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Geology of the Thistle Quadrangle, Utah*

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ABSTRACT.—A regional pre-Price River (Cretaceous unconformity and a local pre-North Horn (Cretaceous-Paleocene) unconformity attest to strong Laramide compressive forces which folded Mesozoic strata at Thistle, Utah. Comparison of Mesozoic stratigraphic sections of equivalent autochthonous and allochthonous sediments implies that the leading edge of the Charleston-Strawberry-Nebo fault lies concealed within the Thistle Quadrangle.

The basic westward-dipping monoclinal structure of the Wasatch Plateau was modified first by early Cenozoic folding and by Oligocene and later high-angle normal faulting of Basin and Range affinity. Axes of Cenozoic folds show recurrent movement which may have begun in the Cretaceous but which definitely folded in earliest Cenozoic as shown by a local pre-Flagstaff unconformity. The greatest Cenozoic folding has been post-Green River (Eocene) in age.

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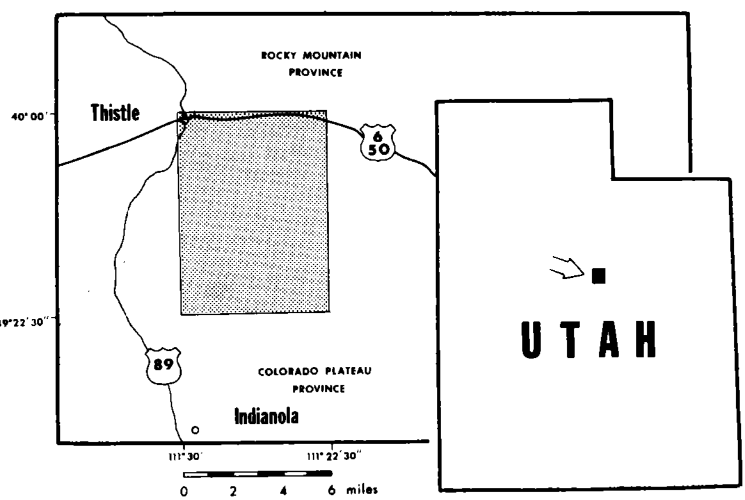
*A thesis submitted to the faculty of the Department of Geology Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science.

INTRODUCTION

Laramide tectonics, interpreted from structural and stratigraphic evidence within the Thistle Quadrangle, indicate that the covered leading edge of at least one of the major Laramide thrusts is located a few miles east and southeast of Thistle. Post-Laramide tectonics has produced potential petroleum traps in strata beneath and adjacent to the major thrust plate.

The Thistle $7\frac{1}{2}$-minute Quadrangle lies near the intersection of the Rocky Mountain, Colorado Plateau, and Basin and Range Physigraphic provinces (see Text-fig. 1). The quadrangle covers 58 square miles, with its northwest corner at 40°00' north latitude and 11°30' west longitude. The town of Thistle, population less than 50, is situated at the junction of U.S. Highways 89 and 50-6 in Spanish Fork Canyon and is in the northwest corner of the area. Dirt roads permit access to within three miles of any of the points in the quadrangle but are passable to automobiles only during dry weather.

The Wasatch Plateau of the High Plateaus section of the Colorado Plateau Province is the dominant physiographic feature of the Thistle area. The Wasatch Range of the Rocky Mountain Province is physiographically represented north of Soldier Creek in the northernmost portion of the area of study. Although the Basin and Range Province is not physiographically represented,



TEXT-FIGURE 1.—Index map of Thistle Quadrangle.

normal faults similar to Basin and Range geology are present (Wooley, 1946, Plate 1).

Previous Work

Howell, King, Dutton, Loughlin, and other pioneer geologists made reconnaissance geologic investigations of the general area covered in this report. Harris (1953, p. 7-10) describes the extent and importance of these regional investigations.

The principal recent worker in the area is E. M. Spieker, who delineated Jurassic, Cretaceous, and Tertiary stratigraphy and the related tectonic history of Central Utah (Spieker and Reeside, 1925; and Spieker, 1936, 1946, 1949a, 1949b).

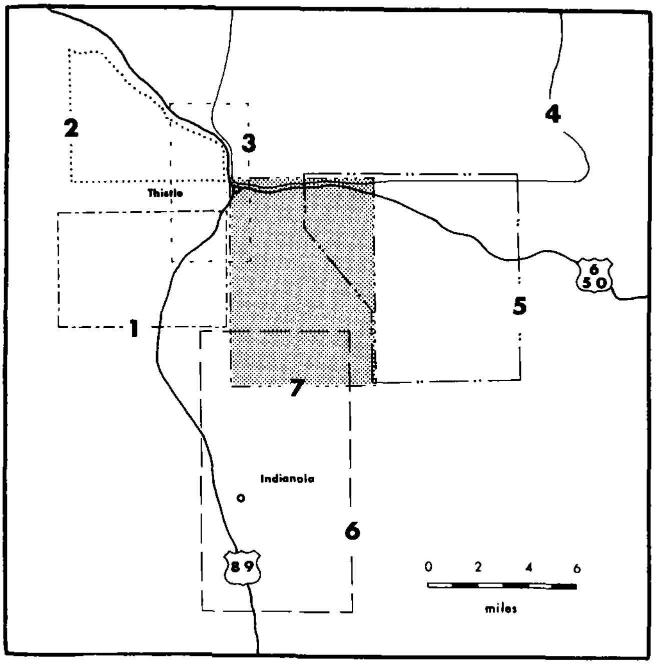
Under the direction of Spieker, several graduate students at Ohio State State University did thesis work which was, in part, within the Thistle Quadrangle. K. Y. Lee, in 1950, made a petrographic study of the Price River Formation in Sanpete Valley. One of the sample locations was in the Lake Fork area of the Thistle Quadrangle. He expanded this work in completing a Ph.D. thesis of a study of the petrography of the Price River and North Horn formations of central Utah (Lee, 1953). R. W. Bayley completed a heavy mineral study of the Morrison Formation in 1950. His sample locality in Spanish Fork Canyon was near Thistle. R. E. Metter (1955) studied the geology of the northern part of the southern Wasatch Mountains. In 1956 and 1957 M. Khin and R. E. Mase worked together to make a geologic map of the Indianola area. Their map covers a portion of the Thistle Quadrangle (see Text-fig. 2, area 6), but it is difficult to interpret since it was completed before topographic maps of the area were published.

Graduate students from Brigham Young University have made significant contributions to the geology directly adjacent to and within the Thistle Quadrangle. P. R. Peterson (1952) mapped approximately 15 square miles in Spanish Fork Canyon (see Text-fig. 2, area 3). Harris (1954) published a study of the geology including a geologic map of the Birdseye area west of the Thistle Quadrangle (Text-fig. 2, area 1). Bullock and Bordine each completed a study of the paleoecology of the Twin Creek Limestone in the Thistle area in 1956. In 1967, R. C. Merrill undertook a geologic mapping problem of the Mill Fork are, east of the Thistle Quadrangle. The writer has had access to Merrill's preliminary manuscript and geologic map, which, in part, overlaps the Thistle Quadrangle (Text-fig. 2, area 5).

A. A. Baker's stratigraphic sections (1947) of the Wasatch Mountains have served as valuable reference material in comparing regional geology to that of the Thistle Quadrangle. Also, Baker's open-file geologic map of the Strawberry Valley Quadrangle (Baker, 1960) includes the Wasatch Mountain portion of the Thistle Quadrangle (Text-fig. 2, area 4).

Present Work

Field work began in September of 1970 and was completed in July of 1971. Structural features and contacts were plotted in the field on aerial photographs (scale 1:20,000) and later transferred to a topographic map (scale 1:24,000). Measurements of stratigraphic thicknesses were made with a 100-foot tape, a Brunton compass, and a Jacob staff and were computed from air photos.



TEXT-FIGURE 2.—Geologic mapping adjacent to the Thistle Quadrangle. 1. H. D. Harris, 1953; 2. R. R. Rawson, 1957; 3. P. R. Peterson, 1952; 4. A. A. Baker, 1947; 5. R. C. Merrill, 1972; 6. M. Khin, 1956 and R. E. Mase, 1957; 7. M. L. Pinnell, this report.

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STRATIGRAPHY

General Statement

Pre-Laramide formations in the northern part of the Thistle Quadrangle differ in thickness and lithology from equivalent formations in the southern part. These differences may be explained by Laramide thrusting with Nugget Sandstone, Twin Creek Limestone, Entrada-Curtis-Summerville formations, Morrison Formation, and Indianola Group of the Thistle area representing allochthonous rocks which have been thrust to a position near autochthonous Arapien Shale, Twist Gulch Formation, Indianola Group, and Blackhawk (?) Formation exposed near Indianola.

A regional pre-Price River Formation (Cretaceous) unconformity and a local pre-North Horn (Cretaceous-Paleocene) unconformity attest to strong Laramide compression forces which folded Mesozoic strata at Thistle. Post-Laramide clastic wedges of the Price River and North Horn formations are overlain by lacustrine rocks of the Flagstaff and Green River formations. The youngest consolidated sediments of the area are Tertiary volcanic sedimentary rocks. (Local and regional stratigraphy are summarized in Plate 4.)

Jurassic System

Nugget Sandstone.— One of the more striking topographic features in the Thistle area of Spanish Fork Canyon is the east-dipping hogback of cross-bedded, massive, and homogenous Nugget Sandstone which crops out at the town of Thistle. Nugget Sandstone was proposed by Veatch (1907, p. 56) for exposures near Nugget Station on the Oregon Short Line, Lincoln County, Wyoming. This section of Nugget Sandstone is very similar to outcrops in the Thistle area.

At the type area, Nugget Sandstone is underlain by Thaynes Formation and overlain by Twin Creek Limestone. The upper contact with Twin Creek Limestone at the type locality and in the study area is straightforward. Although the lower contact is not exposed in the Thistle Quadrangle, Pipiringos (1957, p. 8) states that there is some question as to where the lower contact of Nugget Sandstone should be placed in the Wasatch Mountains. Baker (1947) says that Ankareh Formation underlies Nugget Sandstone in the Wasatch Mountain area.

The U.S. Geological Survey has designated the Nugget Sandstone as Lower Jurassic (Keroher and others, 1966, p. 2783).

Nugget Sandstone is an extensive formation covering parts of southwestern Wyoming, southeastern Idaho, and northeastern Utah. It is correlated by many geologists, including Baker (1947), with another widespread formation, the Navajo Sandstone of the plateau region of southwestern Utah and the Uinta Mountains in northeastern Utah.

Thickness of the Nugget Sandstone is quite uniform, especially in central Utah. Thickness of the type section is reported by Pipiringos (1957, p. 8) to be 1,900 feet. Baker (1947) mentions 1,500 feet at Scott's Draw near Heber. The writer did not measure the thickness of Nugget Sandstone because other workers agree on its approximate thickness near Thistle: Baker (1947) measured 1,450 feet, Peterson (1952, p. 33) measured 1,390 feet, and Harris (1954, p. 197) measured 1,280 feet a few miles south of Thistle in Crab Creek Canyon.

Nugget Sandstone crops out only in the northwesternmost corner of the Thistle Quadrangle. Lithologically and texturally, the Nugget Sandstone here is very similar to exposures in other areas. Harris (1954, p. 197) describes it:

> One hundred and eighty-five feet of red cross-bedded, medium-grained sandstone at the base, overlain in sequence by 135 feet of a cockscomb

ledge of red, coarse-grained, highly cross-bedded sandstone, 60 feet of medium-grained, friable, cross-bedded sandstone, 335 feet of interbedded red and white, highly cross-bedded, medium-grained, tightly cemented sandstone, 210 feet of red, fine-grained, cross-bedded sandstone, 170 feet of friable, red, medium-grained, cross-bedded sandstone, and 110 feet of white to tan, medium-grained cross-bedded sandstone at the top.

Twin Creek Limestone.—Veatch (1907, p. 56) proposed the name "Twin Creek Limestone" for calcareous rocks exposed at Twin Creek, Wyoming, above Nugget Sandstone. The type section of Twin Creek Limestone consists of mostly grey, thin-bedded limestone with some yellow to red siltstone and yellow limestone (Imlay, 1967, p. 16). In the type area, and in the study area, Twin Creek Limestone is underlain by Nugget Sandstone (Imlay, 1967, p. 17). The top of the Twin Creek is not exposed in the Thistle Quadrangle; however, Baker (1947, 1960) mapped and described Entrada as conformably overlying Twin Creek Limestone a few miles north of the Thistle Quadrangle in Monks Hollow. Entrada Sandstone correlates with Preuss Sandstone (Wright and Dickey, 1963), which conformably overlies Twin Creek Limestone in the type area (Imlay, 1967, p. 51).

The southernmost rocks, called "Twin Creek Limestone" by Imlay, are at USGS Mesozoic locality 17019 (Imlay, 1967, p. 64, 74), located south of Smiths Reservoir within the Thistle Quadrangle, where fossils were collected by Spieker in 1931 and identified as belonging to the Twin Creek Limestone. However, in reference to the same locale some years later, Spieker (1946, p. 1233-124) called the same Jurassic rocks "Arapien Shale" in a publication which named and defined Arapien Shale. Twin Creek Limestone at Thistle is quite different in facies and thickness from equivalent shale south of Thistle. This subject is pursued further in following sections entitled "Stratigraphy-Twist Gulch Formation" and "Structure-Thrust Faulting."

Lower Twin Creek Limestone is exposed in nearly continuous outcrops as massive cliffs from just north of Thistle southwestward, nearly paralleling Thistle Creek, to where the limestones go under cover of pyroclastic rocks mapped by Harris (1954, p. 199). Upper Twin Creek Limestone has been identified by Baker (1947, 1960) and described by Imlay (1967, p. 45-51) in Monks Hollow north of Thistle. However, to the writer's knowledge, no exposures of upper Twin Creek Limestone have been described to date in the Thistle area. Upper Twin Creek Limestone is represented by good outcrops nearly one mile due south of Thistle Junction, east of U.S. Highway 89. An incomplete stratigraphic section of the upper Twin Creek Limestone is described in Appendix 1.

Imlay (1967) named and described seven mappable members of the Twin Creek Limestone in the western United States, all of which are represented in the study area. The members, in ascending order are:

1. Gypsum Springs Member, whose type locality is in Lincoln County, Wyoming, is composed of red beds and is usually associated with brecciated limestones. It is nine feet thick at Thistle (Imlay, 1967, p. 17).
2. Slide Rock Member, whose type section is in Lincoln County, Wyoming, consists of dark, fossiliferous, medium- to thin-bedded limestone. It is approximately 100 feet thick at Thistle (Imlay, 1967, p. 22).

3. Rich Member, whose type section is in Rich County, Utah, consists of medium-grey, shaly limestone. It is 180 feet thick near Thistle (Imlay, 1967, p. 30-31).
4. Boundary Ridge Member, whose type section is in Bear Lake County, Idaho, consists of interbedded, soft, red, green, and yellow siltstone, silty limestone, oolite limestone, and silty green grey claystone. It is 40 feet thick near Thistle (Imlay, 1967, p. 36-37).
5. Watton Canyon Member, whose type section is in Rich County, Utah, is composed of medium- to thin-bedded limestone. It is 300 to 400 feet thick in the Wasatch Mountains (Imlay, 1963, p. 41).
6. Leeds Creek Member of the Twin Creek Limestone, at its type section in Lincoln County, Wyoming, consists of 1,118 feet of soft, dense, light-grey, shaly limestone. Southward, however, the Leeds Creek Member becomes more clayey and silty to the extent that it begins to be similar to the upper part of the Twelvemile Canyon Member of the Arapien Shale. Thickness also increases southward and westward to 1,290 feet at Devil's Slide and 1,500 feet at Burr Fork. This member thins some southward in the Wasatch Range, but "the thickness of only 275 feet measured at Monks Hollow is not in line with regional thickness trends and may reflect elimination of beds by faulting" (Imlay, 1967, p. 16, 45-46). Imlay's supposition of elimination of Twin Creek Limestone beds by faulting in Monks Hollow is substantiated by the writer's incomplete section of upper Twin Creek Limestone (Appendix 1, p. 88). Of the 950 feet measured, the writer suggests that the lower 645 feet have Leeds Creek lithologic affinities.
7. Giraffe Creek Member consists of yellowish, greenish, or pinkish grey, silty to finely sandy, ripple-marked, thin-bedded limestone interbedded with sandstone of its type section in Lincoln County, Wyoming. This member thickens southward and westward from 111 feet at the type section to 200 feet at Burr Fork, and 280 feet at Monks Hollow (Imlay, 1967, p. 50-51). In the Thistle Quadrangle, the Giraffe Creek Member of the Twin Creek Limestone, consists of approximately 300 feet of greenish grey to grey, very thin to medium-bedded siltstone and sandstone.

On the basis of announced zones, Imlay (1967, p. 3) considers the age of Twin Creek Limestone to range from middle or late Bajocian through Bathonian to Callovian. The Twin Creek Limestone is correlated with the Carmel Formation of southern Utah and the Twelvemile Canyon Member of the Arapien Shale. The sediments comprising these three rock units were deposited contemporaneously in a trough that extended from southwestern Utah northwestward into central Utah and then northward through north central Utah into southern Idaho. The Twin Creek Limestone differs from the Twelvemile Canyon Member of the Arapien Shale and the Carmel Formation by being divisible into members and by being more calcareous, less shaly, and less red in its upper part (Imlay, 1967, p. 4). Thickness of the Twin Creek Limestone ranges from 665 feet in northwestern Wyoming to about 2,850 feet at Burr Fork (Imlay, 1967, p. 4) near Salt Lake City. From the Salt Lake area, the formation thins southward to an abnormally thin section of 1,106 feet at Monks Hollow (Baker, 1947). The 620 feet of lower Twin Creek Limestone measured by Bordine (1965, p. 92) added to 950 feet of upper

Twin Creek Limestone measured by the writer give a minimum total thickness of 1,570 feet at Thistle.

Arapien Shale.—Named by Spieker (1946, p. 123-125) and redefined by Gilliland (1951, p. 10-15) to include only Spieker's lower (Twelvemile Canyon) member, Arapien Shale has been identified by the writer south of Smiths Reservoir. Here the formation is in fault contact with Blackhawk (?) Formation and may either be faulted against or unconformably overlain by Price River Formation. It is composed of grey and yellowish brown, thin-bedded limestone interbedded with red and grey calcareous shale. Fossils from the locality, identified by W. A. Cobban of the U.S. Geological Survey, include *Camptonectes stygius* White, and crinoid fragments. The outcrops of Arapien Shale near Smiths Reservoir probably represent the basal rocks of the formation, whose upper part has been identified by Khin (1956, Plate 1) a few miles to the west.

Twin Creek Limestone exposed near Thistle and Arapien Shale exposed near Smiths Reservoir and near Indianola differ substantially in thickness and lithology, although these two rock units represent time-equivalent formations (Imlay, 1967, p. 4). Near Indianola, Khin (1956 p. 18-19, 178-179) measured 4,927 feet of a succession of thin-bedded, red sandstone and siltstone interbedded with brick-red shale. Twin Creek Limestone consists of grey, thin-bedded limestone, greenish grey to grey silty shale, and greenish grey to grey calcareous sandstone 1,106 feet thick in Monk's Hollow (Baker, 1947) and estimated by the writer to be 1,570 feet thick at Thistle. In explanation of the difference in the rocks of these contemporaneous formations, the writer submits that Twin Creek Limestone at Thistle may represent part of the Charleston-Strawberry-Nebo allochton which has been thrust to a position near autochthonous Arapien Shale exposed near Indianola.

Twist Gulch Formation.—Originally the upper member of the Arapien Shale (Spieker, 1946, p. 123-125; and Gilliland, 1951, p. 10-15), Twist Gulch Formation is exposed in extensive outcrops near Smiths Reservoir. Here it is composed of thin- to medium-bedded red sandstone and laminated to thin-bedded, green to red siltstone and shale. Occasional grit layers are interbedded with the sandstone. The formation is in fault contact with Green River Formation (see Pl. 3, fig. 1), Tertiary volcanic sedimentary rocks, and Blackhawk (?) Formation. In the same area, Twist Gulch Formation is either in fault contact (as mapped by Khin, 1956, Pl. 1) or unconformable contact (as mapped by the writer, Pl. 5) with Price River Formation.

Although no definite fossil data have been published for the Twist Gulch Formation, available evidence indicates its age to be approximately Upper Jurassic (Imlay, 1967, chart p. 20).

Correlation of Twist Gulch Formation is generally accepted to be with Entrada, Curtis, and Summerville formations (Spieker, 1946, p. 124; Wright and Dickey, 1963; and Hardy, 1952, p. 27-28). There are, however, local differences in facies and thickness of these equivalent formations. In Monk's Hollow, just north of the study area, Baker (1947) measured 1,270 feet of Entrada Formation described as "essentially homogenous tan to brown, soft, silty sandstone which is, in general, thin and very evenly bedded" and Curtis and Summerville formations consisting of 510 feet of greenish grey sandy shale and sandstone with some chocolate brown mudstone. The aggregate thickness of the Entrada-Curtis-Summerville formations is 1,780 feet. Khin (1956, p.34) measured an incomplete section of 2,381 feet of Twist Gulch Formation (whose lithology is described above) near Smiths Reservoir and estimated the thickness of the formation of that area to be about 3,000 feet. The facies and thickness differences in the equivalent formations described above may be the result of either rapid facies changes in their environments of deposition or of Laramide thrusting. Entrada-Curtis-Summerville formations, representing allochthonous rocks, may have been thrust into closer proximity to autochthonous Twist Gulch Formation than when they were deposited.

Entrada-Curtis-Summerville Formations—Although the Entrada, Curtis, and Summerville formations are present just north of the study area in Monks Hollow (Wright and Dickey, 1963), no beds were positively identified as such in the Thistle Quadrangle, but they are probably present under Quaternary gravel. Their presence is assumed in normal stratigraphic position above Twin Creek Limestone and below Morrison Formation in the writer's geologic map and cross section A-A' (see Pl. 5).

Morrison Formation.—The Morrison Formation of the Wasatch Plateau is correlated with that of the San Rafael Swell and the type locality as suggested by Spieker (1946, p. 125; 1949b, p. 18), Bayley (1950), and others. Morrison Formation of the Wasatch Plateau, as indicated by the studies above, includes a Morrison-like sequence of sandstone, shale, and conglomerate in the Thistle Quadrangle along the north and south sides of U.S. Highway 50-6, two miles east of Thistle.

In the Salina Canyon area of the Wasatch Plateau, Morrison Formation intertongues with both the overlying Indianola Group, and the underlying Twist Gulch Formation. South of Smiths Reservoir, just outside the Thistle Quadrangle Khin (1956, p. 40) mapped Morrison Formation in gradational contact with underlying Twist Gulch Formation. The lower contact of Morrison Formation in the study area along U.S. Highway 50-6 is covered by Quaternary gravel. However, the writer's cross section A - A' (see Plate 5) suggests that Morrison Formation east of Thistle may be underlain by Curtis and Summerville formations mapped as Curtis Formation by Baker (1960) in Monks Hollow.

The upper contact of the Morrison Formation throughout most of the Colorado Plateau is disconformable with Dakota Sandstone. Near Thistle, Dakota Sandstone is either absent or meagerly represented; the upper Morrison Formation contact is not clear cut (Bayley, 1950, p. 13). The writer has drawn the upper contact of Morrison Formation at the top of a bed of poorly sorted conglomerate containing a mud matrix and pebbles up to two inches in diameter. This conglomerate gives way abruptly with no apparent unconformity to buff and brown marine sandstone and maroon and brown calcareous siltstone and shale of the Cretaceous Indianola Group. The Morrison-Indianola contact is best seen along the northeast side of Lake Fork, approximately one mile south of U.S. Highway 50-6.

Morrison Formation in the Thistle area is also overlain in angular unconformity by North Horn Formation. This unconformity is seen north and south of U.S. Highway 50-6 (see Plate 5).

Morrison Formation of the Thistle area consists primarily of buff, grey, and brown conglomerate and sandstone in the upper part which grade downward into finer variegated beds, sandstone, limestone, and conglomerate containing dense chert.

The U.S. Geological Survey considers the age of the Morrison Formation to be Late Jurassic (Keroher and others, 1966, p. 2595). Spieker (1949b, p. 19) believes the age of the Morrison Formation of the Wasatch Plateau to be partially Late Jurassic and partially Early Cretaceous. Spieker's age assignment is based wholly upon stratigraphic position and lithology, since no fossils have yet been reported from the Morrison Formation of central Utah. The writer collected many small dinosaur bone fragments from the Morrison Formation in a calcareous siltstone at a road cut along U.S. Highway 50-6 (see Plate 1, fig. 1). James Jensen (pers. comm., 1971) identified some of these fragments as rib bones. On the basis of these bone fragments, stratigraphic position, and lithology, the writer believes the strata near Thistle originally called Morrison (?) Formation by Spieker (1946, p. 125) to be definitely Morrison Formation.

Thickness of the Morrison Formation varies from about 300 feet at the type locality to a maximum of 1,300 feet near Craig, Colorado (Cobban, 1945, p. 1269). Because regional studies of the Morrison Formation do not indicate a thickening toward the Salina-Thistle area, the 1,300 feet of Morrison (?) Formation in Salina Canyon (Spieker, 1946, p. 125) and the 1,900 feet of Morrison Formation at Thistle (Bayley, 1950, p. 18) may indicate that either part of the Indianola Group or the Entrada Formation has been measured as Morrison (Hardy, 1962, p. 54; and Spieker, 1946, p. 125). The Morrison Formation of the western Wasatch Plateau area may be a clastic wedge that grades into marine Indianola Group further to the east.

Cretaceous System

Indianola Group.—Proposed by Spieker (1946, p. 126-129), the Indianola Group represents an undifferentiated rock sequence whose type section, just north of Indianola, consists of buff and grey continental, buff and grey marine, and red-bed continental deposits. According to Spieker, rapid facies changes render the Indianola Group not divisible into formations in the type area, in the area between Salina and Gunnison, in the Gunnison Plateau, and in the Cedar Hills. In the Manti area, Spieker divided the Indianola Group into four formations, which are, in ascending order, Sanpete Formation, Allen Valley Shale, Funk Valley Formation, and Sixmile Canyon Formation. Correlation of the formations of the Indianola Group is possible only on a limited basis in the Manti area (Hintze, pers comm., 1971). Therefore, the term *Indianola Group* is used in this paper for outcrops that may possibly belong to various formations within that group.

The basal Indianola Group contact in the type area near Hjorth Creek is conformable upon Arapien Shale (Khin, 1956, p. 20). In the southern Wasatch Mountains near Nephi, Indianola Group rests with angular unconformity on Arapien Shale. In Salina Canyon and the northern part of the study area, Indianola is conformably underlain by Morrison Formation. In the southern portion of the study area, the base of the Indianola Group is not exposed. The upper contact of the Indianola Group is a regional angular unconformity (Spieker, 1946, p. 126) caused by pre-Price River folding and erosion (Hintze, 1962, p. 71). In Dry Creek, in the southern portion of the Thistle Quadrangle, Price River Formation overlies Indianola Group in angular unconformity (see Pl. 1, fig. 2). In Dry Hollow and along Lake Fork, Indian-

EXPLANATION OF PLATE 1

FIG. 1—Roadcut of Morrison Formation from which dinosaur bone fragments were collected by the writer; northside of U.S. Highway 50-6, 1½ miles east of Thistle Junction.

FIG. 2.—Unconformity between conglomerate of the Price River Formation above and massive sandstone of Indianola Group below; Dry Creek Canyon area.

ola Group is overlain in angular unconformity in part by Price River Formation and in part by North Horn Formation (see Pl. 3, fig. 2).

Indianola strata crop out along Dry Creek, four and a half miles north of the town of Indianola. A small portion of these outcrops, part of Spieker's type Indianola Group (1946, p. 128-129), is within the Thistle Quadrangle. Here Khin (1956, p. 186-187) describes an incomplete section 2,987 feet thick composed of interbedded conglomerate, sandstone, siltstone, and some shale. Spieker (1946, p. 128) suggests that these strata correlate with Funk Valley Formation of the Manti area. Indianola strata which are exposed on both sides of Lake Fork and in Dry Hollow consist of an upper unit of clean, well-sorted, light-colored marine sandstone, 1,350 feet thick, underlain by interbedded fossiliferous sandstone, shale, and minor amounts of conglomerate which make the total thickness of the exposed strata 2,610 feet. Spieker (1946, p. 127) suggests that these strata correlate with Sanpete Formation of the Manti area.

The Indianola Group is Upper Cretaceous (Spieker, 1946, p. 130). Indianola strata of Dry Creek are definitely Niobraran, determined by bivalves *Corbula nematophora* found by Spieker and *Ostrea anomioides* found by the writer and identified by W. A. Cobban of the U.S. Geological Survey. Although much time and effort were spent searching for diagnostic fossils in Indianola strata along Lake Fork, the fossils which were found by the writer did not indicate a more specific age than Upper Cretaceous (see Appendix 2).

Spieker (1946, chart, p. 122) correlates Indianola strata of the Wasatch area with lower Mancos Shale of eastern Utah and western Colorado. Niobraran Indianola Group of the Dry Creek area probably correlates with the Middle Shale Member of the Mancos Shale. Since no definite age was determinable for Indianola strata which crop out along Lake Fork, their exact relationship to members of the Mancos Shale is uncertain; Spieker (1946, p. 127) suggests that Lake Fork Indianola strata correlate with the Lower Shale Member of the Mancos Shale.

Cretaceous Sandstone.—Buff, coarse- to medium-grained sandstone exposed south of Smiths Reservoir are in fault contact with Arapien Shale and Twist Gulch Formation. Khin, who found poorly preserved dicotyledonous leaves "indicative of Upper Cretaceous age" called the sandstone unit "South Flat Formation" (Khin, 1956, p. 63). The writer prefers "Blackhawk (?) Formation" because of similar lithology to that formation and close proximity to extensive outcrops of the unit south of Soldier Summit.

Price River Formation.—The Price River Formation was named by Spieker and Reeside (1925, p. 445-448) for strata in Price Canyon above Castlegate between the Blackhawk Formation and what is now called North Horn Formation. Here, the Price River Formation consists of about 1,100 feet of medium- to coarse-grained sandstone with some grit layers, conglomerate, and some shale. Castlegate Sandstone, originally the lower member of the Price River Formation, has since been raised to formation rank (Fisher and others, 1960, p. 11, 13). Beds equivalent to both the Price River and Castlegate formations are probably represented in the study area and are called "Price River Formation."

The basal contact of the Price River Formation at the type section is gradational with Castlegate Sandstone. Castlegate Sandstone is disconformably underlain by Blackhawk Formation. Where the base of the Price River Formation is observable in the southern portion of the Thistle Quadrangle, it is underlain in angular unconformity by Indianola strata. In the Smiths Reservoir area, the basal contact of the Price River Formation is not exposed; however, a Cretaceous sandstone unit similar to Blackhawk Formation, but called "South Flat Formation" by Khin (1956, p. 54), is in fault contact with, but elsewhere may underlie, the Price River Formation. The upper contact of the Price River Formation is nearly always gradational with the North Horn Formation and is arbitrarily placed at the top of the horizon of greatest change between sandstone and conglomerate of the Price River Formation and the variegated and other beds of the North Horn Formation, (see Text-fig. 3) (Spieker, 1946, p. 131). In the southern portion of the study area, in the Dry Creek and Lake Fork regions, the Price River-North Horn contact is arbitrarily selected as described above. However, at the base of the North Horn Formation in the vicinity of Dry Hollow near Thistle, there exists an angular unconformity between the two formations similar to the angular unconformity at Wales Gap described by Burma and Hardy (1953, p. 551-553) and in the Cedar Hills described by Hintze (1962, p. 71). The conglomerate of the Price River Formation of the Dry Hollow area is composed principally of sandstone clasts derived from the underlying Indianola strata, which contain some of the Upper Cretaceous bivalves of the Indianola Group.

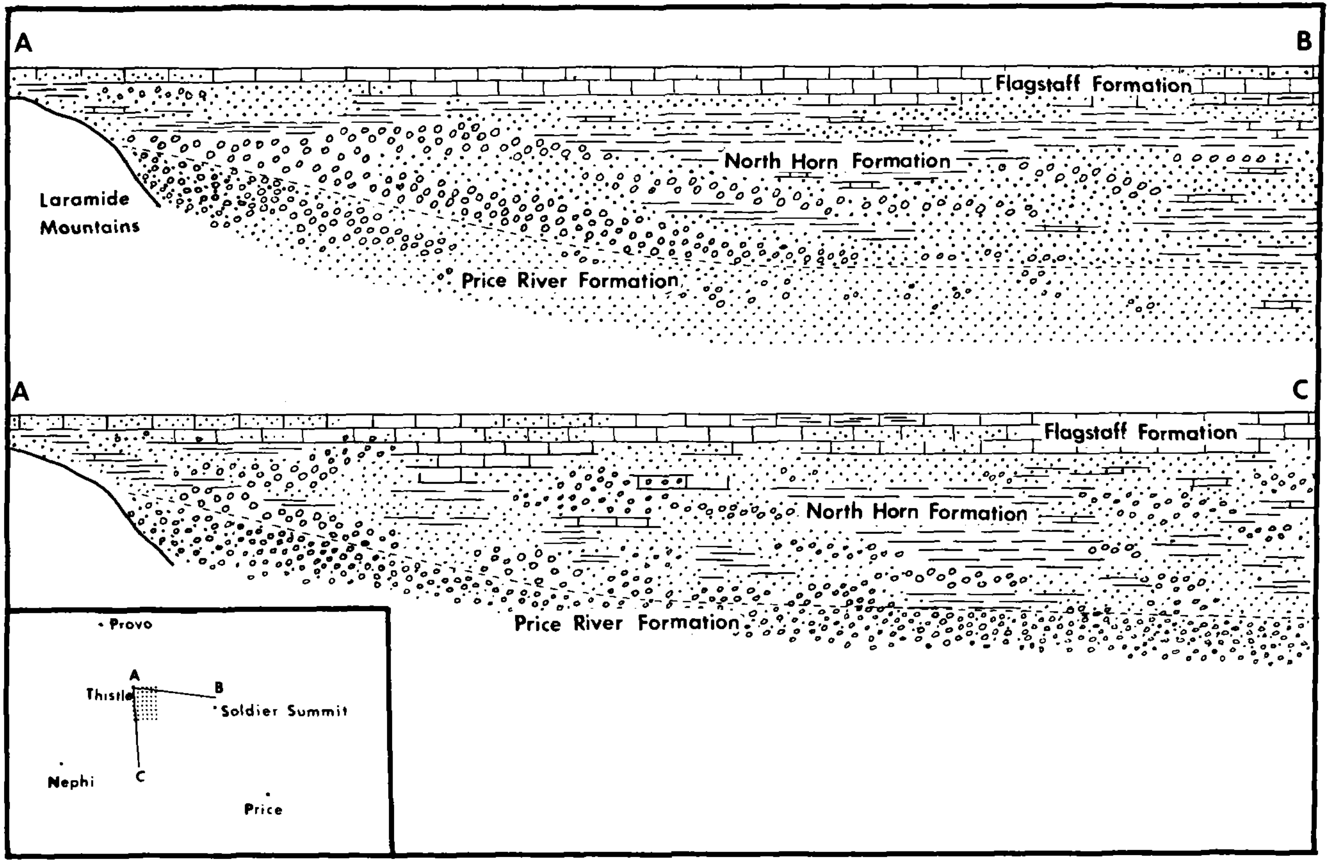
Price River Formation crops out in three areas in the Thistle Quadrangle: in Dry Hollow near Thistle, in Dry Creek in the southwestern portion of the study area, and at the headwaters of Lake Fork in the southeastern corner of the Thistle Quadrangle. In all three of these areas, the Price River Formation consists of medium-bedded to massive white to buff-colored conglomerate composed of clasts of sandstone and quartzite up to three feet in diameter. Minor lenses of buff, coarse-grained, thin-bedded sandstone are present.

Spieker reports the age of the Castlegate Formation as definitely Montanan and probably Late Montanan. No fossils have been found in the upper part of the Price River Formation (Spieker, 1946, p. 131). Although no fossils indigenous to the Prive River were collected within the study area, the writer assumes the age of the Price River Formation near Thistle to correlate with that of the eastern Wasatch Plateau given as Montanan (Upper Cretaceous). The U.S. Geological Survey gives the age of the Price River Formation as Upper Cretaceous (Keroher and others, 1966, p. 3134).

Thickness of the coarse-grained western facies of the Price River Formation is variable, since it represents the first sedimentary record of the Laramide Orogeny (Hintze, 1962, p. 71). Between Indianola and Thistle, Spieker (1946, p. 132) reports its composition to be between 1,000 and 2,000 feet of coarse conglomerate. The only complete section of Price River Formation in the Thistle Quadrangle is in Dry Creek,where it ranges from about 100 to 250 feet in thickness and is composed almost entirely of coarse conglomerate as described above. The thicker sections of Price River Formation in the study area are only partial sections.

Cretaceous-Tertiary Systems

North Horn Formation.—Spieker proposed North Horn Formation for outcrops on North Horn Mountain along the eastern margin of the Wasatch Plateau, where the formation consists of red, grey, and black shale, buff and



TEXT-FIGURE 3.— Schematic interrelations of Price River, North Horn, and Flagstaff formations of the northwestern Wasatch Plateau.

cream sandstone, conglomerate, and freshwater limestone (Spieker, 1946, p. 132-133).

North Horn Formation of the type locality is conformably overlain by Flagstaff Limestone and conformably underlain by sandstone of the Price River Formation. Regionally, the lower gradational contact is placed at the horizon of greatest change between the sandstone and conglomerate of the Price River Formation and the variegated and other beds of the North Horn Formation (Spieker, 1946, p. 131). Lee (1953, p. 164), who made a detailed study of the petrography of the North Horn and Price River formations, differentiates conglomerates of the two formations by a great abundance of limestone clasts to less frequent limestone clasts and a medium- to coarse-grained, brown to and light grey, fine-grained matrix of the North Horn Formation as opposed buff matrix found in the conglomerates of the Price River Formation. This differentiation was useful in distinguishing the two formations in the study area. Local angular unconformity exists between the North Horn and Price River formations at Wales Gap (Burma and Hardy, 1953, p. 551-553) and in the Cedar Hills (Hintze, 1962, p. 71). The significance of this unconformity is not fully understood, but according to Hintze (1962, p. 71), air photos demonstrate a striking discord between the two units in the Cedar Hills area. The writer shows a similar angular unconformity between the North Horn and Price River formations (geologic map and cross sections, Pl. 5; see also Text.-fig. 3). This relationship is seen only in the northwestern portions of the study area, where Price River and other formations are overlain unconformably by the North Horn Formation. Where the North Horn-Price River contact is seen in the southern portion of the Thistle Quadrangle, the contact is gradational.

The upper contact of the North Horn Formation is strikingly angular with Flagstaff Limestone in the southeastern portion of the Thistle Quadrangle (see Pl. 2, fig. 2). Although the extent of this angular unconformity is not known, it is similar to an unconformity between the same formations near Manti described by Spieker (1946, p. 133, 136-137, 155). Elsewhere, rapid facies changes in the North Horn Formation make its differentiation from Flagstaff Formation difficult, especially locally where the formations are represented by the same facies. The writer attempted to draw the upper contact of the North Horn Formation at the top of the clastic unit of shale, siltstone, or sandstone (usually red) which is, in turn, overlain by widespread lacustrine facies of the Flagstaff Formation. This differentiation is easily made in the northern part of the study area; however, south of U.S. Highway 50-6 this differentiation becomes increasingly more difficult because the lithology of the North Horn Formation becomes increasingly more lacustrine. This dominantly lacustrine phase of the North Horn Formation appears to have been situated near the ancient mountain front but was not extensive. Fluvial conditions again become the dominant environment of deposition south of the Thistle Quadrangle in the Indianola area and in the Mill Fork Quadrangle east of Thistle. The writer believes that in the Thistle area, algal limestone and other lacustrine deposits of the North Horn Formation represent lacustrine environments of deposition produced during the coalescence of major alluvial fans. This lacustrine environment of deposition may also have been accentuated by a tectonic fold a few miles basinward from the ancient mountain front. This fold was later partially eroded and is now represented by a local angular unconformity between the North Horn and Flagstaff formations. The lacustrine conditions which were present during North Horn time near Thistle were incorporated into the much larger Lake Flagstaff.

Because of numerous subenvironments of deposition, many lithologic types are represented within the North Horn Formations of the Thistle area (see Pl. 2, fig. 2). Clastic rocks range from shale to conglomerate and from red to light grey. Carbonate rocks are also locally abundant and consist primarily of red, grey, and brown algal limestone. (Weiss [1969] explains in some detail the depositional environments of the North Horn and Flagstaff formations). In the Red Narrows area, the North Horn Formation consists primarily of piedmont conglomerates which are dominantly red. Merrill (1972 p. 65-68 this volume) described detailed relationships of the North Horn Formation in this area. In the central portion of the Thistle Quadrangle, the piedmont facies of the Red Narrows area changes to a grey and brown, thin- to thick-bedded algal limestone interbedded with medium- to coarse grained sandstone with some siltstone, shale, and conglomerate lenses. This lacustrine facies changes to a piedmont-valley flat facies in the southern portion of the study area.

Facies changes are extremely rapid in the area of the Thistle Quadrangle because of the close proximity of the mountain highland source area of the North Horn Formation. This close proximity is shown by the thickness variations of the formation. Near Thistle, North Horn Formation thickens southeastward from a pinch-out on the remnant topographic high of the Laramide Mountains to a thickness of 3,684 feet near Indianola (Mase, 1957, p. 88-91). A few miles east of Thistle, Merrill (1972, this volume, p. 65-88) reports nearly 3,000 feet at Red Narrows and at least 2,500 feet of North Horn Formation in the southern part of the Mill Fork area. The writer measured a complete section of North Horn Formation two miles east-southeast of Thistle consisting of 432 feet of interbedded red sandstone and shale and some grey conglomerate.

Dinosauran remains distinctive of Late Cretaceous found in lower North Horn and freshwater mollusks of Tertiary age found in the upper part of the type locality of the North Horn Formation indicate the Cretaceous-Paleocene boundary to be present within the formation. There is no indication of a break in sedimentation at the type locality (Spieker, 1946, p. 134-135). North Horn Formation of the Thistle area is considered to be in part of Cretaceous and in part of Paleocene age, even though no indicative fossils were found by the writer.

North Horn Formation of the Wasatch Plateau probably correlates at least in part with the Lance and Fort Union formations of the northern plains and with the Ojo Alamo, Puerco, and Torrejon formations of the San Juan Basin (Spieker, 1946, p. 135).

The validity of calling the conglomerate at Red Narrows "Price River Formation," as suggested by Spieker (1946, p. 131), has been questioned by many geologists. Merrill, elsewhere in this volume, discusses the problem at some length and concludes that the conglomerate at Red Narrows represents a piedmont phase of the North Horn Formation. Relationships between Price River and North Horn formations in the northwestern portion of the Thistle Quadrangle support Merrill's hypothesis

Tertiary System

Flagstaff Limestone.—The term *Flagstaff* was first used by E. M. Spieker and J. B. Reeside, Jr. (1925, p. 435), for the middle member of the Wasatch

EXPLANATION OF PLATE 2

FIG. 1.—Channel of conglomerate in bedded sandstone and siltstone, North Horn Formation; four miles east of Thistle Junction, north side of U.S. Highway 50-6.

FIG. 2.—Angular unconformity between sandstones of the Flagstaff Formation and siltstone and conglomerate of the North Horn Formation; east wall of Lake Fork Canyon near Spring Hollow.

Formation of the Wasatch Plateau, with its type section on the slopes of Flagstaff Peak located on the east central margin of the Wasatch Plateau in Sanpete County, Utah. The Flagstaff Member was later raised by Spieker (1946, p. 135) to formation rank because it is one of the major stratigraphic units of the region in thickness and extent. The Flagstaff consists of dominantly freshwater limestone of many varieties interbedded with some grey shale and grey to buff sandstone, gypsum, oil shale, and volcanic ash (Spieker, 1946, p. 136).

The lower boundary of the Flagstaff Limestone is gradational with the underlying North Horn Formation (see Text-fig. 3) except locally where an unconformity separates the Flagstaff Limestone from North Horn and other older formations (Spieker, 1946, p. 137). Spieker describes the pre-Flagstaff unconformity as being widely present in the western border belt of the Wasatch Plateau and adjacent valleys between Manti and Salina (Spieker, 1946, p. 136). This unconformity was also described by Spieker as being with Arapien Shale and exposed just east of Indianola (Spieker, 1946, p. 136); but in mapping the area, R. E. Mase (1957, p. 14) was unable to locate these outcrops. The pre-Flagstaff unconformity may have resulted, in part, from erosional highs of the Laramide Orogeny which were covered by the Flagstaff Lake and subsequently received Flagstaff sediments (Spieker, 1946, p. 137). Spieker, however, believes most of the pre-Flagstaff unconformity to have resulted from post-North Horn and pre-Flagstaff folding. Spieker's primary evidence for this folding is the angular discordance between the Flagstaff and North Horn formations exposed in Sixmile Canyon just south of Manti (Spieker, 1946, p. 133, 136, 155). This type of angular unconformity is present between the same formations in the Thistle Quadrangle about two miles north-northeast of Smiths Reservoir (see Plate 2, fig. 2). Where the gradational contact exists between the Flagstaff and North Horn formations, there is evidence of intertonguing, which frequently makes the contact difficult to define. West and southwest of Sky High in the eastern portion of the study area, directly north of Smiths Reservoir, and north of Blind Canyon in the western portion of the study area are exposures of the North Horn and Flagstaff formations where contact is difficult to determine because one formation grades into the other. Algal limestones, present in both upper North Horn and lower Flagstaff formations in these areas, (except just north of Smiths Reservoir), grade into one another. The writer attempted to place the base of the Flagstaff Limestone at the base of the lowest widespread lacustrine limestone, which is, in turn, underlain by clastic beds, shales (usually red), siltstone, or sandstones. Because of extremely rapid change in the lithofacies of the North Horn Formation, the contact of the Flagstaff and North Horn formations was determined for one area and then followed laterally into areas where the contact was questionable (see Text-fig. 3).

The upper contact of the Flagstaff is conformable with the Colton Formation between Salina and Mount Pleasant and locally in the Gunnison Plateau. In the western and northwestern sections of the Wasatch Plateau, LaRocque (1960, p. 8) and Spieker (1946, p. 136, 139) say that the Colton intertongues with the Flagstaff and Green River formations, so that in the area of Thistle there are no Colton strata immediately overlying the Flagstaff Formation. Metter (1955, p. 138), on the other hand, identified Colton in the Birdseye area west of Thistle. Wherever the top of the Flagstaff Formation is exposed in the study area, Green River strata are present. The contact between the Green River and Flagstaff formations is discussed in the section on Green River stratigraphy.

Exposures of Flagstaff Limestone in the Thistle Quadrangle show rapid facies changes typical of Cretaceous and Tertiary rocks of the Wasatch Plateau. Flagstaff Limestone along the upthrown block of the Martin Mountain fault in the eastern portion of the study area changes from a grey, very thick-bedded to massive sequence of predominantly algal limestone and thin-bedded sandstone and shale in the Sky High area to sandstone and sandy limestone in the area of Spring Hollow, north-northeast of Smiths Reservoir. This sandy limestone and calcareous sandstone sequence in the Spring Hollow area is usually buff and white, very thin- to medium-bedded, and contain some *Viviparus*. The strata form cliffs and ledgy slopes on the south-facing canyon walls and covered slopes on the north-facing canyon walls. North and west of Smiths Reservoir, calcareous sandstones like those described above, only with more shades of buff and other brown tones, are the dominant lithofacies of the Flagstaff Formation, and *Goniabasis tenera* becomes very abundant near the top of the formation.

Flagstaff Formation in the western portions of the study area near Barney Hollow consists of basal conglomerate in the northern outcrops which changes laterally southward into thin-bedded, grey to white algal limestone. The rest of the Flagstaff Formation consists of algal and microcrystalline limestone interbedded with calcareous shale; all rocks are grey and white. The uppermost unit on the unnamed peak (elevation 8,445 feet) near Barney Hollow is a buff calcareous sandstone which contains abundant fossil roots of some unknown plant.

Exposures of Flagstaff Formation in the northwestern part of the Thistle Quadrangle in the area of Wildcat Canyon consist mostly of buff, grey, and tan, thin- to medium-bedded algal limestone and interbedded sandstone. Near the top of the exposed part of the formation are thick units of dark brown, grey, and brownish grey ostracodal limestone. Abundant tar is present in some of the limestone and seems to be related to small, normal faults of tens of feet of displacement. Near the base of the Flagstaff are extensive deposits of tar, which were mined some years ago for road fill. Tar is still seeping from the sandstones in the mine tunnels where tar stalactites and stalagmites are continuously enlarging. Tar has penetrated some of the algal limestones, seeping through small, tar-lined pores up to one-quarter inch in diameter. Approximately two-thirds of the way up the north fork of Wildcat Creek are exposures of these asphaltic limestones and sandstones. At this locality, tar may be seen on the outcrop in drips up to one inch wide and two feet long.

Exposures of Flagstaff Formation north of U.S. Highway 50-6, which are partially shown in the map of the Thistle Quadrangle of this report, show interesting lithofacies variation from west to east. Over a distance of about three and one half miles, the Flagstaff Formation thickens from a few hundred feet near Thistle to nearly 600 feet north of Chicken Hollow. Near Thistle, the Flagstaff Formation consists of interbedded calcareous sandstone and limestone. The rocks become more calcareous eastward to where the section is nearly 100 percent grey, algal, ostracodal, and microcrystalline limestone near Chicken Hollow. Abundant asphalt material present in the sandstone near Thistle gradually thins to meager tar shows in ostracodal limestones near the top of the Flagstaff in the Chicken Hollow area.

Flagstaff Formation which crops out just southeast of the junction of Lake Fork and Soldier Creek is composed of buff to white, thin- to medium-bedded sandy limestone and grey algal limestone. Exposures facing Lake Fork are highly fractured by a series of six or eight minor faults. The fracturing seems to be recent, as evidenced by asphaltic material present only in a very few of the major joints; fractures frequently cut tar-filled joints with no evidence of tar having entered these younger features.

Fossils contained in the Flagstaff Formation are not diagnostic as to exact age. The age of the Flagstaff Formation is considered to be Late Paleocene and early Eocene (?) by the U.S. Geological Survey (Keroher and others, 1966, p. 1362). LaRocque, (1960, p. 73-74) divided the Flagstaff Formation of the Sanpete Valley area into three zones on the basis of molluscan fauna: Zone 1 contained fauna of Paleocene age; Zone 3 contained fauna indicating possibly Eocene age. LaRocque identified fossils from the Flagstaff Formation just west of Thistle for Metter (1955, p. 137) as representing the upper part of Zone 3 of the Sanpete Valley area. Flagstaff Formation of the Thistle Quadrangle is therefore more probably Eocene than Paleocene in age.

The Flagstaff Formation was deposited over approximately 7,000 square miles and probably correlates with the lacustrine carbonate rocks exposed in the Bryce Canyon area (Schneider, 1964, p. 131-132). Schoff mentions the Puerco and Torrejon formations of the San Juan Basin, the Ferris Formation of central Wyoming, and part of the Fort Union Formation of Wyoming and Montana as probable correlatives with the Flagstaff Formation of central Utah (Schoff, 1951, p. 632).

The thickness of the Flagstaff Formation, according to Spieker (1946, p. 135-136), ranges from 300 to 1,500 feet, with a general thickening southward and westward. Locally, Baker (1947) describes the Flagstaff Formation as thickening from a wedge-out a few miles north of Hobble Creek to about 60 feet near the mouth of Diamond Fork Canyon. Neighbor (1959, p. 181) reported 235 feet of Flagstaff Formation in the area of the Diamond Fork Anticline. Metter (1955, p. 135-137) measured 350 feet a few miles west of the Thistle Quadrangle. South of the study area, Khin measured 537 feet of buff and grey limestones of the Flagstaff Formation (Khin, 1956, p. 196-197). East of the Thistle Quadrangle, Merrill measured a partial section of 641 feet of Flagstaff Formation in Beaver Dam Canyon. A comparison of these thicknesses to the 563 feet measured by the writer about two and one-half miles east of Thistle indicates that the Flagstaff Formation of the Thistle area represents a nearly westernmost lacustrine part of the formation. Abundant conglomerate and sandstone in some of the measured sections and a usual abundance of algal concretions of Flagstaff Formation of the northwestern Wasatch Plateau indicate a near-shore, near-source, shallow-water environment of deposition.

Colton Formation.—Colton Formation, originally designated the uppermost member of the Wasatch Formation, was raised to formation rank by Spieker (1946, p. 139). The Colton Formation was not positively identified in the Thistle Quadrangle. Metter (1955, p. 138) identified strata above Flagstaff Formation as Colton Formation just east of Thistle, but according to Spieker (1946, p. 136, 139) and LaRocque (1960, p. 8), no variegated beds resembling Colton Formation directly overlie the Flagstaff Formation in the Thistle district.

Beds of probable fluvial origin which may be partly equivalent to the Colton Formation were mapped north-northeast of Smiths Reservoir as an angular unconformity with underlying North Horn Formation.

Green River Formation.—The Green River Formation is a well-known fluvial-lacustrine rock sequence named by Hayden (1869, p. 90) for exposures along the Green River west of Rock Springs, Sweetwater County, Wyoming. In the type locality and Uinta Basin area, the Green River Formation is unconformably overlain by the Bridger Formation (Bradley, 1931, p. 38). Along the western flank of the Wasatch Plateau in central and southern Sanpete County, the Green River Formation is disconformably overlain by the Crazy Hollow Formation (Spieker, 1949b, p. 36-37). In the southern part of the study area the Green River Formation is overlain by pyroclastic rocks which were probably deposited as valley fill by streams. Because of slumping and extremely dense vegetative cover, the contact between the units is not exposed.

Until Spieker (1946, p. 135-139) revised the stratigraphic nomenclature of Tertiary rocks of central Utah, the Green River Formation was underlain by rocks included in the Wasatch Formation. Spieker (1946, p. 135-139) described the Colton Formation from the eastern Wasatch Plateau and the Flagstaff Limestone from the western Wasatch Plateau as the underlying formations, using the name "Colton Formation" to include the underlying red-bed units. In the study area, however, the Colton Formation is absent, and the Green River Formation is conformably underlain by the Flagstaff Limestone. The writer places the base of the Green River Formation at the base of a coquinoid limestone containing abundant *Goniabasis* sp. Baer (1969, p. 11) describes this basal limestone just east of Red Narrows as ranging in thickness from two to ten feet, and as grading laterally into lenticular channel sandstone.

Extensive exposures in the study area are along the downthrown block of a normal fault along the east flank of the Thistle Quadrangle and east, north, and southwest of Smiths Reservoir (which Khin mapped as North Horn Formation, 1956, Pl. 1). Near the reservoir, a basal grey limestone is overlain by thin-bedded limestone interbedded with laminated shale, which grades upward into greenish grey laminated shale with infrequent interbedded grey to white medium-bedded limestone. Although there are some good exposures along Martin Mountain Fault, outcrops around Smiths Reservoir are patchy because of heavy vegetation and intermittent slumping.

The age of the Green River Formation is Early to Middle Eocene (Bradley, 1931, p. 9). However, LaRocque (1955, p. 141) suggests that the entire Eocene may be represented.

Thickness of the Green River Formation varies greatly, from at least 5,000 feet in Indian Canyon to a feather edge on the southwestern margin of Uinta Basin between the headwaters of Hobble Creek and the headwaters of the Strawberry River (Baker, 1947). Locally, a total of 365 feet of grey to greenish grey shale, grey sandstone, and sandy, grey limestone are exposed in the area of the Diamond Fork structure (Neighbor, 1959, p. 181). Khin (1965, p. 198-200) measured near Indianola, an incomplete section 665 feet thick of sandstone and limestone like those described above, interbedded with some conglomerate. Another incomplete section, measured by Merrill (1972, this volume p. 65-88) in Beaver Dam Canyon of the Mill Fork area, totaled 1,767 feet. Because of poor exposures, no section of Green River Formation was measured in the study area, but the writer estimates a thickness of approximately 1,800 feet in the Smiths Reservoir area.

Tertiary Volcanic-Sedimentary Rocks.—Stream-deposited volcanic debris representing the youngest consolidated rocks of the Thistle Quadrangle overlie

Green River Formation in the vicinity of Smiths Reservoir in the southeastern portion of the study area. Probably equivalent rocks of the Cedar Hills, Long Ridge, and other areas have been given various formational names (Black, 1965, p. 72); but because of poor exposure and no means of correlating these formations with rocks of the study area, the term *Tertiary volcanic-sedimentary rocks* will be used in this paper.

The basal contact of the Tertiary volcanic-sedimentary rocks described above seems to be unconformable wherever exposed, including the Cedar Hills (Schoff, 1951, p. 635), west of the study area near Birdseye (Metter, 1955, p. 148), south of the study area in the Indianola district where Khin (1956, p. 102) described an angular unconformity between Tertiary volcanic-sedimentary rocks and North Horn Formation. The northernmost outcrops of volcanic-sedimentary rocks mapped by Khin were also mapped by the writer. Khin mapped the basal contact of Tertiary volcanic-sedimentary rocks as unconformable, with underlying North Horn Formation in the Thistle Quadrangle (Khin, 1956, Plate 1), while the writer has mapped Green River Formation in unconformable (?) contact with Tertiary volcanic-sedimentary rocks in the same area. There is no upper contact of Tertiary sedimentary volcanic rocks with other formations because the volcanic-sedimentary material of the study area represents the youngest consolidated rocks.

Tertiary volcanic-sedimentary rocks in the sandy area, adjacent to Smiths Reservoir, are in unconformable (?) contact with Green River strata to the northwest, north, and northeast and in fault contact with Twist Gulch Formation to the southeast. Good exposures of consolidated volcanic-sediments are found only on the highest peaks surrounding the reservoir. Contact of Tertiary volcanic-sedimentary rocks with Green River strata was nowhere observed by the writer because of luxuriant plant growth caused by spring water which seems to be directly related to faults in the area.

Khin (1956, p. 96-102, 201-214) includes detailed megascopic and microscopic descriptions of 13 samples of clasts of the basaltic conglomerate from the Tertiary volcanic-sedimentary rocks of the Indianola district. Baker (1947) describes water-laid volcanic rocks of the Diamond Fork area which are the same as in the study area:

> The volcanics consist of light-grey, medium- to coarse-grained, fairly well bedded tuff with scattered pebble and irregular pockets and lenses of conglomerate with pebbles and boulders from a fraction of an inch to two feet or more in diameter. The boulders are mostly rounded to subrounded and consist of sandstone, quartzite, limestone, grey angular pumice, and black to red vesicular igneous rock.

Age estimation of the volcanic-sedimentary rocks of the central Utah area varies from Oligocene (Baker, 1947) to Eocene (Muessig, 1951, p. 97-99). The writer found neither fossils nor other evidence in the Tertiary volcanic-sedimentary rocks of the Thistle Quadrangle to indicate their age to be other than post-Eocene Green River Formation.

Although correlation of Wasatch Plateau-Cedar Hills volcanic-sedimentary deposits is highly speculative, Baker (1947) and Schoff (1951, p. 635) suggest an equivalence to those north of Heber and to those along the Weber River where Oligocene vertebrate remains have been identified. Schoff also suggested a correlation of Wasatch Plateau volcanic rocks with the volcanic rocks in widely separated areas of the High Plateaus to the south, the Oquirrh Mountains to the northwest, and the Strawberry Valley area to the northeast.

Inasmuch as the Tertiary sedimentary rocks of the Wasatch Plateau area were deposited on an ancient erosional surface, their thickness should vary from place to place. The volcanic-sedimentary rocks in the southern part of the study area appear to fill a Tertiary stream valley which was cut into Green River Formation. This ancient stream valley is in approximately the same position but just north of Little Clear Creek and the headwaters of Lake Fork. The writer estimates the Tertiary volcanic-sedimentary rock unit to range from approximately 150 to 400 feet in thickness near Smiths Reservoir.

Quaternary Deposits

Terrace gravel, landslide debris, recent alluvial fans, and stream alluvium comprise the Quaternary deposits mapped in the quadrangle. Terrace gravel present along Lake Fork and Dry Creek document a period of stability in streams of the region attributed by Merrill (this volume) to Lake Bonneville. These high gravel terraces may, on the other hand, indicate periods of stream equilibrium interrupted by rejuvenation of streams resulting from faulting along the Wasatch Front.

Landslide debris mapped by the writer east of Smiths Reservoir is in an area where gravity movements intermittently produce scars in the Green River Formation. Although chaotic debris of all sizes is present in the slide area, the movement took place a sufficient length of time ago that the initial scar and much of the typical debris slump shape are hidden by vegetation and more recent geologic processes.

Recent alluvial fans and recent stream deposits represent a cycle of erosion recently instigated, most probably, by both a change in climate of the central Utah area and a change in stream gradient caused by recent uplift of the Wasatch Mountains.

STRUCTURAL GEOLOGY

General Statement

The structure of the area can be described as consisting of steeply dipping beds, unconformities, and related complex structure typical of the Rocky Mountains, and gently folded, nearly flat strata like the Wasatch Plateau, modified by high-angle normal faults characteristic of Basin and Range geology. The most prominent physiographic province represented in the Thistle Quadrangle, the Wasatch Plateau, has basically a monoclinal structure with a westward regional dip, which is gentle on the east and steepens toward the west. Superimposed on the basic structure are numerous broad folds which are, in turn, modified by north-trending fault zones with displacements of thousands of feet in some cases. The regional westward dip of the Wasatch Plateau is related to the origin of the San Rafael Swell. The greatest folding of the plateau has been post-Cretaceous. The complex zones of faulting are post-folding tensional features which cut all surface features, including Pleistocene deposits (Stokes, 1956,p. 790).

Cedar Hills Orogeny

Abundant conglomerates and thick sandstone of the Upper Cretaceous Indianola Group exposed in the Dry Creek of the study area represent an abrupt change in sedimentation from the underlying Jurassic shales and siltstones. Thick orogenic deposits of the same group in the Cedar Hills and Gunnison Plateau area represent an Early or Mid-Cretaceous Cedar Hills Orogeny (Eardley, 1951, p. 274; and Hintze, 1962, p. 70).

Laramide Deformations

Pre-Price River and Pre-North Horn Unconformities.—In the southern and northern portions of the study area, the Price River Formation overlies the Indianola Group in angular unconformity. This unconformity represents the first evidence of major Laramide tectonism in the mapped area. The pre-Price River unconformity is expressed throughout the southern Wasatch Mountains, on the western margin of the Wasatch Plateau and related areas. To the east the unconformity is represented by a disconformity between Blackhawk Formation and the overlying Castle Gate Sandstone as exposed in Price River Canyon (Spieker, 1946, p. 132).

A later regional Cretaceous unconformity is present immediately beneath the North Horn Formation. It is exposed south of Wales Gap (Burma and Hardy, 1953, p. 551-552), at the head of Hop Creek in the Cedar Hills (Hintze, 1962, p. 71), and along Dry Hollow in the northern portion of the mapped area. Burma and Hardy (1953, p. 552) relate this unconformity to pre-North Horn post-Price River thrusting of probably greater than two miles magnitude. The thick, coarse clastics of the Red Narrows facies of the North Horn Formation may very well be the result of thrusting as suggested by Walton (1959, p. 151). Neither Price River nor North Horn formations in the southern part of the mapped area show the unconformable relationship present in Dry Hollow, near Thistle.

The Thistle area of Spanish Fork Canyon is an excellent location to study the major Laramide unconformable surface. Resistant formations such as the Nugget Sandstone, lower Twin Creek Limestone, some conglomerates of the Morrison Formation, and sandstone of the Indianola Group must have formed hogbacks along the Cretaceous Laramide Mountain Front. These landforms were covered by early Cenozoic sediments and are now being exhumed by present geologic processes. Nonresistant rock units—including upper Twin Creek Limestone, Entrada-Curtis-Summerville formations, and shaly units in the Morrison Formation and Indianola Group—represent valleys within the Laramide Mountains. These low areas became filled with Cenozoic clastics of North Horn and younger formations to such an extent that the nonresistant pre-North Horn strata are still buried in this area.

Laramide Folding.—Indianola Group and older formations in the Thistle area comprise the easternmost limb of a broad Laramide anticlinal fold. These strata dip more steeply eastward, culminating in nearly vertical beds of Indianola Group in Lake Fork Canyon and Dry Hollow (see Pl. 3, fig. 2). This fold is similar to the upper part of the Provo Rock Canyon Anticline, described by Baker (1950, p. 154). Baker also believes that the Charleston thrust may underlie the Provo Rock Canyon structure. The Laramide fold east of Thistle has been modified by Cenozoic folding, as is described later.

Laramide Normal Faults.— Hintze (1962, p. 73) suggests that many of the east-west trending faults in the vicinity of the east face of the Wasatch Mountains are probably related to Laramide tectonics and occurred definitely

EXPLANATION OF PLATE 3

FIG. 1.—Fault contact of shale and limestone of Eocene Green River Formation on the left and red shales of Jurassic Twist Gulch Formation on the right; one half mile northeast of Smiths Reservoir.

FIG. 2.—Angular unconformity between Indianola Group below and North Horn Formation which is overlain by Flagstaff Formation; east side of Lake Fork, 1½ miles southeast of Thistle Junction.

before Cenozoic faulting. The east-west trending fault in the Morrison Formation near Thistle apparently does not cut post-Laramide Formations and probably is the result of Laramide tectonics, as described above. The thin veneer of Quaternary gravel makes examination of the fault surface impossible. Local discordance in attitude of beds of the Morrison Formation caused by this faulting is shown on the geologic map that accompanies this report.

Laramide Thrust Faults.—Although no exposures of Laramide thrust faults are present within the mapped quadrangle, unique stratigraphic and structural relations of the Thistle area indicate major thrusting. The leading edge of a major Laramide thrust, the Charleston-Strawberry-Nebo Fault, is likely present in the subsurface. Stratigraphic evidence is listed in stratigraphic sequence, beginning with the oldest formation (see also, Pl. 4).

1. Autochthonous Paleozoic formations in the Wasatch Mountains show substantial differences in thickness and lithology from allochthonous Paleozoic formations (Crittenden, 1961, p. 75-89), although these stratigraphic units are not exposed in the Thistle Quadrangle.
2. Arapien Shale exposed north of Indianola differs notably from equivalent, Twin Creek Limestone, at Thistle. Near Indianola, Arapien is composed of approximately 5,000 feet of mostly red siltstone (Khin, 1956, p. 178-179), compared with less than 1,600 feet of grey and green limestone, siltstone, and shale of the Twin Creek Limestone at Thistle and 1,106 feet of the same formation measured by Baker (1947) in Monks Hollow.
3. An incomplete section of Twist Gulch Formation measured near Smiths Reservoir consists of 2,381 feet of mostly brick red and some chocolate brown sandstone and shale. Khin (1956, p. 34), who measured the section, estimates that a complete section would be at least 3,000 feet thick. Equivalent allochthonous strata, Entrada-Curtis-Summerville Formations, have an aggregate thickness of 1,780 feet in Monks Hollow (Baker, 1947). Here the Entrada is 1270 feet thick and is composed of tan to brown, soft, silty sandstone. (Curtis-Sommerville Formation consists of 510 feet of greenish grey, sandy shale and sandstone, and chocolate brown mudstone interbedded with grey sandstone and greenish grey shale.
4. Indianola Group near Thistle is lithologically different from Indianola Group exposed along Dry Creek, north of Indianola (see columnar sections 3 and 5 in Pl. 4). Different suites of fossils were collected from the two different localities, but only one suite contained diagnostic fossils (see Appendix 2). Spieker (1946, p. 130) believes that the two sections cannot be correlated. The differences in litho- and biofacies may be explained by thrust displacement.
5. Khin's "South Flat Formation" which crops out southwest of Smiths Reservoir has a lithology different from the type section (Hunt, 1954, p. 123; and Khin, 1956, p. 63) and is more like the Blackhawk Formation which crops out extensively south of Schofield Reservoir and along the Book Cliffs. If this sandstone unit is Blackhawk Formation, it represents the westernmost outcrop of this formation which is exposed only on the autochthon of the Laramide thrust belt. Structural ele-

ments indicating vigorous tectonic activity are described by Walton (1959, p. 150-151), who believes that the Thistle Dome-Indianola Anticline lineation represents the eastern edge of pre-Tertiary thrusting along which later movement arched Tertiary strata. These elements indicating vigorous tectonic activity are described above with Laramide folding.

Amount of Crustal Shortening Represented by Folds and Faults.—Various estimates of Laramide crustal shortening have been submitted by various geologists. Eardley (1933, p. 385) supposed the displacement to be approximately 12 miles. Hintze (1962, p. 75) suggests the possibility that thrust displacement may be as much as 75 miles in places.

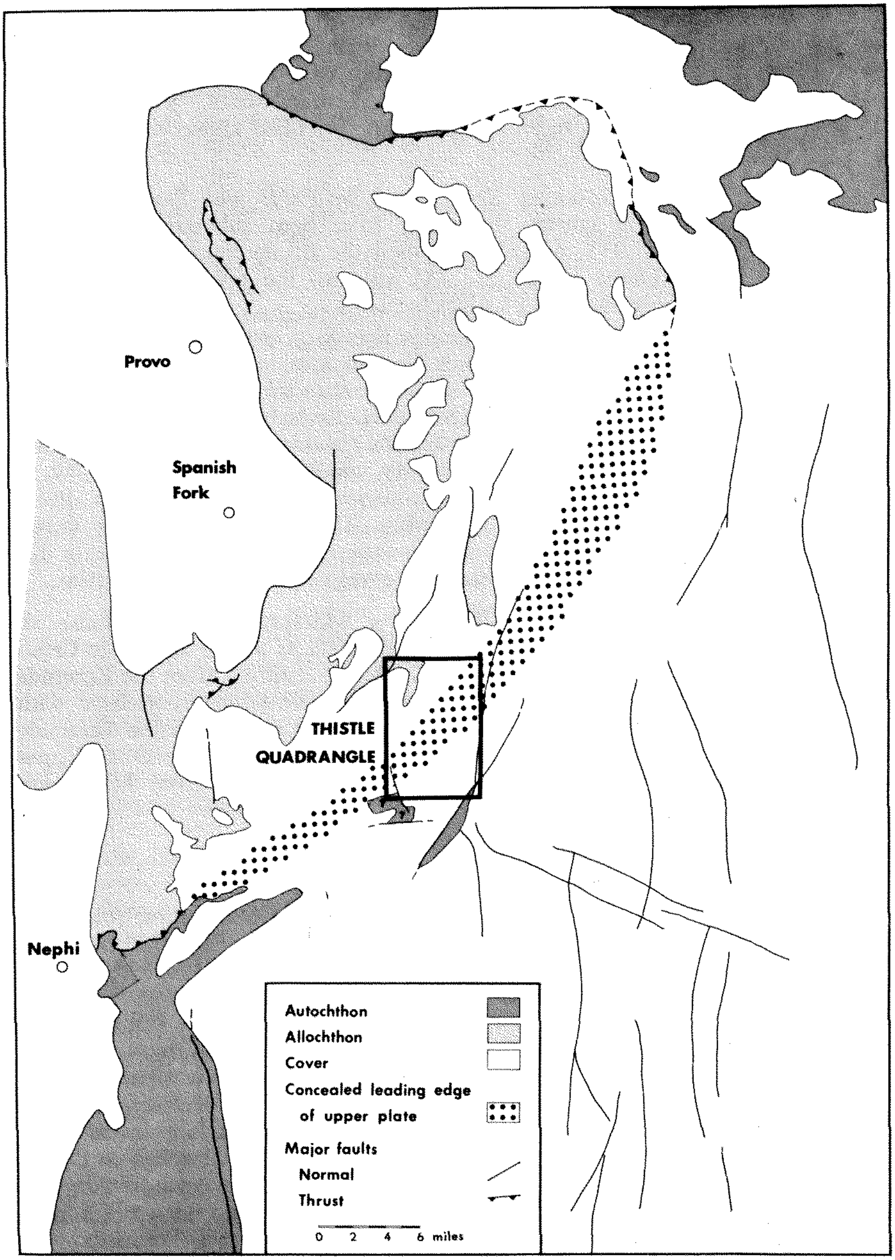
To conclude the discussion of Laramide thrusting: evidence in the Southern Wasatch Mountains—northern Wasatch Plateau area indicates (1) that Laramide thrusting in excess of 10 miles has occurred in the central Utah area, and (2) the leading edge of the Charleston-Strawberry-Nebo Thrust is present but hidden beneath post-thrusting cover within the boundaries of the Thistle Quadrangle. The schematic diagram (Text-fig. 4), modified from Bissell (1959, p. 160) and Stokes and Madsen (1961), summarizes relationships between allochthonous sedimentary rocks and the autochthon. That part of the diagram shown as "cover" includes minor amounts of autochtonous Cretaceous, not easily differentiatable from post-thrusting Cretaceous cover near the Uinta Mountains.

Age of Laramide Deformation.—The major widespread orogenic pulse attributed to Laramide deformation has folded strata as young as Upper Cretaceous Indianola Group near Thistle. The highland resulting from the Laramide orogeny produced deposits of coarse conglomerate tentatively correlated with Price River Formation (Late Montana) of Price Canyon. Major Laramide deformation in the Thistle area is therefore dated as pre-Late Montanan Upper Cretaceous. This time of deformation concurs with that given by Spieker (1946, p. 152), who dates major folding as having taken place between Middle and Late Montanan.

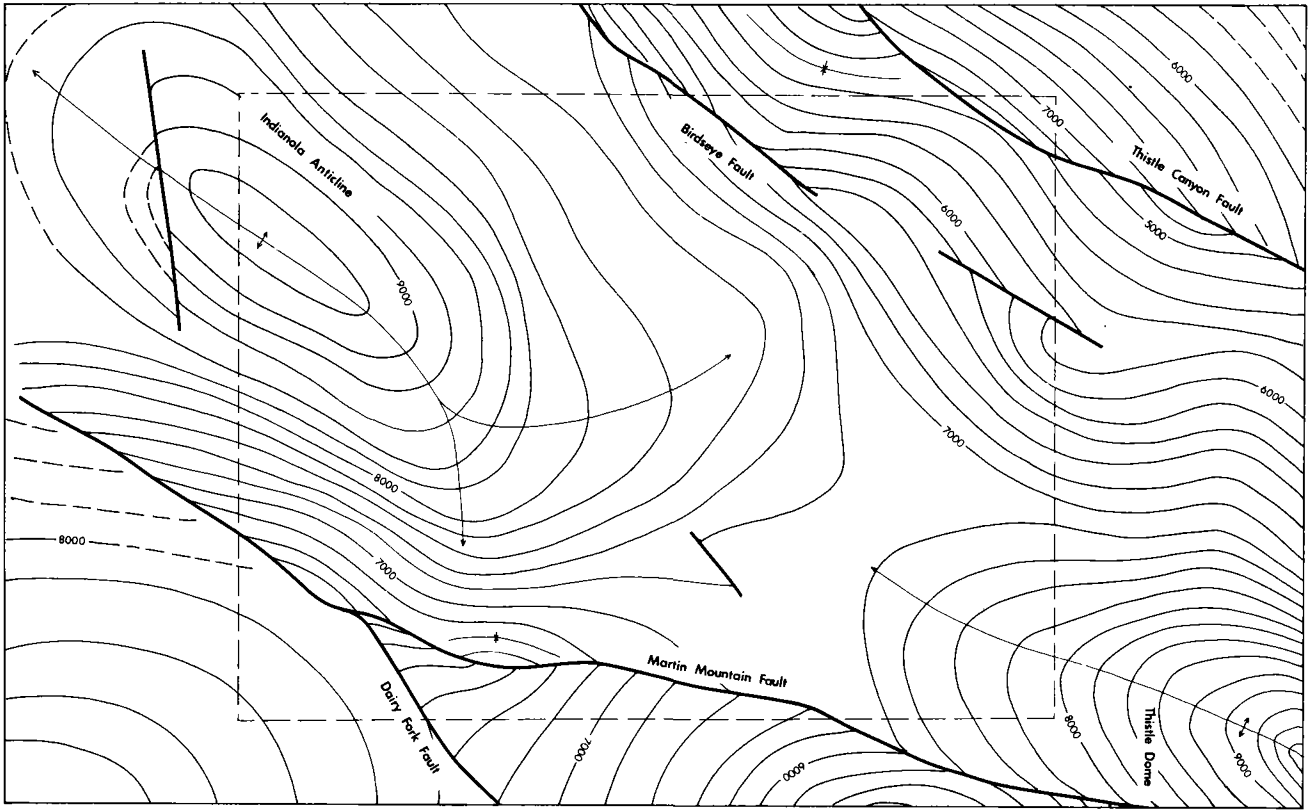
Cenozoic Folds

Thistle Dome—Indianola Anticline.—A broad lineation of Cenozoic folds, recognized by Weiss (1969, p. 1,110) and named the "Two Tom Hill—Thistle dome—Indianola anticline lineament" by Walton (1959, p. 151), is well expressed in the Thistle area (see form line structure contour map of the Thistle area, Text-fig. 5). The southern flanks of the Thistle Dome are located in the northeastern part of the study area. This structure, with a subsurface closure of 5,000 feet (Neighbor, 1959, p. 180), is similar to the smaller Indianola Anticline, where surface geology indicates a closure of about 1,000 feet. The subsurface closure of the Indianola structure is definitely greater than the surface closure because this anticline, like the Thistle Dome, has experienced intermittent folding. Evidence for this sporadic folding is seen in the angular unconformity between North Horn and Flagstaff formations (see below) and a marked thinning of the Flagstaff Formation just north of Smiths Reservoir.

Pre-Flagstaff Unconformity.—Spieker (1946, p. 155) named and described a North Horn-Flagstaff unconformity as the "pre-Flagstaff movement." This movement produced a single fold, not more than six miles wide, which was



TEXT-FIGURE 4—Approximate location of the covered leading edge of the Charleston-Strawberry-Nebo Fault (modified from Bissell, 1959, and Stokes and Madsen, 1961).



TEXT-FIGURE 5.—Form line structure contour map of the Thistle area. The dashed area is the Thistle Quadrangle. Structure contours are approximately drawn at the base of the Flagstaff Formation. Contour interval equals 200 feet.

confined to a belt now occupied by the Sevier-Sanpete Valley and part of the margin of the western Wasatch Plateau. Spieker postulated this fold to occupy at least the southern half of the western border of the Wasatch Plateau.

The pre-Flagstaff movement in the Thistle Quadrangle is expressed near Spring Hollow as an angular unconformity between the Flagstaff and North Horn formations shown in Pl. 2, figure 1. The truncated North Horn Formation is a blotched red and grey sandy siltstone underlain by a maroon sandstone. The overlying Flagstaff Formation is a thin- to thick-bedded buff calcareous sandstone. The axis of the truncated North Horn fold appears to be less than a mile north of the axis of the Indianola Anticline described above. However, dense vegetation and post-anticlinal faulting make interpretation of the exact location of the pre-Flagstaff movement difficult.

Age of Folding.—Greatest post-Laramide movement which produced folding in the western Wasatch Plateau area has been post-Green River (Eocene) in age. Some folding in the Indianola anticline has taken place post-North Horn—pre-Flagstaff, as explained above. Walton (1954, p. 32) postulates pre-Flagstaff—post-Castlegate folding along the Soldier Summit-Clear Creek axis and a post-Ferron—pre-Starpoint episode of folding for the same area. The latest and most profound flexure which affected the Thistle area was that post-Green River rejuvenation of the principal folds with contemporaneous downsinking of the Sanpete and Sevier valleys to form the present Wasatch Monocline (Walton, 1954, p. 82).

Cause of Folding.—The major folds of the Wasatch Plateau are believed by Walton (1954, p. 82) to have had a genesis common with folding of the San Rafael Swell. These folds were caused by deep-seated faulting associated with isostatic adjustment between the stable San Rafael area to the east and downsinking Cordilleran trough to the west.

Cenozoic Normal Faults

All major Cenozoic faults in the mapped area have a north-northeasterly, south-southwesterly trend which is approximately parallel to the general structural grain of the central Utah area and parallel to Basin and Range fault patterns (Slemmons, 1963, p. 889).

Dairy Fork and Martin Mountain Faults.—The Dairy Fork and Martin Mountain faults, named by Merrill (1972), are high-angle normal faults which bound the Dairy Fork Graben. The Martin Mountain Fault—which drops down west—and the Dairy Fork Fault—which drops down Green River Formation to the northwest against North Horn, Price River, and Twist Gulch formations to the southeast (see Pl. 3, fig 1)—appear to join in the southeastern part of the Thistle Quadrangle to form a single major fault. This major fault drops down Green River Formation and Tertiary volcanic-sedimentary rocks against Twist Gulch Formation. Here the Price River Formation is in juxtaposition with Twist Gulch, Blackhawk (?), and Arapien in complex fault relationships. The Blackhawk (?) and Jurassic formations are probably in fault contact with each other. There is, however, some question as to the relationship between Price River Formation and older strata. The writer believes the contact in the mapped area to be unconformable with Price River Formation, truncating all old formations present. This relationship indicates that the fault contacts between Jurassic strata and Blackhawk (?) Formation took place during the Laramide orogeny. The writer found no evidence to prove or disprove this hypothesis.

Birdseye Fault:—This fault has been named and described by Harris (1954, p. 206) in the Birdseye area as a normal fault of variable trend, dipping approximately 45 degrees west. However, in the Thistle Quadrangle the fault has a north-northeast trend and is nearly vertical. The fault drops Flagstaff and North Horn formations against North Horn and Indianola formations. The Birdseye Fault is in line with, and may connect onto, another normal fault exposed two miles east of Thistle, north of U.S. Highway 50-6. This high-angle normal fault is downthrown to the east as it faults Flagstaff Formation against North Horn Formation and North Horn Formation against Indianola Group. This fault cuts out most of Indianola strata in Spanish Fork Canyon; a more complete Indianola section crops out in Lake Fork.

Billies Mountain - Thistle Canyon Fault:—The Billies Mountain Fault described by Peterson (1952, p. 64-65) and the Thistle Canyon Fault named by Harris (1954, p. 205) refer to the same fault that is present in the northwest corner of the study area where it follows a shaly unit of Twin Creek Limestone. The outcrop of Flagstaff Formation at the location of the fault just northeast of Thistle owes its position both to faulting, being downdropped to the east, and to more recent slumping, which has caused its outcrop pattern (shown on the geologic map which accompanies this report).

Minor Faults

Many minor faults that have similar trends to major faults are present throughout the mapped area, but their study is hampered by poor exposure. Khin (1956, p. 116-123) described a series of normal faults exposed along Dry Creek in the southern portion of the study area. These faults have a north-south trend and are mappable only where shown on the writer's geologic map.

Other exposures of minor faults are in the Flagstaff Formation on the north wall of Spring Hollow, just southwest of the junction of Lake and Soldier forks, and in tar and sands in Wildcat Canyon southeast of Thistle.

Joints

Dry Hollow, part of Spring Hollow, Coal Hollow, and other canyon tributaries to Lake Fork have a similar trend, which is probably joint controlled.

Age of Faulting

Other than being definitely younger than folding, the age of faulting in the study area is uncertain. Walton (1954, p. 81) suggests that the faulting may be as young as or younger than Oligocene. In a study of the Basin and Range, Nolan (1943, p. 138) concluded that the block faulting (which would also relate to the Thistle area) began there in Oligocene and has continued to the present.

Cause of Faulting

Basin and Range-like graben-tensional stresses which have produced the monocline-like sequences of grabens in the western plateau area may owe their origin to subsidence and solution effects in the salt-bearing Jurassic rocks below.

ECONOMIC GEOLOGY

Metals

A minor uneconomic deposit of manganese oxide is located within the Price River Formation in the southeast corner of the study area. This deposit is associated with the unconformable surface where Jurassic Twist Gulch Formation is overlain by conglomerates of the Price River Formation. Outcrops of the oxides are located approximately 1,000 feet east of Lake Fork Creek, up Rock Canyon.

Nonmetals

Small deposits of gravel located on the north side of U.S. Highway 50-6, 1,200 feet east of Thistle, have been quarried for local use. This gravel, of recent origin, is of low quality, is not extensive, and is no longer quarried.

Limestone from the Thistle area has been quarried for use as building stone. This pisolitic or algal limestone, called "birdseye marble," has been quarried only from the North Horn Formation, one and one-half miles east of Birdseye. Birdseye marble or algal limestone could be quarried from the North Horn Formation along Lake Fork Creek southeast of Thistle near Coal and Right Fork hollows. Many buildings in the Intermountain area have interior trim made of this birdseye limestone.

Water

Water is an important product of the Thistle area. Ranchers, farmers, and other local residents depend on water from springs of the region to water their crops and herds. Smiths Reservoir, located in the southeast corner of the mapped area, is used by local ranchers as a water source for summer irrigation of lowland crops and the watering of herds of cattle that spend the summer months in the mountain highlands.

Petroleum Products

Asphalt.—Three localities of substantial quantities of tar-sands mined years ago for use as a road pavement, are located within the Thistle area. Two of these deposits are in the Flagstaff Formation located in the cliffs both north and south of U.S. Highway 50-6, one mile east of Thistle. These asphaltic deposits occur in limestone and pebbly sandstone but are most common in fine- to coarse-grained, laminated- to medium-bedded sandstone. The impregnated sands, which are frequently cross-bedded, usually contain abundant gastropods and some bivalves, which are frequently near the basal bedding planes.

The third locality of asphalt occurrence is at the head of Spring and Oil hollows, eight miles southeast of Thistle near the Dairy Fork road. The asphalt at this locality is in sandstone of the Green River Formation, which is overlain and underlain by impregnated green shale. Most of the sandstone is well saturated with tar but unfossiliferous. This sandstone is approximately 15 feet thick and is not similar to the occurrences within the Flagstaff Formation described above because the asphalt saturates only the sandstone, while in the Flagstaff, all units may contain hydrocarbons. Numerous minor faults cut the Flagstaff tars, but no minor faults are associated with the tars in the Green River sandstone.

Source of the hydrocarbons which saturate the Tertiary lake deposits of the Thistle quadrangle is unknown. The writer believes the tar to be indigenous to the respective formation of its occurrence.

Oil and Gas Possibilities.—Since the early 1950s, when significant Cretaceous reservoirs of natural gas were discovered south of Schofield Reservoir, the entire Wasatch Plateau, including the mapped area, has been explored by seismic surveys and surface geologic investigation. A well drilled by Tennessee Gas and Transmission Company near Moroni, located only three and one half miles east of thousands of feet of Indianola conglomerate, encountered a normal Wasatch Plateau-Clear Creek section, bottoming below Dakota. No Indianola-like strata were penetrated (Walton, 1959, p. 150). The anomalous position of Indianola strata may be interpreted as being the result of extensive eastward Laramide thrusting. A similar interpretation applied to the study area indicates possible structural oil traps there.

Although the Thistle Dome has been drilled numerous times, Paleozoic strata may yet produce oil or gas. A deep test drilled through the Laramide thrust plate may encounter both Ferron and Dakota sands, which are the major producing horizons in the Clear Creek Field near Schofield Reservoir.

Subsurface closure much greater than the surface closure of about 1,000 feet (shown in Text-fig. 5) makes the Indianola Anticline one of the most significant gas prospects of the Thistle Quadrangle. This structure is near producing fields and is probably east of most of the Laramide thrusting. A normal Wasatch Pleateau-Clear Creek stratigraphic section might be present in the subsurface.

The fact that folding predates faulting in the Wasatch Plateau area does not rule out the Smiths Reservoir Fault as a possible structural trap. A probable closure in excess of 3,000 feet, close proximity to producing fields, and possibility of encountering a normal Wasatch Plateau-Clear Creek stratigraphic section demonstrates definite petroleum potential in the fault southeast of Smiths Reservoir.

APPENDIX 1, MEASURED SECTIONS

Flagstaff Limestone

Complete section of Flagstaff Limestone measured near Chicken Hollow, Section 26, T. 9 S., R. 4 E.

Unit No.		Thickness	Feet Above Base
	Green River Shale Conformable contact Tertiary Flagstaff Limestone:		
7	Limestone, oolitic, fossiliferous, silty in places, light grey-brown, weathers same, ⅛ to 2 mm. in diameter, some calcitic mud fragments range to 5 mm. in diameter; fair sorting in individual beds; very thin beds especially where silty, to medium beds; forms slopes and cliff slopes, ostracods	72.5	563.0
6	Limestone, oolitic, fossiliferous; grey-brown and light grey, weathers bleached grey-brown, calcite, 1 to 6 mm. ooids, some calcitic mud fragments range to 6 mm. in diameter, good sorting, very thin to thin beds; traces of tar present in upper third and lower third of unit; forms rounded slabby cliffs at top to cliffy slopes in middle to massive cliffs at base; ostracods	83	490.5
5	Limestone, sucrosic, oolitic in part grey to grey-pink, weathers light grey to white, lichen covered; lime-	23.5	407.5

Appendix 1 (Continued)

	stone is finely crystalline, $\frac{1}{8}$ to $\frac{1}{2}$ mm. in diameter with sorted ooids; poorly sorted, angular quartz grains; medium beds at top to very thin beds at base; forms rounded cliffs at top, angular cliffs toward middle, and rubble-covered slope at base; ostracods, gastropods: *Gyranulus sp.* and *Physa* sp.		
4	Limestone, oolitic microcrystalline, and finely crystalline; light buff, pink-grey to grey, weathers grey, lichen covered; changes laterally to lenses and pockets of buff oolitic limestone; calcite, quartz, limestone clasts; $\frac{1}{8}$ to $\frac{1}{2}$ mm. ooids, some calcitic mud fragments range to 12 mm. in diameter, dark grey, angular limestone fragments near base of unit range to 6 mm., quartz clasts are fine to coarse sand-size; beds of ooids are well sorted, poor sorting in limestone which contain quartz and limestone clasts; very thin beds to massive beds; forms cliffs at top which persist intermittently with ledgy slopes throughout, forms rubble-covered slope at base; bivalve, gastropoda: *Physa* sp. occur in very thin-bedded talus fragments	164.5	384
3	Limestone, oolitic, locally sandy and conglomeratic, locally algal; grey, weathers dark grey, lichen covered, algal limestone grey-pink, weathers light brown; well sorted; ooids to 2 mm., sand is medium to coarse sand-size, conglomerate clasts to 1$\frac{1}{2}$ inch diameter, algal oncolites up to 12 mm.; poorly sorted and angular quartz, sand, and chert pebbles in top of unit; crossbedding to 18 inches high in sandy limestone near top of unit; thin to thick beds; forms rounded cliffs at top, meringue weathering, massive cliffs and some rubble-covered slopes; varies laterally; base covered; infrequent fossils	78.5	219.5
2	Limestone, oolitic, algal in part fractured with recrystallized calcite in fractures; very light brown-white, weathers same and light grey with frequent dark lichen covering; calcite; ooids to 1/16 mm., well sorted, 8 mm., algal balls or pisolites; thick and massive beds; forms massive, angular cliffs	96	141
1	Limestone, algal, locally oolitic, light grey, weathers white; algal oncolites to 20 mm. in diameter, $\frac{1}{2}$ to 2 mm. ooids; not well cemented; forms rubble-covered slopes; poorly exposed	45	45
	Conformable contact North Horn Formation		
	Total thickness of Flagstaff Limestone	563.0	

North Horn Formation

Complete section of North Horn Formation measured along Lake Fork Canyon, Sections 2 and 3, T. 10 S., R. 4 E.

Unit No.		Thickness	Feet Above Base
	Flagstaff Formation Conformable contact North Horn Formation:		
27	Shale, calcareous; maroon and red with grey blotches, mostly red; clay- and silt-size; calcite cement; upper contact with Flagstaff Formation partly covered;	29	432.0

Appendix 1 (Continued)

	contains 2-foot-thick sandstone bed near the middle; forms soil-covered slope		
26	Sandstone, calcareous, buff, weathers grey, partially iron oxide stained red from above unit; quartz, rock fragments, clay; medium sand-size; moderately sorted, calcite cement; some poorly developed cross-beds to 6 inches in height, thick beds form ledgy to massive cliffs; thickness varies laterally	6.5	403
25	Conglomerate; weathers buff and red; clasts of Paleozoic limestones dominate with minor clasts of sandstone and quartzite; clasts to 6 inches in diameter, matrix is calcareous sand and silt; large, flat pebbles are imbricated near base of unit; forms massive cliffs	25	396.5
24	Shale, calcareous; red with some grey to white blotches, weathers red; clayey calcite cement; thin laminae to laminae; forms soil covered slopes	13	371.5
23	Conglomerate; weathers red; clasts are predominantly dark grey limestone; clast size is $\frac{1}{4}$ to 6 inches in diameter, matrix is calcareous, silty mud; some lenses of poorly sorted coarse-grained sandstone of lateral variance are in lower third of unit; forms massive cliffs	10	358.5
22	Interbedded sandstone and siltstone, calcareous, both buff, weather grey; quartz, clay, some dark minerals; silt- and medium sand-size; poorly sorted; calcite cement, laminae to very thin beds; grading gradually from sand to silt to sand; forms rubble-covered, ledgy slopes, thickness varies laterally; unfossiliferous	4.5	348.5
21	Interbedded conglomerate and silty sandstone, silty sandstone like unit 22; conglomerate weathers buff; clasts of limestone, some chert; clasts to 4 inches in in diameter, $1\frac{1}{2}$-inch average size; matrix is calcareous mud and sand; pebbles well rounded; forms massive cliffs, silty sandstone forms rubble-covered, ledgy slopes	20	344
20	Sandstone, like unit 26, except medium to fine sand -size	8	324
19	Shale, like unit 24	16	316
18	Sandstone, silty, calcareous; buff, partly red stained from unit 19; quartz, some dark minerals; silt and very fine sand-size; moderate sorting; calcite cement, thin beds; forms ledgy slopes, unfossiliferous	5	300
17	Interbedded conglomerate and sandstone like unit 21; sandstone lenses form slopes, conglomerate forms cliffs, bedding varies laterally	42	295
16	Conglomerate like unit 25	15	253
15	Conglomerate; weathers grey and buff; clasts composed of limestone and sandstone; size of clasts ranges to 4 inches, well sorted; calcareous mud and silt matrix, poorly cemented; forms clast-covered slope, poorly exposed	5	238
14	Shale like unit 24	8	233
13	Limestone, sandy; pink and grey, weathers grey with red mottling, calcite, quartz; limestone texture is crystalline, appears sugary; clastic particles very fine sand-size; very well sorted; thin beds, forms cliffs; some bioturbation	4	225
12	Shale like unit 24	15.5	221
11	Conglomerate; weathers red because of stain from over-		

Appendix 1 (Continued)

Unit No.	Description	Thickness	Feet Above Base
	lying unit, clasts composed of fossilferous limestone and sandstone; size of clasts ranges to 8 inches, 3 inches average size; poorly sorted; thin beds of grit-size clasts and medium beds of coarser conglomerate; forms massive cliffs		
10	Shale like unit 24 with a 3 foot layers of sandstone like unit 18, seven feet from the base	21	204.5
9	Sandstone, very calcareous; grey, weathers grey with red mottling; quartz, calcite; very fine sand-size; well sorted; calcite cement comprises up to 35% of rock volume, forms cliffs; burrows to ½ inch wide, 8 inches long	8	183.5
8	Interbedded shale and sandstone, calcareous; shale like unit 24; sandstone, calcareous, dark grey, weathers red, quartz, calcite; fine and medium sand-size; well sorted; calcite cement comprises up to 25% of sandstone volume, medium bedded; forms ledgy slopes, bioturbated	30	175.5
7	Interbedded shale and sandstone like unit 8; sandstone beds are at base and top of unit, bioturbation in sandstone more evident than unit 8	37	145.5
6	Sandstone like unit 9	4.5	108.5
5	Interbedded sandstone and shale	40	104
4	Conglomerate like unit 25, clast size to 8 inches, average size 4 inches	10	64
3	Shale like unit 24; grey blotching not as abundant as unit 24, lense of sandstone at upper contact like sandstone of unit 8	8	54
2	Conglomerate; weathers white; clasts are mostly white sandstone, clast size averages 1 inch, maximum size 2 inches, well sorted, well bedded, forms ledgy slope at top of cliff near base	12	46
1	Shale like unit 24, grey blotching not as abundant as unit 24	34	34
	Unconformable contact Price River Formation		
	Total thickness of the North Horn Formation	432.0	

Indianola Group

Stratigraphic section of Indianola Group measured along the east side of Lake Fork Canyon. Section 3, T. 10 S., 4 E.; and Section 34, T. 9 S., R. 4 E.

Unit No.		Thickness	Feet Above Base
	Price River Formation Angular Unconformity Indianola Group·		
6	Sandstone, quartzose; white, minor amount light buff, weathers off-white to very light grey-brown, quartz, calcite, clay; well sorted, very fine and fine sand-size, locally floating pebbles to 1 inch diameter, angular clay clasts to 4 mm in diameter at top; calcite cement in most beds, calcite may have been leached out where not present; frequent large and small scale cross-beds, thick to massive beds, forms rounded cliffs and ledgy slopes; cliffs stand out in bold relief, abundant bur-	1350	2610

Appendix 1 (Continued)

	rows in most beds parallel and normal to bedding planes		
5	Covered, probably shale	240	1260
4	Interbedded calcareous sandstone and shale; sandstone locally clayey and pebbly; sandstone light to buff, weathers same; quartz, clay, calcite; clay-size, medium to coarse sand-size, local conglomerate with clasts to 2 inches in diameter; sandstone not well sorted to well sorted; calcite cement, cross-beds with amplitudes to 3 feet; laminae to very thick beds; forms alternating rounded cliffs and soil covered slopes; unfossiliferous, no burrows	250	1020
3	Interbedded calcareous sandstone and conglomerate; white, weathers buff, minor thin shale lenses near top are maroon and chocolate brown, weathers same; quartz, calcite, and clay; clay-size, fine to medium-sand-size, conglomerate clasts up to 2 inches; fair to good sorting; calcite cement; cross-beds; medium to thick beds of sandstone and conglomerate, laminated shale; form massive rounded cliffs which stand out in bold relief; bivalves in base of unit	300	770
2	Sandstone, quartzose, fossiliferous, silty, calcareous white, weathers buff, alternating white and grey; quartz, minute particles of black organic material in silty beds; silt-size, very fine to fine sand-size, some floating pebbles in upper part of unit; well sorted except in silty layers; all clasts well rounded; calcite cement; cross-beds, minor channeling, graded beds near top; thin to thick beds; forms alternating rounded cliffs and partially covered slopes where silty, burrows, abundant fossils; bivalves	370	470
1	Interbedded sandstone like unit 2, but unfossiliferous, medium beds, moderate sorting; and shale, calcareous; maroon, purple, green, grey, weathers same and red-brown; clay, calcite, quartz; clay-size; well sorted, clay and calcite cement; very thin laminae to thin laminae; shale forms, soil covered slope, but exposed in a quarry; sandstone forms cliffs; unfossiliferous; unit terminates below a shale, where underlain by poorly sorted conglomerate	100	100
	Conformable contact Morrison Formation		
	Total thickness exposed, Indianola Group	2,610	

Twin Creek Limestone

Incomplete section of Upper Twin Creek Limestone measured one mile south of Thistle, east of U.S. Highway 89; Section 4, T. 10 S., R. 4 E.; and Sections 32 and 33, T. 9 S., R. 4 E.

Unit No.		Thickness	Base Feet Above
	Terrace gravel Unconformable contact Twin Creek Limestone:		
1	Sandstone, calcareous, clay pebble; green-brown, weathers grey-brown; quartz and clay; fine to coarse sand-size; well sorted; calcite cement; cross-beds and os-	70	950

Appendix 1 (Continued)

	cillation ripples; thin to very thick beds, forms cliffs; scarce fossils		
2	Sandstone, calcareous; green-grey, weathers grey-green; quartz; fine to medium sand-size, clay pebbles at top, well sorted, calcite cement; cross-beds; thick beds; forms cliffs; bivalves	17.5	880
3	Shale, calcareous; green-grey, weathers grey-green; clay-size; well sorted; thin laminae; forms soil covered slope; fair exposure, unfossiliferous	10 5	862.5
4	Sandstone like unit 2, without clay pebbles	8.5	852.0
5	Shale like unit 3	20.0	843.5
6	Sandstone, calcareous, clay pebbles, green-grey, weathers grey-green, quartz and clay; very fine sand- and clay-size; moderately sorted; calcite cement, thick beds; forms cliffs; unfossiliferous	2.0	823.5
7	Shale like unit 3	26.5	821.5
8	Sandstone like unit 6	3.0	795.
9	Shale like unit 3	17.5	792
10	Sandstone like unit 6 with prominent oscillation ripples and cross-beds; bivalve fragments	24.5	774.5
11	Shale like unit 3	40.5	750
12	Sandstone like unit 14	7.0	709.5
13	Shale like unit 3	10	702.5
14	Interbedded calcareous sandstone, and siltstone; green-grey, weathers grey-green; quartz, clay and mica, well sorted; calcite cement, some ripple marks; laminae to very fine to fine sand; calcite cement; some ripple marks; laminae to very thin bed, forms ledges and slopes; fair exposure; unfossiliferous	14	692.5
15	Shale like unit 3	8.5	678.5
16	Sandstone like unit 6 with clay pebbles only at the top	15.5	670
17	Interbedded calcareous sandstone, and shale, grey-green, weathers grey-green; quartz and clay, very fine well-sorted sand; calcite cement; thin laminae to laminae, forms cliffs; unfossiliferous	9.5	654.5
18	Shale like unit 3	260	645
19	Interbedded sandstone and siltstone like unit 4	116	385
20	Interbedded calcareous siltstone; and shale; brown siltstone, weathers grey-brown, green-grey shale, weathers grey-green; quartz and clay; siltstone and shale poorly sorted; calcite cement; thin laminae; forms rubble-covered slope, fair exposure, unfossiliferous	26.5	269
21	Sandstone like unit 6	7.5	242.5
22	Interbedded calcareous sandstone, and shale like unit 17	6	235
23	Shale like unit 3	5	229
24	Sandstone, silty arenaceous, calcareous mud pebbles, green-grey, weathers grey-green, quartz and clay; very fine sand- and silt-size; mud pebbles 1½ cm in diameter, average sorting; calcite cement, laminated, forms rubble-covered slope, fair to poor exposure, unfossiliferous	24	224
25	Shale, calcareous; green-grey with some areas blotched chocolate to yellow-brown, weathers grey-green and grey-brown; some silt- to mostly clay-size; thin	55	200

Appendix 1 (Continued)

	laminae; forms rubble-covered slopes, fair to poorly exposed; bivalve fragments associated with silts		
26	Shale, calcareous; green-grey, weathers grey-green; clayey; well sorted; thin laminae; forms soil covered slopes; poorly exposed, unfossiliferous	145	145
	Uncomformable contact North Horn Formation		
	Measured thickness of Upper Twin Creek Limestone	950	

APPENDIX 2, IDENTIFIED FOSSILS

Twin Creek Limestone

Fossils from Twin Creek Limestone, southeast of Thistle, SW 1/4 SW 1/4, Sec. 33, T. 9 S., R. 4 E. Identified by Dr. R. W. Imlay, U.S. Gelogical Survey

Lyosoma cf. *L. enodata* Sohl
Lyosoma sp.
Lopha sp
cf. *Neritina phaseolaris* White
Camptonectes cf. *C. stygius* White
Camptonectes sp.
Pelecypod fragments
Crinoid columnals
Gastropod

Fossils from Twin Creek Limestone northeast of Thistle, NW1/4, SE1/4, Sec. 28, T. 95, R. 4 E. Identified by Dr. R. W. Imlay, U.S. Geological Survey.

Vaugonia conradi (Meek and Hayden)
Moliolus subimbricatus (Meek)
Camptonectes sp
Modiolus sp.
Pelecypod fragments

Arapien Shale

Fossils from Arapien Shale, SW 1/4 SW 1/4, sec. 7, T. 11 S., R. 5 E. Identified only as "Jurassic" by Dr. W. A. Cobban, U.S. Geological Survey.

Camptonectes stygius White
Crinoid columnals

Indianola Group

Fossils from Indianola Group NE 1/4, NE 1/4, Sec. 34, T. 9 S., R. 4 E. Identified by Dr. W. A. Cobban, U.S. Geological Survey.

Veniella (?) sp. (may be undescribed species)

Fossils from Indianola group SE1/4, SW1/4, Sec. 34, T. 9S, R. 4 E. Identified by Dr. W. A. Cobban, U.S. Geological Survey.

Pinna sp.
Ostrea sp
Camptonectes sp.
Legumen sp.
Cardium spp.

Mya sp.
Several other forms representing other genera

Fossils from Indianola Group SW 1/4, NE 1/4, Sec. 9, T. 11 S., R. 4 E. Identified by Dr. W. A. Cobban, U.S. Geological Survey.

Veniella (?) sp.
Ostrea anomioides

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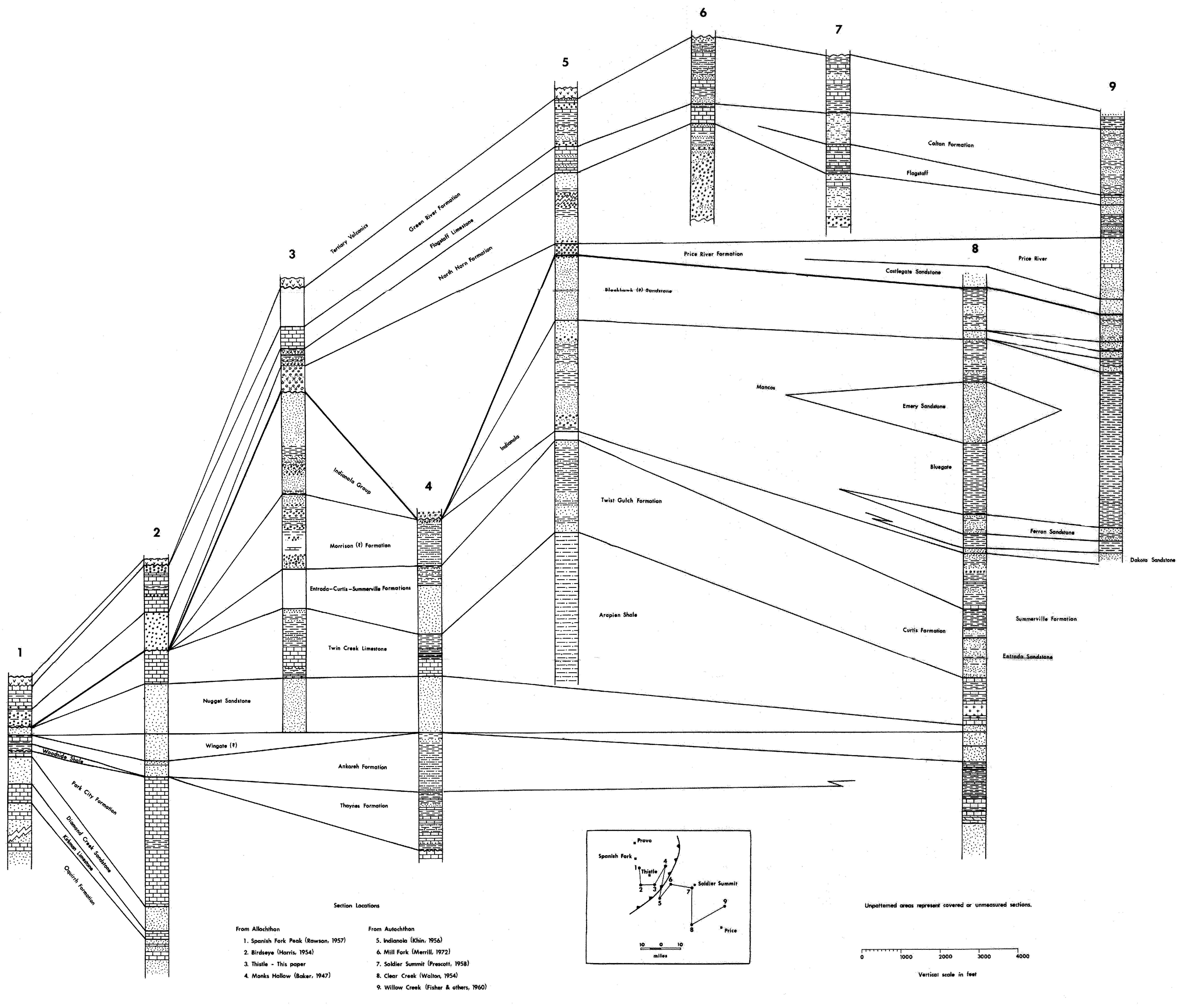

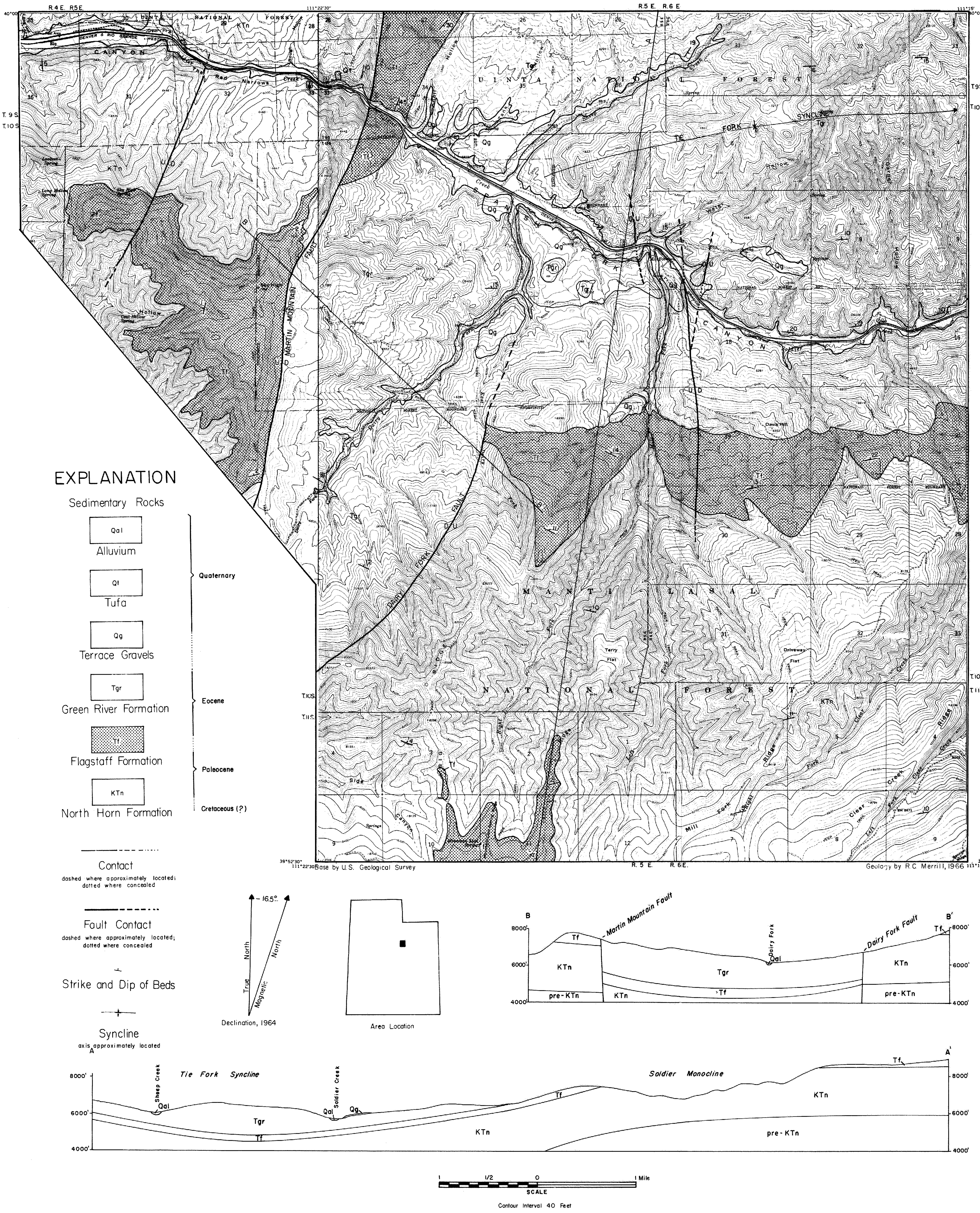

Geologic Map And Sections Of The Mill Fork Area, Utah

By

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