the underlying North Horn but overlaps the tilted Price River toward the south. It wedges out before reaching Mellor Canyon. The present writer believes that this unit may be equivalent to unit A, the lowest unit in the Flagstaff of the Valley Mountains. Then in terms of stratigraphic position, the Fayette facies is roughly correlative with unit B, the next higher unit in the Valley Mountains. Furthermore, the questionable facies is lithologically and, in some measure, faunally similar to unit B. No units comparable to C, D, or E, have been observed in the region east of Fayette.

Willow Creek Facies: In the southeastern part of the quadrangle, there are several exposures of freshwater limestone and conglomerate whose age has long been in question. For many years these beds were correlated with various conglomerate-bearing formations of Cretaceous age. The writer (Gilliland, 1949, p. 70) determined, however, that these limestone and conglomerate beds are correlative with the Flagstaff formation, notwithstanding the fact that their lithology is strikingly different from that which characterizes the Flagstaff in other areas.

The Flagstaff here consists of light gray to white, very dense limestone and gray conglomerate with limestone and quartzite pebbles. Minor amounts of red shale and siltstone are also included. The thickness of the formation is nearly 750 feet. Three units are generally recognizable: a basal conglomerate, a middle limestone unit, and an upper conglomerate (see geol. section 10). The limestone is similar to the Flagstaff limestone in other areas, but the conglomerate is much like beds formerly thought to be restricted in this area to the Cre-

taceous Indianola group. The upper conglomerate unit, however, grades into the red clastics of the Colton formation, and the early Tertiary gastropod, *Goniobasis tenera carterii* Conrad was found during this study in the limestone unit as well as in unit A of the Flagstaff in the Valley Mountains. Therefore, these beds seem almost without doubt to be equivalent to the Flagstaff formation.

All three units of the Willow Creek facies and their relations with adjacent formations are well exposed in a prominent hogback located just south of Willow Creek (see pl. 5, fig. B). The hogback is composed of north-south trending, nearly vertical beds of Flagstaff bounded on the west by more gently-dipping Colton and on the east by Jurassic siltstone and shale. Although there is a marked lessening of dip on the west side of the hogback, the upper Flagstaff beds pass transitionally into the finer clastics of the Colton. At the north end and on the east side of the hogback, the basal conglomerate of the Flagstaff is missing and the vertical limestone unit is exposed in angular unconformity with horizontal red beds of the Twist Gulch formation. This unconformity, although it has been rotated 90 degrees from its original position is similar to the unconformity exposed near the mouth of Salina Canyon where horizontal Flagstaff beds overlie vertical Twist Gulch strata.

Relation to Adjacent Formations

Throughout most of their extent, the lacustrine Flagstaff strata are gradational with the fluviatile sediments of the underlying North Horn formation and the overlying Colton formation. In the Valley Mountains, the basal Flagstaff beds pass transitionally into the upper North Horn strata. This relation is described in the foregoing discussion of the North Horn.

The upper boundary of the Flagstaff in the Gunison Quadrangle is generally marked by a sharp contrast between the massive gray limestone of unit E and the red shale of the Colton formation. However, locally the massive limestone of the Flagstaff grades upward into thin-bedded, yellow to buff limestone typical of the Colton and Green River formations.

At many places in central Sevier Valley and Sanpete Valley, the Flagstaff overlies older beds in angular unconformity. The unconformities are here interpreted as the result of erosion and burial of

areas that remained positive after the Early Laramide orogeny. This problem is considered in detail farther on in the discussion of orogenic movements.

Fossils

The Flagstaff formation contains abundant freshwater gastropods, a few pelecypods, and ostracods. Units A and B of the northern Valley Mountains have yielded notably different faunas and may be true faunal zones. Unit D contains abundant ostracods that are not yet identified. The Fayette facies contains a fauna comparable to that found in unit B.

The species in the fauna of unit A are as follows:

Aplexa atava (White)
Ferrissia (?) *actinophora* (White)
Goniobasis tenera carterii Conrad
"Helix" (Glyptostoma?) spatiosa (Meek and Hayden)
"Helix" (Oreohelix?) aff. *H. peripheria White*
"Helix" aff. *H. veterna veterna* Meek and Hayden
Hydrobia utahensis White
"Planorbis" cirrus White
"Planorbis" sp. (b)
Sphaerium sp.
Viviparus leidyi leidyi (Meek and Hayden)
Viviparus trochiformis (Meek and Hayden)
Viviparus aff. *V. trochiformis* (Meek and Hayden)
Viviparus aff. *V. pecularis* (Meek and Hayden)
Viviparus aff. *V. leai* (Meek and Hayden)

The fossils collected from unit B are listed below:

Holospira leidyi (Meek)
Physa bridgerensis Meek
Physa pleromatis White
"Planorbis" sp. (a)
Viviparus aff. *V. trochiformis* (Meek and Hayden)

The following listed fossils were found in the Fayette facies in Mellor Canyon and due east of Fayette:

Aplexa sp.
Holospira leidyi (Meek)
Physa bridgerensis Meek
Physa pleromatis White
"Planorbis" sp. (a)

Age and Correlation

The early consideration of the Wasatch formation of central Utah as lower Eocene and the resulting assignment of most fossils found in the Wasatch strata to that age has presented numerous difficulties to recent workers attempting to determine the ages of the several formations now known to comprise the former Wasatch. The long range sustained by many fresh-water species further complicates any age determinations.

The previously mentioned discovery of vertebrate fossils in the North Horn established fairly certainly the early or middle Paleocene age of the upper part of that formation. Because the Flagstaff apparently followed the North Horn with little lapse of time, and because in the central Wasatch Plateau it contains fossils suggestive of an age older than Eocene, Spieker (1946, p. 136) considers a late Paleocene age likely for the Flagstaff.

In his summary, Wood (et. al. 1941) assigned the Flagstaff to a Tiffanian and Clarkforkian age, late Paleocene. He correlated the formation with the Fowkes formation of southwestern Wyoming and with the uppermost Fort Union strata of the northern Great Plains (see Table 2). The now known extension of the Flagstaff into the Pavant Plateau suggests a possible correlation with the Bryce Canyon formation of southern Utah.

The fossils found in the Flagstaff and listed in earlier paragraphs furnish little definite evidence regarding the exact age of the Flagstaff. Such indefinite terms as Wasatch and Tertiary have frequently been used in describing the age of many of the species; and originally, many formations in which some of the species have been found were erroneously assigned places in the time scale. Furthermore, the recent general acceptance of the term Paleocene invalidates much information previously reported. As a result, confusion surrounds much of the paleontologic data for nonmarine late Cretaceous and early Tertiary strata. The fauna collected from the Flagstaff during this study does, however, indicate an early Tertiary age no younger than Eocene and, in view of other data, the late Paleocene age for the Flagstaff seems acceptable.

Regional Relationships

The Flagstaff represents widespread and persistent lacustrine conditions following the vacillating fluviatile and lacustrine environments of North Horn time. Deposition of the Flagstaff was in turn, followed over a wide area by a second dominantly fluviatile phase evidenced

by the Colton formation. However, in the vicinity of Thistle, Utah, the Colton and Flagstaff beds change by gradation and intertonguing into typical Green River-type strata indicating a beginning of Green River-type lacustrine conditions at the beginning of Flagstaff time and their uninterrupted continuation through Green River time (Spieker, 1946, p. 136).

As indicated by rather widespread angular unconformity at the base of the Flagstaff, Colton, and Green River formations, a positive area existed in the general area of Sanpete and central Sevier Valleys during part and, in some places, all of Flagstaff time (Gilliland, 1949, p. 74). At most of the localities showing unconformity, the basal Flagstaff beds are missing, and at the mouth of Salina Canyon, the entire Flagstaff and Colton are absent. Highly folded rocks ranging from Jurassic to early Tertiary in age underlie the area. The positive area was almost completely inundated by the Flagstaff lake, but in the vicinity of Salina Canyon where the Flagstaff and the Colton wedge out over Jurassic beds, the area remained positive into Green River time.

COLTON FORMATION

Type Locality and Distribution

The Colton formation is composed of the strata formerly classified as the upper member of the Wasatch formation (see Table 2). The Colton was defined by Spieker (1946, p. 139) as consisting of the beds between the Flagstaff limestone and the Green River formation in the hills north of Colton, Utah. In that area the formation is about 1500 feet thick and contains gray, pepper-and-salt sandstone, greenish-buff sandstone, siltstone, and deep red to variegated and gray shale. The Colton strata, dominantly fluviatile in origin, offer a striking contrast to the generally gray and greenish-gray, lacustrine deposits of the Flagstaff and Green River formations, which bound its upper and lower limits.

Although much gradation and intertonguing takes place between the Colton and adjacent formations, the Colton is widespread in central Utah. It is widely exposed in the Tavaputs Plateau, but is absent on the top of the Wasatch Plateau where the Flagstaff now underlies the surface. Exposures of the Colton occur at numerous places along the western edge of the Wasatch Plateau, where the Flagstaff, Colton, and Green River form the strata in the Wasatch monocline and plunge steeply under the alluvium of Sanpete and Sevier Valleys. The Colton is locally present at the top of the Gunnison Plateau.

Within the Gunison Quadrangle (see pl. 11), the formation crops out at the base of the Caterpillar, a brilliantly colored, steep, and very rugged escarpment extending from near Utah Highway 28 southeast of Fayette to the northeast corner of the quadrangle. It is also exposed in the area south of Willow Creek and along the eastern edge of the Valley Mountains between Green River cuestas and fault blocks of Flagstaff (see pl. 6, fig. A). The Colton is not definitely known south of the area of this report, but it probably continues southwest and forms part of the striking red exposures prominent on the west side of the Sevier Valley near Richfield.

Lithology and Thickness

In spite of much intertonguing and gradation between the Colton and adjacent formations, the lithology of the Colton, where recognized as a fluviatile phase between lake deposits, is essentially constant throughout the area of distribution. The Colton in the Gunnison Quadrangle consists, for the most part, of red, chocolate-brown, greenish-gray, and purple variegated shale. Many different types of limestone occur generally as thin layers or zones in the shale. Much of the limestone is yellow and very thinly bedded or platy. It is very similar to the limestone common in the Green River. A few lenses of gray, pepper-and-salt sandstone and deep red sandstone are interbedded with the shale (see geol. sections 1, 5, 7, 9).

The formation in the area of this report has an average thickness of 410 feet. The thickness is moderately consistent in the area except in the southwestern corner, where it decreases appreciably. Slightly more than 450 feet were measured in the Caterpillar and at the north boundary of the quadrangle (see geol. sections 1, 9). The thickness decreases to about 405 feet at Redmond Canyon, thence to 333 feet at a short distance south in Bald Knoll Canyon (see geol. sections 5, 7, and Pl. 9).

Fossils, Age, and Correlation

A few of the limestones in the Colton contain very poorly preserved plano-spiral gastropods about one-half inch in diameter; other limestones contain abundant ostracods. In the northern Valley Mountains, a limestone bed 1 to 5 feet thick near the base of the formation consists almost entirely of ostracod remains (see geol. section 1). Lozenge-shaped scales and bone fragments of a ganoid fish occur sparingly in the limestones and have been referred to the family Lepidosteidae.

PLATE 5

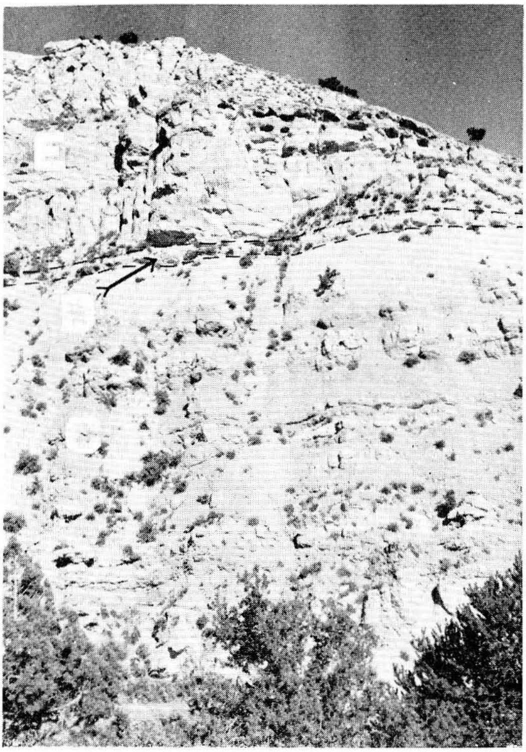
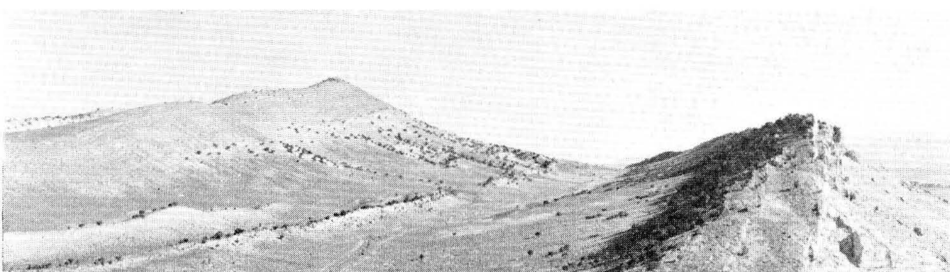


FIGURE A (left) — UPPER UNITS OF THE FLAGSTAFF IN LONE CEDAR CANYON. View east near mouth of Lone Cedar Canyon. Typical development of units C, D, and E of the Flagstaff formation in the northern Valley Mountains.

FIGURE B (below) — GREEN RIVER AND FLAGSTAFF HOGBACKS SOUTH OF WILLOW CREEK. View north from south side of the former Willow Creek Valley. The present Willow Creek flows on far side of the hogbacks. The hogback on the right consists of nearly vertical Flagstaff conglomerate and limestone. At the north end and on the east side of that hogback, nearly horizontal Jurassic shale and siltstone are in depositional contact with the Flagstaff. The left hogback consists of Green River shale capped by limestone. The intervening valley is eroded in the Colton formation.



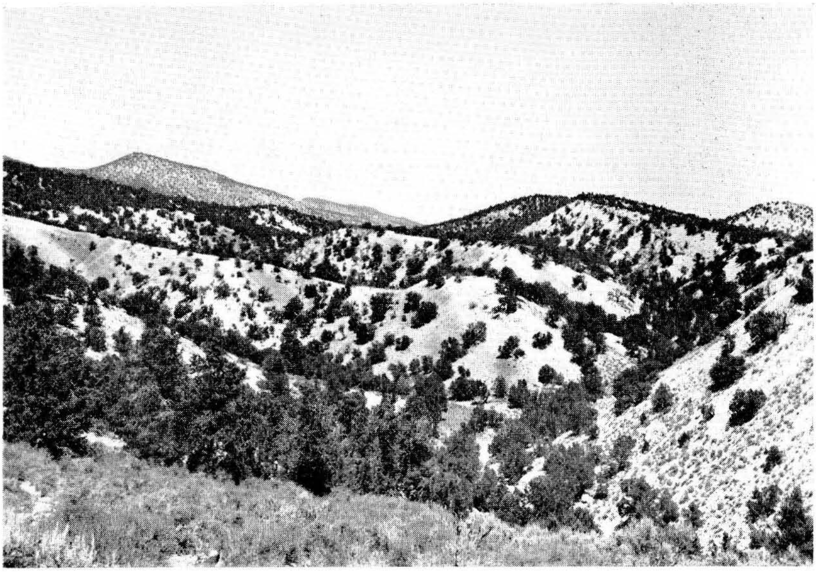


FIGURE A—COLTON FORMATION IN THE NORTHERN VALLEY MOUNTAINS. Typical exposures of the Colton formation (center) on the east side of the Valley Mountains at the north boundary of the Gunnison Quadrangle. Green River escarpments on the right and faul blocks of the Flagstaff in the left background.

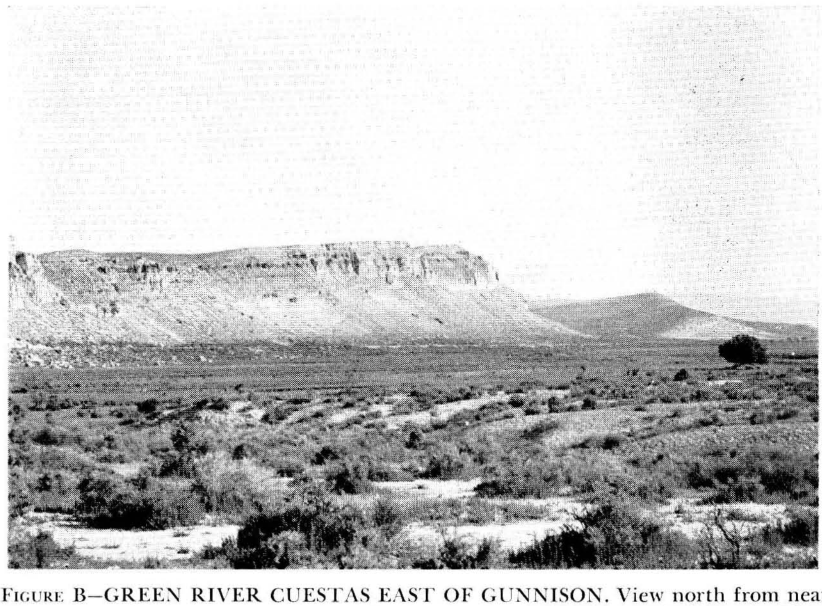


FIGURE B—GREEN RIVER CUESTAS EAST OF GUNNISON. View north from near Denver and Rio Grande Western Railroad station showing typical Green River cuestas consisting of greenish-gray shale capped by yellow, thin-bedded limestone. The notch at the north end of left cuesta is the site of U. S. Highway 89 and a fault, the north side of which has moved down.

The questionable age of the Colton has been adequately discussed by Spieker (1946, p. 139), who, because of lack of evidence to the contrary and in view of general stratigraphic relations, considers it to be Lower Eocene and thus Wasatchian in age. Wood (et. al., 1941), prior to the naming of the Colton, assigned the "Wasatch formation," which is equivalent to the Colton, to the basal Eocene—more specifically to the lower two-thirds of the Wasatchian Provincial Age. Such an age indicates a partial correlation with the Knight formation, which is the upper member of the Wasatch group named by Hayden in southwest Wyoming (see Table 2), and with the Sand Coulee and Gray Bull of the Big Horn Basin, Wyoming. In the northwest part of the Wasatch Plateau, the Colton intertongues completely with the Green River and is equivalent in age to the lower part of that formation (Spieker, 1946, p. 139).

General Relationships

The basal boundary of the Colton has been discussed in foregoing paragraphs. Although the upper strata are transitional with the gray and greenish-gray beds of the overlying Green River, the transition is limited to a comparatively small vertical range—in this work the boundary was placed at the top of the highest occuring red zone.

The red strata of the Colton represent the middle one of three flood-plain and channel units, which are separated by the lacustrine Flagstaff and Green River beds. The other fluviatile phases are the North Horn and the Crazy Hollow formations. The alternation of fluvial and lake conditions began at the end of Price River time and continued possibly through late Eocene time. Each of the formations is, in fact, representative of a single phase in a continuous series of alternating environmental conditions, but each unit is sufficiently distinct and extensive to be of formational rank. Vertical transition, lateral gradation, and intertonguing over broad areas are characteristic of at least the lower four formations. Thus, the boundaries of these formations at any given place merely mark the change from one depositional environment to another and regionally they have no rigorous time significance.

GREEN RIVER FORMATION

Type Locality and Distribution

A group of thinly laminated, chalky shales, well exposed along the Green River near Rock Springs, Wyoming, were named the Green River shales by Hayden (1869, pp. 89-92). He interpreted them as

deposits of fresh-water origin. Subsequently, these shales were recognized and studied over much of Wyoming, Colorado, and Utah. A group of strata exposed at Manti, Utah, were named the Manti beds by Cope (1880, pp. 303-304). These, as Cope suspected, belong to the Green River formation. Their southern equivalents, which for many years were not recognized as part of the Green River, were included in that formation by the writer. (Gilliland, 1949, p. 71).

The extensive distribution of the Green River coincides roughly with the two interior basins, separated by the Uinta Mountains, in which the deposition took place. The northern basin, named Gosiute Lake by King (1878, p. 446), occupied the general area of southwestern Wyoming; the southern basin, Uinta Lake (Bradley, 1930, p. 88), was in east-central Utah and northwestern Colorado. The latter basin, defined by the then known outcrops of Green River, extended much farther southwest than Bradley (1930, p. 89) believed. The western limit of Uinta Lake was placed by Bradley (1930, p. 89) just west of the Denver and Rio Grande Western Railroad, half way between Price and Provo, Utah. However, the recognition of Green River strata as far south as the Gunnison Quadrangle extends the limits of Uinta Lake at least 75 miles southwest.

In the area of this report (see pl. 11), Green River beds form the surface of the southern part of the Gunnison Plateau. The beds occur above the Colton in the Caterpillar, from which they extend southward and disappear below the alluvium of Sevier Valley near Gunnison. Two cuestas bordering U. S. Highway 89 east of Gunnison display excellent exposures of the Green River (see pl. 6, fig. B). Hogbacks composed of Green River shales and limestones lie along the west margin of the Jurassic Badlands. Green River strata form the cuestas comprising the eastern foothills of the Valley Mountains.

Lithology and Thickness

The Green River formation in the Gunnison Quadrangle is characterized by many lithologies (see geol. sections 1, 7, 9), the most distinctive of which are greenish-gray shale and yellow, very thinly-laminated, in part oolitic limestone (see pl. 7, fig. A). Thin- bedded to massive, yellow, buff, and gray limestone is also abundant. Some of the limestone, especially in the upper part of the formation, has been replaced by blue, gray, tan, and brown flint. A few calcareous sandstone lenses are interbedded. A tan, fine-grained tuff about 1 foot thick containing very abundant and distinct biotite crystals was found at an

undetermined stratigraphic horizon in an isolated outcrop of Green River limestone east of the Valley Mountains about three-fourths of a mile south of Hayes Canyon. Float of a green tuff with biotite crystals occurs in exposures at the north boundary of the quadrangle (see geol. section 1). Another green tuff with very abundant and distinct biotite crystals overlies the greenish-gray shale which comprises the lower half of the hogbacks 2½ miles east of Gunnison. These tuffs may correlate with some of those observed by Faulk (1948) in the Green River north of Manti.

Three lithologic zones are commonly recognizable in the Green River formation in the Gunnison Quadrangle. (1) A basal zone of limestone or limestone and shale. The unit, the least persistent of the three, is missing locally in the Valley Mountains and is absent in most of the eastern part of the quadrangle. (2) A middle zone of green or greenish-gray shale, and (3) an upper zone of limestone, that is usually yellow and thinly-laminated to massive. The two higher zones commonly form cuestas and hogbacks capped by the comparatively much more resistant limestone of zone 3 (see pl. 6, fig. B).

About 1150 feet of the Green River was measured in Bald Knoll Canyon (see geol. section 7). This represents the maximum thickness and only complete section of the formation measured in the quadrangle. Incomplete sections of about 500 and 600 feet were measured in the Valley Mountains at the north boundary of the quadrangle and in the Caterpillar respectively (see geol. sections 1, 9). However, the latter figures probably are near the true thickness in the northern part of the quadrangle. If these do approximate the actual thickness, the formation thickens considerably from north to south.

Relation to Adjacent Formations

In the area of this report, the lower strata of the Green River formation pass transitionally into the red beds of the Colton, but the relations with the overlying Crazy Hollow are less clear. The writer has seen the upper contact at only three places. On the west side of a wash 1½ miles due north of the intersection of U. S. Highway 89 and Utah 28, brown flint, part of the Green River formation, contains angular and irregularly shaped silicified fragments of typical Green River limestone. The flint is overlain by about 10 feet of Crazy Hollow conglomerate, that contains rounded black chert and quartzite pebbles generally less than 1 inch in diameter. The upper surface of the flint is slightly irregular, but bedding is lacking so that the stratigraphic

relations are not clearly distinguishable. On the west side of the first Green River hogback north of Willow Creek, thinly bedded Green River limestone underlies 3 feet of Crazy Hollow conglomerate that consists of rounded brown and black chert pebbles up to 1½ inches in diameter. Elongate fragments of Green River limestone up to 14 inches in length are included in the conglomerate, although very little if any erosion of the Green River is evident. Near the mouth of Bald Knoll Canyon, about 23 feet of red and lavender limestone in beds up to two feet thick is exposed at the top of the Green River and directly below massive, cross-bedded Crazy Hollow sandstone (see geol. section 7). The thickness of the limestone is irregular, but because of poor exposure the reasons for the irregularity are not clear.

Spieker (1949b, pp. 36-37) states that in the vicinity of Salina Canyon, Crazy Hollow strata were deposited parallel to Green River beds but upon an erosion surface of considerable relief. In this area there is also evidence of post-Green River, pre-Crazy Hollow faulting but no apparent tilting of Green River beds.

The relation of the Green River and the Crazy Hollow indicates some lapse of time between deposition of the two formations, but the length of the hiatus is not definitely known. However, in view of the considerable relief on the erosion surface between the two formations in the Salina Canyon district, it is probable that the hiatus is of considerable length.

Fossils and Age

The only fossils found in the Green River formation during the course of this study are fish fragments and scales similar to those found in the Colton formation. The fish remains are exceedingly abundant in many layers of the yellow, thinly laminated limestones.

On the basis of numerous plant and fish remains found elsewhere in the Green River, the formation has long been considered middle Eocene in age. For reasons discussed earlier, the Green River has a regionally differing age, which according to Wood (et. al., 1941), ranges from late Wasatchian to Bridgerian (see Table 2).

CRAZY HOLLOW FORMATION

Type Locality and Distribution

The next unit above the Green River formation is the Crazy Hollow formation which, because the Green River of this area was not recognized for many years, was also not distinguished as a distinct unit until this investigation. Recently Spieker (1949b, pp. 36, 37) defined the

formation from exposures in Crazy Hollow, a tributary of Salina Canyon about 2½ miles from the town of Salina. There the formation is about 600 feet thick and is composed of red and orange sandstone, siltstone and shale, pepper-and-salt sandstone, and white sandstone. Pyroclastic sediments probably of Oligocene age overlie the beds in erosional disconformity.

Known exposures of the Crazy Hollow are limited to the general area of central Sevier Valley and southern Sanpete Valley. In the Gunnison Quadrangle (see pl. 11), the formation is exposed in scattered outcrops in the eastern one-half of the quadrangle; it also crops out at the mouth of Bald Knoll Canyon. Higher parts of the southern tip of the Gunnison Plateau are capped by resistant remnants of Crazy Hollow strata. Rocky Point, the prominent red hill immediately west of Gunnison, is made up of strata belonging to the Crazy Hollow formation.

Lithology and Thickness

In the Gunnison Quadrangle the Crazy Hollow formation is a variable assemblage of shale and sandstone with small amounts of limestone all of fresh-water origin. Deep-red or reddish-brown shale with minor amounts of gray, lavender, and purple shale comprises by far the largest part of the formation. Fine-to-coarse-grained sandstone layers rarely exceeding 20 feet in thickness alternate with the shale. Brown, red, gray, and gray pepper-and-salt sandstone are the most common, but light-gray to white sandstone beds are also included in the formation. Some of the sandstone, particularly the brown, characteristically assumes a coating of desert varnish after long exposure to weathering processes. The white sandstone is generally poorly cemented and therefore friable. Upon weathering it very rapidly disintegrates and forms gently curved surfaces. Some of the layers of sandstone are lenticular and cross-bedded; they undoubtedly represent channel fillings. Conglomerate containing chert pebbles averaging less than 1½ inches in diameter and some fragments of Green River limestone is present at the base of the formation. The maximum known thickness of this basal conglomerate is 10 feet. Thin layers of gray, pink, very dense limestone are interbedded with the clastic sediments.

An incomplete section of about 1000 feet of Crazy Hollow strata is exposed on the west side of the Green River hogback north of Willow Creek. This is the greatest known thickness of the unit.

Relation to Adjacent Formations

The lower boundary of the Crazy Hollow has been treated in the discussion of the Green River. Deposition of the Crazy Hollow was followed by accumulation of lake sediments, which makeup the Bald Knoll formation. The writer has seen the contact between these two formations at only one locality. On the south side of a prominent east-west fault, about one mile south-southwest of the Crazy Hollow outcrop at Bald Knoll Canyon, a very small exposure of the contact discloses parallelism or near parallelism of the two groups of strata. A sharp color contrast separates the red strata in the Crazy Hollow formation and the light-colored beds of the Bald Knoll formation, but no evidence indicating a prolonged lapse of sedimentation was observed.

Age

Bone fragments too small to be identified were found near the top of the west side of Rocky Point and were the only fossils found in the Crazy Hollow. Since this study was made, a few molluscs have been found in Crazy Hollow limestone in southern Sanpete Valley but are not yet identified. Therefore, evidence bearing on the age of the formation rests entirely on the stratigraphic position of the formation and on the known progression of Tertiary history in other areas. Owing to the probable middle Eocene age of the Green River in this area, the oldest possible age of the Crazy Hollow is approximately middle Eocene. The Crazy Hollow definitely predates volcanic materials near Salina. Those, according to Callaghan (personal communication), are probably Miocene in age, but Callaghan also indicates the possible presence of Oligocene volcanics there. Therefore, the Crazy Hollow is no younger than Miocene. Furthermore, the overlying Bald Knoll formation, which is no younger than Oligocene, necessitates an even greater age of the Crazy Hollow.

In northeastern Utah, northwestern Colorado, and southwestern Wyoming, the Bridger formation of fluviatile and fresh-water lake origin rests on typical Green River beds. The similarity of environmental succession in that area and in central Utah is suggestive of contemporaneous Crazy Hollow and Bridger deposition. However, the abundant lateral changes that characterize the early Tertiary strata throughout the Western Interior and the hiatus of unknown length, which separates the Crazy Hollow and the Green River, offer little support for such contemporaneity.

The Crazy Hollow is considered late Eocene or Oligocene in age and more likely late Eocene. (Gilliland, 1949, p. 71).

Origin

The variety of composition, the cross-bedded and lenticular nature of some of the sandstones, and the dominant red color point to a fluviatile origin for the Crazy Hollow strata. The flood plains and channels in which the accumulation of the formation took place encroached upon the area formerly occupied by the Green River lake, and, according to Spieker (personal communication) did so after considerable lapse of time following the deposition of the last Green River beds. Locally fragments of Green River limestone were incorporated along with dark-colored chert pebbles in a basal conglomerate. Rapidly shifting stream channels and flood plains characterized the area of accumulation. Fresh-water lakes of probable small extent existed for short periods in the fluvial environment, and in these lakes lime muds were precipitated to later form the typical fresh-water limestones in the formation.

Neither the source of the sediments nor their extent is known. The source of the chert pebbles in the basal conglomerate is especially puzzling. All of the known chert in the underlying Green River is light in color and probably was not the source of the chert in the Crazy Hollow. The Morrison (?) formation, which is truncated by Tertiary strata, contains many-colored pebbles of chert (Spieker, 1946, p. 125) and, in the opinion of the present writer, may have furnished the pebbles in the basal conglomerate of the Crazy Hollow.

BALD KNOLL FORMATION

Definition and General Character

The name Bald Knoll was proposed by the writer (Gilliland, 1949, p. 71) for a succession of very light-colored clays, siltsones, sandstones, and limestones, which rest upon strata of the Crazy Hollow formation and angularly underlie gravels of the Axtell formation. The type locality of the formation is at the mouth of Bald Knoll Canyon in the Southern Valley Mountains; however, Bald Knoll, a conical hill also at the mouth of the canyon, is composed of older strata. The formation consists chiefly of light-green, light-tan, gray, and white calcareous clays with interbedded siltsone, sandstone, and minor amounts of soft limestone of the same colors (see geol. section II). Siegfried Muessig (personal communication) has reported the presence of a few, white ash-like beds in the formation near the mouth of Bald Knoll Canyon.

These beds have not been seen by the writer and their suspected volcanic origin has not been definitely ascertained. The strata of the Bald Knoll are characteristically poorly consolidated and very susceptible to sheet wash; as a result, typical badlands, nearly barren of vegetation, develop in the area of outcrop (see pl. 8, fig. A). The badlands present a striking array of pastel shades of green and tan and gray to brilliant white that contrast strongly with the reds and duller colors of other formations in the region.

The Bald Knoll is not extensively exposed in the area under investigation. Outcrops of the formation are confined to several isolated patches near the mouth of Bald Knoll Canyon (see pl. 11). The formation is, however, extensively, but incompletely, exposed in an area of badland topography on the north side of Utah Highway 63 about five miles west of Salina.

Because of the incomplete exposures, the thickness of the formation is not definitely known. Slightly more than 600 feet of Bald Knoll strata were measured at Bald Knoll Canyon (see geol. section 11), but neither the bottom nor the top strata was observed. It is probable that the formation is considerably thicker, possibly as much as 800 to 1000 feet thick.

The relations of this formation to adjacent formations likewise is not definitely known. The contact of the Bald Knoll formation and the Crazy Hollow is questionable and has been discussed in earlier paragraphs. The upper limit of the formation was not observed during this study; because, in the general vicinity of the type locality, dipping Bald Knoll strata are bevelled and overlain by coarse gravels of the much younger Axtell formation and Recent alluvium which obscure the contact between the Bald Knoll and any formation intermediate in age.

General Relations and Age

The sediments of the Bald Knoll formation are considered typical of fresh-water lake sedimentation. They represent a third and last phase of early Tertiary lacustrine environments that alternate with fluviatile conditions in central Utah. Only one hiatus—that at the Green River-Crazy Hollow contact—is possibly of considerable length in the alternating succession. However, the last two phases repressented by the Crazy Hollow and Bald Knoll formations were apparently much more limited in extent than were the earlier four.

FIGURE A—GREEN RIVER FORMATION ON EAST SIDE OF VALLEY MOUNTAINS. Thin and evenly bedded limestone characteristic of the upper part of the Green River formation.

FIGURE B—CRAZY HOLLOW FORMATION. Typical exposure of Crazy Hollow formation at south end of Valley Mountains showing alternating red shale and standstone.

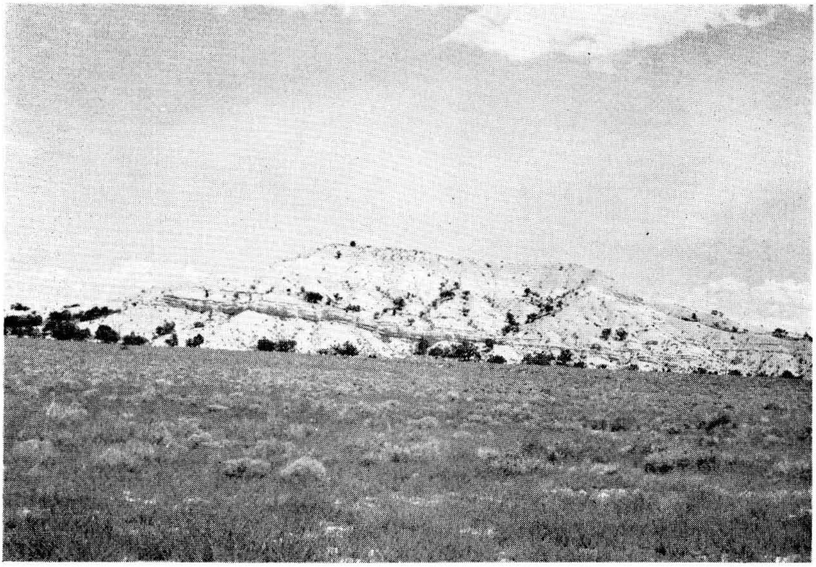


FIGURE A—BALD KNOLL FORMATION. Characteristic topography developed on the soft strata of the Bald Knoll formation.

FIGURE B—BENTONITE HILL CAPPED BY MEXICAN ONYX.

No fossils were found in the Bald Knoll formation, but the writer considers it probably late Eocene or early Oligocene in age. The deposition of the formation probably closely followed the accumulation of the Crazy Hollow fluviatile beds, which may be as old as late Eocene. Furthermore, the Bald Knoll sediments do not, to the writer's knowledge, contain significant quantities of volcanic debris, and therefore, probably preceded extensive vulcanism which perhaps began in Oligocene time and is so extensively represented in nearby areas. The formation, likewise, predates much of the regional structure involving both the warping and faulting of the Valley Mountains. This deformation apparently began during Oligocene time.

PYROCLASTICS AND ASSOCIATED SEDIMENTS

General Character

The Redmond Hills are largely composed of a complex assemblage of volcanic sandstones, quartz sandstones, shales, limestones, mexican onyx, and pyroclastics, great quantities of which have been altered to bentonite (Gilliland, 1949, pp. 71-72). One lava flow is interbedded with the strata and a dike is known to intrude the assemblage. These igneous rocks are described under a subsequent heading.

Outcrops of the pyroclastics and associated sediments are confined, in the Gunnison Quadrangle (see pl. 11), to an elongate, discontinuous belt, which extends nearly the full length of the Redmond Hills. There, countless structural complexities, the analysis of which is virtually impossible because of obscured contacts due to flowage of weathered bentonite, render uncertain the stratigraphic succession of the pycroclastics and their associated sediments. However, consistently different dips and strikes in immediately adjacent exposures of the pycroclastics and Jurassic salt beds indicate with a reasonable degree of certainty that the pyroclastics rest in angular discordance upon the salt. In turn, they are overlain with angular discordance by the Axtell formation. Further, the general complexities of the structures have prevented an accurate determination of thickness for the pyroclastics and other sediments. Estimates indicate a thickness of at least 500 feet and possibly as much as 1000 feet.

Lithology

The pyroclastics and associated sediments are exposed in two general areas of outcrop, each of which is characterized by a distinct lithologic assemblage. One area, in the southern Redmond Hills, extends about 1¼ miles north of Redmond. The rocks in this area are

dominantly pyroclastics with minor amounts of volcanic sandstone, limestone, and mexican onyx. In the northern Redmond Hills, the rocks are chiefly alternating limestone, shale, and sandstone with smaller amounts of interbedded pyroclastics.

Although each of the two mentioned areas have different overall aspects, specific lithologies are common to both. Some of the more common lithologies are described below. The limestones of both areas are white to gray, buff, yellow, yellowish-brown, pink, and thin-bedded; some are dense, and others are finely crystalline. A very small proportion of the limestone is sandy. At the north end of the Redmond Hills, a fossiliferous, thin-bedded, yellow to yellowish-brown limestone is exposed at the base of the southern end of a prominent hogback. This limestone contains numerous unidentified ostracods, high-spired gastropods two-tenths of an inch high, small plano-spiral gastropods, and Sphaerium-like pelecypods. Most of the specimens are preserved as either internal or external molds. Because of the kind of preservation and the general lack of knowledge regarding mid-Tertiary molluscs, these fossils probably cannot be used for a definite age determination.

The quartz sandstones are gray, buff, brown, and yellowish-brown fine to coarse-grained, and are present in layers that are rarely more than one foot thick. Gray, buff, pink, and red shale alternate with the limestone and sandstone. The volcanic sandstones are buff, yellowish-green, bluish-green, brown, medium to coarse-grained, and contain subrounded to rounded grains of felsite or devitrified volcanic glass and quartz. Volcanic ash, in part or wholly altered to bentonite, comprises the bond which is locally calcareous and generally very weak. Because of the rapid disintegration of the cementing material, the volcanic sandstones are very susceptible to weathering and are rarely well exposed.

Mexican onyx, doubtlessly of hot spring origin, is exposed at many places throughout the southern portion of the Redmond Hills. None is known to be present in the northern Redmond Hills. The onyx is distinctly banded with colorless, white, brown, grayish-green, red, and reddish-brown calcite or aragonite. Layers of onyx having highly diversified attitudes cap two prominent bentonite hills in the southern area of outcrop (see pl. 8, fig. B).

Most of the pyroclastics have been altered to bentonite, but ash, unaltered or only partially altered to bentonite, occurs interbedded with the bentonite. The colors of the bentonite and ash include many

shades of gray, purple, pink, red, reddish-brown, yellow, green, and very light green which is the most common color.

Several representative samples of the bentonite and ash have been examined with a petrographic microscope. The dominant minerals that make up the bentonite are undifferentiated members of the montmorillonite group. These are in large part the result of devitrification and alteration of minute shards of volcanic glass, but are also the result of partial alteration of many felsitic and glassy rock fragments as large as 3½ centimeters. Some feldspar and biotite has also been altered.

In addition to the clay minerals, the specimens include well-defined crystals and angular to rounded fragments of minerals and unidentified rock commonly less than 2 millimeters in size. These crystals and fragments range from 1% of the volume in some specimens to 20% in others. Quartz, orthoclase, plagioclase—chiefly andesine, and biotite are the most common accessory minerals. The quartz is often found as pyramidal crystals, some of which display a skeletal development of the faces. Many quartz grains have outlines that indicate resorption of the quartz prior to inclusion in the bentonite. Both the orthoclase and plagioclase occur most commonly as angular crystal fragments but also in euhedral form. Biotite, characteristically present as well-defined, tabular crystals, is very abundant. Other minerals present include: minute apatite needles which are common inclusions in the quartz; traces of zircon and questionably identified amphiboles; and small octahedrons of magnetite, some of which are partially altered to hematite. Traces of other minerals are also present but were not identified.

Secondary calcite is common in most specimens of the bentonite; it occurs in minute veinlets and as replacements. The calcite has partially replaced portions of the clay minerals comprising the shards and in some rare instances has apparently replaced marginal portions of the feldspars which, however, may have been previously altered to the clay minerals.

Origin and Age

The pyroclastics and associated sediments apparently accumulated in a body of fresh water that was confined, in the area of this report, to the central part of Sevier Valley. Volcanoes located south of this area periodically erupted large quantities of ash, some of which fell into the fresh-water lake. Adjacent areas must certainly have received similar deposits that have since been removed by erosion. Deposits of

ash along with larger rock fragments alternated with limestones, shale, and sandstones that were also being deposited in the lake. Calcareous hot springs of short duration existed in the area of the southern Redmond Hills and deposited calcareous material in the form of mexican onyx. The mineral assemblage in the bentonites indicates that they were originally derived from material acidic to intermediate in composition. Subsequently, most of the ash and some of the rock fragments that fell into the lake, were devitrified and altered to bentonite.

Because, at least until the end of Bald Knoll time (late Eocene or early Oligocene), there apparently was very little vulcanism in the area of this report or immediately adjacent regions, the pyroclastics and associated sediments are probably at least younger than Eocene. Furthermore, because of the late Pliocene or early Pleistocene age of the Axtell formation which overlies the pyroclastics and associated sediments, their age is apparently between Eocene and late Pliocene or early Pleistocene.

Callaghan (personal communication) reports the presence of sedimentary beds containing bentonite on the west side of Sevier Valley near Richfield. These beds rest upon strata commonly called Wasatch, and are overlain by the Dry Hollow series of latitic tuffs, latites, and basalts of Miocene age. Callaghan further indicates the presence of bentonitic beds in the Brian Head formation near Panquitch, Utah. Gregory (1945, p. 110), in defining the Brian Head formation, tentatively assigned it to the Miocene. However, near Panquitch the Brian Head rests on the so-called Wasatch strata and underlies the Bullion Canyon formation, which is considered by Callaghan to be Oligocene. No definite evidence bearing on a correlation between the bentonite-bearing beds near Richfield with the Brian Head in the vicinity of Panquitch or with the pyroclastics in the Gunnison Quadrangle is known. But, because no other correlation appears plausible at the present time, it seems possible that the pyroclastics of this report are correlative to the bentonite-bearing beds just mentioned and are also mid-Tertiary and perhaps Oligocene in age (Gilliland, 1949, p. 72).

TERTIARY AND QUATERNARY SYSTEMS

AXTELL FORMATION

Distribution and Lithology

Spieker (1949 b, p. 38) applied the name Axtell formation to a tilted and partially consolidated conglomerate, which is exposed between Willow Creek and the abandoned plant of the Great Western

Salt Company, in the SE¼ sec. 33, T. 20 S., R. 1 E., Salt Lake Meridan. The formation consists of very coarse to fine clastic material representative of all older local bedrock. It was proposed (Gilliland, 1949, p. 72) that the Axtell formation is equivalent to the high level gravels referred to in the foregoing discussion of Sevier Valley, as well as generally finer clastics exposed in the Redmond Hills. These equivalents are here included in the Axtell.

According to present knowledge, exposures of the Axtell are limited to Sevier Valley. The formation is almost continuously present on the west side of Sevier Valley at the base of the Valley Mountains. It is widely distributed on the east side of Sevier Valley south of the San Pitch River and is present in patches in the Redmond Hills (see pl. 11).

Along the margins of Sevier Valley, the Axtell formation consists largely of very poorly sorted, coarse, gray to buff gravel that is locally consolidated and titlted. Pebbles and boulders of all grade sizes and shapes are included. Near the base of the Valley Mountains, boulders as large as 24 inches are common. Composition of the gravel ranges considerably, but, in general, it is reflective of the bedrock exposed in the adjacent highlands.

On the west side of Sevier Valley and south of Dastrup Canyon, the Axtell is pink to orange brown. Significantly, the Flagstaff formation in the southern Valley Mountains is dominantly red and is the probable source of the pink and orange-brown colors in the Axtell.

In the central part of Sevier Valley near Redmond, the Axtell contains much finer material than is typical of the formation along the margins of the valley. These central valley deposits, chiefly light brown and orange-brown in color, consist of clay, silty clay, silt, and siltstone, fine-to coarse-grained sandstone in beds up to 12 inches, and a small amount of conglomerate that contains pebbles of chert and volcanic material generally no larger than one inch. Because the poorly consolidated strata weather rapidly, good exposures are rare. Dips as high as 46° have been observed in exposures of the Axtell near Redmond. Although actual contacts between the Axtell and the adjacent underlying pyroclastics are generally obscured because of the soft nature of both formations, an angular unconformity separates them.

Age and Correlation

Spieker (unpublished notes) tentatively assigned the Axtell to the late Pliocene or early Pleistocene because it is obviously younger than all other bedrock in the region. It is younger than the latest lavas of

the area, which are probably Miocene in age, and it is eroded to a surface which evidently belongs in one of the late cycles of the regional history. The Axtell, according to Spieker, is probably older, on the other hand, than the glacial deposits of middle and late Pleistocene age in the Wasatch Pleateau.

The Axtell formation is possibly correlative with the Sevier River and Parunuweap formations of southern Utah. The Sevier River formation was established by Callaghan (1938, pp. 100-101) to include another very similar group of sediments near Marysvale 60 miles south of Gunnison. The strata are composed of fanglomerate, conglomerate, sand, and silt, which grade laterally into diatomite beds of lacustrine origin. Late Pliocene or early Pleistocene diatoms were found in the layers of diatomite. The formation is extensively dissected and has suffered some faulting.

The Parunuweap formation (Gregory, 1945, pp. 110-115) of southwestern Utah is in many respects similar to the Axtell. The Parunuweap consists of consolidated or partly consolidated masses of boulders, gravel, and stratified sand. The material accumulated in the form of alluvial fans and talus slopes and as disintegrated rock on interfluves. It now occurs on benches and terraces as high as 200 feet above the recent valley filling. Gregory (1945, pp. 114-115) makes a tentative assignment of the Parunuweap to the Pliocene on the basis of its stratigraphic position below Quaternary basalts and fossiliferous Pleistocene sediments. Gregory tentatively correlated the Parunuweap with the Sevier River formation.

Characteristics that are common to the Axtell, Parunuweap, and Sevier River formations are: (1) All consist dominantly of partly consolidated clastic sediments derived from local bedrock. (2) They were, for the most part, deposited in the form of alluvial fans or allied deposits. (3) All have been dissected and now remain as terraces above recent alluvium. (4) Recent diastrophism has affected all three formations. The similarities suggest to the writer that all three of the rather widely separated deposits were accumulated during a single erosional epoch and have undergone comparable events since deposition. The sum of evidence suggests that all these occurrences are more or less contemporaneous and are of late Pliocene or early Pleistocene ages. (Gilliland, 1949, p. 72).

QUATERNARY SYSTEM

VOLCANIC GRAVELS

A previously mentioned (Gilliland, 1949, p. 72) but still unnamed group of dark-gray gravels consisting in large part of pebbles of volcanic rock is confined to an elongate area in the south-central part of the Gunnison Quadrangle. These gravels cover most of the Redmond Hills. Many of the pebbles in the gravel consist of finely porphyritic and vesicular volcanic rock of widely ranging composition; however, no pebbles similar in composition to the igneous rock exposed in the Gunnison Quadrangle were observed. The pebbles of igneous composition are largely dark gray, black, lavender, and green. The other pebbles are composed of black or dark-brown chert and dense limestone or light-colored flint. The proportion of igneous and chert pebbles in relation to the limestone and flint pebbles ranges from nearly 100% of the former in the exposures near Redmond, to about 25% in the northern exposures. All the pebbles are well-rounded and have maximum sizes between 4 and 6 inches. The gravel, which has a very low clay content, is moderately well-sorted but lacks stratification.

The gravel deposits overlie all older rocks exposed in the immediate vicinity including the Jurassic salt beds, the Axtell, and the pyroclastics in angular unconformity. In many localities, a sharp boundary separates the volcanic gravels and adjacent recent alluvium, which, in those places, overlies part of the gravel. Locally, especially along the northwest edge of the area of gravel distribution, the lighter-colored recent alluvium grades into the dark-gray volcanic gravel.

Exact conditions of origin for the gravels is not known, but the source of the igneous pebbles was undoubtedly south of the Gunnison Quadrangle. For many miles south of the quadrangle, there are very extensive lava flows, which have accumulative thickness of several thousands of feet and a composition ranging from rhyolite to basalt (Dutton, 1880).

The source of the chert pebbles, on the other hand, is not definitely known. The Green River formation, which contains abundant light-colored flint and chert, is not known to include dark-brown or black chert similar to that in the gravel. Parts of the Axtell formation contain chert pebbles, but the quantity is very small. Either one or both of two other stratigraphic units in the region may have been the source of the chert. The questionably identified Morrison formation, which is exposed near the mouth of Salina Canyon, contains many-colored chert and quartzite pebbles (Spieker, 1946, p. 125), but no noteworthy con-

centrations of these pebbles have been observed in the washes near the exposures. The previously described conglomerate in the Crazy Hollow formation seems, because of greater proximity, to be the most likely source of the chert pebbles.

The gravels are younger than the Axtell and older than the Recent alluvium; therefore they are probably late Pleistocene in age. (Gilliland, 1949, p. 72).

BEACH SAND

Discovery of an isolated sand deposit by the writer, provided evidence that Lake Bonneville extended much farther south in Sevier Valley than previously suspected (Gilliland, 1949, p. 72). The evidence for the greater extent of the lake is presentd below.

The very well sorted, fine sand partially covers several low hills about one-half mile east of Fayette, Utah, in the north central part of the quadrangle, and is confined to an area about one mile square. The highest elevation at which the sand occurs is approximately 200 feet above the flood plain of the Sevier River and about 150 feet above the nearby washes. Exact elevations were not obtained; but, according to generalized elevations shown on the Reconnaissance Map of the Manti Quadrangle, Utah, the sand lies between the 5,000 and 5,250 contours and probably nearer the upper limit.

About 98% of the sand is composed of equal amounts of sub-rounded quartz grains and partially altered feldspar grains. A few of the quartz grains are rounded and pitted, and a similar number are distinctly angular and vitreous. The feldspar grains are sub-rounded to well-rounded. The rest of the sand consists of grains of epidote, magnetite, brookite, garnet, zircon, titanite, and a carbonate—probably siderite. A few shell fragments were also found. The sand deposits are entirely lacking in stratification and the sand is very well sorted. The following size analysis illustrates the high degree of sorting that characterizes the sand: 1/32–1/16mm 2.11%; 1/16–1/8mm 19.63%; 1/8–1/4mm 73.17%; 1/4–1/2mm 4.14%.

Although the characteristics of the sand might be attributed to either aeolian or fluviatile agencies, the general lack of frosting on the grains, the lack of aeolian cross-bedding, and the topographic position seem to minimize the possibility of the sand's origin by one of those agencies. Furthermore a comparsion of the elevation of the highest stage of Lake Bonneville with elevations in Sevier Valley, strongly indicate that the lake, at the time of its maximum extent, did inundate a

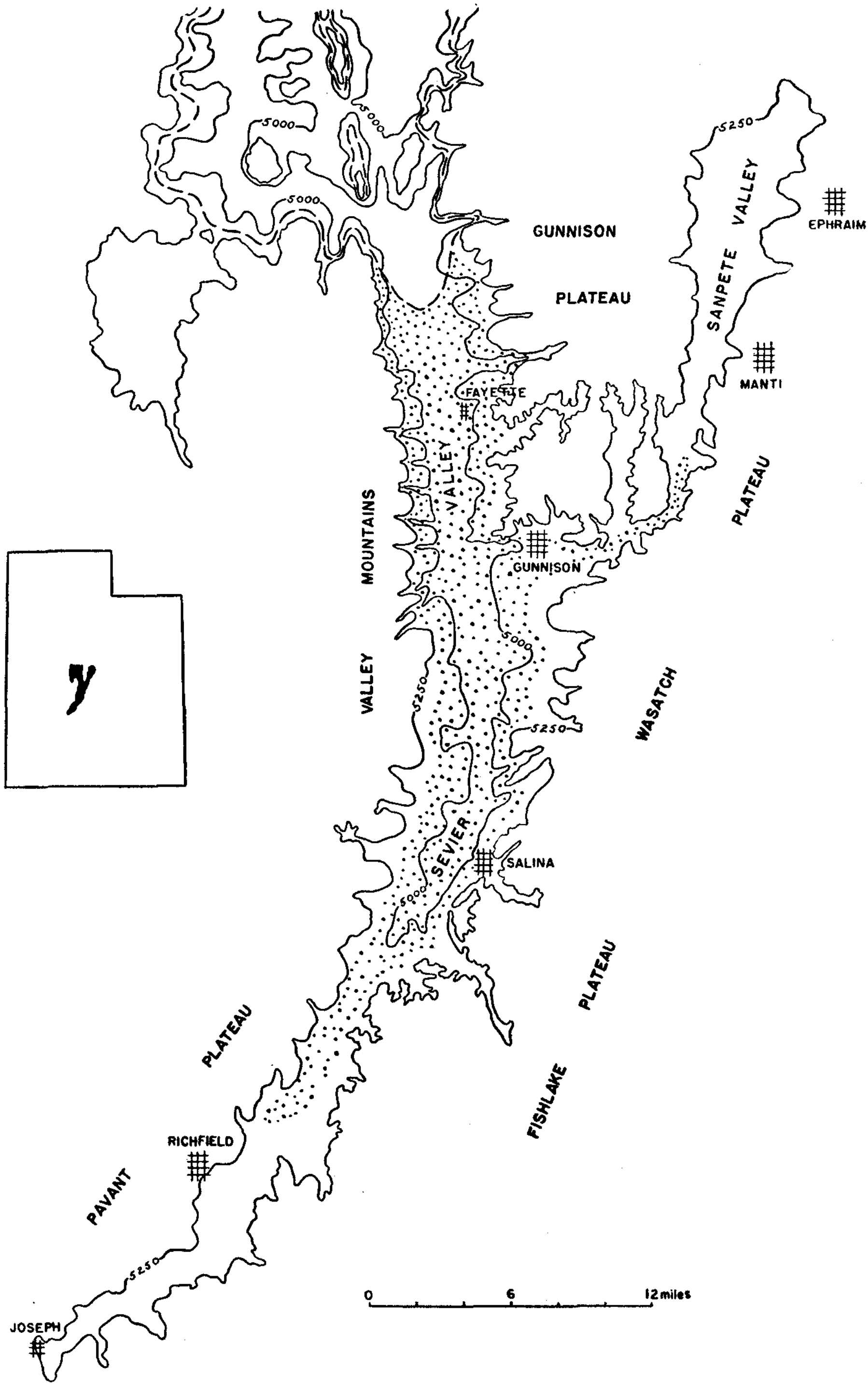


FIGURE 2—Map showing probable extent of Lake Bonneville in Central Sevier Valley, Utah. Dashed line—approximate maximum extent according to G. K. Gilbert (1890). Stippled area—probable area of inundation.

portion of Sevier Valley. The sand is therefore probably of lacustrine origin.

Gilbert (1890, p. 94) states that the elevation of the Bonneville shore line, the highest level of Lake Bonneville, is about 5,200 feet above sea level, presumably in the vicinity of Great Salt Lake. D. J. Varnes (personal communication) has indicated that the elevation of the corresponding shore line near Delta, Utah is about 5,180 feet. Figure 2, prepared from data on the reconnaissance topographic maps of the area, shows the general area of Sevier and Sanpete Valleys that occurs below the highest elevation of Lake Bonneville and thus the areas of probable inundation.

Other features of lacustrine origin such as wave-cut terraces, spits, and bars have not yet been recognized in Sevier Valley. However, absence of such features may be explained, perhaps, by the fact that the inundation of the valley by Bonneville was during the lake's maximum extent and therefore, probably of short duration. Furthermore, the valley would have offered a very limited fetch and thus, would not have been conducive to extensive wave and current action.

The sand is older than the most recent alluvium. Because of complete lack of any lithification, the sand undoubtedly can not have suffered long erosion and is probably no older than early Pleistocene. If it is truly a Lake Bonneville beach sand, then the age of the sand is certainly Pleistocene.

RECENT ALLUVIUM

Nearly all of Sevier, Sanpete, South, and Japs valleys are floored with recent alluvium consisting of silt, sand, and gravel. The finer-textured material, along with minor amounts of gravel, is generally concentrated in the central parts of the valleys; whereas toward the adjacent highlands, coarse, poorly-sorted material becomes dominant and locally grades into the Axtell formation. The alluvium, most of which is derived from the nearby highlands, contains fragments from all the local bedrock.

Evidence regarding the thickness of alluvium is scanty. Richardson (1907, p. 13) states that the minimum thickness of alluvium in the main parts of Sevier and Sanpete Valleys is 530 and 650 feet respectively. The first thickness was observed in a well southwest of Redmond (NE¼, sec. 19, T. 21S., R. 1W., Salt Lake Meridian); the second, in a well in Sanpete Valley north of Ephraim (NW¼, sec. 9, T. 16S., R. 3E., Salt Lake Meridian). H. J. Hartsanders, General Manager of the

Gunnison Sugar Inc., Centerfield, Utah, reported that a well drilled there reached a depth of 547 feet without reaching firm rock (personal communication, 1947). The lower few feet of the well penetrated red clay, and the water obtained was high in salt content. The combination of red clay and abundant salt suggest strongly that the red,salt-bearing zone of the undifferentiated Arapien or Twist Gulch was encountered, and that the alluvium is less than 547 feet thick at that place. Unfortunately, the log was lost, and no samples were collected.

IGNEOUS ROCKS

Two exposures of igneous rocks—one a composite dike, the other a lava flow—were first observed in the Gunnison Quadrangle by the writer and are described below.

The dike forms the resistant crest of a prominent cock's-comb-like ridge roughly 200 yards long and about 50 or 75 feet high. The ridge, commonly called Niggers Heel, is approximately 3¼ miles north and one-half mile east of Redmond. The dike, which trends north-south and dips about 80° west, has intruded greenish-yellow, volcanic sandstones. The exposure of the dike shows two types of igneous rock in contact; fragments of a third type were found at the south end of the dike. About 14 feet of dark-lavender, porphyritic andesite that contains phenocrysts averaging 1 millimeter in size forms the west side of the dike. On the east side of the lavender andesite are 4½ feet of black, amygdaloidal andesitic vitrophyre. Along the contact of the two rocks, about 1 inch of the lavender andesite has been altered to a pink, bentonite-like material speckled with abundant biotite crystals. The alteration possibly indicates the priority of the lavender andesite. Fragments of brownish-red, porphyritic andesite with a sub-glassy ground mass were found at the south end of Niggers Heel. The phenocrysts are generally no larger than 1 millimeter. Accessory magnetite is abundant.

The other occurrence of igneous rock is a dull, brick-red, vesicular lava about 6 feet thick. It is interbedded with bentonite, sandstone, and limestone and exposed just north of a prominent wash about one-quarter of a mile north of the Albert Poulson Salt Mine. The lava is an andesite. It contains some accessory magnetite. Calcite and a yellow, clay-like mineral partially fill the vesicles of the lava.

The age of the lava is perhaps Oligocene for the reasons set forth in the discussion of the pyroclastics; the dike, however, is of questionable age, but either an Oligocene or Miocene age for it seems to be the most plausible surmise.

STRUCTURE

GENERAL FEATURES

The Gunnison Quadrangle lies athwart Sevier Valley, a great structural trough which is joined a short distance east of Gunnison by Sanpete Valley, another great structural depression. North of their juncture, the valleys are separated by the Gunnison Plateau. Sanpete Valley and that portion of Sevier Valley south of Gunnison are bounded on the east by the Wasatch Pleateu. The boundary between this plateau and Sevier Valley is a great west-dipping monocline, the first of the large displacements that characterize the Great Basin.

In the area covered by this report, Sevier Valley is bounded on the west by the highly faulted, monoclinal Valley Mountains which, with the northern part of the Pavant Plateau due west of the Gunnison Quadrangle, form a western counterpart of the Wasatch Plateau (see fig. 3). However, the nearly flat-lying strata in the Pavant Plateau are separated from the monoclinal structure of the Valley Mountains by Round Valley, analyzed by the writer as a large graben.

The northeastern part of the quadrangle is occupied by the southern tip of the Gunnison Plateau which, in this area, is composed of faulted and gently folded rocks of Cretaceous and early Tertiary age.

Hogbacks and cuestas along the southeast side of the quadrangle form the foothills of the Wasatch Plateau. These are characterized by low angle thrust faulting.

On the following pages, the structure of the quadrangle, as observed and mapped by the writer, is described and related to regional structure wherever possible. The thrust faulting in the southeast portion of the quadrangle, originally mapped by E. M. Spieker and described by M. P. Billings (1933), is reconsidered in terms of new stratigraphic and structural knowledge. The new analysis offers an explanation for one of the great enigmas in the region, i.e., the present structural position of the Arapien shale and the Twist Gulch formation.

VALLEY MOUNTAINS

ATTITUDE OF THE STRATA

The strike of the strata in that portion of the Valley Mountains in the Gunnison Quadrangle, ranges from N. 10° W. to N. 24° E. Locally, where the beds have undergone severe disturbance, there is even greater diversity of strike. Nothwithstanding the wide differences, the general trend is slightly east of north.

The prevailing dip is about 25° east, but it decreases gradually to about 20° or 22° along the east margin of the range. On the west side of Japs Valley, as well as in much of the western part of the mountains, the strata are horizontal or nearly so. Many local irregularities in attitude are found when the structure is examined in detail.

FAULTS

The most striking structural features of the Valley Mountains are the numerous faults which divide the range into roughly rectangular blocks (see pl. 11). Only a few fault planes have been observed because of the general presence of talus at the scarp bases. Those that were seen are vertical or dip between 80° and 90° west. Because the traces of almost all the faults are straight or uniformly arcuate and are not visibly affected by topography, most of the faults are considered to be nearly vertical. They are typically normal, dip-slip faults. The faults range in length from less than one-half a mile to 8 or 9 miles; some that extend beyond the margins of the quadrangle may be considerably longer.

Two distinct sets of faults are present in the mountains (see pl. 11). The principal set trends approximately north, parallel to the regional trend and contains the greater number of faults. These are vertical or nearly vertical, antithetic strike faults along which, with few exceptions, the western sides are down-thrown (see pl. 10). Displacements along the faults range from a few tens of feet to about 2200 feet along the west side of Japs Valley.* The faults in this group strike between N. 10° W. and N. 34° E; however, most of the faults strike between N. and N. 8° E. Based on 40 observations, which did not include the few distinctly anomalous bearings, the average strike was determined to be about N. 3° E.

The minor set contains the faults that trend across the major structure. At most places, the larger faults of this group roughly coincide with the major canyons. Two general directions of strike were observed. At some places they represent variations along a single fault. One direction is slightly north of west, the other, slightly north of east. The northwest-striking faults range in bearing between N. 30° W. to N. 88° W., but 15 of 18 observations were between N. 63° W. and N. 88° W. and averaged N. 76° W. Six measurements of the fewer north-

* Elevations used in determining displacement of most faults were obtained by using aerial photographs and an Austin Photo Interpretometer. Therefore, the displacements given here are approximate.

east-striking faults ranged between N. 71° E. and N. 85° E. The average of these is N. 78° E.

In spite of the rather pronounced regularity of the strike of faults in the several sets and the angular relations between the sets, it has not been possible to analyze the fault system in terms of causative forces.

No evidence indicative of priority of either major fault set was observed. Furthermore, individual members of both sets terminate at faults belonging to the other set, and, except in Picket Canyon where relations are questionable, there is no indication of offsetting of one set by the other. For these reasons, it is concluded that the faulting in both sets was essentially simultaneous. Such relations suggest little if any horizontal movement along either set.

Similarly trending fault sets are present on the east side of the Gunnison Plateau, where Hunt (1948) has found one set trending N. to N. 10° E., and another trending about N. 80° W. Both sets there are of the same age. Other similar fault relations are also known in the Wasatch Plateau. It might be concluded then, that the fault system in the Valley Mountains is merely part of a regional pattern rather than a local development.

JAPS VALLEY GRABEN

Japs Valley is a prominent secondary structural feature of the Valley Mountains. Throughout its length it is a north-south trending graben in which Flagstaff strata have dropped to the level of North Horn beds in the valley walls, but are now largely covered by alluvium. Subsidiary faulting is present in the downthrown block at the north end of the valley and in the central part of the southern half where a low fault scarp is present in recent alluvium (see pl. 11).

Both of the faults which bound the graben are concealed beneath valley alluvium but undoubtedly trend approximately north, parallel to the valley walls. The east fault is apparently continuous from Lone Cedar Canyon to the northern edge of the quadrangle. It has caused an escarpment, which, because of transverse faulting on the east side, consists in part of Flagstaff strata and in part of North Horn strata.

The west fault is at the base of a steep escarpment of North Horn beds. The many streams which descend from the high area west of the escarpment empty into Japs Valley through very narrow tributary valleys carved in the scarp, and, in comparison with those streams flowing down the east escarpment, have formed less extensive alluvial

fan deposits. Because of the smaller alluvial deposits and conspicuous fault facets on the west side of Japs Valley, it is believed that the west fault has suffered more recent movement than has the east fault.

GUNNISON PLATEAU

A broad and shallow southwest-plunging syncline dominates the southern end of the Gunnison Plateau (see pl. 10 and pl. 11). Near Gunnison, a small anticline lies immediately west of the syncline. Northward, the anticline is highly faulted.

The axis of the syncline trends about N. 25° E. It extends southwest from the north edge of the quadrangle to about 1½ miles northeast of Gunnison, where it plunges gently beneath the alluvium of Sevier Valley.

The syncline's east limb is well-exposed in a prominent escarpment on the west side of Antelope Valley. The escarpment, composed of west-dipping Green River and Colton strata, extends approximately in a straight line, from 1 mile south of U. S. Highway 89 to the northern boundary of the quadrangle. Thence, it veers sharply and continues southwest to near Utah Highway 28 southeast of Fayette; this portion of the escarpment exposes the northwest limb and is known as the Caterpillar. The escarpments define the general configuration of the syncline. East dips not exceeding 12° are present along the Antelope Valley escarpment. These dips decrease northward. Along the Caterpillar and in the area due north, the dip is 6° to 10° southeast.

The anticline which bounds the syncline on the west is defined by consistent west dips along the west edge of the plateau in contrast with the southeast dips in the west limb of the syncline. The west dips range from 15° to 47°. These west-dipping strata form the east limb of the great Sevier Valley trough (see pl. 10).

The anticlinal structure continues north beyond the quadrangle, but east of Fayette it is highly complicated by a zone of high angle normal faults (see pl. 10 and pl. 11). The traces of the faults are nearly straight or slightly curved and trend between N. and N. 10° W. They continue north along the west front of the Gunnison Plateau, where they constitute the controlling structure. Some of the faults are downthrown on the west, others downthrown on the east; the net effect, however, is a dropping of the west side of the zone. As a result, the west edge of the Gunnison Plateau north of Mellor Canyon is an imposing west-facing fault scarp consisting of massive Price River conglomerate capped by Flagstaff limestone.

The easternmost fault of the zone continues north from the Gunnison Quadrangle paralleling the escarpment. South of Mellor Canyon, the displacement along the fault is probably less than 250 feet; one-quarter of a mile north, the displacement is about 1000 feet. Several miles farther north, the fault attains a maximum throw of about 1700 or 1800 feet (Hardy, 1948).

In addition to the faults on the west side of the plateau, several faults of small displacement occur along the Antelope Valley escarpment. As in the Valley Mountains, two distinct fault sets are present. Two faults trend slightly east of north, and three trend northwest. The southernmost fault trends northwest and coincides with U. S. Highway 89, 2½ miles east of Gunnison. On the north side of this fault, Green River strata exposed in the Antelope Valley escarpment have moved down an estimated 100 to 200 feet (see pl. 6, fig. B).

Another structural feature of interest is a prominent unconformity near the mouth of Mellor Canyon where the Flagstaff formation overlies the much older Price River conglomerate in angular unconformity (see pl. 3, fig. B). There, the conglomerate of the Price River strikes N. 10° W. and dips 20° NE; the Flagstaff strata strike N. 45° E. and dip 10° SE. If correction is made for the secondary tilt, which affected both formations, it is evident that the attitude of the Price River, prior to deposition of the Flagstaff was not so great as it now appears. Furthermore, owing to the proximity of the source of the sediments which was in the vicinity of the Pavant Plateau, the conglomerate was possibly deposited with an appreciable initial dip. Therefore, the amount of folding of the Price River prior to the secondary tilting was less than that suggested by the present angular difference.

FOOTHILLS OF THE WASATCH PLATEAU

In the area covered by this report, the foothills of the Wasatch Plateau consist of cuestas and hogbacks of west-dipping, early Tertiary rocks broken up into an imbricate structure by thrust faults. The structure is further complicated by some normal faulting and some folding. The thrust faulting has chiefly affected strata of the Flagstaff, Colton, Green River, and Crazy Hollow formations which have, in general, ridden eastward over the soft shales of the Arapien and Twist Gulch formations along horizontal or low angle thrust faults. However, one depositional contact between the Jurassic strata and Flagstaff was observed on the west side of the Flagstaff hogback just south of Willow Creek.

The Jurassic strata which is extensively exposed east of the imbricate structure now has a persistent east dip, but its structure is extremely complicated by much obscure faulting and tight folds overturned toward the west. Nevertheless it is known now that much of the Jurassic was vertical or nearly so prior to deposition of the Flagstaff, Colton, Green River, and Crazy Hollow formations. The evidence for this conclusion is shown by the Salina Canyon unconformity and by the angular unconformity at the north end of the Flagstaff hogback immediately south of Willow Creek. In both places, the Tertiary strata were deposited at approximately right angles to truncated Jurassic beds.

East of the belt of Jurassic strata, the west-dipping Wasatch monocline is largely composed of the same early Tertiary strata which form the hogbacks and cuestas (see fig. 3). The monocline parallels the trend of the cuestas and hogbacks as well as the general trend of the Jurassic strata. However, the alluvium-filled Arapien Valley parallels the base of the monocline and obscures the relations between the Jurassic and the monocline.

Billings (1933, pp. 134-135) referred to the thrust faults in this area as strip thrusts and discussed their nature and history. His interpretation is quoted below with added comments in parenthesis by the present writer.

> "The general sequence of events involved in producing the structure near Salina (and Willow Creek) may be surmised. The Eocene rocks (Flagstaff, Colton, Green River, and Crazy Hollow) have been sheared off from the underlying Jurassic (Arapien and Twist Gulch) and have slid eastward. The upper sheet, being much more brittle than the underlying rocks, was sliced by a series of minor shear-thrusts and rode forward as a unit over the Jurassic. If the fracture developed as in Cadell's experiment . . ., the most westerly of the minor faults is the oldest and they are progressively younger toward the east. What stresses were acting on the Jurassic rocks during the thrusting of the Eocene is not certain. The Jurassic may not have been subjected to any compression and may have behaved as a relatively passive body. On the other hand, it may have been compressed, but being composed of soft shales and salt beds, it may have folded while the overlying brittle limestones yielded by breaking into flakes that rode successively over one another. The horizontal displacement may be only a few thousand feet or it may be greater."

The writer agrees in general with Billings' interpretation but further postulates major thrusting within the Jurassic strata near the

base of the monocline at the same time as the strip thrusting. It is believed that deep-seated compressional forces acting on the area chiefly from the west, and subsequent to the formation of the Wasatch monocline, sheared the incompetent Jurassic shale which at this time was nearly vertical. The shearing probably occurred along low angle thrusts that, because of the monocline which acted as a resistant buttress or strut, were resolved, towards the east, into high angle overthrusts (see fig. 3). Furthermore the Jurassic strata in the area of the foothills was relatively high during early Tertiary time, and the early Tertiary rocks here, in comparison with regions to the east and west, formed a comparatively thin cover over the Jurassic (see fig. 3). The presence of only a thin cover above the unconformity may have facilitated the resolution of the forces.

Because the Jurassic beds were vertical or nearly so throughout the area of the foothills prior to thrusting, their present persistent east dip may be explained in the following manner. As the Jurassic beds moved east along gradually steepening, west-dipping faults, there would be drag folding near the fault surfaces, of course, but the net effect would be an overturning of the mass of strata toward the west. As this overturning took place, the Tertiary rocks, deposited horizontally and at right angles to the Jurassic, would tend to dip west and eventually become vertical. The hogback immediately south of Willow Creek (see fig. 3 and pl. 5, fig. B) illustrates the resulting effect of the Jurassic and the Tertiary strata. The traces of the major faults are perhaps covered by alluvium at the base of the monocline or not yet observed in the complicated structure of the Arapien.

REDMOND HILLS ANTICLINE

The Redmond Hills anticline, which extends north-south for 6 miles along the full length of the Redmond Hills, is the principal structural feature of those hills (see pl. 10, and pl. 11). Its maximum observable width is approximately half a mile. The core of the anticline consists of vertical Jurassic salt beds that strike N. to N. 20° E. (see pl. 2, fig. B). Pyroclastics and other associated strata undoubtedly overlie the salt beds in angular unconformity; although, because of the thick residual clay blanket covering the salt, and because of the flowage of the weathered bentonite, contacts between the two formations were not observed. The pyroclastics are in turn overlain in angular unconformity by the Axtell formation.

In the northern half of the Redmond Hills, the east limb of the

anticline is well defined by clearly exposed strata associated with the pyroclastics. The average dip of the beds is between 30° and 40°, but dips as high as 72° are present. Only three outcrops sufficiently well exposed to permit measurement of dip were observed on the west limb. A northwest dip of 66° was measured at the northernmost exposures of the pyroclastic unit, and west dips of 16° and 21° were measured in poor outcrops of the Axtell beds.

The southern end of the anticline is exposed northwest of Redmond in a roughly triangular area where countless poorly exposed minor structures in the soft pyroclastics have largely obscured the major anticlinal structure. However, low gravel-capped cuestas of poorly exposed Axtell strata and several good exposures of Axtell beds dipping southeast clearly locate the east limb. The west limb of the structure in this area has not been clearly observed, but a low gravel-covered ridge along the west margin of the area is undoubtedly composed of strata that dip toward the west. Evidence of these strata may be seen on aerial photographs which reveal numerous low, flat-iron-like prominences reflected in the gravel cover.

EPISODES OF FOLDING AND FAULTING

GENERAL STATEMENT

Since Late Jurassic or Early Cretaceous time, central Utah has been the scene of considerable crustal unrest. The preservation and excellent exposure of much evidence concerning the diastrophic history in this area has contributed a great deal to the general understanding of orogenesis. Much of the orogenic history of central Utah has been presented by Spieker who listed 14 crustal movements for the region during the Late Mesozoic and Cenozoic (1949b, p. 78). The Gunnison Quadrangle was probably affected by all of these episodes, but specific evidence of most is absent in the quadrangle; therefore, only the most significant of the episodes with additional data and interpretation by the present writer will be discussed.

Evidence for the pre-North Horn (?) movement, originally cited by the writer (Gilliland, 1949, p. 74), is also described. The existence of a positive area in the region of central Sevier Valley and Sanpete Valley, lasting from its inception during the early Laramide orogeny until Green River time has been postulated earlier (Gilliland, 1949, p. 74). Evidence for the positive area is presented and related to regional sedimentation and structure. A summary of the principal episodes effecting the quadrangle is given below.

TABLE SUMMARIZING NATURE OF DEFORMATION

Normal faulting and associated disturbances	Normal faulting and warping of all strata in the Gunnison Quadrangle.
Pre-Flagstaff Movement	Folding of North Horn and all older rocks in vicinity of Sixmile Canyon.
Pre-North Horn (?) Movement	Local folding of Price River strata in the vicinity of Mellor Canyon.
Early Laramide Orogeny	Intensive folding of pre-Price River strata in area west of Wasatch Plateau.
Mid-Cretaceous Orogeny	Folding of mountains probably not far west of Gunnison Quadrangle

MID-CRETACEOUS OROGENY

The earliest Mesozoic orogeny in central Utah was the mid-Cretaceous orogeny, which is inferred from the character of the Indianola group. The Indianola in central Utah contains much very coarse conglomerate consisting largely of debris derived from Paleozoic lime-

stones and quartzites. The conglomerates are the coarsest and thickest toward the west in the northern Gunnison Plateau and in the Cedar Hills, where Schoff (1937, p. 39) reports a thickness of nearly 15,000 feet. The rocks thin eastward and grade into marine strata exposed along the west margin of the Wasatch Plateau. Farther east they eventually grade into the marine Mancos shale (Spieker, 1946, p. 150). The immense thickness of the conglomerate and its coarse character as well as the lateral gradation, most certainly indicate a mountainous area of considerable relief not far to the west of the Gunnison Plateau and Cedar Hills.

Although fossils have not been found in the lower part of the Indianola conglomerate facies, its upper part contains fossils of Colorado age (Schoff, 1937, pp. 41-43). Inasmuch as the whole group is definitely a unit, it is considered to be entirely of Colorado age. The date of the orogeny is therefore somewhere near the beginning of Upper Cretaceous time (Spieker, 1946, p. 150).

The orogeny apparently did not affect the area of the Gunnison Quadrangle directly, as there seems to be no angular discordance between the Morrison (?) and the Indianola in nearby areas. However, in view of thick sections of Indianola very near the quadrangle, it seems likely that the group did extend over the entire area at one time although none of the strata are exposed in the quadrangle. Later-orogenic movements have folded the strata, and it may well be that folds of Indianola are concealed below younger rocks in the Gunnison Quadrangle.

EARLY LARAMIDE OROGENY

The early Laramide orogeny, defined by Spieker (1946), is clearly recorded in central Utah by pronounced angular unconformities at the base of the Price River formation in the western districts. Furthermore, a disconformity which is locally present between the Price River and the Black Hawk formations in the eastern areas is considered as the eastern continuation of the angular unconformities (Spieker, 1946, p. 130). The orogeny is further indicated in the northern Wasatch Plateau by the very coarse conglomeratic facies of the Price River changing to progressively finer clastics toward the east.

The date of this orogeny, in contrast with that of the Mid-Cretaceous orogeny, can be shown fairly certainly (Spieker, 1946). The youngest beds below the angular unconformities belong to the Indianola group of Colorado age, but if the Price River-Black Hawk discon-

formity is the eastern equivalent of the break, the orogeny occurred after deposition of the Black Hawk formation of middle Montana age. These relations, plus the probable late Montana age of the Price River, establish the date of the orogeny between middle and late Montana time.

The only specific evidence of this orogeny observed by the writer in the Gunnison Quadrangle is the massive conglomerate of the Price River formation exposed in Mellor Canyon. However, the entire quadrangle was undoubtedly affected by the movement and a part of the Arapien shale and Twist Gulch formation which were originally folded by it are exposed in the area.

Further evidence of the effect of the orogeny on this area can be inferred. On the basis of numerous angular unconformities in the vicinity of Sevier and Sanpete Valleys, Spieker (1936, p. 152) recognized the existence, at the beginning of late Montana time, of an elongate, north-south trending, folded belt in central Utah. The east edge of the belt approximately coincides with the west margin of the Wasatch Plateau. It was postulated by the present writer (Gilliland, 1949, p. 74) that a part of this folded belt including the eastern portion of the Gunnison Quadrangle, the western margin of the Wasatch Plateau due east of the quadrangle, and probably the southern end of Sanpete Valley rose gradually from its inception during the early Laramide orogeny and remained positive into Green River time. This hypothesis was suggested in part by the absence of Price River and North Horn strata at angular unconformities in Salina Canyon, at Willow Creek, and at Christiansburg about 5 miles east of Gunnison. The absence of the Price River and North Horn in those places, all of which are in the area assumed to have been positive, is in itself a possible indication that they were not deposited in that area. Major changes in sedimentation in the region and the wedging out of the Flagstaff and Colton beds at the angular unconformity in Salina Canyon indicates the continuation of the positive area through Flagstaff and Colton time.

The hypothesis is also supported by the fact that distinct facies of the Price River occur on either side of the area postulated as postive. East of the postive area—in the part of the Wasatch Plateau due east of the Gunnison Quadrangle—the Price River consists mainly of medium-to coarse-grained sandstone. It includes some grit and conglomerate and a minor amount of shale. The lithology of the Castlegate member of the Price River formation is in part illustrated by the

following section measured by Spieker and Baker (1928, p. 141) about 13 miles east-southeast from the Salina Canyon angular unconformity. However, the member is somewhat finer here than it is elsewhere. The upper member of the formation has a comparable lithology.

Section of Castlegate sandstone member of Price River formation on north side of Salina Canyon.

	Feet
1. Sandstone, buff, medium-grained, massive	7
2. Sandstone, gray, mottled with orange, medium-to coarse-grained, massive	4
3. Sandstone, white, medium-grained	12
4. Sandstone, similar to No. 2	16
5. Sandstone, gray, medium-grained, massive	2
6. Conglomerate, pebbles of chert and quartz irregularly bedded in matrix of coarse gray sandstone	11
7. Sandstone, white, fine-grained, massive	11
8. Sandstone, white, cliff-forming, coarse-grained	50
9. Sandstone, white, cliff-forming, fine-grained	17
10. Concealed	11
11. Sandstone, buff, and gray shale, interbedded	22
12. Sandstone, medium-grained, massive, cliff-forming	55
13. Sandstone, gray, coarse-grained, massive; forms base of series of cliffs	11
	229

West of the area postulated as positive—in the Pavant Plateau and in the southern part of the Gunnison Plateau—the Price River beds are very coarsely conglomeratic (see geol. section 8). The coarse conglomerates were deposited as fan gravels at the base of high and deeply dissected mountains which consisted largely of tilted Paleozoic strata with some early Mesozoic rocks. In late Price River time, the east front of the mountains extended from the southern Wasatch Mountains southwest to Long Ridge, thence south to the Pavant Plateau.

The lithologic contrast of the Price River at the southern end of the Wasatch Plateau with the Price River in the Pavant Plateau and the southern part of the Gunnison Plateau might, of course, be explained simply by gradation away from the western Paleozoic mountains. However, it may also be explained if a positive area separated the two facies. The existence of the positive area must be granted during at least the early part of Price River time, when the newly folded rocks were first exposed. Then at least, the lower part of the conglomerate facies was deposited in a basin bounded on the west by the high Paleozoic moun-

tains and on the east by the folded positive area.

If we assume continuation of the positive area during all of Price River and North Horn time, other features of the regional stratigraphy are more easily explained. In the folded belt, the Indianola group, the youngest unit involved in the folding, would of course have been eroded first. The debris from the Indianola, which in this area is 7000 to 8000 feet thick and largely buff and gray marine sandstone, shale, and conglomerate, probably furnished most of the material that constitutes the similarly colored Price River strata in the southern Wasatch Plateau. Locally the Morrison (?) formation may have been exposed and furnished the chert pebbles in the Price River. Continued erosion of the folded area would have caused the exposure and subsequent erosion of the finer clastics of the thick Jurassic shale which is red in part. Significantly, the Price River strata grade upward into the finer clastics and variegated beds of the North Horn formation. Furthermore, the composition of the North Horn in the Valley Mountains and the Pavant Plateau is distinctly different from its composition in the Wasatch Plateau. In the first two localities, the North Horn contains much more clastic material and lacks the four-fold alternation of fluviatile and lacustrine strata common in the Wasatch Plateau. This contrast too could be explained in terms of distance from the western mountains, but it also could be explained by deposition of the sediments in two basins separated by the folded positive area. The positive area certainly would have furnished sediment to the basins on either side of it, but the Paleozoic mountains would have furnished additional and coarser material to the basin west of the positive area thus explaining the coarser clastics there.

The possibility that the Price River and North Horn strata did extend over the entire area should also be considered. If they did, then later profound orogenies would necessarily have occurred soon after North Horn time with ensuing erosion to remove the thick deposits from the area here postulated as continuously positive from the early Laramide orogeny to early Green River time. Except possibly in the southern Valley Mountains, the composition of the Flagstaff formation, which rests upon the North Horn, is certainly not reflective of prolonged erosion of adjacent areas. Furthermore, the stratigraphic succession from Price River through Green River is gradational except in Sixmile Canyon and Mellor Canyon. Therefore, it is unlikely that there were profound orogenies in the area between North Horn and Green River time.

Unfortunately at most places along the margins of the folded belt, the Price River and the North Horn strata are concealed; as a result their exact relations to the folded belt are incompletely known.

PRE-NORTH HORN (?) MOVEMENT

The pre-North Horn (?) movement was postulated by the writer (Gilliland, 1949, p. 74) on the basis of the angular unconformity between the Price River and Flagstaff formations in the vicinity of Mellor Canyon. As interpreted by the writer, the movement was confined to an area in the vicinity of Mellor Canyon and is reflective of a longer more sustained movement discussed at greater length in later paragraphs concerning the Pre-Flagstaff movement.

Evidence bearing on the date of the movement rests on relations of the North Horn formation with the Price River and the Flagstaff on the west front of the Gunnison Plateau near Mellor Canyon. The North Horn is missing in Mellor Canyon where the Flagstaff rests on truncated Price River conglomerate beds (see pl. 3, fig. B). However, in Timber Canyon about 8 miles north of Mellor Canyon, the North Horn is 410 feet thick and according to Hardy (1948) is gradational below with the Price River and above with the Flagstaff. Except near the mouth of Sixmile Canyon in the Wasatch Plateau (Spieker, 1946, p. 133), this gradational relation of the three formations, where all are present and known, is true throughout central Utah. In Timber Canyon, the North Horn consists largely of medium to coarse-grained sandstone and blue-gray, massive limestone with abundant dark-brown algal nodules. Southward toward Mellor Canyon, the formation thins and finally pinches out about 4 miles north of the canyon (Hardy, 1948).

The date of the pre-North Horn (?) movement is believed by the present writer to be somewhere near the boundary of Price River-North Horn time (Gilliland, 1949, p. 74). If the Price River, North Horn, and Flagstaff are truly gradational north of Mellor Canyon, the region of Mellor Canyon was an area of erosion during North Horn time and therefore folded before that time. Otherwise, this area most likely would also have received North Horn sediments.

Further evidence of the pre-North Horn movement is apparently present on the east side of the Gunnison Plateau where Hunt (1948) and Taylor (1948) observed very pronounced facies changes in the North Horn formation. The facies change abruptly from very thick and coarse conglomerate to medium to coarse-grained sandstone, silt-

stone and shale. The conglomerate contains pebbles and cobbles similar to those in the Price River conglomerate. Such facies changes in distances of less than half a mile can be explained by deposition of the material in alluvial fans. If the Price River were exposed in the region of Mellor Canyon during North Horn time, the writer suggests it may have furnished much of the coarser material in the North Horn on the east side of the Gunnison Plateau.

In view of the pre-Flagstaff movement recognized from angular relations between the North Horn and Flagstaff formations in Sixmile Canyon (Spieker, 1946, pp. 133, 136-137), it seems advisable to also consider the possibility that the North Horn strata did extend over the area of Mellor Canyon but were removed by erosion prior to deposition of the Flagstaff. If such is the case, then an unconformity must be present between the North Horn and Flagstaff at least near the place where the North Horn wedges out north of Mellor Canyon. No unconformity has yet been recognized there. Furthermore, the Price River, North Horn, and Flagstaff are gradational on the east Gunnison front (Hunt, 1948) between the Mellor Canyon area and Sixmile Canyon. This certainly indicates that the North Horn-Flagstaff unconformity did not extend continuously from Sixmile Canyon to the west side of the Gunnison Plateau. Present evidence does not warrant extension of the pre-Flagstaff movement to the Mellor Canyon area.

PRE-FLAGSTAFF MOVEMENT

Spieker (1946, p. 155) postulated the pre-Flagstaff movement on the basis of the angular unconformity beneath the Flagstaff near the mouth of Sixmile Canyon. There, all four units of the North Horn formation were tilted and truncated prior to deposition of the Flagstaff. Elsewhere, in southern Sanpete Valley and central Sevier Valley, the Flagstaff truncates all older rocks, but at no other place is it known to truncate North Horn beds at the outcrop. Furthermore, less than one mile from the unconformity in Sixmile Canyon, the Flagstaff and the North Horn are definitely gradational as they are elsewhere in central Utah where both are present. However, it is certain that some movement did occur in the Sixmile Canyon area just prior to Flagstaff sedimentation. But this movement and the pre-North Horn (?) movement are interpreted by the present writer as local and reflective of a more sustained period of disturbance rather than as distinct episodes of regional extent.

For reasons presented in the foregoing discussion of the early

Laramide orogeny, it is believed that the part of the folded belt that occupied the area of the eastern part of the Gunnison Quadrangle, the western margin of the Wasatch Plateau due east of the quadrangle, and the southern end of Sanpete Valley, came into being during that orogeny and existed as a positive region during all of Price River and North Horn time. The many angular unconformities at the base of the Flagstaff in southern Sanpete Valley and central Sevier Valley show that in this area, the folded belt was still positive at the beginning of Flagstaff time. In the Salina Canyon district where Flagstaff and Colton beds wedge out between Jurassic and Green River strata, and possibly in the southeastern part of the Gunnison Quadrangle, the positive area remained exposed until early Green River time. In general the positive area never was very high and became progressively smaller until in Green River time it was probably completely inundated.

In the southeastern part of the Gunnison Quadrangle and in the Salina Canyon district, the positive area apparently consisted largely of highly folded and faulted Jurassic strata from North Horn time to early Green River time. The reasons for the great persistence of such an area have long been a puzzle. About 6000 feet of Price River, North Horn, Flagstaff, and Colton beds were deposited in the basin west of the positive area (see fig. 3).* A comparable thickness was deposited on the east side in the Wasatch Plateau region. If the early Laramide orogeny were the sole cause of the folded area, then the land after erosion must have been at least 6000 feet higher than the bottom of the adjacent basins (see fig. 3). This seems impossible because of the extensive erosion that occurred in the area and also because of the very weak character of the Jurassic shale and siltstone which formed the core of the folded belt.

The persistence of the positive area is much easier to explain if frequent or sustained uplift with erosion, nearly keeping pace with the uplift, is assumed. If frequent or sustained compressional forces acted at right angles to an elongate area of incompetent Jurassic strata bounded by more resistant strata, the effect would probably be squeezing with accompanying uplift of the incompetent shale and siltstone while the adjacent resistant beds remained relatively unchanged. Rapid

* The hypothesis presented in Fig. 3 is partially based on data collected by E. M. Spieker who, during earlier work, had observed and analyzed most of the geology shown in the eastern half of the figure.

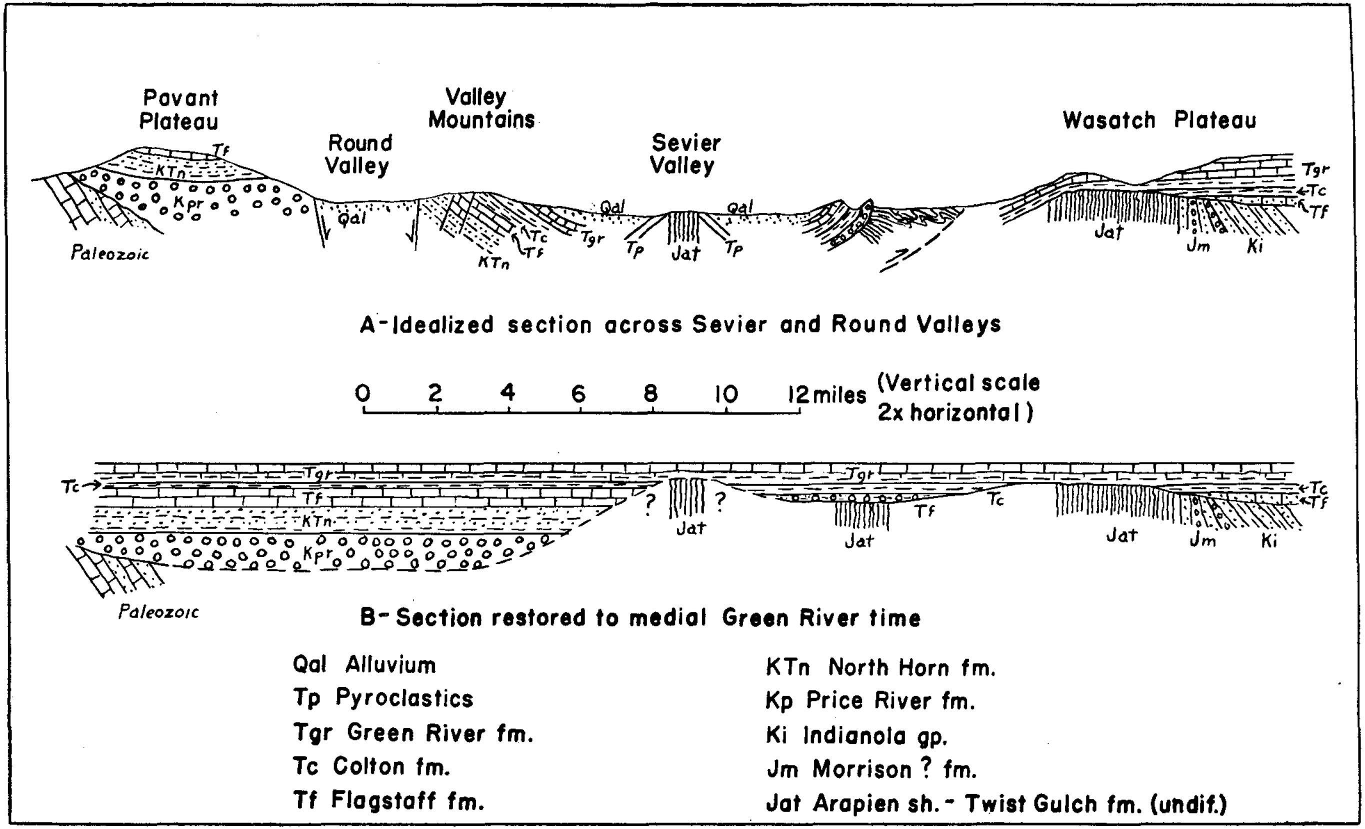


FIGURE 3—Idealized sections across Sevier and Round valleys.

erosion of the soft Jurassic beds would tend to negate the effects of uplift, but deposition in the adjacent basins would at the same time raise the local base level of erosion. Therefore, erosion could not entirely keep pace with the rise, and relief of the uplifted area probably was not great at any time.

Compression of the sort postulated would, of course, cause a narrowing of the belt, but because the currently accumlating strata did not extend across the belt, the compression need not cause those strata to fold. It is likely, however, that the beds near the rising land might have been locally warped in conjunction with the uplift. The unconformity in Sixmile Canyon and the one in Mellor Canyon are here interpreted as due to marginal folding along the slowly rising positive area.

Subsidence, perhaps accompanied by gradual diminution of the intensity of compression and finally cessation of the forces, permitted complete inundation of the positive area by the Green River lake.

NORMAL FAULTING AND ASSOCIATED DISTURBANCES

In general, the normal faulting such as is present in the Gunnison Quadrangle has been considered part of the extensive fault system characteristic of the Great Basin. The time of initiation of the faulting in the Great Basin has been variously determined by many writers as from "pre-Miocene" to "post-Pliocene" with a general tendency to favor a late beginning. However, evidence present in the vicinity of the Gunnison Quadrangle indicates an earlier age for the inception of the faulting in this area.

The normal faulting and associated disturbances of the strata in the Gunnison Quadrangle was the last important movement in the region. Because of many similarities in structure and for lack of evidence to the contrary, the normal faults and associated disturbances are assumed to be the same age as comparable structures in the Wasatch Plateau. There, Spieker (unpublished notes) has interpreted the recent complex structural history as consisting of the following major events.

1) Folding of Wasatch monocline accompanied by antithetic faulting.
2) Strip thrusting along the base of the monocline.
3) Normal faulting and folding of minor magnitude continuing until present time.

There also appears to have been intense thrusting along the entire east front of the Gunnison Plateau, but the mechanics involved and the date of movement are by no means clear.

The warping and faulting of the Wasatch monocline without doubt preceded extensive lava flows in the Salina region. Callaghan (personal communication) believes these flows to be of Miocene age. The formation of the monocline may also predate pyroclastics which are probably Oligocene in age. The youngest formation affected by the major folding and faulting in the Valley Mountains is the Bald Knoll formation which is probably late Eocene or early Oligocene. If the Valley Mountains, the Gunnison Plateau, and the Wasatch Plateau were formed simultaneously, then the date of the principal deformation in the region is apparently sometime during the Oligocene.

The strip thrusting near Willow Creek and Salina occurred after the formation of the Wasatch monocline and prior to the spread of the Miocene lava which was dammed by pre-existing thrust blocks. Thus, the date of the strip thrusting is also probably during Oligocene.

The lateness of some faulting in the region is indicated by faults that have broken recent alluvium in Japs Valley and north of Fayette. The diversion of Willow Creek also was probably due to very recent faulting. Comparatively late folding has affected the Axtell formation of late Pliocene or early Pleistocene age. Dips as high as 46° have been observed in the Axtell. The volcanic gravels of probable Pleistocene age have also been tilted indicating very late disturbance.

GEOLOGIC HISTORY

Spieker (1946, p. 156-160) has adequately presented the major features of Paleozoic, Mesozoic, and early Cenozoic history of central Utah. The following paragraphs briefly summarize the features of that history which, in the opinion of the present writer, affected the area of the Gunnison Quadrangle. The late Cenozoic history of the area is also summarized. Most of the evidence contributing to the record of late Mesozoic and Cenozoic history in the area west of Sevier Valley has been observed and interpreted by the present writer.

During Cambrian and Carboniferous time, a great geosyncline existed in eastern Nevada and western Utah. It extended with shallower depth into central and eastern Utah. Great thicknesses of limestone and sandstone, later converted to quartzite, were deposited in the trough. During the time between the Cambrian and Carboniferous, the area was relatively positive and received only minor quantities of sediment.

In the Triassic and the Lower and Middle Jurassic, relatively positive conditions existed again. Brackish water, fluviatile, and aeolian deposition took place from time to time, producing the diverse Moenkopi, Shinarump, Chinle, and Navajo formations exposed on the west side of the Pavant Plateau (Maxey, 1946, pp. 334-337).

Central Utah was inundated by the southwestern extension of the Sundance Sea in Upper Jurassic time. Great thicknesses of fine clastics with some limestone accumulated. Restricted basins locally existed; salt was precipitated in some—gypsum in others. The probable great thickness of the Arapien shale and Twist Gulch formation indicates profound submergence of this portion of the sea. As subsidence ceased and the sea gradually withdrew, the fluviatile deposits of the Morrison (?) formation spread over the area.

The region was apparently totally positive during much of Lower Cretaceous time. However, erosion and diastrophiam were at their minimum and, other than absence of Lower Cretaceous strata, little other evidence of a protracted hiatus is present.

Near the beginning of the Upper Cretaceous time, mountains consisting chiefly of Paleozoic rocks, were uplifted probably not far west of the Gunnison Quadrangle (mid-Cretaceous orogeny). Throughout Colorado time, gravels, sand, and mud that now constitute the Indianola group were swept eastward from the mountains and deposited

chiefly in a marine basin which extended throughout much of the Western Interior. Near the margin of the mountains, the coarser deposits were laid down on land; eastward, littoral and some swamp sediments were formed. These grade and intertongue with marine sediments still farther east.

Littoral enviroments and coal-forming swamp conditions prevailed in the region of the Wasatch Plateau during early and middle Montana time (Black Hawk formation). Whether the deposits of these environments extended over the area of this report is not known.

Approximately at the beginning of late Montana time, the early Laramide orogeny built mountains west of the Gunnison Quadrangle or perhaps rejuvenated the then much-eroded mid-Cretaceous mountains. In addition, an area extending as far east as the west front of the Wasatch Plateau was folded. West of southern Sanpete Valley and the central part of Sevier Valley, there was a narrow basin separating the western mountains and the easternmost part of the folded belt which apparently remained positive. This basin received very coarse gravels from the west and finer materials from the exposed part of the folded area, while a basin east of the exposed portion received finer debris (Price River formation) derived from the Indianola formation exposed in the positive area.

The region was probably subjected to periodic compressional forces which uplifted the positive area and locally warped the margins of the newly formed Price River strata (pre-North Horn (?) movement). Erosion nearly kept pace with the uplift, but continually accumulating strata progressively raised the local base level of erosion. Consequently there never was much relief of the positive area, yet it was constantly rising. These conditions probably persisted from the time of the early Laramide orogeny until early Eocene when the area was apparently inundated.

Continued erosion of the positive area beyond Price River time exposed the Upper Jurassic formations. Their erosion and the subsequent deposition of the debris followed the accumulation of the Price River formation without interruption. Most of the positive area, alternating fluviatile and lacustrine deposition of fine clastics and limestone extended throughout most of the Wasatch Plateau region. In the western basin, coarser clastics, largely sandstone fluviatile in origin, were deposited (North Horn).

Again, compressional forces caused local warping of strata bordering the folded positive area (pre-Flagstaff movement).

Without break in sedimentation, a vast lake spread throughout much of central Utah. It inundated most of the positive area, but small land areas of low relief continued in the region of the southeastern part of the Gunnison Quadrangle and near the mouth of Salina Canyon. Lime muds were precipitated in most of the lake (Flagstaff formation). In the area now occupied by the southern Valley Mountains and the Pavant Plateau, clastic materials were deposited along with the calcareous precipitates. These sediments, red in large part, were probably derived from remaining positive areas south or southeast of the site of deposition.

The lake contracted and rivers swept variegated muds and some sand over the area (Colton formation). Locally calcareous muds were precipitated. The lake once again spread over the area and well laminated muds and limy material were deposited (Green River formation). The long existing positive area was apparently completely inundated.

A third group of red fluviatile deposits (Crazy Hollow formation) accumulated after an hiatus following deposition in the Green River lake. These were followed shortly by still another lake, in which fine clastics and some lime were deposited (Bald Knoll formation).

Subsequent to the deposition of the Bald Knoll formation in late Eocene or early Oligocene, the area was subjected to stresses which warped the rocks into monoclines, synclines, and anticlines. At this time the rocks were also broken by many normal faults. A time of compression followed closely and strip thrusting occurred in the vicinity of Willow Creek.

Vulcanism followed in Oligocene time, and pyroclastics were accumulated along with other sediments in a fresh-water lake that existed in the vicinity of the Redmond Hills. The volcanic ash was subsequently converted to bentonite. Lava flows and intrusions also occurred in the Gunnison Quadrangle at this time, but were much more extensive south of the area during Miocene and later time.

The order of later events is very difficult to ascertain. Minor faulting and folding has continued up to the present. Erosion of the highlands cut present stream channels and produced the present land forms. At the same time, alluvial materials were deposited in the valleys. Some of the oldest of these deposits have been markedly deformed (Axtell formation). A short-lived inundation of Sevier Valley by an extension of Lake Bonneville probably occurred in Pleistocene time.

ECONOMIC GEOLOGY

Salt, bentonite, limestone, and gravel are the principal deposits of economic value in the Gunnison Quadrangle. The area has been examined as a potential source of oil and small amounts of lead and zinc have been mined in the past. The following summary indicates the possibilities with regard to some of the more important materials.

SALT

Salt has long been mined in the Salina-Redmond area, for as early as 1880 Dutton wrote (1880, p. 170),

> "Fourteen miles south of Gunnison is the little Mormon village Salina, a wretched hamlet, whose inhabitants earn a scanty subsistence by lixiviating salt from the red clay which underlies the Tertiary beds in the vicinity."

The salt, a part of the undifferentiated Arapien and Twist Gulch formations, has been mined by open pit methods at many places in the Redmond Hills and at the south end of the Green River hogback just north of the former Willow Creek Valley. All but two of the mines are now abandoned. The Poulson Brothers Mine is in the Redmond Hills about 3 miles north of Redmond. The Albert Poulson Mine is also in the Redmond Hills about 4 miles north of Redmond. The salt beds in both mines are vertical, and the depth to which they extend is unknown. Albert Poulson (personal communication) has estimated the thickness of the salt beds as about 800 feet, most of which is covered by residual clay streaked with salt. Assuming that salt underlies the entire area covered by the distinctive residual clay, the width of the area indicates a thickness of about 1000 feet for the vertical beds. Core drilling in the vicinity of the salt might disclose even greater thicknesses.

Although most of the salt is deep red because of finely disseminated red clay, the percentage of impurities is lower than the red color suggests.

The following analysis of the rock salt was furnished by the Poulson Brothers Salt Company.

Salt (NaCl)	95.60%
Silica	2.16%
Sulphates	1.10%
Calcium	0.51%
Iron and alumina oxide	0.04%
Magnesium	0.04%
Iodine	0.03%

The silica content is moderately high but has not proved objectionable. The iodine content is sufficiently high so that no addition of iodine is necessary in order for the salt to be used by livestock.

The unprocessed rock salt is now used for stock salt and is shipped throughout Utah and to several adjacent states. Formerly the salt was crushed and molded into blocks for stock use. It also has been refined for human consumption.

BENTONITE

Bentonite is now being mined by open pit methods at several places in the Redmond Hills. The material is mined by the Western Clay and Metals Company and shipped to Aurora, Utah where it is processed. The processed bentonite is used chiefly as drilling mud and as a detergent in the dry cleaning and laundry industry. Locally it is widely used as roofing for small farm buildings and as a lining for irrigation ditches.

Davis and Vacher (1940) have listed many uses for bentonite and have suggested many other possible ones. Chemical and physical analyses of the bentonite in the Redmond Hills might suggest many more uses for it.

The complex structure in the area of the bentonite exposures has prevented an estimation of the reserves.

STONE

The very dense and pure Flagstaff limestone exposed south of Willow Creek is now being quarried for use by the Gunnison Sugar Company at Centerfield. It is used in the process of refining beet sugar. The limestone in this area has also been quarried and burned for lime. Much of the Flagstaff limestone in the northern Valley Mountains and in the area east of Fayette is dense and hard, so some of the thicker beds may be suitable for use as building stone. Some would be satisfactory as road metal. Several small, now-abandoned kilns in the Valley Mountains were used to burn some of the purer rock for lime.

Near Ephraim and Manti, the regularly bedded and oolitic limestone in the Green River formation has been quarried in large amounts for building stone. Similar limestone, which might also be used for building stone, is present in the Green River formation of the Gunnison Quadrangle where it caps most of the southern part of the Gunnison Plateau and locally forms the foothills of the Valley Mountains.

The sandstones of the North Horn, in general, are too variable in

texture, bedding, and degree of cementation to be suitable for building purposes.

GRAVEL

The widespread deposits of volcanic and chert gravel in the Redmond Hills are quarried for use in cement and concrete and also for making cement blocks. The gravel is moderately well-sorted and has a low clay content.

The gravel of the Axtell formation has also been quarried but not extensively.

FUEL

Coal is absent in the area, although the Wasatch Plateau coal field a few miles east contains an abundance of it.

Oil and gas are probably absent also. The most likely sources for either oil or gas are in the marine beds of the Indianola, which may possibly be present below angular unconformities in the quadrangle. The Indianola group was folded during the early Laramide orogeny as well as during later movements. The eroded folds are overlapped by early Tertiary beds, which might prevent vertical migration of any oil present in the Indianola. Although the location and structural trend of the folded Indianola can be fairly definitely ascertained along the west front of the Wasatch Plateau, the group is completely missing at the surface in the Gunnison Quadrangle. On the basis of present known evidence, any attempt to locate stratigraphic traps involving the Indianola seems unwarranted in the area covered by this report.

The Arapien shale, because of its brackish-water origin, seems an improbable source for oil. Many folds are plainly discernible in the Arapien in nearby areas, but because of the incompetent nature of the Arapien, it seems very unlikely that they could be reflective of deep structures in the more massive beds of earlier Mesozoic or Paleozoic age.

It is probable that some of the Paleozoic limestones exposed in the Pavant Plateau underlie the Gunnison Quadrangle, but the nature of their structure, the depth at which they are present, and the possibility that they contain petroleum is entirely conjectural.

Elsewhere, the Green River formation contains an abundance of oil shale, but none is known in the immediate area of this report.

A small amount of bituminous limestone has been previously described in the discussion of the Flagstaff formation. Because of the small amount and limited extent of the limestone, it is not a likely source for commercial quantities of oil.

The Redmond Hills anticline is a possible oil structure, but stratigraphic relations between the Arapien exposed there and the older Tertiary or Cretaceous beds below the alluvium are unknown. A well on the east side of the structure in sec. 21, T. 20 S., R. 1 W. was begun in 1942 but abandoned in the same year. In 1948, the drilling was continued, but to the writer's knowledge is not yet completed.

METALS

Lead and zinc have been mined from along a mineralized fault zone on the east side of the first Green River hogback east of Redmond. The operation was on a small scale and was of short duration. Many prospect openings have been made along faults throughout the area, but mineralization of the faults has been very minor.

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LOCAL SECTIONS

SECTION 1

SECTION ON EAST SIDE OF VALLEY MOUNTAINS AT NORTH BOUNDARY OF GUNNISON QUADRANGLE.

	Feet
Green River formation:	
Limestone, light gray, chalky, porous, partially replaced by buff flint which weathers yellowish brown	
Sandstone, calcareous, light gray to buff, fine-to medium-grained, regularly bedded, beds up to 2 feet thick, some arenaceous limestone	11
Limestone, dominantly yellow also some gray, yellowish buff, light green; thinly laminated; some yellow and buff limestone conglomerate with pebbles up to 1/2 inch in diameter; upper 1/2 of unit contains brown, fine-to medium-grained, calcareous sandstone in beds up to 2 feet thick	68
Shale, grayish green, green, blocky, weathers light greenish gray, poorly exposed	6
Limestone, white, chalky, massive, weathers to very rough surfaces, forms prominent ledge	25
Shale, grayish green, green, blocky, weathers to light greenish gray, poorly exposed	169
Limestone, light gray, grayish buff; some brick red in upper 1/4 of unit, dense to finely crystalline, beds up to 1 foot thick; minor amount of float of a tuff, light green with abundant biotite crystals	82
Flint, tan, bluish gray, oolitic in part, weathers brown	1 1/2
Limestone, brown, finely crystalline; and very light-gray, dense, platy limestone, also chalky, greenish-gray, blocky limestone; beds up to 5 inches	24
Limestone, light gray, buff, yellowish buff, porous, massive, weathers to very rough surfaces	69
Shale and limestone, green and yellowish buff, poorly exposed	19
Sandstone, light buff, fine-grained, calcareous	2 1/2
Limestone, yellow, yellowish buff, light gray, dense, rough surfaced, poorly bedded, weathers into chips	18
Total Green River	495
Colton formation:	
Shale, reddish brown, purple, greenish gray, blocky; few beds up to 18 inches thick of light-gray, yellowish-brown, dense to finely crystalline limestone	36
Limestone, rough surface, weathers yellowish brown	3
Limestone, gray to buff interbedded with green and purple shale	27

	Feet
Shale, chocolate brown, with few white and light greenish-gray, dense to finely crystalline limestone beds 1 inch thick	122
Shale, greenish gray, blocky with small amount of finely crystalline, light brownish-gray and light greenish-gray, thin-bedded limestone containing few fish fragments and ostracods	20
Shale, purple, green, reddish brown, variegated	18
Shale, olive green with 6 inch brown limestone layer at top	4
Shale, chocolate brown, greenish gray and purplish gray, variegated; few layers of thin-bedded, fine-grained, reddish-brown sandstone and greenish-gray limestone in beds not more than 1 foot thick	62
Shale, greenish gray, purplish gray, variegated, blocky; small amount of laminated greenish-gray limestone	16
Shale, chocolate brown, blocky	24
Shale, dark green to olive green, weathers light greenish gray; occasional layers of greenish-gray and tan to yellow, dense limestone containing fish fragments, ostracods, and Planorbis-like gastropods	83
Limestone, buff, weathers yellowish buff, consists almost entirely of ostracods, also contains some gray limestone pebbles ½ inch in diameter	3
Limestone, yellow to buff, some light gray and dense, platy to thick and regularly bedded; ostracods	38
Total Colton	456
Flagstaff formation:	
Unit E	
Limestone, dominantly light gray, but some is yellowish buff, very dense to finely crystalline, weathers in part to angular chips and in part to rough surfaces; massive, forms prominent ledges; a few unidentifiable fossil fragments	82
Unit D	
Limestone, yellow to buff, regularly bedded, beds up to 2½ feet thick, weathers to slightly rounded blocks; ostracods	8
Unit C	
Limestone, dominantly red, mottled with yellow and gray	
Total Flagstaff	90

SECTION 2

	Feet
SECTION ON NORTH SIDE OF HAYES CANYON.	
Colton formation:	
Shale, red, green	
Flagstaff formation:	
Unit D	
Limestone, yellow, weathers to rounded blocks 1 to 2 feet square; ostracods	3
Unit C	
Limestone, red, lavender, gray, yellow, mottled, massive, weathers to slopes	142
Unit B	
Limestone, grades upward from gray and nearly white, dense to finely crystalline limestone containing limestone pebbles 1/8 inch in diameter into mottled pink, red, lavender, gray, and white dense limestone; blocky, beds up to 4 feet	101
Limestone, dark gray, dense to finely crystalline, thin-bedded to beds as much as 8 feet thick	33
Limestone, grayish brown, massive, contains black and gray limestone pebbles 1/2 inch in diameter, weathers light gray, weathered surface pitted	24
Limestone, dark gray to chakly white, dense to finely crystalline, poorly bedded, forms series of low cliffs and steep talus slopes, some yellow limestone in lower part	355
Total Unit B	513
Unit A	
Limestone, yellow, gray, dense, beds up to 15 feet thick; algal nodules near base, gastropods abundant in lower 75 feet, forms prominent cliff which grades laterally into steep talus slopes	117
Limestone and shale, alternating layers of light-gray, dense, blocky limestone, gray shaly limestone with algal nodules, gastropods and pelecypods, and bluish-gray shale	101
Limestone, yellow, gray, dense to finely crystalline; scattered algal nodules, gastropods and pelecypods	17
Shale, gray, weathers light gray	8
Limestone, yellow, sandy, gray; a few fragments of gastropods	8
Limestone and shale, alternating layers of gray shale and dark-gray to light-gray, dense to finely crystalline limestone; gastropods abundant	93
Limestone, gray to buff, finely crystalline	12
Limestone, gray, dense, weathered surface appears somewhat nodular	13

	Feet
Limestone, gray to buff, finely crystalline	7
Shale, gray, weathers light gray; occasional thin bed of gray limestone	91
Total Unit A	467
Total Flagstaff	1125
North Horn formation:	
Limestone and shale, red, lavender, yellow, gray mottled, limestone in beds up to 6 feet thick, in part sandy, interbedded with gray and purple shale; shale is less than 10% of total; overall appearance of unit is brick red	139
Sandstone, gray, brown, fine-grained, in beds up to 3 feet thick; gray algal bed near base	48
Conglomerate, gray and blue limestone and quartzite pebbles, average 1½ inches in diameter, some are 4 inches in diameter, medium to coarse matrix	13
Shale, green, red	9
Limestone, gray, finely crystalline	16
Shale, dark gray, purple, occasional limestone layers	133
Limestone, blue gray, buff, dense, beds up to 3 feet thick	92
Conglomerate, blue-gray limestone and quartzite pebbles up to 6 inches, a few brown, medium-grained sandstone lenses	32
Sandstone, brown, fine-to medium-grained, beds 1 to 6 feet thick; some green and purple shale and brown to gray silty limestone; an algal bed 2½ feet thick at top, contains nodules up to 6 inches in diameter	160
Total North Horn	642

SECTION 3

SECTION AT NORTH SIDE OF PICKET CANYON.

Colton formation:	
Limestone, buff, dense, platy; ostracods	25+
Flagstaff formations:	
Unit E	
Limestone, buff, dense, bedding irregular	153
Limestone, light gray, dense, weathers to rough surfaces	102
Unit D	
Limestone, yellow, buff, lower 3 feet forms ledge; ostracods	8
Unit C	
Limestone, brick red, mottled with purple and lavender, colors become lighter upward, dense to finely crystalline, massive	108

	Feet
Unit B	
Interval, largely concealed but apparently consisting of gray limestone	46
Limestone, light gray, bluish gray, grayish buff, weathers to light blue gray and chalky white, very dense, weathers in part to chips and in part to blocky fragments or very rough surfaces, bedding generally poor, some distinct beds 2 feet thick; fresh-water gastropods generally abundant but very difficult to extract	390
Limestone, black to dark gray, weathers medium gray; macerated shell fragments abundant; bituminous	3
Unit A	
Limestone, yellow, yellowish brown, gray mottled with yellow, blue gray, dense and locally arenaceous, a few brown sandstone lenses in lower portion; massive, weathers to chips; some gastropods and algal nodules	352
Total Flagstaff	1162
North Horn formation:	
Sandstone, brown, yellowish brown, medium-grained; few scattered algal nodules	4
Shale, light gray, calcareous, with some argillaceous limestone	16
Limestone, yellowish brown, light gray, arenaceous, occasional calcareous sandstone lenses with algal masses, gradational with unit below	46
Limestone, light gray, mottled with yellow, arenaceous, weathers to chips, massive	15
Sandstone, brown, tan, medium-grained, cross-bedded; lower 6 inches contains algal masses as large as 5 inches; ledge	3½
Interval, probably yellow sandy limestone	14½
Sandstone, brown, medium-to coarse-grained, cross-bedded	4½
Limestone, yellowish brown, sandy, poorly exposed	21
Sandstone, tan, weathers gray brown, medium-grained, irregularly bedded, beds up to 2 feet thick; gray algal masses at base; ledge	4
Limestone, yellowish tan, sandy, weathers to chips, a few thin tan sandstone lenses	51
Limestone, tan, gray, dense, grades upward into brown, gray sandstone containing yellow limestone pebbles up to 5 inches in diameter; scattered algal nodules up to 7 inches in diameter	24
Shale, light gray	4
Sandstone, tan, medium-grained, cross-bedded	12
Sandstone, gray, fine-grained, interbedded with yellowish-brown and light-gray, dense, poorly bedded, blocky lime-	

	Feet
stone; lenses of light-gray shale near top	65
Sandstone, brown, yellow, medium-grained, weathers brown and pink; ledge	8
Sandstone and shale interbedded, sandstone, brown, gray, fine-grained, thin-bedded; shale, light gray	8
Sandstone, brown, gray, medium-to coarse-grained, thinly laminated to beds 2½ feet thick, cross-bedded; a few lenses contain yellow dense limestone pebbles some of which have algal growth surrounding them	42
Limestone, yellowish brown, dense, thin and irregularly bedded	22
Sandstone, brown, medium-grained; contains rounded pebbles of yellowish brown limestone similar to that in unit below; gray algal nodules up to 10 inches in diameter; ledge	4
Limestone, yellowish brown, thin and irregularly bedded	87
Sandstone, gray to brown, locally red, medium-to coarse-grained	36
Sandstone and limestone interbedded, sandstone, gray, yellowish brown, calcareous; limestone, yellowish brown, arenaceous; poorly exposed	32
Sandstone, gray to brown, slight pinkish cast, medium-to coarse-grained, irregularly bedded, scattered pebbles	15
Limestone, gray to buff, silty and shaly	2
Sandstone, buff to brown, medium-grained, cross-bedded; contains conglomerate lenses with pebbles 1 inch in diameter	26
Sandstone, red, scattered quartzite and blue-gray limestone pebbles; some red shale near top	30
Total North Horn	596½

SECTION 4

SECTION MEASURED AT WEST END OF DASTRUP CANYON.

Flagstaff formation:	
Unit B	
Limestone, gray with traces of lavender, weathers to irregular surfaces, beds up to 2½ feet thick	
Unit A	
Limestone, yellow, gray, pink, lavender, mottled, massive; few algal nodules	123
Limestone, brownish yellow, buff, some pink and gray, dense, locally slightly sandy, massive, weathers to chips	67
Limestone, purple, brick red, brownish yellow, mottled, colors pale, dense, weathers to chips	32
Limestone, same as the limestone above, but darker colors	43

	Feet
Limestone, lavender, yellow, gray, pink, buff, dense, massive, weathers to chips and rounded surfaces	47
Limestone, gray, chalky	18
Limestone, pink, lavender, buff, yellow, tan, some slightly sandy and some gray pure limestone, bedding poor, weathers to chips and blocks; also few gray medium-grained sandstone lenses	164
Total Flagstaff	494

North Horn formation:

Sandstone, reddish brown, medium-to coarse-grained, beds up to 4 feet thick	21
Limestone, gray, buff, locally pink, dense and pure to sandy weathers to chips	105
Sandstone, buff, brown, gray, calcareous; interbedded grayish-buff, yellow, sandy limestone forming less than 30% of zone; algal nodules common; unit forms slopes and discontinuous ledges up to 6 feet high	360
Limestone, arenaceous, yellow, brick red, buff, mottled, also some buff calcareous sandstone	45
Sandstone, gray, tan, brown, medium-to coarse-grained; conglomerate lenses up to 5 feet thick with red and gray quartzite, dark-gray and yellow limestone pebbles up to 1½ inches in diameter, pebbles form about 90% of lenses; unit forms prominent ledge	23 ±
Sandstone, tan to brown, calcareous, medium-to coarse-grained, generally thin-bedded, but lenses up to 12 feet thick; grayish-buff, yellow, and slightly red sandy limestone forms about 10% of unit	241
Sandstone, gray, tan, medium-grained; ledge	15
Sandstone, grayish brown, medium-grained; small amount of thin-bedded and yellowish-buff dense limestone; slope	36
Sandstone, tan to brown, medium-grained; lenticular; ledge	14
Sandstone, buff, brown, gray, red, calcareous, beds up to 2 feet thick; about 25% of zone consists of grayish-buff, purple, dense, and sandy limestone, slope	126
Sandstone, gray to tan, medium-grained, beds up to 5 feet; ledge	11
Sandstone, light buff, tan, traces of red, medium-grained, beds up to 2 feet thick, slope	180
Sandstone, red, medium-to coarse-grained, slightly mottled with reddish gray, beds up to 1 foot; upper part grades laterally into red and purple, blocky, calcareous shale	18
Conglomerate, red, reddish brown, pebbles and cobbles of red and gray quartzite up to 6 inches, 95% of unit composed of pebbles and cobbles	12

	Feet
Sandstone, reddish brown, medium to coarse, cross-bedded; ledges up to 7 feet	44
Sandstone, brown, red locally, medium-to coarse-grained, calcareous bond, thin-bedded to ledges 10 feet thick, some conglomeratic zones with gray and yellow limestone pebbles up to 2½ inches, about 5% of unit is yellow and buff, dense to finely crystalline limestone in beds 1 foot thick	327
Total North Horn	1578

SECTION 5

SECTION ON NORTH SIDE OF REDMOND CANYON.

Green River formation:	
Limestone, gray, massive, in part silicified, brown and blue flint	
Colton formation:	
Shale, red, green, weathers greenish gray and brick red, minor amounts of gray and buff thin-bedded dense limestone	405
Flagstaff formation:	
Unit E	
Limestone, gray, dense, poorly exposed	97
Limestone, dense, beds 1 foot thick to massive ledges, weathers to rough surfaces	303
Unit D—absent	
Unit C	
Shale, gray, red purple, blocky	18
Sandstone and limestone, interbedded, light pink, gray, and buff, sandstone is fine to medium-grained	64
Limestone, arenaceous, dominantly brick red, also pink, lavender, and gray, dense to finely crystalline; interbedded with siltstone and sandstone, same colors as limestone; unit forms alternating ledges and slopes	339
Unit B	
Limestone, gray, buff, pink, very dense, blocky	
Total Flagstaff	821

SECTION 6

SECTION OF BIG RED BLUFF AT WEST END OF BALD KNOLL CANYON.

Flagstaff formation:	
Unit E	
Limestone, gray, tan, dense, weathers to irregular surfaces	
Limestone, red, lavender, light gray, generally lighter colors than in lower red units, about 10% of unit is brick red, calcareous, medium-to coarse-grained sandstone	216

	Feet
Unit D—absent	
Unit C	
Conglomerate, coarse matrix, quartzite and limestone pebbles up to 2 inches	6
Limestone, brick red, mottled with gray	19
Conglomerate, quartzite and gray and blue limestone pebbles and cobbles up to 18 inches, grades laterally into coarse sandstone; ledge	10
Sandstone, brick red, mottled with purple and gray, medium-grained; upper 5 feet largely brick red sandy limestone	85
Sandstone, gray, fine-grained, locally stained red by wash from above, grades laterally into red, coarse-grained sandstone	7 ±
Sandstone, brick red, slightly mottled with purple and gray, medium-grained, bedding poor	63
Limestone, brick red, mottled with gray, weathers to very rough surfaces, forms prominent ledge	3
Sandstone, brick red, calcareous, medium-grained, grades upward into brick red limestone	22
Limestone, red, reddish brown, lavender, slightly mottled with yellow, weathers to irregular surfaces, grades into unit below	245
Total Unit C	460
Unit B	
Limestone, gray, pink, mottled, weathers to rough surfaces or chips and angular blocks; small amount of limestone conglomerate with pebbles 1/8 inch in diameter; some fossils, probably *Physa,* impossible to extract; gradational with unit above, forms alternating slopes and ledges 10 to 15 feet high	296
Unit A	
Limestone, dominantly buff and gray, also pink, brick red, and lavender, massive, weathers to chip-like fragments, small amount of yellow limestone conglomerate near top with pebbles 1/8 inch in diameter; few lenses of pink to brown sandstone up to 3 feet thick; small amount of greenish-brown, red, reddish-brown, blocky shale; steep float-covered slopes	287
Sandstone, brown, medium-to coarse-grained, finely conglomeratic	4½
Limestone, buff, sandy, also gray dense, weathers to irregular surfaces, bedding poor	38

	Feet
Limestone, yellow, sandy, weathers to irregular surfaces, ledge	8
Total Unit A	337½
Total Flagstaff	1309½
North Horn formation:	
Sandstone and shale, brown, red, purple	

SECTION 7

SECTION MEASURED ON NORTH SIDE OF BALD KNOLL CANYON.

Crazy Hollow formation:	
Sandstone, gray, tan, pink, medium-grained, cross-bedded, massive, relation to underlying Green River not clearly evident	42+
Green River formation:	
Limestone, red, lavender, platy to beds 2 feet thick, irregular thickness due to possible disconformity with overlying beds	23 ±
Limestone, gray, some pink, bedding moderately distinct with beds up to 18 inches, oolitic in part; partial replacement by brown, dark-gray, and blue flint which weathers dark brown	40
Limestone, gray, yellow, cream, pink, generally massive, locally platy, weathers to chips and rough surfaces, locally conglomeratic with limestone pebbles; partial replacement by gray and blue flint which weathers brown	410
Limestone, gray to buff, slightly pink, limestone and shale pebbles ¼ inch in diameter, massive, weathers to very rough surface, forms prominent ledge	18
Limestone, pink, greenish gray, dense, massive	28
Limestone, gray, buff, yellow, thinly laminated to beds 8 feet thick, small amount of green shale interbedded with limestone	103
Limestone, gray, sandy, weathers brown	1
Shale, greenish brown and greenish gray, calcareous, weathers greenish gray; few greenish-gray, argillaceous, blocky limestone layers	188
Limestone, buff, yellowish green, platy to blocky	18
Limestone, gray, locally pink and buff, dense, massive, weathers to irregular surface and to chips	324
Total Green River	1153
Colton formation:	
Shale, dominantly reddish brown, also green, maroon, gray, and some yellow, blocky, poorly exposed	15
Sandstone, red, mottled with gray and lavender, medium- to coarse-grained, massive	8

	Feet
Shale, dominantly reddish brown, also green, maroon, gray, and some yellow, blocky, poorly exposed	238
Sandstone, red, mottled with gray and lavender, medium-to coarse-grained, massive in upper part, thin-bedded in lower portion	13
Shale, reddish brown interbedded with bluish-lavender, dense limestone	27
Sandstone, red, mottled with gray and lavender, medium-to coarse-grained, massive	32
Total Colton	333
Flagstaff formation (undifferentiated):	
Limestone, gray, lavender, dense, beds up to 3 feet thick	128
Limestone, arenaceous, gray, red, lavender, mottled, some calcareous sandstone layers, forms slopes	55
Sandstone, red, gray, medium-to coarse-grained; few red and gray quartzite pebbles, ledge	16
Limestone, arenaceous, gray, red, lavender, mottled, some calcareous sandstone, forms slopes	57
Sandstone, gray, pink, coarse-grained, ledge	10
Limestone, arenaceous, gray, red, lavender, mottled, some calcareous sandstone, forms slopes	18
Sandstone, gray, pink, coarse-grained, conglomerate lenses with gray, tan, and pink quartzite pebbles up to 6 inches; ledge	9
Limestone, arenaceous, gray, lavender, mottled, contains some calcareous sandstone and gray, dense and pure limestone	126
Sandstone, gray, pink, coarse-grained, conglomerate lenses with gray, tan, and pink quartzite pebbles up to 6 inches; ledge	12
Limestone, arenaceous, gray, red, lavender, mottled, some calcareous sandstone; forms slopes	35
Sandstone, gray, coarse-grained, lenticular; ledge	7
Limestone, arenaceous, gray, red, lavender, mottled, some calcareous sandstone; forms slopes	66
Sandstone, gray, pink, medium-grained; ledge	5
Limestone, arenaceous, red, lavender; slope	58
Total Flagstaff (undiff.)	602

SECTION 8

SECTION ON NORTH SIDE OF MELLOR CANYON.

Price River formation:	
Sandstone, conglomeratic, light gray, white quartzite pebbles up to 3 inches	80

Conglomerate, light gray, pebbles dominant, a few cobbles up to 10 inches; pebbles and cobbles chiefly white quartzite, some are pink, red and banded, matrix coarse; locally stained with limonite; grades upward into conglomeratic sandstone, light gray, medium-to coarse-grained, weathers white, pebbles scattered; unit forms prominent cliff	115
Sandstone, conglomeratic, light gray with some purple below unconformity, medium to coarse matrix, weathers irregularly, pebbles of white and red quartzite; locally stained by limonite; grades laterally to sandstone, light buff, medium-grained, thin-bedded, 10 to 12 feet	214
Conglomerate, light gray, weathers light buff in part, pebbles of white, pink, and red quartzite form 20 to 30% of unit; fine to medium almost pure quartz sandstone; near top, pebbles almost absent	67
Conglomerate, quartzite pebbles less than 1 inch in diameter; interbedded with fine-to medium-grained sandstone; thin-bedded at top	42
Sandstone, light gray, medium-to coarse-grained, thin-bedded, two 8 to 10 inch beds of light-buff, finely crystalline, slightly arenaceous limestone near top	14
Conglomerate, light gray, medium-grained matrix, quartzite and sandstone pebbles	14
Sandstone, light gray, fine-to medium-grained, weathers buff and white, beds from 2 to 5 feet, minor cross-bedding; very fine sandstone in irregular laminae, and beds from 2 to 4 inches thick interbedded with conglomerate	31
Conglomerate, quartzite pebbles and scattered cobbles up to 5 inches, also light gray limestone pebbles especially in lower part, weathers buff and yellow; lenses of light-gray, medium-grained, firmly cemented sandstone in ledges 10 to 20 feet high	262
Conglomerate, dark gray, pebbles of light and dark-gray limestone 1 to 1½ inches, form 50% of total number; pebbles of white, gray, and red quartzite, cobbles of red banded and brown quartzite up to 6 inches, numerous conglomeratic sandstone lenses 2 to 3 feet thick; unit forms steep cliffs	310
Conglomerate, dark gray, coarse matrix, pebbles and cobbles up to 10 inches, pink, white, red, banded quartzite, gray sandstone, also pebbles of light-gray and blue-gray dense limestone forming 20 to 40% of total number; infrequent coarse sandstone lenses 10 to 18 inches thick	165
Total Price River	1314

SECTION 9

SECTION OF CATERPILLAR, 2.3 MILES EAST OF FAYETTE.

Green River formation:

Limestone, dominantly yellow, some gray, very thin-bedded to 4 feet thick, some oolitic limestone, some blue, brown chert and flint, forms prominent yellow cliff	150+
Shale, gray, greenish gray, small amount of thin platy gray to white limestone, unit usually appears distinctly green from distance, forms gentle slopes	360
Limestone, white, platy, interbedded gray shale	11
Limestone, yellow, platy	4
Shale, greenish gray, sandy	5
Sandstone, greenish gray, medium-grained, biotite flakes, calcareous bond	2
Limestone, yellow, platy, interbedded with greenish-gray shale	22
Shale, gray, green, few beds of yellow, platy limestone in upper part	39
Limestone, white, dense; forms prominent ledge	3
Shale, drab, green, gray	29
Total Green River	625

Colton formation:

Shale, red, brown	5½
Limestone, white, dense; forms prominent ledge above red slopes	16
Shale, gray, blocky	6½
Limestone, gray, nearly white, slightly chalky	5½
Shale, gray, blocky	5½
Shale, purple, ochre, a little red shale	22
Limestone, gray, dense	3½
Shale, gray, purple, weathers gray	12
Shale, largely red, also gray, green, purple, blocky	16
Limestone, gray, dense	1
Shale, largely red, also gray, green purple, blocky	28
Limestone, gray, very finely crystalline	½
Shale, largely red, also gray, green, purple, blocky	28
Shale, gray, green, blocky	5½
Limestone, gray, contains rounded algal masses	1
Shale, gray	4
Shale, brownish red; a few thin, red, fine-grained sandstone beds with abundant muscovite	35
Shale, greenish gray, weathers light gray	5½
Limestone, white, dense, thin-bedded	4
Shale, greenish gray, weathers light gray	6½
Shale, red, poorly exposed; some thin-bedded red sandstone layers	11

Sandstone, gray, pepper-and-salt, medium-grained, loosely cemented	10
Shale, red, poorly exposed, grades upward into dark-gray shale	33
Sandstone, deep red, micaceous, generally thin-bedded but beds up to 2 feet present; red shale interbedded with sandstone	39
Shale, gray, sandy	8
Sandstone, deep red, in part mottled with purple, very thin-bedded, fine-grained, micaceous; small amount of red shale interbedded	11
Shale, brick red	22
Covered, probably largely yellow limestone	53
Limestone, yellow, thin-bedded	4
Shale, greenish gray, blocky	5½
Limestone, yellow, thin-bedded	1
Covered, probably yellow thin-bedded limestone	11
Limestone, yellow, thin-bedded	5½
Shale, light gray to white, contains nodular yellow limestone	1½
Limestone, buff, sandy, fish fragments plentiful	1
Limestone, gray, buff, shaly	2
Limestone, yellow, platy but some beds 6 inches thick, small amounts of gray shale interbedded	22
Total Colton	452

SECTION 10

SECTION AT SOUTH END OF FLAGSTAFF HOGBACK IMMEDIATELY SOUTH OF WILLOW CREEK.

Colton formation:	
Sandstone, siltstone, thin-bedded, brick red, slightly mottled with pink and gray, calcareous, some reddish-brown and greenish-gray shale	
Flagstaff formation:	
Conglomerate, gray; pebbles of gray, dense limestone and red, brown, and gray quartzite up to 3 inches; locally gray, medium-to fine-grained sandstone lenses	130
Limestone, shale, and siltstone, interbedded, brick red	50
Limestone, light gray, bluish gray, and white, minor amount of pink mottling, very dense, massive, bedding poor, weathers to angular chip-like fragments; *Goniobasis teuera* Conrad abundant in a few layers	224
Conglomerate, same as above	340
Total Flagstaff	744

SECTION 11

SECTION OF BALD KNOLL FORMATION ON NORTH SIDE OF WASH AT MOUTH OF BALD KNOLL CANYON.

Bald Knoll formation:	
Clay, alternating dark to very light green, pure to silty clay, small amount of tan clay in upper portion, a few layers of soft argillaceous limestone	308
Limestone, gray to greenish gray, argillaceous, slightly porous and soft	3
Clay, green, weathers to very light green	14
Siltstone, tan, argillaceous, poorly consolidated, weathers to very light tan	14
Clay, green, pure, weathers very light green	14
Siltstone, tan, argillaceous, poorly consolidated, weathers to very light tan	10
Limestone, gray to greenish gray, argillaceous, slightly porous and soft	10
Clay, green, calcareous, weathers light greenish gray, pure to silty, some tan to brown silty clay and a minor amount of light greenish-gray limestone	231
Total Bald Knoll	604