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# GEOLOGY OF THE SOUTHERN WASATCH MOUNTAINS AND VICINITY, UTAH

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**Brigham Young University Geology Studies**

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# Geology of the Southern Wasatch Mountains and Vicinity, Utah

*a symposium*

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*Extra copies of map available at $1.00 each.*

# Contents

# Geology of the Southern Wasatch Mountains and Vicinity, Utah

## INTRODUCTION

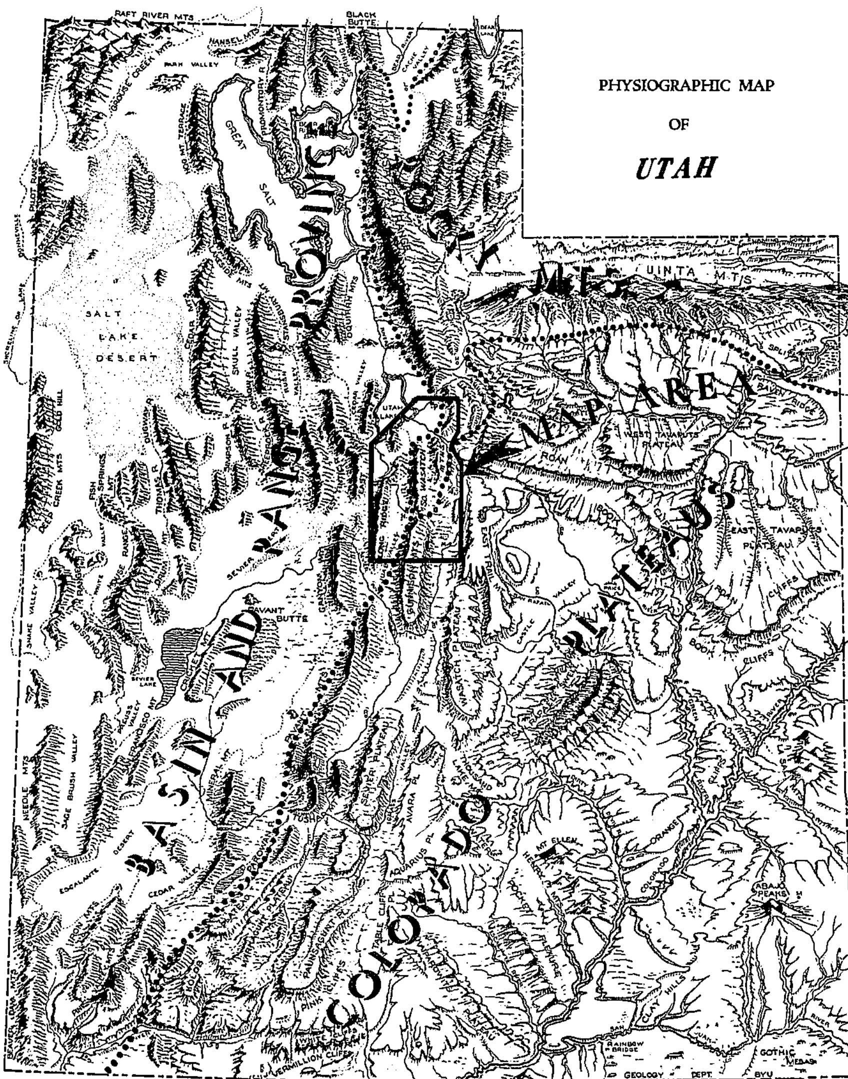
Utah is blessed with geologic features of unusual interest and great variety. The Canyon Lands, the Henry Mountains, the San Rafael Swell, the High Plateaus, the features of Lake Bonneville, the famous mining districts of Tintic, Bingham, and Iron Springs, the magnificent stratigraphic sections exposed in the Book Cliffs and in the Basin Ranges, all have revealed to geologists the tremendous sweep of geologic history and have been made classic through the writings of such pioneer geologists as C. E. Dutton, William M. Davis, C. D. Walcott, and G. K. Gilbert. So complex is Utah's geologic history and so numerous its problems that further detailed work, using improved procedures, continues to increase our understanding of this fascinating area. Each year some aspect is clarified and we wonder why it did not seem more obvious to us before.

In this light we embark on a summary of the current knowledge of the geology of the Southern Wasatch Mountains. The area lies at the junction of three major physiographic divisions: the Middle Rocky Mountains, the Colorado Plateaus, and the Basin and Range Province. It includes sedimentary, igneous, and metamorphic rocks ranging in age from Precambrian to Quaternary, and representing dominantly marine deposits of the Early Paleozoic Cordilleran miogeosyncline, the later Paleozoic Madison and Oquirrh Basins, the Cretaceous Rocky Mountain exogeosyncline, and Cenozoic deposits in freshwater lakes. The area has been involved in major structural deformation in Precambrian time, in folding and thrusting in Late Cretaceous (Laramide) time, and in block faulting in later Cenozoic time. In all, a greater variety of geologic features can scarcely be found in so limited an area.

The area is part of what is sometimes referred to as the "transition zone" in Utah. The transition involves more than the change from Basin and Range landforms to those of the Plateaus, it also involves older transitions from Cretaceous orogenic elements on the west to depositional sites on the east, from Paleozoic cratonic deposition on the east to geosynclinal behavior on the west. Two previous guidebooks have discussed the transition zone in Utah: to the north the Intermountain Association of Petroleum Geologists 10th Annual Field Conference in 1959 considered the Wasatch-Uinta Mountains transition area; to the south the Utah Geological Society 4th Annual Field Conference in 1949 traversed the transition between the Colorado Plateaus and the Great Basin in central Utah.

## GEOLOGIC MAP

The geologic map accompanying this report was compiled from a great many sources, most of them published and unpublished theses by graduate students of Ohio State University and Brigham Young University (see "Index to sources of data" printed on the map). The original mapping was done on a variety of base maps, some prepared by plane table, some from air photos, and some on U.S.




INDEX MAP.—Shows Southern Wasatch map area in relation to physiographic provinces.

Geological Survey topographic quadrangles. In transferring the mapping from these diverse bases to the common base used innumerable minor adjustments were made in order to fit the original mapping to the new base as well as possible. Air photos aided in making the transfer for it was sometimes necessary to transfer data from the original map to the photos and thence to the final map in case the original map was too distorted to use directly.

In addition, in cases where adjacent mappers disagreed, the compiler has attempted to resolve their differences as best he could in order to eliminate map boundary faults. Many problems, yet to be solved, became apparent during the compilation and it is hoped that the present map may serve as a means of pointing out these problems in their regional setting for the benefit of future students of this complex and interesting area.


## ACKNOWLEDGMENTS

Although many famous pioneer geologists such as William M. Davis and G. K. Gilbert had made reconnaissance observations pertaining to the Southern Wasatch Mountains, the first modern areal mapping in the area was done by Armand J. Eardley in the early 1930's. All later workers are indebted to the perspicacity of his observations.

Impetus for further work in the area came from Professor Edmund M. Spieker who extended his earlier interest in the Mesozoic problems of central Utah by directing Ohio State University graduate students in areas surrounding that of his initial work with the U.S. Geological Survey. Under him, S. L. Schoff's work in the Cedar Hills in 1937 was followed by that of many others of whom the following did work in the area of the present report: Dorothy Taylor, H. D. Zeller, R. E. Hunt, S. J. Muessig, R. E. Metter, A. C. Fograscher, J. E. Cooper, M. A. Khin, R. E. Mase, J. D. Hayes, and G. E. Thomas. Professor George E. Moore, Jr., of Ohio State University acted as graduate thesis advisor for some of these students.

For the past 25 years Professor Harold J. Bissell has been involved in problems relating to Utah Valley and the adjoining ranges. He has inspired a number of students to work in the West Mountain-Long Ridge-Southern Wasatch area and has served as adviser to most of the following Brigham Young University graduate students who have worked in this area: W. O. Abbott, R. S. Brown, R. S. Clark, L. C. Demars, J. H. Elison, D. R. Foutz, P. W. Gaines, R. W. Gates, T. A. Gwynn, H. D. Harris, R. A. Hodgson, K. D. Johnson, J. W. Madsen, D. F. Mecham, C. H. Peacock, H. N. Petersen, D. J. Peterson, D. O. Peterson, R. P. Peterson, J. R. Price, R. R. Rawson, J. A. Rhodes, S. F. Schindler, G. K. Sirrine, C. V. Smith, J. W. Swanson, and B. O. White.

Arthur A. Baker of the U.S. Geological Survey has mapped in the Wasatch Range from Spanish Fork Canyon northward and his work and advice have served as a guide to many of the above listed workers. In addition to the many people whose field work has made the present compilation possible, I wish to acknowledge the efforts of the authors of the papers in the present volume. I also wish to thank Professors Clyde T. Hardy and J. Keith Rigby for help in preparing the road log, and Mr. Colbeth Killip for drafting the geologic map.

*The Editor*

# Mesozoic and Cenozoic Stratigraphy of North-Central Utah

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Many stratigraphic units of Mesozoic and Cenozoic age are found in the region of the field excursion. Numerous local studies have supplied a great deal of information about these units. An evaluation of available data leads to an exceedingly intricate stratigraphic picture. This summary is intended to guide the reader to original literature and to acquaint him with certain outstanding problems. Table 1 is a generalized representation of stratigraphic units and does not show all names that have been used in the region.

## TRIASSIC

Rocks of Triassic age crop out in four areas among which the most notable is that along the north side of Spanish Fork Canyon. A small outcrop occurs on Crab Creek, a western tributary of Thistle Creek, at a point two miles south of Thistle, Utah. An extensive outcrop is found on the north side of Salt Creek Canyon, east of Nephi. It extends from Red Canyon, northeast of Nephi, eastward to the North Fork of Salt Creek, a distance of about five miles, and is above the Nebo thrust fault. A small outcrop has recently been discovered below the Nebo thrust fault in the lower part of Red Canyon, about seven miles northeast of Nephi.

### Woodside, Thaynes, and Ankareh Formations

In Spanish Fork Canyon, Baker (1947) identified the Woodside Shale, Thaynes Limestone, and Ankareh Shale. The Woodside rests unconformably on the Park City Formation of Permian age and, as a consequence, is thinner here than northward. Baker (1947) reported a thickness of 150 feet; however, Peterson (1952, p. 17) considered this too great. Here the Woodside consists of siltstone, shale, and red sandstone. The Thaynes, apparently conformable on the Woodside, consists of pink and greenish-gray sandy limestone, sandstone, and variegated shale. It is 1340 feet thick (Baker, 1947). The overlying Ankareh is 1530 feet thick (Baker, 1947) but the lower contact is indefinite. Two units are recognized in the Ankareh as follows:

2. Shale, red and variegated; sandstone, red and gray; conglomeratic sandstone; 680 feet

1. Sandy shale, reddish-brown; sandstone; 850 feet

The sandstone of Unit 2 is in the upper part of the unit in Spanish Fork Canyon; northward a prominent conglomeratic sandstone occurs at the base of Unit 2. In Crab Creek, the locality cited previously, only 282 feet of Triassic rocks are exposed (Harris, 1954, p. 195). Metter (1955, p. 115) identified this outcrop as the Ankareh Formation.

The Triassic section north of Salt Creek Canyon, east of Nephi, is known from the work of Eardley (1933, p. 324-329) and Johnson (1959, p. 16-19).

| AGE | UNITS | THICKNESS (FEET) | |
|---|---|---|---|
| Q | Lake Bonneville group | | |
| | Salt Creek fanglomerate | | |
| T | Moroni formation | 2147--Composite | Cedar Hills--south |
| | Laguna Springs latite | 500-1000--Estimate | Long Ridge--north |
| | Crazy Hollow formation | 220--Exposed | Cedar Hills--south-east |
| | Green River formation | 1015 | Fairview--north |
| | Colton formation | 580 | Cedar Hills--west-central |
| | Flagstaff limestone | 354 | Fairview--east |
| | North Horn formation | 1397 | Mount Pleasant--east |
| K | Price River formation | 248 | Mount Pleasant--east |
| | Castlegate sandstone | 583 | Mount Pleasant--east |
| | Blackhawk formation | 1753 | Mount Pleasant--east |
| | Indianola group (upper) | 5330 | Cedar Hills |
| J-K | Indianola group (lower) | 5560 | Levan--east |
| | Morrison (?) formation | 1900 | Thistle--southeast |
| J | Arapien shale (Twist Gulch member) | 1874 | Levan--east |
| | Twin Creek limestone | 815--Exposed | Thistle--south |
| | Nugget sandstone | 1450 | Thistle |
| Tr | Ankareh shale | 1530 | Spanish Fork Canyon |
| | Thaynes limestone | 1340 | Spanish Fork Canyon |
| | Woodside shale | 150 | Spanish Fork Canyon |

TABLE 1. Mesozoic and Cenozoic Stratigraphic Units

Eardley identified the Woodside Shale, Thaynes Limestone, and the Ankareh Shale but included the Nugget Sandstone with the Ankareh. Johnson reported Woodside, Thaynes, and Ankareh between the Park City Formation of Permian age and the Nugget Sandstone. Johnson estimated the thickness of the Woodside as 300-400 feet; however, the contact with the overlying Thaynes is placed at the base of the lowermost limestone and is therefore indefinite. This may account for the fact that Eardley reported only 150-200 feet in the North Fork of Salt Creek. The exposed upper part of the Woodside, examined by Johnson, is red sandstone. The Thaynes is 1000 feet thick on the north side of Salt Creek Canyon (Eardley, 1933, p. 326) and the Ankareh is at least 850 feet thick where the Nugget is recognized (Johnson, 1959, p. 18).

At Red Canyon, the Ankareh is exposed beneath the Nugget Sandstone (Johnson, 1959, pl. 8). It consists of red shale. The rocks are intensely deformed as the outcrop is near the Nebo thrust fault.

Baker (1947) suggested correlation, based on lithologic similarity, of the Woodside, Thaynes, and the lower part of the Ankareh with the Moenkopi Formation. He indicated that the upper part of the Ankareh is similar in stratigraphic position and lithology to the Chinle Formation. Therefore, the conglomeratic sandstone at the base of the upper part of the Ankareh, not seen in Spanish Fork Canyon, might represent the Shinarump member of the Chinle. Baker expressed this correlation with considerable caution but Peterson (1952, pl. 1) mapped Moenkopi, Shinarump, and Chinle in the Ankareh of Baker. It seems evident that Baker believed that the sandstone and conglomerate occur at various stratigraphic positions and that Peterson viewed the Shinarump as a well-defined unit of great lateral extent. In Crab Creek, Harris (1954, fig. 1) identified Shinarump and Chinle, whereas Metter (1955, pl. 27) mapped only Ankareh.

## JURASSIC

Jurassic rocks are exposed in three areas in the region of the field excursion. One extends, from a point about 2 miles north of Thistle, southward a distance of six miles. South of Thistle it is mostly on the west side of Thistle Creek. A larger area includes Salt Creek Canyon, east of Nephi, and extends southward along the western margin of the Gunnison Plateau. A narrow belt of outcrops is present along the northeastern margin of the Gunnison Plateau adjacent to Sanpete Valley.

### Nugget Sandstone

The Nugget Sandstone is well exposed in a prominent road cut at Thistle (Baker, 1947). Here it is 1450 feet thick and consists of gray cross-bedded sandstone; however, in some areas it is partly red. The Nugget rests on the Ankareh (Baker, 1947) and is overlain by the Twin Creek Limestone of Jurassic age. The lower contact of the Nugget may be located within close limits; the upper contact is clearly exposed.

In Crab Creek the Nugget is at least 1800 feet thick according to Metter (1955, p. 119). Harris (1954, p. 195-197), however, assigned 665 feet to Wingate (?) and 1280 to Navajo or Nugget. The Wingate (?) is a fine-grained sandstone unlike the basal beds of the Nugget at Thistle; furthermore, the Crab Creek section would be abnormally thick if the lower distinctive part is not separated. Metter, nevertheless, identified only Nugget in Crab Creek. Regional studies suggest that the Nugget of this area is equivalent to the Wingate, Kayenta, and Navajo Sandstones, taken together, of eastern Utah (MacLachlan, 1959, p. 22).

The Nugget Sandstone is present north of Salt Creek Canyon but it was not separated from the Ankareh on the North Fork of Salt Creek by Eardley (1933, p. 331). Farther west, Johnson (1959, pl. 8) recognized the Nugget but an incomplete section is present due to faulting. The isolated outcrop in Red Canyon (Johnson, 1959, pl. 8) is of importance in that it marks the base of the overlying Arapien Shale.

### Twin Creek Limestone and Twelvemile Canyon Member of Arapien Shale

At Thistle the Twin Creek Limestone overlies the Nugget Sandstone (Baker, 1947), but only half the total thickness is exposed. In Monk's Hollow, about seven miles northeast of Thistle, a complete section crops out. Here the lower 600 feet is mostly gray thin-bedded limestone, whereas the upper 600 feet is mostly gray shale with interbedded sandstone in the upper part (Imlay, 1953, p. 58). The Entrada Sandstone and the Curtis Formation overlie the Twin Creek at Monk's Hollow but are poorly exposed near Thistle. The Twin Creek also crops out on Crab Creek where the lower 815 feet is exposed (Harris, 1954, p. 198-199). Ammonites of early Callovian age were found here by Harris. The Twin Creek is correlated with the Carmel Formation of eastern Utah and with the Twelvemile Canyon Member of the Arapien Shale of central Utah.

The Twelvemile Canyon Member of the Arapien Shale crops out in Salt Creek Canyon and along the western side of the Gunnison Plateau (Spieker, 1946, p. 124). It overlies the Nugget Sandstone which is exposed only at one point northeast of Nephi below the Nebo thrust fault. The lower part of the Twelvemile Canyon Member consists mostly of gray thin-bedded limestone with beds of anhydrite; the upper part is gray shale with interbedded sandstone.

The total thickness of the Twelvemile Canyon Member in Salt Creek Canyon and in the Gunnison Plateau is certainly greater than at Thistle. Eardley (1933, p. 331) gave a thickness of 3-10000 feet, at least, for Salt Creek Canyon; Johnson (1959, p. 22) estimated 8500 feet in the same area. The correct thickness in Salt Creek Canyon is unknown due to complex structure. Hardy (1952, p. 89-95) cited only the exposed thickness east of Levan where the structural complexity is much less. Here 2480 feet of the Twelvemile Canyon Member is exposed. The underlying Nugget Sandstone does not crop out and the lower 800 feet of Twelvemile Canyon consists of intensely folded thin-bedded limestone with some interbedded anhydrite.

### Twist Gulch Member of Arapien Shale

The Twist Gulch Member of the Arapien Shale is found in a small outcrop on the North Fork of Salt Creek. A thick section is exposed on the western side of the Gunnison Plateau where it overlies the Twelvemile Canyon Member and underlies a conglomerate of Early Cretaceous (?) age. Here the Twist Gulch is 1874 feet thick and consists of red siltstone and sandstone. An unconformity is present at the top of the Twist Gulch (Hunt, 1950, p. 42-43) as evidenced by faulting which occurred before the deposition of the conglomerate mentioned above.

Along the eastern edge of the Gunnison Plateau, the Twist Gulch Member of the Arapien Shale crops out in places. It is 1264 feet thick at a point about 1½ miles south of Wales, Utah (Taylor, 1948, p. 11-13). The Twist Gulch at Wales Canyon consists of red siltstone and sandstone which dips eastward at a high angle but with top toward the west. Beds identified as Morrison (?) overlie the Twist Gulch at this point.

### LATE JURASSIC (?) AND EARLY CRETACEOUS (?) UNITS

Rocks assigned to the Morrison (?) Formation of Late Jurassic (?) and Early Cretaceous (?) age crop out east of Thistle and in places along the eastern side of the Gunnison Plateau. The lower part of the Indianola Group, in the western part of the Gunnison Plateau and in the western part of the Cedar Hills, is probably Early Cretaceous in age although it might also be Late Jurassic.

#### Morrison (?) Formation

About 1½ miles east of Thistle, Utah, on the north side of Soldier Fork, a small outcrop of the Morrison (?) Formation occurs beneath a sandstone of Cretaceous age (Baker, 1947). In Lake Fork, a few miles southeast of Thistle, it is 1900 feet thick (Bayley, 1950, p. 18). The Morrison (?) is not as extensive as once thought (Spieker, 1949, p. 87-88).

At Wales Canyon, west of Wales, a section of conglomerate, sandstone, and shale overlies the Twist Gulch Member of the Arapien Shale in apparent conformity. This unit is beneath a sandstone thought to be of Cretaceous age; nearby it is overlain unconformably by conglomerate of the Price River Formation. Little evidence exists for the prevailing identification of this outcrop as Morrison (?). It is probably not the same as the Morrison (?) exposed in the southeastern part of the Gunnison Plateau; furthermore, some beds of conglomerate occur in the upper part of the Twist Gulch Member on the western side of the Gunnison Plateau.

#### Indianola Group (lower)

The basal unit of the Indianola Group on the western side of the Gunnison Plateau, here considered Indianola (lower), is 5560 feet thick (Hunt, 1950, p. 49). It consists of conglomerate, sandstone, red shale, and limestone. The conglomerate must have been derived from the west. The Indianola (lower) overlies the Twist Gulch Member of the Arapien Shale unconformably and underlies conglomerate and sandstone of the Indianola (upper) which is described later.

In the west-central part of the Cedar Hills, the Indianola (lower) consists of conglomerate, sandstone, shale, and limestone. It is 9350 feet thick (Schoff, 1951, p. 624); however, the lower contact is not exposed and about half of the unit is covered by volcanic sedimentary rocks.

The basal unit of the Indianola Group on the western side of the Gunnison Plateau is regarded as equivalent, in part, to the basal unit in the Cedar Hills. Schoff (1951, p. 624) reported marine sandstone and conglomerate of Colorado age above the lower unit in the Cedar Hills; Thomas (1960, p. 43) suggested that part of the Indianola above the lower conglomerate, in the Gunnison Plateau, may be equivalent to the marine unit of the Cedar Hills. Because of the unconformity beneath the Indianola conglomerate of the Gunnison Plateau, the basal unit of the Indianola Group in both the Gunnison Plateau and in the Cedar Hills is here provisionally regarded as of Early Cretaceous age. It should be noted, however, that Hunt (1950, p. 52) found plant fragments 4000 feet above the base of the Indianola in the Gunnison Plateau which were identified by R. W. Brown as of Late Cretaceous age. Thus, Thomas (1960, table 1) considered this unit to be of Late Jurassic, Early Cretaceous, and Colorado age.

## CRETACEOUS

The upper part of the Indianola Group is best known from outcrops in the western Cedar Hills and in the northern Gunnison Plateau. Here it has not been divided into formations as in Sixmile Canyon, near the southern end of Sanpete Valley. The Blackhawk Formation and the Castlegate Sandstone occur in canyons on the western side of the Wasatch Plateau, east of Mount Pleasant, Utah; correlative units are probably present in the Gunnison Plateau. An extensive outcrop of conglomerate in the vicinity of Red Narrows, about 5 miles east of Thistle, is mapped as the Price River Formation; however, the Price River is less coarse where known to overlie the Castlegate as in the area east of Mount Pleasant.

### Indianola Group (upper)

A sandstone of Cretaceous age (Baker, 1947) overlies the Morrison (?) Formation at a point about 1½ miles east of Thistle. The exposed thickness is only about 300 feet. This unit may be the basal formation of the Indianola Group (Spieker, 1949, p. 87). Near Indianola, about 10 miles south of Thistle, the Indianola Group occurs under complex structural circumstances and the identity of some outcrops is open to question (Khin, 1956, pl. 1; Mase, 1957, pl. 1).

In the western part of the Cedar Hills, the Indianola Group is abnormally thick according to Schoff (1951, p. 624). The lower part of the section may be of Early Cretaceous age and, for this reason, the basal unit of Schoff, which is 9350 feet thick, is discussed above as Indianola (lower). The remaining units, here considered Indianola (upper), total 5330 feet in thickness (Schoff, 1951, p. 624). They consist mostly of sandstone and conglomerate and are of Colorado age as evidenced by both invertebrate and plant fossils (Schoff, 1951, p. 625-626).

In the northern part of the Gunnison Plateau, the Indianola (upper) overlies at least 5560 feet of conglomerate described above as Indianola (lower). The Indianola (upper) of the area is 2996 feet thick and is divided into 3 units (Thomas, 1960, p. 35) as follows:

3. Conglomerate, shale and coal near top; 1426 feet
2. Sandstone; 0-1390 feet
1. Sandstone, shale, limestone, some coal; 0-180 feet

Unit 1 occurs only in a limited area; Unit 2 thickens southward to 1390 feet and rests directly on the Indianola (lower) in the absence of Unit 1. The Indianola (upper) was included in the section of the South Flat Formation measured by Hunt (1954, p. 123-125). Unit 2 is correlated with the sandstone and conglomerate which overlies Indianola (lower) in the Cedar Hills (Thomas, 1960, p. 43). The upper part of Unit 3 may be equivalent to the Blackhawk Formation of the Wasatch Plateau.

During late Early Cretaceous and early Late Cretaceous time, a sea invaded central Utah with the result that the upper part of the Indianola Group was deposited. At Thistle (Bayley, 1950, p. 36), sandstone containing Turonian fossils rests directly on the Morrison (?). In Salina Canyon, 75 miles south of Thistle, Turonian fossils are found 700-750 feet above the Morrison (?).

### Blackhawk Formation

Blackhawk Formation is found in several canyons on the western side of the Wasatch Plateau. East of Mount Pleasant it is 1753 feet thick and consists of sandstone, shale, and coal (Pashley, 1956, p. 12). The lower 1262 feet is not exposed but was drilled by the U.S. Bureau of Mines (Duncan, 1944). The base of the Blackhawk was taken at the top of a thick sandstone which could be part of the lower Blackhawk or possibly the Star Point Sandstone which underlies the Blackhawk in the eastern part of the Wasatch Plateau. Near the base of the Blackhawk are 5 coal beds 2-6 feet thick. The Castlegate Sandstone conformably overlies the Blackhawk. In Sanpete Valley, a test of the Tennessee Gas Transmission Company located 1 mile south of Moroni penetrated a coal-bearing unit that is probably the same as that of the Wasatch Plateau to the east.

In the Gunnison Plateau the Blackhawk seems to be represented by the upper part of the Indianola Group as identified by Thomas (1960, p. 56) but included in the South Flat Formation by Hunt (1954, p. 123-125). Hays (1960, p. 98) reported the same pollen grains from this unit as in the Blackhawk coals of the Wasatch Plateau. These rocks have been described as part of Unit 3 of Indianola (upper).

### Castlegate Sandstone and South Flat Formation

Castlegate Sandstone, east of Mount Pleasant, is 583 feet thick (Pashley, 1956, p. 12). It overlies the Blackhawk Formation conformably and underlies the Price River Formation. The Castlegate contains lenticular beds of conglomerate in this area.

In the Gunnison Plateau, the South Flat Formation is restricted by Thomas (1960, p. 67) overlies Indianola Group (upper). It is mostly gray sandstone and is 947 feet thick (Thomas, 1960, p. 50). It rests on the upper part of the Indianola Group with angular discordance at the eastern edge of the Gunnison Plateau but is parallel with the Indianola in the interior of the plateau. The Price River Formation overlies the South Flat in angular discordance (Thomas, 1960, pl. 17). The South Flat was defined by Hunt (1954) and correlated with the Blackhawk Formation of the Wasatch Plateau. The restricted South Flat is now correlated with the Castlegate Sandstone of the Wasatch Plateau (Thomas, 1960, p. 56).

The sandstone which overlies the Morrison (?) at Wales Canyon and which is also unconformably beneath the vertical Price River Formation is mapped simply as a sandstone of the Indianola Group. Nevertheless, it may be South Flat or even Castlegate. At Birch Creek, about 7 miles north of Wales Canyon, this sandstone rests directly on the Twist Gulch Member of the Arapien Shale. A short distance to the west, across a north-south fault, the South Flat is said to rest on the upper part of the Indianola Group (Thomas, 1960, pl. 17).

### Price River Formation

A conglomerate, which rests on the Nugget Sandstone at a point 2 miles north of Thistle, was mapped as the Price River Formation by Peterson (1952, pl. 1). A massive conglomerate about 1000 feet thick, exposed at Red Narrows east of Thistle, is generally identified as the Price River. It extends southward into Lake Fork where it is at least 900 feet thick (Lee, 1950, p. 10). North of Indianola, at a point about 10 miles south of Thistle, it is only 275 feet thick. Clastic rocks overlying the conglomerates are usually taken to represent the North Horn Formation; however, Baker (1947) identified only the Price River in the area north of Thistle. Elsewhere, in the Cedar Hills and north of Salt Creek Canyon, conglomerates resting on older rocks have been called Price River.

East of Mount Pleasant, the Price River is represented by 248 feet of sandstone, with lenses of conglomerate, that conformably overlies the Castlegate Sandstone and underlies the North Horn Formation (Pashley, 1956, p. 34). This unit is presumed to be continuous with the massive conglomerate at Red Narrows, east of Thistle.

The Price River crops out along the eastern side of the Gunnison Plateau from Wales Canyon northward to Maple Canyon. At Wales Canyon it is 325 feet thick (Lee, 1953, p. 61) and at Maple Canyon 870 feet thick (Lee, 1950, p. 10). It overlies Twist Gulch Member of the Arapien Shale, Morrison (?), and an unidentified Cretaceous sandstone in angular unconformity. In the northern part of the Gunnison Plateau, it rests on the South Flat Formation with slight angular discordance (Thomas, 1960, pl. 17).

Spieker (1946, p. 131-132) believed that the Price River Formation, including the basal Castlegate Sandstone Member, changed westward to the massive conglomerate at Red Narrows. He also recognized the less coarse upper Price River, underlain by well-defined Castlegate, in the area east of Mount Pleasant. With the redefinition of the Price River so as to exclude the Castlegate, it is necessary to indicate that both the Price River Formation and the Castlegate Sandstone are believed to be represented by the Price River near Red Narrows.

Spieker argued that the Castlegate Sandstone, as a member of the Price River, loses its identity northwestward in the Wasatch Plateau. Walton (1955, pl. 1), however, has mapped the Castlegate in the westernmost outcrops of Spieker's undifferentiated Price River (Spieker, 1931, pl. 31; Spieker, 1946, p. 131-132). These outcrops are separated from the conglomerate at Red Narrows by a covered interval of 11 miles. It seems impossible, therefore, that the Castlegate changes into the conglomerate and it is doubtful that the upper part of the Price River makes such a change. Perhaps the conglomerates east of Thistle are part of the North Horn formation. This does not mean that the conglomerate along the eastern margin of the Gunnison Plateau is not Price River.

## TERTIARY (NONVOLCANIC)

North Horn and Flagstaff Formations are exposed near Thistle and southward along the western side of the Wasatch Plateau. The Green River Formation crops out northeast of Thistle and also in two important areas along the Wasatch Plateau. The Colton Formation may also be present near Thistle. In the western part of the Cedar Hills, the Colton is overlain successively eastward by the Green River and Crazy Hollow Formations. All nonvolcanic Tertiary units, except Crazy Hollow, are found in the northern part of the Gunnison Plateau.

The North Horn Formation is of Late Cretaceous and Paleocene age in the eastern part of the Wasatch Plateau. Evidence of Cretaceous age has not been found in the western outcrops here described; thus, the North Horn is regarded as Tertiary in age.

North Horn Formation

Northeast of Thistle the North Horn Formation overlies conglomerate assigned to the Price River Formation (Peterson, 1952, pl. 1). Here it is 415 feet thick and consists of conglomerate, sandstone, and red shale. At a point about 2 miles north of Thistle, Peterson also identified a conglomerate as Price River and the less coarse overlying beds as North Horn. In the area north of Thistle, Baker (1947) did not recognize the North Horn and, therefore, reported only Price River. It is evident that little reason exists for identifying the North Horn in the area except as the varicolored unit overlying conglomerate assigned to the Price River.

In the west-central part of the Cedar Hills, the North Horn is 6700 feet thick according to Schoff (1951, p. 629). Two units are recognized. The lower one rests on a conglomerate mapped as Price River and is restricted to the Hop Creek area. The upper unit is more extensive than the lower and overlaps Paleozoic rocks in the northern part of the Cedar Hills. The upper unit, about 2700 feet thick, is here regarded as the North Horn formation. The lower unit, about 4000 feet thick, and the conglomerate identified as Price River need additional study in view of the complex regional stratigraphic relations now known. Hintze, on the map accompanying this report, shows the North Horn as truncating folded Price River and Indianola beds near the head of Hop Creek in the Cedar Hills, thus differing from Schoff's earlier map which shows Price River continuous beneath the basal North Horn in this area.

East of Mount Pleasant, the North Horn is 1397 feet thick (Pashley, 1956, p. 12). It rests conformably on the Price River formation and is overlain by the Flagstaff Limestone. Furthermore, the Price River rests on Castlegate in this area and is more certainly identified than in many places. The North Horn consists of sandstone and shale in this area.

In the northern part of the Gunnison Plateau, in Wales Canyon, the North Horn is 1663 feet thick (Lee, 1953, p. 174-179). It is conformable with the Price River according to Spieker (1946, p. 129) and also conformable with the Flagstaff Formation above. The lower contact, however, is placed at the base of a red bed which is conformable with the sandstone and conglomerate of the Price River exposed in the lower part of Wales Canyon. An angular unconformity separates the vertical Price River, top on the west, from the North Horn Formation above and toward the west (Burma and Hardy, 1953, p. 550). This angular unconformity, according to Spieker (personal communication), is within the North Horn, if it exists, and is of no particular significance. Burma and Hardy, on the other hand, accepted it as an appropriate division between Price River and North Horn and also show that it has regional significance. Lee (1953, p. 164) did not admit a tectonic break between Price River and North Horn but his conclusions were based on petrographic studies.

In summary, the North Horn is conformable with the Price River in the area east of Mount Pleasant. Here the Price River rests on the Castlegate Sandstone. Elsewhere several relationships are found as follows:

(1) The North Horn rests on beds that are mapped as lower North Horn but may be older.

(2) The North Horn rests on beds that are mapped as Price River but which may be North Horn.
(3) The North Horn overlaps older rocks including those of Paleozoic age.
(4) The North Horn overlies the Price River formation in angular unformity.

The upper contact is conformable with the Flagstaff Formation. The North Horn is said to intertongue with the Flagstaff but this relationship has never been demonstrated in the field. Repetition of a rock type characteristic of the North Horn in the Flagstaff is not proof of intertonguing.

### Flagstaff Limestone

The Flagstaff Limestone is exposed beneath the Green River Formation at a point about 1½ miles northeast of Thistle. It overlies the North Horn according to Peterson (1952, pl. 1) or the Price River according to Baker (1947). Here the Flagstaff is 100-200 feet thick and consists of limestone, shale, and sandstone.

West of Thistle the Flagstaff overlies the North Horn. North of Crab Creek it is 350 feet thick (Metter, 1955, p. 135). Harris (1954, p. 201) reported 1207 feet from this locality but did not separate the North Horn below and the Colton above. The Flagstaff overlaps Paleozoic rocks on the flank of the Wasatch Mountains to the west. It is believed by some investigators to intertongue with the North Horn Formation except, of course, where it overlies older rocks. Individual beds have not been traced throughout the region; therefore, beds identified as Flagstaff in some areas might be North Horn. Algal limestone has been quarried from the Flagstaff east of Birdseye, Utah, and used as marble. (Eardley, 1932).

In the Cedar Hills the thickness of the Flagstaff is uncertain due to incomplete exposures and faulted outcrops. Possibly it is 750 feet thick (Schoff, 1951, p. 631). East of Fairview, however, it is 354 feet thick (Pashley, 1956, p. 12). The Flagstaff is 720 feet thick in the Gunnison Plateau (Hunt, 1950, p. 83) but the position of the contact with the overlying Colton Formation is uncertain. It rests on the North Horn in the eastern part of the plateau and overlaps the Indianola Group in the western part (Hunt, 1950, p. 44).

The Flagstaff Limestone formed as a result of deposition in a series of lakes. It is of Paleocene and Eocene age (LaRocque, 1960, p. 73-75).

### Colton Formation

The Colton Formation is not recognized in the Thistle area by investigators who hold that it terminates about 15 miles eastward by intertonguing with the Green River Formation as described by Prescott (1958, p. 12). Metter (1955, pl. 27) mapped a unit of conglomerate and red beds above the Flagstaff, in the Thistle district, as Colton. If this is Colton, it is separated from the type Colton by intertonguing Green River Formation. It may be well to include these beds in the Flagstaff (Rawson, 1957, pl. 3).

Colton is mapped in the central and northern parts of the Cedar Hills where it was identified with some reservation (Schoff, 1951, p. 632) but represents a lithologically distinct unit between the Flagstaff and Green River Formations. In the west-central part of the Cedar Hills, it is 580 feet thick and consists of conglomerate, sandstone, and red shale (Schoff, 1951, p. 632). A small outcrop is present on the western flank of the Wasatch Plateau, northeast of Fairview, bue elsewhere in the vicinity the Green River rests directly on the Flagstaff.

The Colton is 310 feet thick in the Gunnison Plateau (Hunt, 1950, p. 86). It resembles the Flagstaff and Green River Formations except for beds of red shale.

### Green River Formation

The Green River Formation overlies the Flagstaff Limestone northeast of Thistle (Peterson, 1952, pl. 1). It also rests on the Flagstaff in a limited area about 5 miles south of Thistle and east of Thistle Creek.

The main occurrence of Green River, in the area of the field excursion, is on and near the divide between Thistle Creek and the northeastern end of Sanpete Valley (Spieker, 1949, p. 35). Here it has been studied in considerable detail by Fograscher (1956, p. 5) who recognized 5 informal units as follows:

5. Shale, tuff, limestone and chert; 25-75 feet
4. Shale, some limestone; 100 feet
3. Limestone, algal, oolitic; shale; tuff; 600 feet
2. Shale, brown; tuff; 140 feet
1. Shale, green; tuff; 100 feet

In this area the Green River is about 1015 feet thick. The Crazy Hollow Formation overlies the Green River (Fograscher, 1956, p. 30).

### Crazy Hollow Formation

The Crazy Hollow is known to overlie the Green River unconformably else-part of the Cedar Hills, west of Fairview, Utah (Fograscher, 1956, p. 30). It is 175-200 feet thick in the area; however, the lower contact is not exposed. Volcanic sedimentary rocks of the Moroni Formation rest uncomformably on the Crazy Hollow. In the northern part of this outcrop, the Crazy Hollow is mostly sandstone and conglomerate; in other parts, it consists of sandstone, varicolored shale, and limestone.

The Crazy Hollow is known to overlie the Green River unconformably elsewhere in central Utah. Isolated outcrops of Crazy Hollow are found between the Cedar Hills and the type section in the lower part of Salina Canyon. The Crazy Hollow was defined by Spieker (1949, p. 36).

### Uinta Formation

Baker (1947) states: "Rocks assigned to the Uinta Formation conformably overlie the Green River Formation. They are similar in lithology to the rocks of the Upper Cretaceous Price River formation and where the intervening Flagstaff Limestone and Green River Formation are absent the Uinta and Price River are inseparable on the basis of lithology. The thickness of the Uinta is 500 feet or less in the southern part of the area between lower Diamond Fork and Soldier Fork, but it increases rapidly eastward into the Uinta Basin where the formation is several thousand feet thick and is the surface rock in much of the central part of the basin."

### Salt Lake Formation

H. J. Bissell (per. comm.) identified two small outcrops near Payson as the Salt Lake Formation. The rocks exposed consist of a few tens of feet of friable tuffs, tuffaceous sandstones, and tuffaceous limestones. In the outcrop west of Payson the Salt Lake Formation rests with angular discordance on Paleozoic Diamond Creek Sandstone. Poorly preserved ostracods found in these exposures are not definitive but the Salt Lake Formation is generally considered to be Late Cenozoic.

## TERTIARY (VOLCANIC)

Volcanic sedimentary rocks cover a large part of the Cedar Hills, north of Moroni, Utah. A volcanic breccia underlies most of the northern part of Long Ridge, west of Nephi and Santaquin, Utah. The latter unit will be described first because it may be older than the volcanic rocks of the Cedar Hills.

### Laguna Springs Latite

The northern part of Long Ridge is almost entirely underlain by volcanic breccia or agglomerate, with a few included flows. This unit was mapped by Muessig (1951a, pl. 1) as the Laguna Latite. In the East Tintic district, west of Long Ridge, it is now called the Laguna Springs Latite by H. T. Morris and T. S. Lovering.

The Laguna Springs Latite, in Long Ridge, is represented largely by the agglomerate member which is 500-1000 feet thick. Deposition on a surface of considerable relief produced great variations in thickness. Muessig (1951a, p. 129) reported that the volcanic breccia of the Laguna Springs Latite grades southward into a volcanic conglomerate of the Golden's Ranch Formation. The latter is conformable with the Green River Formation and was dated, on the basis of plant fossils in an included limestone, as middle Eocene (Muessig, 1951b).

### Moroni Formation

Volcanic sedimentary rocks, with welded tuff in the upper part, overlie older rocks in the Cedar Hills as well as in some outlying areas. These were studied by Schoff (1937, p. 105) who first referred to them as the Moroni Formation. In later publication, however, he dropped the formal name (Schoff, 1951, p. 634). Cooper (1956), who studied the unit in much greater detail, employed the name utilized earlier by Schoff.

The Moroni Formation rests unconformably on the Crazy Hollow Formation as well as on older rocks including those of Paleozoic age in the northern part of the Cedar Hills. Cooper (1956, p. 8) identified 6 units within the Moroni which are described in a later paper in this report. The composite thickness of the Moroni Formation is 2147 feet (Cooper, 1956, p. 21). The thickest and most extensive unit of the Moroni is a sandstone and volcanic conglomerate, and the formation as a whole is of mixed volcanic and sedimentary origin.

## QUATERNARY

Stratigraphic units of Quaternary age have not been extensively studied, in the region of the field excursion, except for the Lake Bonneville group of Utah Valley. Sediments of Lake Bonneville also occur in the southern part of Juab

Valley south of Nephi, Utah. A Quaternary fanglomerate, possibly older than the Lake Bonneville group, is present in places east of Nephi.

### Salt Creek Fanglomerate

The Salt Creek Fanglomerate is found in the area north of Salt Creek Canyon and west of the North Fork of Salt Creek (Eardley, 1934, map 11). The larger outcrop unconformably overlies both the Moroni Formation and the Arapien Shale. A smaller outcrop farther west overlies Ankareh Shale, Nugget Sandstone, and Arapien Shale (Johnson, 1959, pl. 8). Fanglomerate is also present in the foothills of the Gunnison Plateau, southeast of Nephi (Hunt, 1950, p. 106).

The Salt Creek is composed of locally derived rock fragments set in a red matrix. It is younger than the Moroni Formation. Eardley (1933, p. 337-338) suggested a Pleistocene age based on the physiographic setting of the outcrops.

### Lake Bonneville Group

The sediments of the Lake Bonneville Group, in Utah Valley, overlie a fan gravel and reveal the following events (Bissell, 1952, p. 1358):

(7) 4th lake—maximum about 4760 feet
(6) Recession—at least 4700 feet
(5) 3rd lake (Provo)—4800 feet
(4) Recession—at least 4500 feet
(3) 2nd lake (Bonneville)—maximum 5135 feet
(2) Recession—at least 4600 feet
(1) 1st lake (Alpine)—maximum 5100 feet

Lake Bonneville sediments are well displayed at the mouth of Spanish Fork Canyon. The highest shoreline was formed by the 2nd lake; Utah Valley was probably dry between the 2nd and 3rd lakes. The largest depositional shoreline features were formed in the 3rd lake. A massive spit of the 3rd lake separates the southeastern extension of Utah Valley from Juab Valley (Bissell, 1948, p. 229). Alluvial fans dominate the eastern side of Juab Valley but a shoreline of the 2nd lake is evident on the western side (Muessig, 1951b, p. 112). A large delta of the 3rd lake is present at the end of the canyon of Currant Creek where the latter enters Goshen Valley after crossing Long Ridge from Juab Valley (Gilbert, 1890, p. 165; Muessig, 1951, p. 111). The Lake Bonneville Group has been mapped in detail by C. B. Hunt *et al.* (1953) and Bissell (in press).

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