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Geology of Billies Mountain Quadrangle, Utah County, Utah

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ABSTRACT.—One of the most complete and best-exposed stratigraphic sequences of the leading edge of the Cretaceous Sevier Orogenic belt and its early Tertiary cover yet observed lies within Billies Mountain quadrangle. The quadrangle is located 30 miles south of Provo, Utah, near the junction of the Basin and Range, Colorado Plateau, and Central Rocky Mountain provinces. Stream dissection within this quadrangle has exposed parts of 20 formations ranging from Permian through Oligocene. The structural style within this quadrangle is mostly broad open folds reflecting the influence of the Colorado Plateau Province, but tight overturned folds, high-angle reverse faults, and normal faults are also present.

The Permian Park City Formation and Triassic Woodside Shale are separated by an angular unconformity attesting to local deformation in late Permian. A disconformity representing a considerable hiatus occurs between the Jurassic age Morrison Formation and the early Upper Cretaceous rocks. The Upper Cretaceous and earlier rocks were folded and thrust during the Sevier Orogeny. However, prior to deposition of the latest Cretaceous sediments and later orogenic activity, erosion of Triassic and Jurassic soft shales left the Nugget Sandstone, Morrison Formation, and Upper Cretaceous conglomerates standing as major hogbacks. These hogbacks were positive features during the late Cretaceous and Paleocene eras. The late Cretaceous through Oligocene deposits which cover the hogbacks and encroach onto the western highlands are dominated by conglomerate and red shale. A new formation, a 1,400-foot sequence of conglomerate exposed in Red Narrows Canyon, is proposed for part of these deposits. The red shale associated with the Tertiary rocks is believed to have been derived from local erosion of Triassic redbeds.

Laramide tectonism in late Cretaceous and Paleocene caused broad folds in the Flagstaff Limestone and older rocks. These folds parallel the leading edge of the Sevier orogenic belt. Basins forming among these folds were continuously being filled with lacustrine deposits, fluvial sediments, and water-lain volcanic debris. A calcite-lined hot water conduit indicates local thermal activity and may indicate a nearby volcanic source for some of the volcanic rock found within the quadrangle.

Recurrent uplift in the Miocene with Basin-and-Range-associated faults further increased the structural complexity of the Billies Mountain quadrangle.

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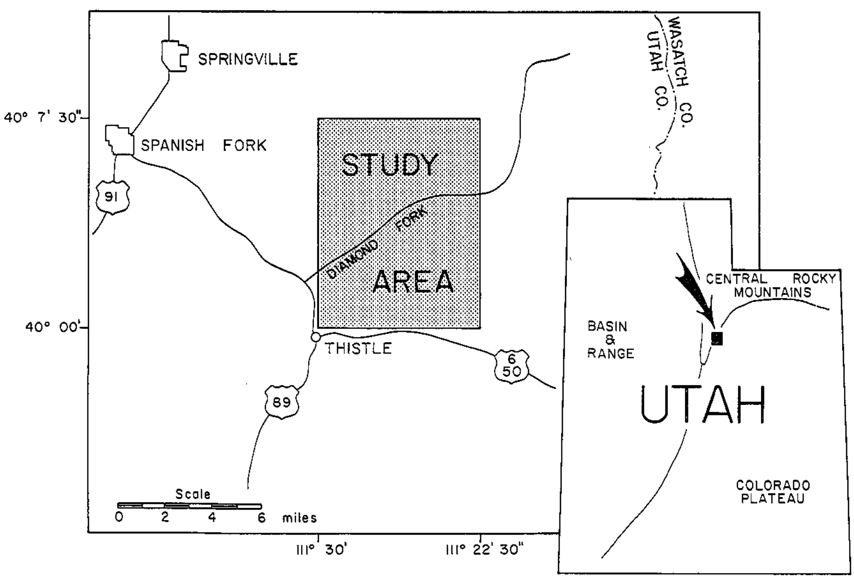
INTRODUCTION

One of the most complete and best-exposed sections of the stratigraphy of the leading edge of the Sevier Orogenic belt is found in the Billies Mountain quadrangle. Upper Cretaceous and older rocks which were folded and faulted during the Sevier Orogeny lie partly concealed beneath a thick wedge of Tertiary clastic rocks near the southern end of the Central Wasatch Mountains. Within this quadrangle, the entire stratigraphic sequence from the Permian Oquirrh Formation to Miocene (?) volcanic rock is exposed. Geologic data obtained by detailed mapping of stratigraphic units and structural trends, and measured stratigraphic sections within the well exposed area of this quadrangle, will aid in unraveling the geology of more poorly exposed adjacent areas along the eastern edge of the Sevier Orogenic belt. Presentation of these data is made under the major headings of stratigraphy, structural history, and economics.

Location

Billies Mountain 7½-minute quadrangle is located 30 miles south of Provo near the junction of the Basin and Range, Colorado Plateau, and Central Rocky Mountain provinces (Text-fig. 1). Dirt roads provide access during summer months to within three miles of all points in the mapped area, but permission to cross private lands must be obtained from local land owners.



TEXT-FIGURE 1.—Index map of Billies Mountain Quadrangle.

Spanish Fork Peak (10,192 feet) lies west of the quadrangle and the summit of Teat Mountain (8,573 feet) lies just beyond the quadrangle to the southeast. Red Mountain parallels the eastern edge of the mapped area. The central part of the quadrangle consists of moderate-sized rolling hills. Billies Mountain, located in the south-central portion of the quadrangle, is one of these hills.

Teat Mountain and eastward is part of the High Plateaus Subprovince. Spanish Fork Peak is part of the Central Wasatch Mountains of the Central Rocky Mountain Province. The Basin and Range Province lies west of the mapped area, but the north trending faults in the area are Basin-and-Range-type structures.

Douglas fir and quaking aspens cover the northern slopes at higher elevations. Cedar trees, scrub oak, and sagebrush are common in the lower elevations. A moderate climate leaves the lower parts of the area accessible throughout most of the year.

Previous Work

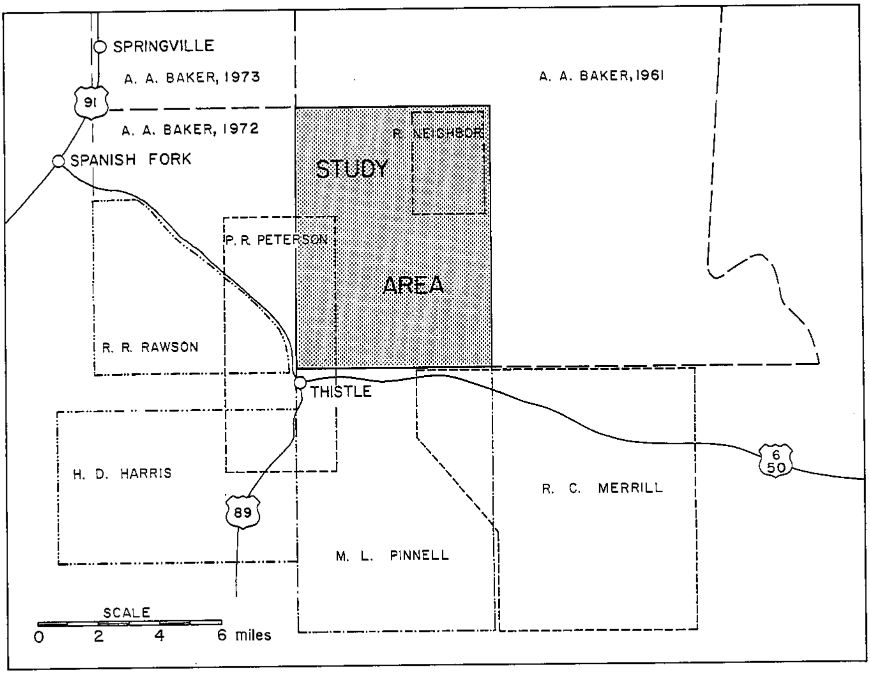
Between 1875 and 1920, pioneer geologists such as Howell, Emmons, Dutton, and Loughlin made significant contributions to our present-day understanding of the geology of central Utah. During the following decade, Campbell did reconnaissance geology and mapping in Spanish Fork Canyon, and Eardley did work to the south of the study area and north of Birdseye. Details of these early investigations are outlined by Harris (1953, p. 7-10) and Rawson (1957, p. 3-5). During this time, Boutwell (1907), working in the Park City Mining District, delineated the Upper Permian and Triassic stratigraphy of central Utah. His nomenclature is applicable to units in the mapped area.

Significant contributions were made by Spieker and his students in the late 30's and 40's. Spieker (1946) described Late Jurassic, Cretaceous and Early Tertiary stratigraphy. Two of his students, Schoff (1951) and Lee (1953), did significant studies on the Price River Formation and North Horn Formation to the south of the mapped area.

Several recent studies have been done in and adjacent to the study area (Text-fig. 2). Baer (1969) studied the paleoecology of the Lower Green River Formation southeast of the mapped area. Baker (1947, 1961, 1972, 1973) did extensive mapping and stratigraphy from Thistle north to Heber. His maps and stratigraphy have been consulted extensively throughout this project. Bullock (1965) studied the Twin Creek Limestone at Thistle. Merrill (1972) mapped the Mill Fork area. Neighbor (1959) compiled and published data from test wells drilled in the Diamond Creek Anticline. Peterson (1952) mapped the Thistle area. Pinnell (1972) mapped the Thistle quadrangle which lies south of the present study. Rawson (1957) mapped the geology west of Spanish Fork Canyon and north of Thistle.

Methods of Investigation

Field work was begun in the fall of 1972 and continued during the summers of 1973 and 1974. Structural features and contacts were plotted on aerial photographs (scale 1:20,000). Stratigraphic sections were measured using a 100-foot tape, a Brunton compass, and a jacob staff, and were computed from aerial photographs.



TEXT-FIGURE 2.—Geological studies within or adjacent to Billies Mountain Quadrangle: A. A. Baker, 1947; A. A. Baker, 1972; A. A. Baker, 1973; H. D. Harris, 1953; R. C. Merrill, 1972; R. Neighbor, 1959; P. R. Peterson, 1952; M. L. Pinnell, 1972; R. R. Rawson, 1957.

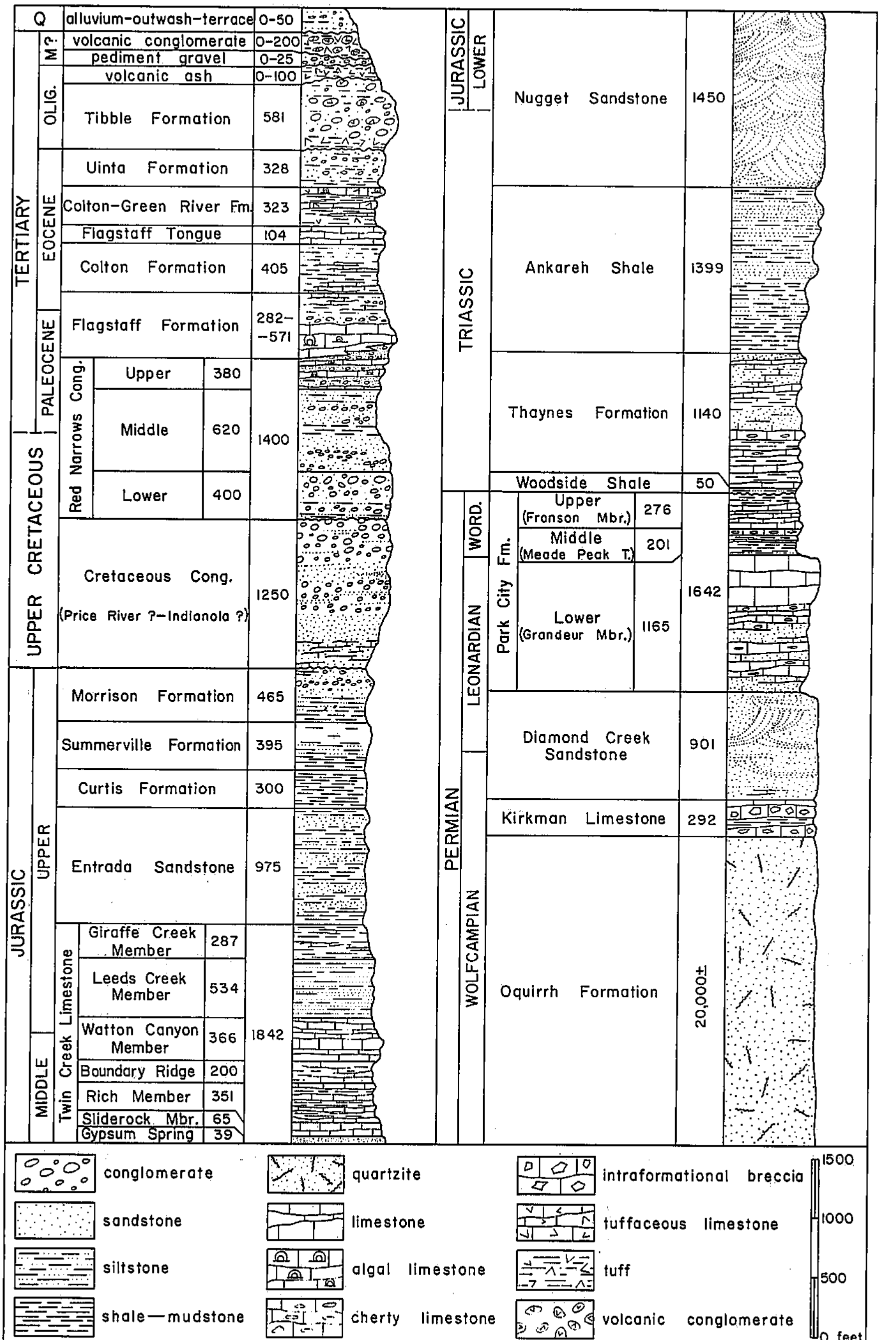
STRATIGRAPHY

General Statement

Billies Mountain quadrangle contains an exposed stratigraphic sequence from Permian (upper Oquirrh Formation) through Oligocene and possible Miocene volcanic rocks. Paleozoic and Mesozoic rocks on the flank of Spanish Fork Peak in the western part of the quadrangle are separated from Mesozoic strata exposed on the east side of the quadrangle by a central graben containing Paleocene through possible Miocene rocks. Quaternary deposits occur along stream courses and in high meadows.

Mapped units generally conform to established regional stratigraphy (Text-fig. 3). Problems with unit identification occurred mainly in Cretaceous and Tertiary strata where similar red shale, siltstone, and conglomerate are the dominant rock types in nine formations (Text-fig. 4), and algal balls occur in four formations instead of being exclusive to the Flagstaff Formation as assumed by some (Text-fig. 4). With these problem units, the position within the stratigraphic sequence proved the best means of identification.

Two mapped units are not rock stratigraphic units. These units are Tertiary and Quaternary terraces that occur mainly along Diamond Fork River. Most of these are cut terraces but some are built terraces. They are mapped because of their relationship to paleodrainage.



TEXT-FIGURE 3.—Stratigraphic section of Billies Mountain Quadrangle. Thickness given in feet.

CONGLOMERATE COMPARISON CHART

Conglomerate Bearing Unit	Clast Type	Clast Size	Depositional Structures	Limestone	Interbedded Units	Fossils	Consolidation
Stream lain volcanic conglomerate	all dark andesite and basalt	pebble to boulder	none	none	none	none	not consolidated
Pediment and terrace gravel	*quartzite light color	boulders up to 5'	*thin veneer lenticular	none	none	none	not consolidated
Tibble Formation	*andesite and Paleozoic cobbles	granules to cobbles, some small boulders	horizontal beds	a few white tuffaceous ls. beds	tuffaceous beds very common	none	fair to well consolidated
Uinta Formation	Paleozoic limestone and quartzite	granules to cobbles some small boulders	generally horizontal beds	*underlain by white tuffaceous, algal ball ls.	lots of reddish siltstone, some tuffaceous beds	none found (possible gastropods)	poorly consolidated
Flagstaff Formation	Paleozoic limestone and quartzite	granules to cobbles	generally horizontal beds	*lots of ls. tan to light gray, algal balls	some shale light gray to reddish brown	*gastropods ostracods bivalves bone	well consolidated
Red Narrows Conglomerate	Paleozoic ls., quartzite and some (J) sandstone clasts	granules to boulders up to 3'	massive to channeled	thin to thick limestone with algal balls	*red shale and red sandstone	gastropods	fair consolidated
Cretaceous conglomerate	sandstone, white, and quartzite	granules to small boulders	massive	some sandy limestone near base	*white sandstone minor red sandstone	*bivalves in calcareous sandstone	well consolidated
Morrison Formation	*chert, limestone quartzite	chert pebbles limestone and quartzite cobbles	horizontal beds, some channeling	algal ball limestone near top	red to purple shale and sandstone	none	fair consolidated
Entrada Sandstone	quartz	*granule only	some channeling	none	*maroon shale and mudstone	none	well consolidated

Note: Stratigraphic sequence is best guide for distinguishing various units.
*Important distinguishing characteristics

TEXT-FIGURE 4.—Chart comparing various conglomerate units found within Billies Mountain Quadrangle.

Permian System

Oquirrh Formation.—At the type locality in the Oquirrh Mountains (Gilluly, 1932), the Oquirrh Formation is about 17,000 feet of sandstone, quartzite, and limestone. In the Wasatch Mountains east of Provo, Baker (1947) measured 26,000 feet of Oquirrh Formation. By using brachiopods, corals, and bryozoans in the lower part and fusulinids in the upper part, Baker determined this sequence as ranging in age from Morrowan (?) through Wolfcampian.

Only the uppermost 1,000 feet of Wolfcampian Oquirrh Formation is encountered in the mapped area and it consists of brown to reddish brown to yellowish brown sandstone or quartzite containing trace fossils consisting of pasichnia burrows. Fusulinids were also noted in stream cobbles, but none were found *in situ.*

Oquirrh Formation sediments represent marine accumulation in a localized basin of what is now central Utah. Bissell (1959b, p. 165) suggests derivation of these sediments from the volcanic eugeosynclinal belt in western Nevada and from the Antler Peak orogenic belt of central Nevada. The sediments appear to represent both deep water and shallow water environments. Maxfield (1957, p. 15) interpreted cyclic sediments of marine limestone, shale, cross-bedded sandstone and thin dolomite beds as representing marine through beach deposits with some possible intratidal dolomite present. Maxfield's study was in the Morrowan part of the Oquirrh Formation. Trace fossils, conodont occurrences, and fluxoturbidites are used by Chamberlain and Clark (1973, p. 675) as evidence for deep water deposition of the Wolfcampian portion of the Oquirrh Formation. This variance suggests that there was a progressive subsidence during deposition of the Oquirrh Formation.

Kirkman Limestone.—Baker and Williams (1940) proposed this name for a sequence of gray to black fetid limestone found in the right fork of Hobble Creek near Springville, Utah. They reported that this unit has a maximum thickness of 1,590 feet in Hobble Creek Canyon and that it thins to a minimum thickness of 75 feet in Spanish Fork Canyon. This drastic change in thickness may be due to paleo relief on the Oquirrh Formation during deposition of the Kirkman Limestone. This hypothesis implies an unconformity at the Kirkman Limestone—Oquirrh Formation contact (Baker, 1947). The Kirkman is overlain conformably (?) by the Diamond Creek Sandstone.

Within the mapped area the Kirkman Limestone forms strike valleys and minor ridges parallel to the Oquirrh Formation in the northwest corner of the map. A complete measured section (see Appendix) was 292 feet thick and composed of limestone and intraformational breccia. The intraformational breccia includes contorted dark gray laminated limestone and pinkish gray, coarsely crystalline limestone. This intraformational breccia is believed to be a collapse breccia. The limestone beds are composed of pinkish gray sandy limestone.

The dark limestone of the Kirkman Limestone represents marine deposition in a shallow, stagnant basin, as evidenced by dark color, lutaceous texture, and fetid odor (Harris, 1953, p. 23). This formation is upper Wolfcampian (Hintze, 1973, p. 50). Fossils include bryozoans, brachiopods, and crinoid stems.

Diamond Creek Sandstone.—Baker and Williams (1940) proposed this name for a thick Permian sandstone found near the head of Little Diamond Creek, Utah County. It is underlain conformably (?) by the Kirkman Limestone and overlain conformably by the Park City Formation. Diamond Creek Sandstone forms rounded cliffs in the northwest corner of the mapped area.

The Diamond Creek Sandstone was measured and described (see Appendix) by the writer and found to be 901 feet thick. The lower contact is covered, but a suggestion of possible interfingering with the Kirkman Limestone was observed. This section is composed of pink to white, fine- to medium-grained sandstone with calcite cement. The bedding is thin to massive, cross-bedding is common, and some horizontal bedding is present. This unit is generally friable. There were no fossils.

Regionally, Diamond Creek Sandstone thins to the northeast from a maximum thickness of 1,140 feet near Castilla to 165 feet in North Strawberry Valley(Bissell, 1952, p. 589). It correlates with the Weber Sandstone of northeastern Utah and is contemporaneous with Cedar Mesa Sandstone of the San Rafael Swell (Hintze, 1973, p. 50).

Park City Formation.—This formation was first proposed by Boutwell (1907) for economically important ore-localizing carbonate rocks of the Park City mining district, Utah. Later work by Baker and Williams (1940) established its regional extent and assigned it to the Permian. McKelvey and others (1956, p. 2842) recognized three units in the Park City Formation and named the upper unit the Franson Member. It was separated from the lower member (at that time unnamed) by a black phosphatic shale member, the Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation. Cheney (1959, p. 12) later gave the name Grandeur to the lower member. For simplicity the units are mapped by the writer as upper, middle, and lower Park City, with an explanation in the map legend.

Park City Formation crops out as a major chain of hills in the northwest portion of the mapped area. Typical exposures are steep slopes and rounded cliffs. The section measured by the writer (see Appendix) in Little Diamond Creek Canyon was overlain unconformably by Tertiary conglomerates. Southward in the vicinity of Diamond Fork—Spanish Fork junction, Triassic Woodside Formation overlies the Park City Formation with angular discordance. The total thickness measured is 1,642 feet, with the thickness of the subdivisions shown in Text-figure 3. The Grandeur Member consists of light brown to light gray limestone with white chert nodules. Brachiopod fossils and crinoids are very common near the top of the member. The Meade Peak Tongue consists of a basal, pasichnia burrowed, oolitic phosphate bed overlain by black shale. Some limestone was found with black chert nodules near the top. This member yielded oil and gas shows when drilled in 1942 in the Diamond Fork Anticline. The Franson Member is composed of light brown limestone with some chert. Brachiopods are common near the base. Generally, the limestone above and below the Meade Peak Tongue become slightly pinkish and very fossiliferous just at the contact with the Meade Peak Tongue.

The Franson Member and Grandeur Member represent shallow marine limestone and the Meade Peak Tongue is slightly deeper marine, where cold water, rich in nutrients, upwelled over shoals causing precipitation of phosphate (McKelvey, 1959, p. 24; Sheldon, and other, 1967, p. 12).

Regionally, the Franson Member is contemporaneous with the Kaibab Limestone. The Meade Peak Tongue is part of the Phosphoria Formation, and the Grandeur is equivalent to the Toroweap Formation (Hintze, 1973, p. 50).

Triassic System

Woodside Shale.—The type section of the Woodside Shale at Woodside Gulch in the Park City mining district (Boutwell, 1907) is composed of moderate red to reddish brown shale, siltstone, and very fine-grained sandstone. Boutwell designated this formation as Triassic based on its unconformable position above the Permian Park City Formation and its conformable position below the Triassic Thaynes Limestone.

In the mapped area the Woodside Shale forms a narrow strike valley between the Park City Formation and Thaynes Limestone from Spanish Fork Canyon eastward about two miles, to where a fault intersects the shale. Small exposures of Woodside Shale are seen in roadcuts near the junction of Diamond Creek and Spanish Fork Canyons. At this junction, its thickness was estimated to be less than 50 feet. The thinness of this sequence may be due in part to bedding-plane faulting. To the northwest it correlates with the Lower Thaynes Limestone and Dinwoody Formation and to the east with the lowermost Moenkopi Formation.

Thaynes Formation.—The name Thaynes Formation was proposed by Boutwell (1907) for exposures of limestone, calcareous sandstone, sandstone, and shale between the Ankareh and Woodside Formations in Thaynes Canyon, Park City District, Utah. Kummel (1954, p. 171) defined the regional extent and correlations. He assigned this sequence to Lower Triassic based on the presence of *Meekoceras* in the basal limestone.

The Thaynes Formation within the mapped area forms moderate hills along the crest of an anticline on the west central portion of the map just north of Diamond Fork Canyon and in the center of the Diamond Fork Anticline located in Red Hollow. The writer measured Thaynes exposures along Spanish Fork and Diamond Fork Canyons (see Appendix). The possibility of error due to folding and faulting is believed to be minimal. The contacts are gradational. The section is composed of grayish yellow to reddish brown limestone, pink sandy limestone to pink calcareous sandstone, and red to green shale. The total thickness is 1,140 feet. The sequence represents fluctuations from tidal flat to shallow marine. Fossils include crinoids, bivalves, and sponges.

The greatest thickness of the Thaynes Formation is found in western Wyoming. From Wyoming the Thaynes Formation thins to the east and southeast. The *Meekoceras*-bearing basal limestone does not occur in the mapped area but is replaced by the Woodside Shale (Kummell, 1954, p. 172), inferring a slightly more continental section locally than is encountered farther north. The Thaynes Formation correlates with the Moenkopi to the east (Kummell, 1954, p. 174).

Ankareh Shale.—Boutwell (1907) proposed the name Ankareh Shale to designate the red shale between the Nugget Sandstone and the Thaynes Formation found at Ankareh Ridge, Park City District, Utah. The Ankareh Shale is generally accepted as Lower and Upper Triassic.

Within the mapped area the Ankareh Shale forms a valley with low hills in the Diamond Fork Anticline in Red Hollow, and a valley between the Thaynes and Nugget Formations near Thistle. A 1,399-foot-thick section was measured along Spanish Fork Canyon beginning at the Diamond Fork junction and proceeding southward to the Nugget contact (see Appendix). Both the lower and upper contacts appear gradational. This section grades from red shale at the base to red siltstone with interbedded sandstone to thick sandstone interbedded with siltstone at the top. The thick sandstone beds are cross-bedded, the thin beds are tabular with oscillation ripple marks. The upper contact was drawn at the top of the last siltstone below the massive, cross-bedded Nugget Sandstone.

The lower Ankareh Formation correlates with the upper Moenkopi Formation, and the upper Ankareh Formation correlates with the Chinle Formation (Hintze, 1973, p. 56).

Triassic-Jurassic

Nugget Sandstone.—Veatch (1907) proposed the name Nugget Sandstone for a sequence of red shale which grades upward to thick sandstone that occurs between the Thaynes Formation and Twin Creek Limestone at Nugget Station, Lincoln County, Wyoming. The lower red shale correlates with what Boutwell described as Ankareh Formation. In Utah what is mapped as Nugget Sandstone is equivalent to Veatch's Upper Nugget Sandstone Member. This restricted Nugget Sandstone bounded below by Ankareh Formation and above by Twin Creek Limestone has generally been accepted as the Nugget Sandstone, although the exact lower boundary is not always obvious (Pipiringos, 1957, p. 8). Early workers placed the Nugget Sandstone in the Jurassic, but recent studies (Lewis and others, 1961) place the Triassic—Jurassic contact within the Nugget Sandstone.

Nugget Sandstone forms a prominent hogback from Thistle north to Diamond Fork Canyon and forms cliffs near Monks Hollow. The Nugget Sandstone consists of red to grayish yellow, medium- to coarse-grained, cross-bedded sandstone. The red color is associated with the finer-grained portions of the formation. If the red color is primary, then the coarser units are leached; if the red color is secondary, then the finer sediments have acted as a filter and trapped the iron oxides from percolating ground water. Near Thistle, the total thickness of the Nugget Sandstone was measured by Baker (1947) at 1,450 feet and by Peterson (1952) at 1,390 feet.

This eolian sandstone deposit is widespread, and is being called Nugget Sandstone in Wyoming, Colorado, and northern Utah, Navajo Sandstone in southern Utah and Arizona, and Aztec Sandstone in Nevada.

Jurassic System

Twin Creek Limestone.—Veatch (1907) proposed the name Twin Creek Limestone for rocks occurring at Twin Creek, Lincoln County, Wyoming. This formation was divided into members with detailed information on regional extent, trends, and depositional environments by Imlay (1967). The age of the Twin Creek Limestone ranges from Middle or Late Bajocian through Bathonian to Callovian, based on ammonite occurrences (Imlay, 1967, p. 3).

Within the mapped area the Twin Creek Limestone forms a hogback that extends from Thistle Junction to east of the Diamond Fork-Spanish Fork junction. It forms rounded hills in the vicinity of Monks Hollow. A complete section (see Appendix) 1,842 feet thick was measured in Sam's Canyon just west of Monks Hollow, and a partial section of the upper 400 feet was measured, where better exposed, in Monks Hollow. Paleoecology of the Twin Creek Limestone near Thistle was described by Bullock (1965). Twin

Creek Limestone conformably overlies the Nugget Sandstone and interfingers with the Entrada Sandstone above. The upper contact was drawn at the top of the uppermost grayish green shale, which contrasts with the reddish brown mudstone of the Entrada Sandstone. Imlay (1967) divided the Twin Creek Limestone into seven members. A general description of each member and its thickness as measured by the writer within the mapped area follows in descending order.

7. Giraffe Creek Member, 287 feet, is composed of light grayish green shale and mudstone interbedded with minor thin beds of light green to light grayish yellow calcareous siltstone and calcareous sandstone. It forms slopes with minor ledges.
6. Leeds Creek Member, 534 feet, is composed of gray calcareous shale interbedded with major sequences of thin bedded, grayish yellow to light brown, calcareous sandstone. Some thin beds of limestone are present. It forms a slope with rounded ledges.
5. Watton Canyon Member, 366 feet, is composed of reddish shale and siltstone with minor greenish shale interbedded with grayish green calcareous sandstone. A thick sequence of gray green to brown micrite is also present. The micrite limestone increases near the base and forms rounded cliffs. The upper portion is dominantly red shale forming slopes with grayish yellow sandstone ledges.
4. Boundary Ridge Member, 200 feet, is composed of gray green shale and gray green splintery micrite. It forms slopes.
3. Rich Member, 351 feet, is composed of interbedded gray green limestone and shale with the limestone becoming medium brown near the base. It forms a ledge-slope sequence.
2. Sliderock Member, 65 feet, is composed of dark brown to light brown oolitic limestone, micritic limestone, and gastropod hash, coquina limestone. Some sandy limestone is present. It forms thick ledges to rounded cliffs.
1. Gypsum Spring Member, 39 feet, is composed of red calcareous shale and siltstone near the top and pink, thick-bedded, slightly calcareous sandstone near the base. Crinoids are present. The base forms a cliff and the top forms a reddish slope.

Generally the Twin Creek represents deposition in shallow marine water. Most of the upper sequence was deposited in an evaporite basin as attested to by gypsum found in the float from upper Twin Creek Limestone and in fractures in the overlying Entrada Sandstone. Farther south in central Utah thick deposits of Jurassic salt are found in the Arapian Formation, which correlates with the upper Twin Creek Limestone. The Twin Creek Limestone correlates with the Carmel Formation in southwestern Utah (Hintze, 1973, p. 62).

Entrada Sandstone.—Entrada Sandstone was proposed by Gilluly and Reeside (1926) for dark red, fine-grained, earthy sandstone at Entrada Point in the northern part of the San Rafael Swell, Utah. The Entrada Sandstone has been designated as upper Jurassic (Gilluly and Reeside, 1927).

Entrada Sandstone crops out in Monks Hollow, and forms rounded hills with covered slopes. Best exposures are found in gullies where erosion has been rapid. The section measured in Monks Hollow (see Appendix) is 975 feet thick. Both contacts are gradational. The section is composed of dusky to moderately red mudstone and siltstone, interbedded with fine to coarse, light pink sandstone. Shale is commonly variegated and the sandstone is friable. Some channel-filled sandstone lenses occur near the middle of the formation. Cross-bedding is common in coarser sandstone, ripple marks are common in siltstone. The formation forms slopes with rounded ledges.

Entrada Sandstone is correlated with the Preuss Sandstone in northern Utah (Thomas and Krueger, 1946).

Curtis Formation.—Gilluly and Reeside (1926) proposed the name Curtis Formation for a greenish gray glauconitic conglomerate, sandstone, and shale sequence near Curtis Point on the northern side of the San Rafael Swell, Utah. The formation is overlain by the Summerville Formation and underlain by the Entrada Sandstone. Upper Jurassic marine fossils are contained in these beds.

Within the mapped area the Curtis Formation forms a shelf slope above the Entrada Sandstone in Monks Hollow. The section measured in Monks Hollow (see Appendix) is 300 feet thick and is composed of green to gray mudstone and shale with minor dusky red mudstone. Both contacts are gradational. Baker (1947) reports a few fossils from this locality near the top of the formation. The writer found no fossils.

Curtis Formation represents a transgression of the Jurassic sea. It correlates with the Stump Formation of northern Utah (Hintze, 1973, p. 62).

Summerville Formation.—Gilluly and Reeside (1926) proposed Summerville Formation for alternating beds of dusky red gypsiferous mudstone and laminated sandstone near Summerville Point at the north end of the San Rafael Swell, Utah. Age designation, based on stratigraphic position, is Upper Jurassic.

The unit called Summerville (?) Formation in the Billies Mountain quadrangle is a 395-foot-thick sequence of red orange mudstone, shale, siltstone, and sandstone above the Curtis Formation and below the Morrison Formation as exposed in Monks Hollow (see Appendix). Contact with the Curtis Formation is conformable. Contact with the Morrison Formation is gradational. The upper contact was mapped at the color change and the lithology change from red orange shale and siltstone of the Summerville Formation to the dusky red mudstone of the Morrison Formation. This sequence forms a steep slope with exposures occurring in stream gullies. These sediments, based on their position above the Curtis Formation and below the Morrison Formation, are late Jurassic.

Morrison Formation.—The Morrison Formation was named by G. H. Eldridge but it was described prior to that time by W. Cross (Keroher, 1966, p. 2595). This formation consists of lenticular sandstone, limestone, and shale near Morrison, Jefferson County, Colorado. Dinosaur remains date this formation as Upper Jurassic. The Billies Mountain quadrangle contains the westernmost occurrence of the Morrison Formation at this latitude. Local outcrops of the Morrison Formation are found in Monks Hollow and south of the mapped area on U.S. Highway 50-6, east of Thistle. Pinnell (1972, p. 98) found dinosaur bone fragments at the latter locality. A 465-foot-thick section on the east side of Monks Hollow (see Appendix) contains dusky red mudstone which grades upward into moderate yellowish orange to gray sandstone and conglomerate at the top. The conglomerate beds are composed of rocks ranging in size from cobbles to boulders, which are mostly hard sandstone and quartzite, but include some limestone clasts that were derived from Paleozoic rocks. Algal balls were found at the head of Brimhall Canyon, in the uppermost exposure of the Morrison Formation. Algal balls are also found in the Morrison Formation exposure east of Thistle on U. S. Highway 50-6. The Morrison Formation is underlain conformably by the Summerville (?) Formation and overlain unconformably by a Cretaceous conglomerate. The Morrison Formation typically forms slopes and rounded ledges. However in Monks Hollow, where slumping occurs, the unit forms a steplike topography. The regional extent of the Morrison Formation is outlined by Hintze (1973, p. 65).

Cretaceous System

Upper Cretaceous Conglomerate.—Cretaceous rocks overlie the Morrison Formation disconformably in Monks Hollow and are exposed in angular discordance below Tertiary conglomerates to the south in Chicken Hollow and Long Hollow (Pl. 1, fig 2). In Monks Hollow the Cretaceous conglomerate is distinguished from the Morrison Formation by a slope change and lithology contrast. The Cretaceous conglomerate is slightly harder, forming a rounded ledge capping the Morrison Formation. The lithology of the Cretaceous conglomerate is sandstone cobbles with white, medium- to coarse-grained matrix, whereas the lithology of the Morrison Formation includes quartzite and limestone cobbles in addition to the sandstone cobbles. The matrix of the Morrison is often purplish.

In contrast to the Cretaceous conglomerate overlying the Morrison Formation in Monks Hollow, a Cretaceous sandstone overlies the Morrison Formation in the exposure east of Thistle. The difference in lithology between the two Cretaceous rock outcrops overlying the Morrison Formation is believed to be due to a variance in the age of the two Cretaceous rock exposures. The Cretaceous rocks exposed in Long Hollow appear to overlie the marine sandstone outcrop east of Thistle and to grade upward into the Cretaceous outcrops found in Monks Hollow. From this relationship, it is believed that the outcrop in Monks Hollow is late Upper Cretaceous, possibly a Price River Formation equivalent, whereas the exposure east of Thistle is early Upper Cretaceous, possibly an Indianola Formation equivalent. The majority of the Cretaceous conglomerate is believed to be equivalent to the Indianola Formation. The Cretaceous conglomerate and older rocks were folded during Sevier tectonism, as evidenced by the angular discordance between the Cretaceous rocks and the younger strata. South of the mapped area, Pinnell (1973, p. 100-101) mapped an unconformity between the Price River Formation and the Indianola Formation. This unconformity cannot be identified within the mapped Cretaceous conglomerate. However, the lack of this unconformity could be due to the exposures occurring along the crest of a large anticlinal structure where the variation in dip is slight. Lithology contrast between the lower and upper portions of the Cretaceous conglomerate are slight, indicating similar source material. A few miles south of the mapped area the attitude and composition of Price River Formation and Indianola Formation vary sufficiently to distinguish them (Pinnell, 1973). Of the 1,250-foot-thick section measured in Long Hollow (see Appendix) the upper unit is slightly grayer and more massive than the underlying units. This upper unit may grade southward into the well-defined Price River Formation. The Cretaceous rock below this upper unit is composed of sandy limestone to calcareous sandstone at the base and grades upward to interbedded conglomerate and sandstone with some red

PLATE 1

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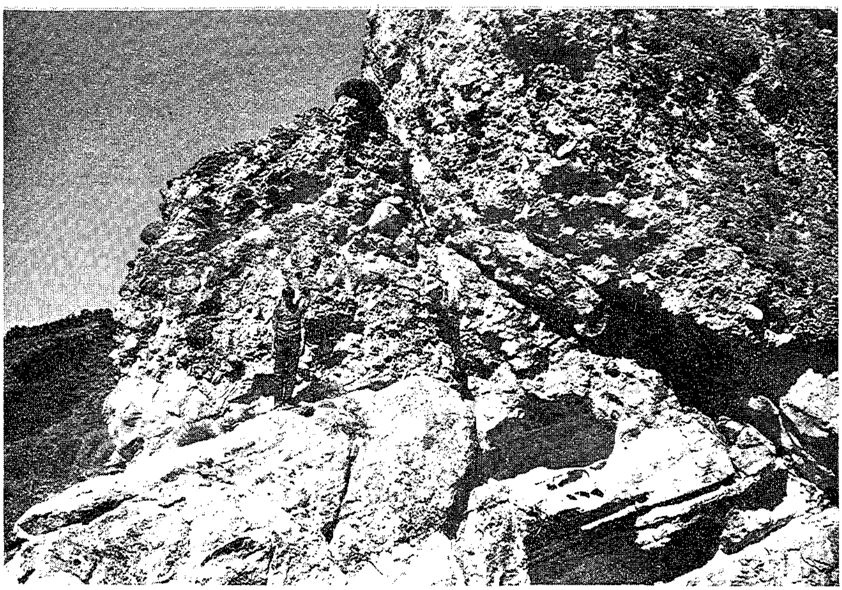

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EXPLANATION OF PLATE 1

FIG. 1.—East dipping, imbricate stream channels in the Red Narrows Conglomerate exposed in Red Narrows Canyon.

FIG. 2.—Angular unconformity between Red Narrows Conglomerate and underlying Cretaceous sandstone and conglomerate. Exposure taken at head of Long Hollow.

shale and siltstone near the top. This lower portion is believed mostly equivalent to the Indianola Formation.

The Indianola Formation was proposed by Schoff (1938) for a thick sequence of conglomerate, sandstone, shale, and some limestone exposed in the Indianola area of central Utah. There it is underlain by either Arapien Shale or Morrison Formation and overlain by Price River Formation. The Indianola Formation is assigned to Upper Cretaceous.

The Price River Formation was proposed by Spieker and Reeside (1925) for a sequence of buff to gray sandstone and conglomerate found in Price River Canyon, Utah. It is overlain by North Horn Formation and underlain by Blackhawk Formation. Speiker (1946) dated the Price River Formation late Montanan.

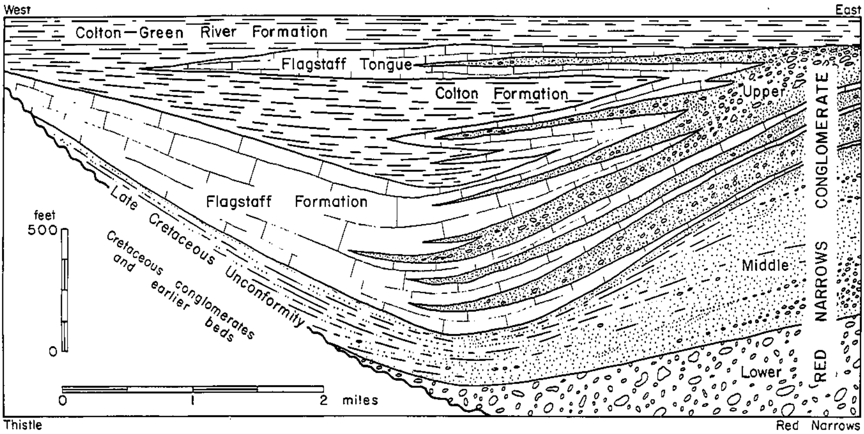
The fossiliferous marine sandstone overlying the Morrison Formation east of Thistle differs from the fossiliferous sandstone found 250 feet above the base of the measured section in Long Hollow by being cleaner, finer grained, and more calcareous. Both contain bivalve molds, but those in Long Hollow also contain some reed remains. Lithology and fossil remains indicate the marine sandstone outcrop in Long Hollow is more continental that the marine sandstone outcrop east of Thistle. From this the following conclusions were formed: (1) lowermost exposed Cretaceous marine sandstone east of Thistle is older and represents a more extensive marine transgression than the marine outcrop in Long Hollow; (2) the Cretaceous section becomes progressively more continental upwards; (3) Cretaceous rocks were deposited contemporaneously with folding; and (4) younger Cretaceous rocks wedge out against western Sevier highlands. Based on the suspected correlation of the Cretaceous conglomerate to the Indianola Formation and Price River Formation, the mapped Cretaceous conglomerate probably ranges from Coloradoan through Montanan.

Upper Cretaceous—Paleocene

Red Narrows Conglomerate (*new formation*).—A 1,400-foot conglomerate sequence with interbedded sandstone, siltstone, and shale, predominantly red to reddish brown, is exposed from Red Narrows Canyon east of Thistle to the summit of Teat Mountain, two miles north of the canyon. The correlation of this sequence has been the center of much controversy. The sequence has been placed in the Wasatch Formation (Moore, 1933, p. 537), Price River Formation (Spieker, 1946, p. 131), North Horn Formation (Boyd, 1959), and Bennion Creek Formation (Moussa, 1965). Merrill (1972, p. 76-8) outlines the chronology of this controversy.

Detailed mapping of the conglomerate in and north of Red Narrows Canyon reveals that the strata in question rests unconformably on older Cretaceous rocks, probably an Indianola Formation equivalent (Pl. 1, fig. 2). The portion of the conglomerate immediately overlying this unconformity is light gray to yellowish gray. This conglomerate interfingers eastward with a reddish brown conglomerate. The light-colored conglomerate has some similarity to the Price River Formation outcrops to the south of the mapped area. The writer believes that this lowermost conglomerate is equivalent to the upper Price River Formation.

The youngest exposures of the conglomerate sequence of Red Narrows Canyon are found on the summit of Teat Mountain. At this location the for-



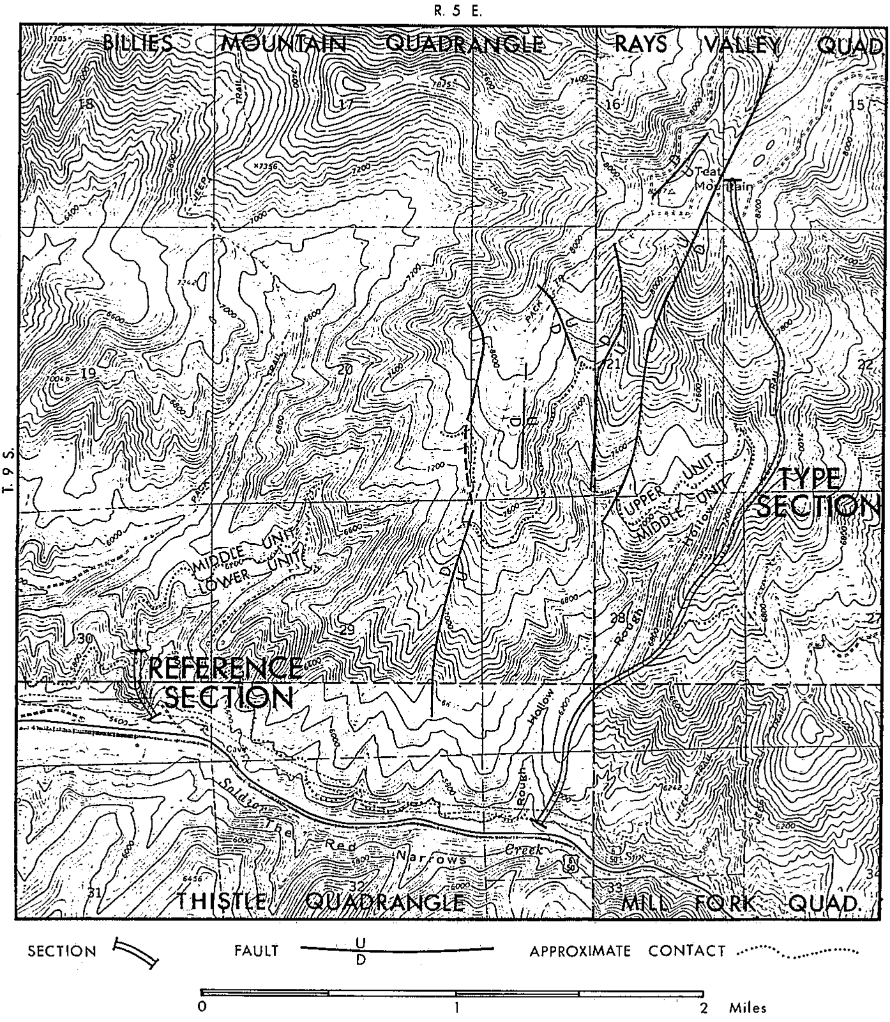
TEXT-FIGURE 5.—Schematic cross section showing the interfingering of the Flagstaff Formation with Red Narrows Conglomerate below and Colton Formation above.

mation is composed of interbedded light-colored conglomerates, reddish siltstone, and limestone beds. A series of sections studied outward from Teat mountain reveals significant amounts of conglomerate in the mountain-flanking Flagstaff Limestone outcrops. As the studied sections increased in distance from Teat Mountain the conglomerate content decreased (Text-fig. 5). These sections reflected the intertonguing of the upper portion of this conglomerate sequence with the Flagstaff Limestone. This implies that the conglomerate in Red Narrows Canyon represents a coarse clastic sequence from upper Price River Formation through North Horn Formation and into the Flagstaff Limestone.

The stratigraphic range of the exposure in Red Narrows Canyon plus the dominant conglomerate lithology of the sequence separates it from the Price River Formation, North Horn Formation, and Flagstaff Limestone. Bennion Creek Formation, proposed by Moussa for a conglomerate outcrop in Bennion Creek, was restricted to rocks unconformable above the Price River Formation and unconformable below the North Horn Formation. Bennion Creek Formation is therefore too restricted to apply to the sequence found in Red Narrows Canyon.

In order to provide a base for meaningful correlations it is proposed that a new name, Red Narrows Conglomerate, be assigned to the sequence of strata exposed in Red Narrows. Red Narrows Canyon is in the northeast corner of the Thistle quadrangle, Utah County. Locally the conglomerate is divided into three units. The lower unit is massive conglomerate. The middle unit is interbedded conglomerate-filled channels, sandstone, and shale. The upper unit is interbedded conglomerate, sandstone, shale, and limestone. Although this threefold division is obscured where local relief is less, the divisions clarify the stratigraphic relationship of Red Narrows Conglomerate to adjacent formations.

The top of the type section begins at the top of the exposed sequence, about 300 yards east of the summit of Teat Mountain (NW$\frac{1}{4}$, SW$\frac{1}{4}$, SW$\frac{1}{4}$,



TEXT-FIGURE 6.—Index map to Type Section of Red Narrows Conglomerate.

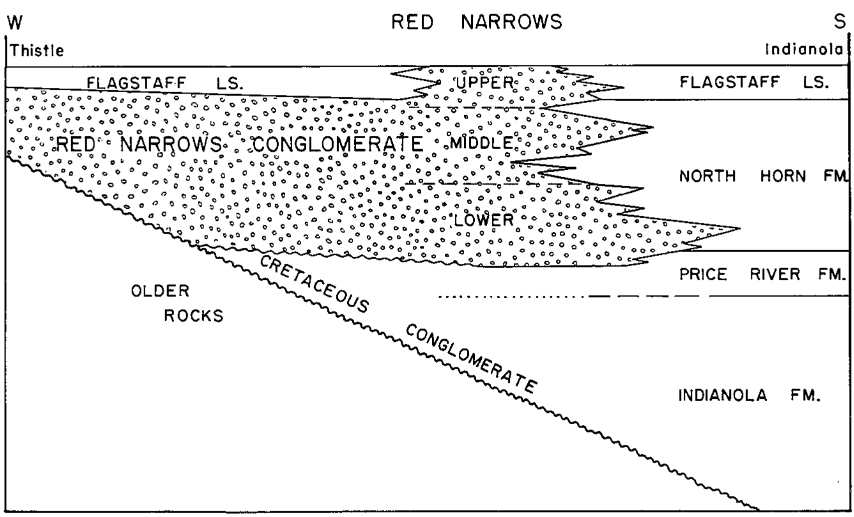
Section 15, R. 5 E, T. 9 S). The section follows the ridge crest on the east side of Rough Hollow down to U.S. Highway 50-6 (NE$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, Section 33, R. 5 E, T. 9 S; Text-fig. 6). The type section spans the upper and middle units of Red Narrows Conglomerate. A reference section for the lower unit is established at the west end of Red Narrows Canyon in Section 30, R. 5 E, T. 9 S (top in NE$\frac{1}{4}$, NW$\frac{1}{4}$, SE$\frac{1}{4}$; bottom in NE$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$; Text-fig. 6; see Appendix).

The lower unit of Red Narrows Conglomerate lies angularly unconformable on older Cretaceous conglomerate (Pl. 1, fig. 2). Exposures of this contact are found in Long Hollow and in the hollow of the reference section. The lower unit can be subdivided into two parts. The basal portion which overlies the unconformity is a massive conglomerate, very light gray to grayish yellow, containing well-rounded sandstone and quartzite cobbles. Minor amounts of interbedded reddish brown lenticular bodies of sandstone, siltstone, and shale are present. The upper portion of the lower unit is also a massive conglomerate. This upper portion is red to light gray, containing well-rounded sandstone, quartzite, and limestone cobbles and boulders. Reddish lenticular bodies of sandstone, siltstone, and shale are much more common in this upper portion than in the lower portion. The light-colored basal portion may be locally derived from the underlying Cretaceous conglomerate. The increased reddish tone in the upper portion is due in part to stain derived from the overlying and interbedded finger-grained clastic beds. The light-colored basal conglomerate of the lower unit grades upward and eastward into the reddish upper portion of the lower unit. This lower unit has an estimated thickness of 400 feet and forms massive cliffs.

The lower unit is correlated with the upper Price River Formation based on its position above a Cretaceous conglomerate believed to be equivalent to the Indianola Formation, and on a similarity in lithology of the basal portion of the lower unit with Price River Formation outcrops to the south of the mapped area (Text-fig. 7). This unit is overlain conformably by the middle unit.

The middle unit consists of conglomerate-filled channels at the base, grading upward into pink sandstone, red siltstone, and red shale. Occasional conglomerate-filled channels are interbedded in the upper half of this unit. The lower channels are stacked in imbricate fashion with the younger channels migrating to the east. (Pl. 1, fig. 1). This middle unit is overlain conformably by the upper unit. The middle unit has an estimated thickness of 690 feet, and forms a ledge-slope sequence at the base and long slopes in the upper half.

The middle unit is correlated with the North Horn Formation based on stratigraphic position and lithology. The stratigraphic position is above rocks

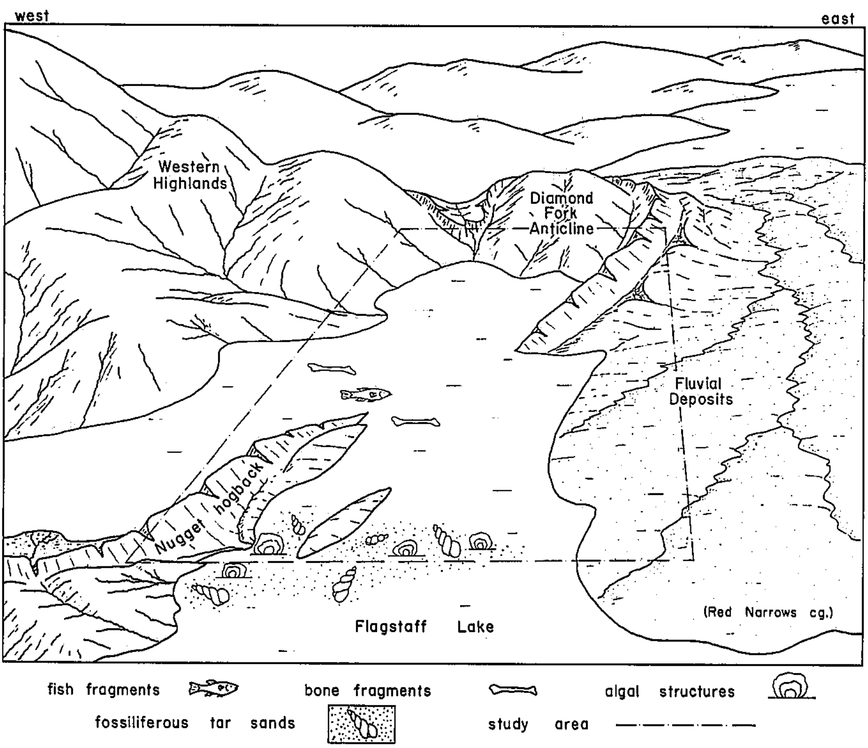


TEXT-FIGURE 7.—Correlation chart of Red Narrows Conglomerate to adjacent formations.

believed to correlate with the Price River Formation and below rocks correlated with the Flagstaff Limestone. The major lithological difference in this middle unit and the lower unit is a marked increase in the percent of sandstone, siltstone, and shale. This increase is attributed to intertonguing with the North Horn Formation (Text-fig. 7). This correlation puts the Cretaceous—Tertiary boundary within this middle unit.

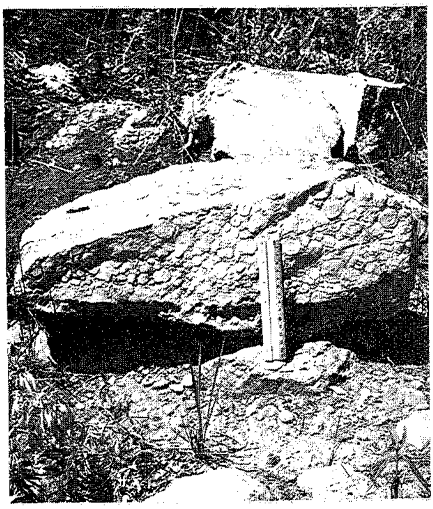
The upper unit conformably overlies the middle unit. The contact is drawn at the first major limestone bed encountered as one measures up-section. In the type section this first bed was 5 feet thick, pink to pinkish gray. The upper unit consists of interbedded conglomerate, red to pink calcareous sandstone, reddish shale, and light gray to pinkish limestone. The cobbles are composed of sandstone, limestone, and quartzite. The limestone beds are finely to coarsely crystalline and often contain oncolites (Pl. 2, fig. 1). Lacustrine deposition mingled with fan deposition is distinctive of this unit. At the type locality no rocks overlie this unit. However, eastward from Teat Mountain this unit appears to interfinger with the Flagstaff Limestone (Text-fig. 8). This unit has an estimated thickness of 380 feet and forms a slope with rounded conglomerate and limestone ledges. It is correlated with the Flagstaff Limestone based on their intertonguing relationship (Text-fig. 7).

The Red Narrows Conglomerate represents the site of active coarse con-



TEXT-FIGURE 8.—Early Tertiary paleographic map of study area.

PLATE 2



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EXPLANATION OF PLATE 2

Fig. 1—Algal balls found in Red Narrows Conglomerate.
Fig. 2.—Large algal ball occurring in Flagstaff Formation near Thistle, Utah.
Fig. 3.—Algal mound found in Flagstaff Limestone near Thistle, Utah.

glomerate accumulation, probably Upper Cretaceous (Maestrichtian) to Paleocene alluvial fan deposits. This formation correlates with upper Price River Formation, North Horn Formation, and lower Flagstaff Limestone. Red Narrows Conglomerate rests against the folded Sevier Mountain belt grading rapidly eastward into finer sediments. Local lacustrine basins are present, as suggested by limestone deposits found in the upper unit. At other localities these limestone beds may be present throughout the entire sequence (Pinnell, 1972, p. 104; Merrill, 1972, p. 83).

A minimum regional extent beyond Billies Mountain quadrangle is at least 10 miles south, comprising what Pinnell (1972) mapped as North Horn Formation, at least 5 miles east, comprising what Merrill (1972) mapped as the Red Narrows facies of the North Horn Formation, and at least 5 miles to the north of Billies Mountain quadrangle. This gives a minimum total extent in the north-south direction of 30 miles and a minimum east-west extent of 15 miles. It is anticipated that future mapping will increase the regional extent of this thick clastic wedge to the south and north along the eastern edge of the Sevier orogenic belt.

Tertiary System

Flagstaff Limestone.—The Flagstaff Limestone was named by Spieker and Reeside (1925) and further defined by Spieker (1946) as gray limestones, shales, and sandstone, with some oil shale at Flagstaff Peak in central eastern Utah. Regionally, the Flagstaff Limestone interfingers with the North Horn Formation below (Spieker, 1946, p. 133) and with the Colton Formation above (LaRocque, 1960, p. 8). LaRocque (1960, p. 73), using molluscan faunas, dated the Flagstaff Limestone as Paleocene to Eocene.

Within the mapped area the Flagstaff Limestone crops out as a prominent cliff between Thistle and Red Narrows. Exposures along Diamond Fork Canyon verify that the Flagstaff Limestone underlies younger Tertiary rock throughout the central graben. On the east side of the graben the Flagstaff Limestone is located on the up-thrown block, where it interfingers with the upper portion of the Red Narrows Conglomerate. The Flagstaff Limestone reappears east of Teat Mountain (Baer, 1969, p. 13). This unit is underlain by the Red Narrows Conglomerate (except where the Red Narrows Conglomerate pinches out against the Nugget Sandstone—Twin Creek Limestone hogback, leaving the Flagstaff Limestone resting in angular discordance on the Nugget Sandstone). The Flagstaff Limestone—Red Narrows Conglomerate contact appears to be conformable throughout the area. Localized slumping, faulting, and folding occasionally give a false impression of angular discordance. The section measured (see Appendix) in Chicken Hollow was 571 feet thick. At Thistle, 282 feet were measured. In Diamond Fork its thickness was approximately 100 feet. The formation is composed of crystalline limestone, oolitic limestone, algal limestone, some tuffaceous limestone, tar bearing coquina, yellowish gray sandstone, gray to red shale, and conglomerate. Ostracods, gastropods, fish scales, and some bone fragments were found.

The Flagstaff Limestone in the study area was deposited in a shallow lacustrine embayment which encroached upon highlands to the west. On the north and east of the mapped area alluvial fan and fluvial sedimentation bounded the embayment (Text-fig. 8). The thickest Flagstaff accumulation in the map area is near Red Narrows; it thins to the west and north. Westward thinning is due to encroachment upon the highlands. Evidence of this is seen where the Flagstaff Limestone overlies Morrison Formation and Twin Creek Limestone hogbacks east of Thistle, and encroaches upon Nugget Sandstone outcrops west of Thistle. The Flagstaff Limestone thickens toward the east and southeast. However, because of thick alluvial fan deposits along the east side of the mapped area, the Flagstaff Limestone interfingers locally with clastic deposits as it thickens to the east (Text-fig. 5, 8). Position of the fan deposits may have been controlled by the resistant units within the Diamond Creek anticlinal structure, which may have guided rivers from the north along its eastern side, shielding the embayment. The water was warm and shallow as attested to by mammal or reptile bone fragments and fish remains found in Diamond Creek, and by algal mounds up to three feet in diameter found near Thistle (Pl. 2, Fig. 2, 3). Tar-rich gastropod coquinas are also found near Thistle.

Regionally, the Flagstaff Limestone becomes thicker to the southeast away from the highlands (Weiss, 1965).

Colton Formation.—The first reference to the Colton Formation was by Walton (1944) even though the formation was only later formally named by Spieker (1946). Spieker applied the name to reddish pink sandstone and shale of variable thicknesses found north of Colton, Utah, at the head of Price Canyon. The sequence interfingers with the overlying Green River Formation and underlying Flagstaff Limestone and is assigned to the Eocene.

In the southern half of the mapped area, a 405-foot sequence of shale, red and reddish purple to brownish green and green, with some gray green shaly limestone near the base, is classified as Colton Formation (see Appendix). This shale and shaly limestone is underlain by the Flagstaff Limestone and overlain by a tongue of the Flagstaff Limestone (described below), which can be traced laterally eastward into the Flagstaff Limestone as the Colton shale pinches out. The atypical color of these sediments is explained by their proximity to the highlands and their deposition in a shallow lacustrine to mud flat basin. In the northern half of the mapped area, the Flagstaff tongue is absent, and no stratum is differentiated as Colton Formation.

Flagstaff Limestone Tongue.—In the southern part of the map, above the Colton Formation and below shale mapped as the Colton-Green River Formation, is a 140-foot sequence (see Appendix for measured section) of light grayish yellow limestone, oolitic limestone, sandy limestone, and some conglomerate which grades laterally eastward into the Flagstaff Limestone proper. Ostracods are present in some of the limestone. Because of their general appearance and the mappable connection with the Flagstaff Limestone, these beds are referred to as Flagstaff Limestone Tongue.

Colton-Green River Formation.—This name is used for a 323-foot sequence of reddish orange and maroon to greenish gray shale interbedded with white tuffaceous limestone (see Appendix). The lower contact in the south half of the mapped area is drawn at the top of Flagstaff Tongue. The lower contact in the northern part of the mapped area is drawn at the top of Flagstaff Limestone. The upper contact is drawn at the top of the 20-foot-thick, white, tuffaceous limestone which contains algal balls. This tuffaceous unit served as a good marker horizon throughout the southern half of the map, but is concealed in the northern half. The Uinta Formation overlies this marker horizon. This sequence is atypical of either the Green River Formation or Colton Formation because of its variable color and lack of sandstone beds. Both names are used because stratigraphic position of the unit indicates it is contemporaneous with both Green River and Colton deposits to the east. These deposits are lacustrine and possibly fluvial. They form slopes with minor limestone ledges.

The Green River Formation was first described by Henry Engelman in 1856 for outcrops near Green River, Wyoming. The formation was named by Hayden and further defined by Bradley (1931), and consists of grayish yellow to brown to green shale, sandstone, and limestone. The Green River Formation is overlain by either Uinta Formation or Bridger Formation and is underlain by either Wasatch Formation, Flagstaff Limestone, or Colton Formation. It is assigned to the lower Eocene (Hintze, 1973, p. 78).

Uinta Formation.—The Uinta Formation was first described by Marsh (1871, p. 196). Lithology, faunal content, and age were clarified by later writers. In the Uinta Basin the formation consists of variegated shale interbedded with gray and grayish yellow sandstone. It overlies the Green River Formation and in turn is overlain by the Duchesne River Formation. The Uinta Formation is assigned to upper Eocene.

In the Billies Mountain quadrangle, rocks assigned to the Uinta Formation form rolling hills in the central graben where they conformably overlie the Colton-Green River Formation. However, near the junction of Diamond Fork and Spanish Fork Canyon the Uinta Formation is resting on the Twin Creek Limestone and Red Narrows Conglomerate. The lack of the Flagstaff Limestone and the unconformable relationship indicates local uplift and erosion prior to deposition of the Uinta Formation. The Uinta Formation is overlain unconformably by Tertiary volcanic rock in the southern half of the quadrangle and is overlain conformably (?) by the Tibble Formation in the northern half. The section measured east of Billies Mountain (see Appendix) is 323 feet thick, consisting of variable-colored shale, mostly reddish but with some green and purple hues, interbedded with minor conglomerate sandstone and limestone. All units are calcareous. Based on the presence of conglomerate and limestone beds, the depositional environment is believed to have been partly lacustrine and partly fluvial.

The Uinta Formation thickens to more than 3,000 feet in the Uinta Basin to the east (Hintze, 1973, p. 144). It is contemporaneous with the Bridger Formation of northeastern Utah, Wyoming, and Colorado (Dana, 1954, p. 419).

Tibble Formation.—Baker and Crittenden (1961) proposed the Tibble Formation for a 2,500-foot sequence of rock exposed near Tibble Fork, North Fork of American Fork Canyon, Utah. There the formation consists of pebble to boulder conglomerate composed of red andesite, Paleozoic quartzite, limestone, and sandstone interbedded with grayish green shale and reddish brown tuffaceous sediments. Lenticular beds of fresh water algal (?) limestone are included. The sequence is interpreted to be chiefly fluvial deposits of boulders of nonvolcanic origin deposited in a shallow basin around which volcanic rocks were accumulating (Baker and Crittenden, 1961). This formation is the youngest of consolidated rocks found in the American Fork Canyon area, and was assigned to the Tertiary (Oligocene?). The formation is believed to be contemporaneous with volcanic rocks deposited near Park City (Baker and Crittenden, 1961).

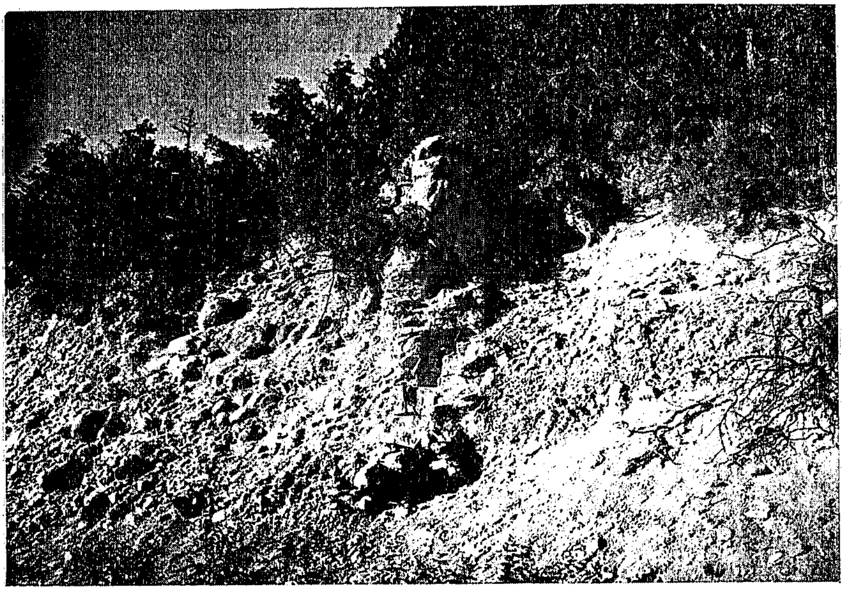
In the mapped area, rocks assigned to the Tibble Formation are located in the northern half of the quadrangle, where they conformably (?) overlie the Uinta Formation. The Tibble Formation appears to be overlain by volcanic ash deposits. The section measured (see Appendix) in Little Diamond Creek Canyon is 518 feet thick and consists of pebble to boulder conglomerate composed of 70 percent Paleozoic rocks and 30 percent red to gray andesite interbedded with tuffaceous sediments, subgraywacke sandstone, shale, and some limestone. Base of the sequence appears to consist of a tuff or tuffaceous limestone about 100 feet thick. These rocks form low foothills with rounded cliffs.

The paleoenvironment is believed to be similar to that described by Baker and Crittenden for the Tibble Formation. This formation is assigned to the early Oligocene because of 1) its position above the Uinta Formation; 2) the first appearance of andesite cobbles; 3) the lithified character of the unit; and 4) its predating of later faulting. In addition to possible contemporaneous units mentioned by Baker and Crittenden, the Bishop Conglomerate mapped by Bissell (1952, p. 616) in Strawberry Valley may correlate with the Tibble Formation.

Pediment Gravel.—A lenticular, white to light pink quartzite conglomerate lies disconformably above the Uinta Formation in the southern portion of the mapped area. This unit is unconsolidated and ranges in thickness from 0 to 25 feet. Clasts appear to be Cambrian or Precambrian quartzite and range in size from pebbles to boulders several feet in diameter. All clasts are very well rounded and strongly pitted. This unit is interpreted as representing a south-sloping pediment surface or stream valley into which later volcanic stream conglomerates were deposited. The assigned age is Oligocene based on the unit's disconformable relationship with the Eocene Uinta Formation.

Oligocene (?) Hot Water Conduit.—The hot water conduit is located about one mile up Wanrhodes Canyon from the Diamond Fork Canyon. This conduit cuts the Tibble Formation. It is fissurelike, expanding from 2 feet wide near the road to 15 feet wide a few hundred yards up the hill to the east (Pl. 3, fig. 1,2). The total length is estimated to be 200 yards. The conduit deposits are zoned with the westernmost zones thicker than the mirror zones on the east side. The outer zone near the country rock is a smear zone composed of conglomerate of the Tibble Formation. All original bedding is lost in the massive, vertical-trending smear zone. This zone is two feet thick on the west, but only one foot thick on the east. The second zone is crystalline calcite which forms a white lining 4 feet thick on the west but only 1.5 feet thick on the east. This calcite zone is composed of a pinkish, silicic, botryoidal crust encasing a mosaic of calcite crystals, some of which are scalenohedrons. No voids were found. The inward calcite walls are smooth. At the road where the conduit thins down toward a probable apex, only the calcite zone is present. The third and innermost zone is 6.5 feet wide and is composed of calcareous, grayish green ash. Xenoliths consisting of reddish andesite are present. Another calcite vein was seen a short distance to the north, up the canyon. Con-

PLATE 3



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EXPLANATION OF PLATE 3

Fig. 1.—Calcite dike found in Wanrhodes Canyon. Represents westward extent of fissurelike hot water conduit illustrated below.

Fig. 2.—Hot water conduit located in Wanrhodes Canyon. The country rock is deformed near the conduit wall. White calcite lines the conduit which is about 15 feet wide. The central portion of the conduit is filled with ash.

duit Oligocene or younger based on the cross-cutting relationship it has with the Tibble Formation.

Oligocene Volcanic Rock.—Volcanic breccia and volcanic tuff and ash beds are mapped in the Billies Mountain quadrangle.

Volcanic breccia occurs near Billies Mountain and near the head of Wanrhodes Canyon. The breccia is composed of white to light gray tuffaceous matrix enclosing angular blocks of andesite and pumice. One outcrop near Billies Mountain appeared bedded but all the others are massive. The deposits are mapped because they may indicate nearby volcanic vents.

Volcanic tuff and ash beds located in the northern half of the mapped area appear to be lenticular or moundlike deposits. A variance of dip was noted where two slightly different ash beds meet near the head of Wanrhodes Canyon. Lenticular conglomerate deposits are common within these ash beds at the head of Wanrhodes Canyon. In contrast to these deposits are the ash beds found near the junction of Wanrhodes Canyon and Diamond Fork Canyon, which are well bedded and finer grained, and contain thin limestone beds reflecting lacustrine deposition. Those at the head of Wanrhodes Canyon reflect a more tectonic-related setting. It is believed this tectonic setting was caused by local volcanism in or near Billies Mountain quadrangle.

Evidences for local volcanism are 1) discordant dips, channeling and lack of lacustrine influence in ash deposits at the head of Wanrhodes Canyon; 2) local hot water conduits indicating thermal activity; and 3) volcanic breccia deposits near the head of Wanrhodes Canyon. A fourth possible evidence is the character of Wanrhodes Basin found at the head of Wanrhodes Canyon. This basin is circular with arcuate faults on the south and east sides. Similar faults are suggested on the north side. Surrounding sediments dip generally toward this basin and volcanic rock fills the basin. These factors may indicate that Wanrhodes Basin is a volcanic caldera and the source of the local volcanism. Volcanic centers developed at Park City, Bingham, and Tintic during the Oligocene, and local volcanism in the Billies Mountain quadrangle is believed to have occurred at about the same time.

Miocene (?) Volcanic Rock.—Stream-lain volcanic conglomerate occurs in the southern half of the mapped area. Unlike the older volcanic rock in the northern part of the mapped area, this deposit appears to be more mafic and is poorly consolidated. Cobbles are well rounded, dark gray andesite interbedded with a dark gray ash matrix. This deposit is channeled into the pediment gravel and into the Uinta Formation. The thickness of the unit is 0 to 200 feet. This volcanic rock unit is questionably assigned a Miocene age based on its individuality and its channeling into Oligocene pediment gravel.

Quaternary System

A variety of Quaternary deposits is found within Billies Mountain quadrangle. Those mapped are discussed below.

Alluvium.—Extensive deposits of alluvium are found along the Diamond Fork River, the Spanish Fork River, and their tributaries. Deposits consist of unconsolidated stream and flood plain gravel, sand, silt, and mud.

Alluvium and Colluvium.—Thick soils that developed from water and gravity action occur extensively throughout the central graben. Typically these deposits are the site of high meadows. These soils were mapped separately because of their areal extent and their importance in future land use.

Fans and Talus Cones.—The alluvial fans occur chiefly along Diamond Fork and Long Hollow. The largest fan-shaped deposit is located one mile up Diamond Fork on the south side of the canyon. This deposit is unique because it is composed of volcanic debris and may be partly landslide material derived from the vicinity of Billies Mountain. Baker (1961) mapped this as a landslide. Small talus cones are found along the hogback of Nugget Sandstone. Both fan and cone deposits are identified by the same map symbol.

Landslides and Slumps.—Landslides and slumps are closely associated in the Billies Mountain quadrangle. Where slumps occur, the toe of the slump is usually expressed as a landslide. The upper portions of the slumps are mapped in the formation in which they occur. The toes are mapped as landslides. Landslides are found in the Uinta Formation along Diamond Fork where soft shale yields and flows during wet months. Major slumpage also occurs in Monks Hollow, where soft shale underlies conglomerate in the Morrison Formation, and north of Thistle, where soft shale underlies the Flagstaff Limestone. Some slumping also occurs in the Flagstaff Limestone along Diamond Fork Canyon and along Spanish Fork Canyon east of Thistle.

Outwash.—Little Diamond Creek Canyon has extensive deposits of glacial outwash. The outwash was produced by Pleistocene alpine glaciers to the west on Spanish Fork Peak. Some moraine material may be present.

STRUCTURAL HISTORY

General Statement

Structural patterns in the mapped area reflect the strong eastward thrust of the Sevier Orogeny with modifications from later uplifts and faulting.

Historical events leading to the present structure of Billies Mountain Quadrangle can be grouped into eight phases: (1) Oquirrh Basin development during the Pennsylvanian and the Permian; (2) shelf deposition on the eastern edge of the geosyncline during the Permian and the Triassic; (3) Jurassic trough development; (4) Sevier orogenic-related tectonism and deposition in early to late Cretaceous; (5) Laramide orogenic-related tectonism and deposition in the late Cretaceous to Eocene; (6) Oligocene andesitic volcanism; (7) Miocene or later Basin and Range uplift and block faulting; and (8) Pleistocene glacial action, stream rejuvenation, and continued Basin-and-Range-type faulting.

Causes of deformation may be explained by relating, first, depositional patterns to a subduction pattern on the west coast; second, by relating Sevier orogenic trends to an interplate reaction; and third, by relating subsequent Laramide uplift and accompanying basins to a period of plate adjustment. Theoretical causes of plate interaction and how the plates adjust (see Armstrong, 1974) is beyond the scope of this paper.

Structural Geology

Folding.—Complex folding in Billies Mountain Quadrangle is the result of three deformational events. The first was uplift and tilting in the late Permian. Second was deformation produced by the Sevier Orogeny in late Jurassic to late Cretaceous time, and third was deformation produced by the Laramide Orogeny in latest Cretaceous to Eocene time.

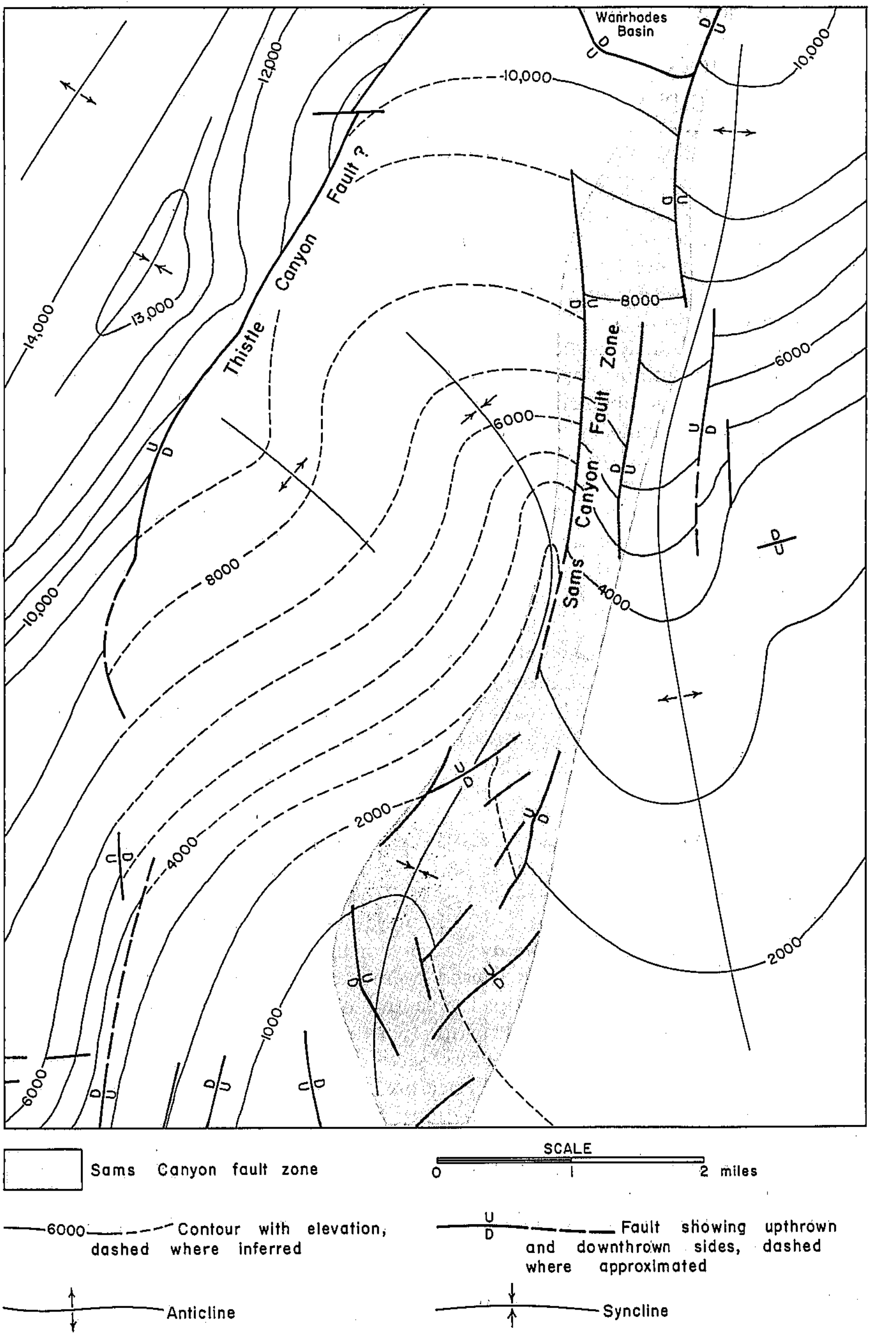
The tilting produced by Permian uplift was probably a broad open fold, but later deformation has obscured this original structure. Evidence for this deformation is the angular unconformity between Permian and Triassic strata and the absence of uppermost Permian strata.

Sevier tectonism in early to late Cretaceous time produced complex folds in Cretaceous and older strata. Overturned folds occur in the Diamond Creek Sandstone in the northeast corner of the map, and in the Thaynes Formation near the mouth of Diamond Fork. Cretaceous marine sandstone units east of Thistle exceed 50-degree dips, and a few miles south they become vertical. These steep folds may indicate close proximity to a thrust plane. Some overturned folds are minor structures on the east limb of a large anticline encompassing the bulk of Spanish Fork Peak on the west side of the mapped area. Another large anticline borders the east edge of the mapped area. Diamond Fork Anticline is part of this latter structure. Evidence for Sevier folding in Early to Late Cretaceous includes (1) the unconformable relationship between Cretaceous conglomerate and overlying Red Narrows Conglomerate and (2) a comparison of form-line contour maps drawn on top of the Nugget Sandstone and the top of the Flagstaff Limestone (Text-fig. 9 and 10). These form-line contour maps indicate extensive deformation prior to deposition of the Flagstaff Limestone.

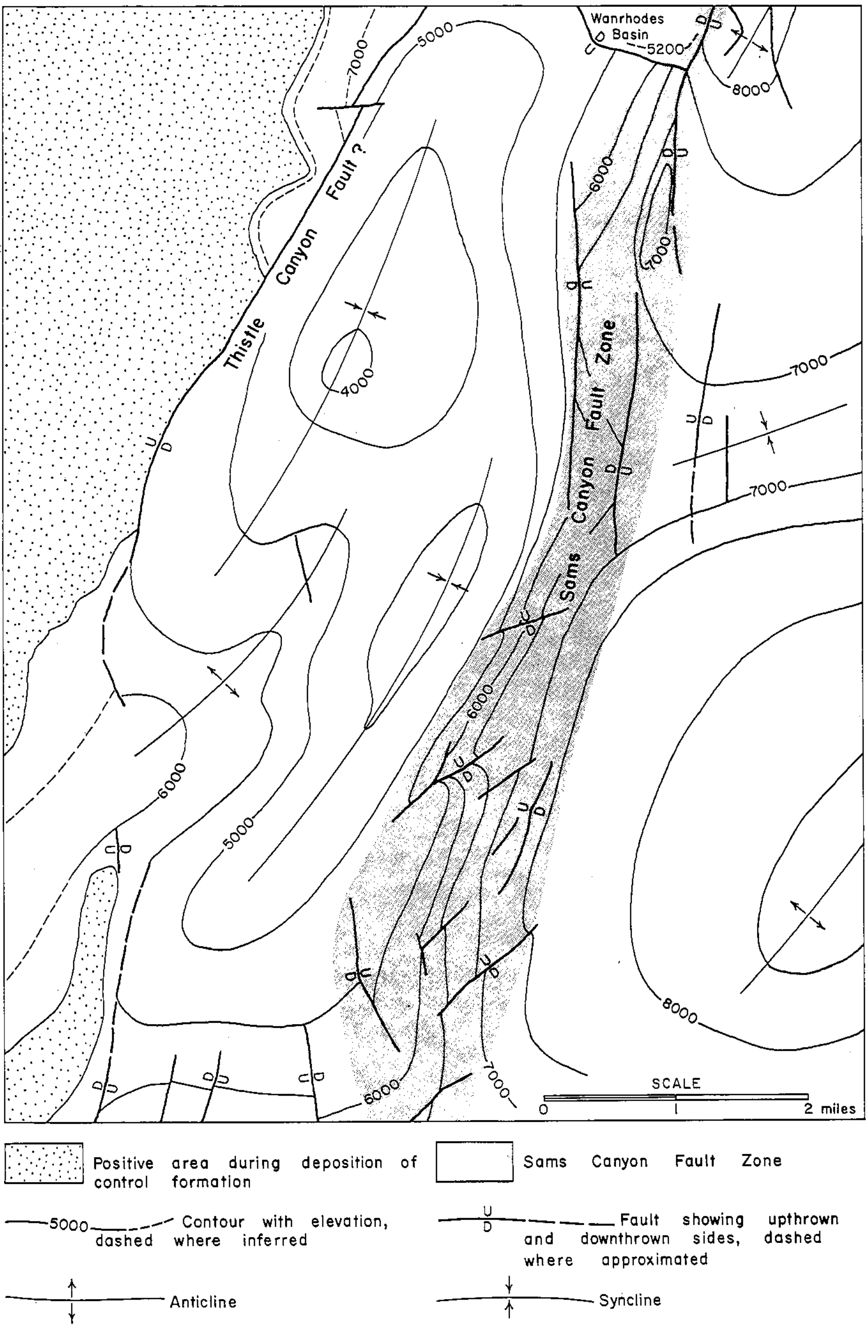
Laramide tectonism in latest Cretaceous through Eocene created broad folds as uplift occurred. Broad folds in the North Horn to Uinta strata give evidence for this tectonism. Deposition and folding were contemporaneous, causing local unconformities near the source areas. The form-line contour map drawn on the top of the Flagstaff attests to the nature of these folds (Text-fig. 10).

Thrusting.—Sevier thrust faults have been mapped to the southwest, on Mount Nebo (Black, 1966), and to the northeast near Strawberry Reservoir (Bissell, 1952 and 1959a). Pinnell (1970, p. 114-115) projects the Strawberry Thrust just east of Billies Mountain quadrangle, with the fault cutting the Thistle quadrangle diagonally from northeast to southwest. Cretaceous folding is believed to have been caused by movement along deep thrusts. Cross sections drawn through the mapped area did not reveal significant changes in formation thickness to suggest thrusting within the upper 2,000 to 3,000 feet of mapped area (see map and cross sections). However, some evidence is suggested for deep seated thrusts. They are (1) overturned strata in Diamond Creek Sandstone and Thaynes Formation; (2) dip change in Cretaceous beds from 24° E at Long Hollow to 54° E at Thistle; and (3) interpretation of electrical logs indicates a repeated section of Twin Creek Limestone in Mountain Fuel Supply Company Thistle Dome no. 1, about five miles to the east of the mapped area. This evidence, plus postulated thrust front by Pinnell, suggests a thrust underlying the mapped area.

East-West Normal Faults.—East-west normal faults are well exposed near Thistle and Monks Hollow. These faults cut Entrada Sandstone and older formations. Poorly defined east-west faults also cut Cretaceous conglomerate in



TEXT-FIGURE 9.—Form-line-structure contour map of Billies Mountain Quadrangle drawn on the top of the Nugget Sandstone (Jurassic). Contour interval equals 1000 feet.



TEXT-FIGURE 10.—Form-line-structure contour map of Billies Mountain Quadrangle drawn on the top of the Flagstaff Formation (Paleocene). Contour interval equals 500 feet.

Chicken Hollow. This faulting is believed to be caused by Sevier tectonism, possibly related to tear fault movement perpendicular to fold axis. These faults normally have less than 100 feet displacement. Their age is Jurassic through Late Cretaceous.

North-South Normal Faults.—Thistle Canyon fault is a continuation of a major fault zone to the south and it accounts for major displacement in the western portion of the map. Within the mapped area the fault lies east of Thistle and continues north along the eastern border of uplifted Paleozoic rocks. This fault is a scissor fault; displacement near Thistle is minor, while near Little Diamond Creek displacement is approximately 2,000 feet. This fault zone near Thistle is composed of three or four faults which seemingly combine into one fault to the north. The Thistle Canyon fault cuts Oligocene sediments but its location is obscure in many of the conglomerate units. A trace of this fault near Thistle is east of the easternmost Twin Creek Limestone outcrop and does not bisect the two Twin Creek Limestone outcrops as previously mapped (Pinnell, 1972). This implies that Flagstaff Limestone is resting undisturbed on Twin Creek Limestone. This fault becomes obscure as it passes into the Miocene (?) volcanic rocks of Billies Mountain. The fault is Oligocene and possibly Miocene.

The name Sam's Canyon fault zone is proposed for north-south faults which are present in the mouth of Sam's Canyon. The dropped block is to the west. Northward the fault cuts the western side of the Diamond Fork anticline. Southward the fault passes beneath Tertiary rocks giving a surface expression of a monocline with 60 degree opposing shear faults. The NNE shear set is composed of high-angle reverse faults. The fault zone appears to be left lateral as evidenced by southward slippage of Flagstaff Limestone on the dropped block east of Billies Mountain. The total displacement is 1,000 feet or more. The fault cuts the Green River Formation and possibly the Uinta Formation. The assigned age is Eocene or younger, and it is associated with either Laramide uplift or Basin and Range faulting.

High-Angle Reverse Faults.—All high-angle reverse faults mapped are related to the Sam's Canyon Fault. They probably were caused by left lateral movement along Sam's Canyon Fault.

Joints and Fractures.—A major fracture pattern is expressed in the Cretaceous conglomerate and its trend (N 5° E) is reflected in stream drainage patterns. Fractures appear to be parallel to the fold axis of the large Mesozoic anticline along the eastern edge of the mapped area. A secondary minor set trends N 80° E.

Nugget Sandstone and Twin Creek Limestone are also extensively fractured. Near Thistle the major fractures appear parallel the north-south faults.

Slumping.—Slumping occurs in exposures of resistant rocks underlain by thick shales. Slump-prone sequences are the Flagstaff Limestone over Red Narrows Conglomerate and Morrison Formation over Summerville-Curtis Formations. Slumps involving the Flagstaff Limestone occur along major drainage areas within the mapped area and west of the mapped area where the Flagstaff-Red Narrows Conglomerate sequence overlies Ankareh Shales. Slumps involving the Morrison Formation occur at the head of Monks Hollow.

Major Events

Oquirrh Basin.—The oldest rocks exposed in Billies Mountain Quadrangle are the Oquirrh Basin sediments. The Oquirrh Basin, like the Paradox Basin in southeastern Utah, was a local, deeply subsiding basin that received sediments throughout the Pennsylvanian and through part of the Permian Wolfcampian. Only the upper few thousand feet of Wolfcampian Oquirrh Formation out of more than 20,000 feet of sediments deposited in the axis of this basin, are exposed in the mapped area. These thick shale, sandstone, and orthoquartzite beds were deposited in a shallow marine environment at the base (Maxfield, 1957, p. 15) to a deep marine environment higher in the section (Chamberlain and Clark, 1973, p. 675). The overlying Kirkman Limestone, a local formation which ranges in thickness from more than 1,000 feet in Hobble Creek, north of the mapped area to 100 feet at the southwestern edge of the mapped area, may represent the final stages of the Oquirrh Basin. Evidence for this is the local extent and the wedge shape of the Kirkman Limestone. The wedge of the Kirkman may be due to deposition on an unconformable surface of the underlying Oquirrh sediments.

Shelf Deposition.—Upper Wolfcampian, Leonardian, and Guadalupean rocks are represented by the Diamond Creek Sandstone and Park City Formation. These formations, 2,500 feet thick, represent a modified yoked basin depositional pattern with clastic sediments from the Uncompahgre Uplift being transported westward into the geosyncline. Local deformation is represented by an angular unconformity between Lower Triassic Woodside Shale and Permian Park City Formation. This unconformity truncates the Upper Park City (Franson member), Middle Park City (Meade Peak Tongue), and part of the Lower Park City (Grandeur member), in the central western part of the mapped area.

The Woodside Shale overlies the Permian-Triassic unconformity and represents the beginning of a marine transgression over the beveled Permian strata. The lack of *Meekoceras*-bearing basal limestone in the lower Thaynes Formation in the mapped area may indicate either a local hiatus of greater duration than exists further north, or near-shore marine conditions which were not suitable for ammonite life and thick limestone accumulation. The first explanation is preferred by the writer. The Thaynes Formation accumulated during the maximum extent of the Triassic marine transgression. Continental deposits of Ankareh Formation and lower Nugget Sandstone accumulated near the shore as the Triassic sea retreated. No break is noted between Lower and Upper Triassic rocks, and the missing Middle Triassic beds (Hintze, 1973, p. 54) may be present but represented by only a few feet of continental nonfossiliferous red beds. Total Triassic thickness is over 2,500 feet.

Jurassic Trough.—Major marine deposition shifted from west in the Triassic to north in the Jurassic. This shift is reflected in marine Jurassic deposits which lie in a narrow belt through central Utah and into Wyoming (Hintze, 1973, p. 64). This shift of marine deposition was caused by developing highlands of the Nevadan Orogeny in western Nevada. The marine waters transgressing from the north overrode the Nugget Sandstone and deposited a 1,800-foot sequence of Twin Creek Limestone. Rocks of the lower Twin Creek Limestone are dominantly marine, but nonmarine red beds occur in the middle and gypsiferous shale occurs in the upper part. A short distance to the south, in central Utah, equivalent beds include very thick accumulations of salt. Sediments overlying the Twin Creek, 2,000 feet thick, represent a marine regression (Entrada Sandstone), marine transgression (Curtis Formation), and marine regression (Summerville and Morrison Formations).

Sevier Orogeny.—Within the mapped area strong evidence is present for major orogenic activity from latest Jurassic through most of late Cretaceous time. The age of this deformation implies it is part of the Sevier Orogenic belt (Armstrong, 1968). Evidences for tectonism are: (1) an unconformity between Jurassic (Morrison) and Upper Cretaceous rocks (Indianola Formation?); (2) north-south folded and overturned Cretaceous and older rocks; (3) thick conglomerate deposition throughout Upper Cretaceous; and (4) contemporaneous deposition and folding in Upper Cretaceous (Text-fig. 11).

Low magnitude east-west normal faults, most likely tear faults, found in the Cretaceous conglomerate and older formations probably developed during the Sevier Orogeny.

Laramide Orogeny.—Following the Sevier tectonism, Laramide uplifts caused additional folding in the study area. This folding affected Green River Formation (Eocene) and older strata (Text-fig. 11).

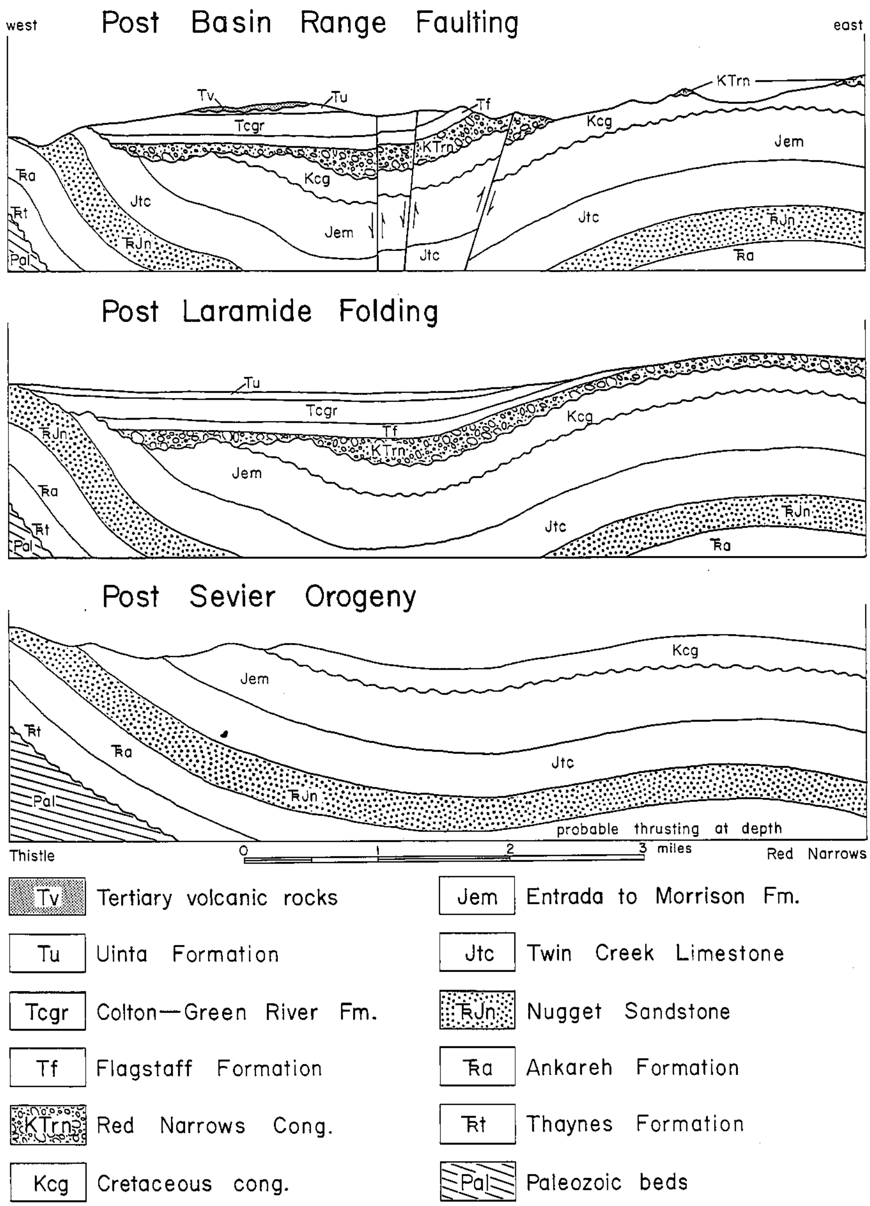
Major evidences for continued folding with Laramide uplift are: (1) an angular unconformity between the Cretaceous conglomerate and the overlying Red Narrows Conglomerate; and (2) north-trending folds in the Nugget Sandstone, in contrast to more northeast-trending folds in the Flagstaff Limestone (Text-fig. 9 and 10).

Oligocene Volcanic Deposits.—Widespread Oligocene volcanism in central Utah affected the composition of contemporaneous sediments in Billies Mountain quadrangle. Andesitic clasts appear intermixed with Paleozoic clasts. Ash beds, water-lain tuff, and tuffaceous limestone accumulated in local basins. The derivation of some of the volcanic rock may have been local, coming from what may have been a caldera in Wanrhodes Basin. Breccia around Billies Mountain may indicate local vents in the southern portion of the mapped area. At least 700 feet of coarse clastics, tuff, and limestone accumulated in basins adjacent to the mountains at this time.

Basin and Range Faulting.—North-south normal faults bounding a central graben bisect the mapped area and reflect the influence of Basin-and-Range-type tectonism. The Thistle Canyon fault on the west separates Paleozoic and Mesozoic rocks from Tertiary rocks; Sam's Canyon fault zone on the east separates Mesozoic rocks from Tertiary rocks. These faults offset Oligocene strata and are believed to represent block faulting, which accompanied Miocene uplift throughout western Utah (Text-fig. 11). Both faults are described below under normal faulting.

Pleistocene Effects.—Evidences of the most recent events affecting the topography are high-level terraces and glacial deposits.

High-level terraces are common along Diamond Fork and Spanish Fork rivers. They indicate stream rejuvenation caused by continual uplift associated with normal faulting and change of base level associated with fluctuating Lake Bonneville.



TEXT-FIGURE 11.—Series of cross sections showing the structural effect of major deformational events.

Glacial action on the north and east side of Spanish Fork Peak resulted in several large cirques outside the mapped area. Moraine and outwash deposits from these cirques are common in Little Diamond Creek Canyon.

Causes of Deformation

Deformational patterns within the mapped area correspond to general Utah structural patterns, Utah's position within the continental plate implies a remote relationship with plate boundary interaction (Hintze, 1973, p. 96). Hintze (1973, p. 95-96) has related Utah's regional patterns to plate tectonic theory as follows: (1) Miogeosynclinal sedimentation on a passive continental plate margin through Paleozoic and Triassic times; (2) compressive orogenic activity chiefly deriving its impetus from the west during Jurassic through Cretaceous and possibly lowermost Tertiary; (3) explosive volcanic activity related to eastward subduction of oceanic lithosphere along the West Coast during Oligocene; and (4) extension of the crust, producing block faulting and basaltic volcanism during Miocene to possible Recent.

Early Paleozoic sediments show deposition in a shallow miogeosyncline to the west of central Utah. Pennsylvanian and Permian Rocks of central Utah represent the oldest rocks exposed in the mapped area. These rocks accumulated in a deep local basin. The cause of these local basins as related to the plate tectonic model is a puzzle. However, following deposition in the Pennsylvanian-Permian basin, the deposition returned to the early Paleozoic pattern with a geosyncline to the west. Deposition shifts to the north through late Triassic and Jurassic. This occurs as a result of highlands developing to the west, probably related to the Nevadan Orogeny.

Cretaceous deposition shifted eastward as the Sevier Orogeny developed in the western and central parts of Utah (Armstrong, 1968, 1974). Eastward-moving thrust sheets, north-south folds, and the eastward thinning clastic wedge attest to the eastward-directed stresses of the orogeny.

Explosive andesitic volcanic activity during the Oligocene has been credited to oceanic plate movement (Atwater, 1970; Lipman, Prostka, and Christiansen, 1971) and a new subduction zone forming along the west coast.

Basin and Range block faulting with accompanying basalts represent crustal extension. Scholz and others (1971) credit release from compression with accompanying plate rotation, and Best and Hamblin (1970) credit plume activity.

For a more detailed and complete comparison of plate tectonic theory to the structural patterns observed see Hintze 1973.

ECONOMICS

Metals

Economic possibilities within Billies Mountain quadrangle are meager for metals, but are good for nonmetal deposits such as clay, gravel, building stone, and phosphate. Water resources are sufficient for local farming. Petroleum potential is also becoming increasingly attractive.

Manganese Oxide.—Minor uncommercial deposits of manganese oxide occur in Long Hollow along the unconformity between Cretaceous conglomerate and Red Narrows Conglomerate. These deposits are paper thin and discontinuous.

Pinnell (1972) reported similar outcrops a few miles south of Billies Mountain quadrangle.

Nonmetals

Clay.—Clay deposits, probably bentonite, occur in decomposed volcanic ash beds in the Flagstaff, Colton, Green River, Uinta, and Tibble formations. Harris (1953, p. 118) reports successful firing of clays from the Flagstaff Formation, Birdseye area. All beds observed were less than 3 feet thick and calcareous. Detailed mapping and core drilling may reveal commercial deposits.

Gravel.—Gravel deposits are common in stream terraces and in the Uinta Formation. Local stream gravel deposits are poorly sorted but they have been quarried to the south of the mapped area along U. S. Highway 50-6. The Uinta Formation has some poorly consolidated conglomerate beds. A new gravel pit recently started operation in these beds in Diamond Fork Canyon.

Although not a gravel, the Twin Creek Limestone near Thistle is highly fractured and has been used successfully as riprap for road construction and for erosion control.

Building Stone.—Possibilities for building stone exist within the area. Algal limestone has been quarried from the North Horn Formation near Birdseye, Utah, and used extensively in older buildings in Utah. Flagstaff Limestone and North Horn equivalent rocks within the mapped area contain this type of limestone. The desired concretionary beds are few but do exist. Twin Creek Limestone may also serve as building stone. Thin sandstone beds in the Ankareh Formation would make good patio stone.

Phosphate.—Low grade phosphate deposits occur in the middle Park City member. This deposit—ten feet thick, oolitic, and slightly silicic—was strip-mined near the head of Little Diamond Creek (Sec. 22, T. 8 S, R. 4 E). The mine is no longer in operation.

Water

Small springs are common at the base of Spanish Fork Peak and around Billies Mountain. Most are developed for use by summer livestock. Diamond Fork and Spanish Fork rivers are used for irrigation.

Petroleum Products

Asphalt.—Tar sands, rich in gastropods, crop out in the Flagstaff Limestone above Thistle. The ten-foot-thick bed is exposed for about two miles east of Thistle (Sec. 26 and 27, T. 9 S, R. 4 E). No comparable bed was found in the Flagstaff Formation along Diamond Fork to the north. These tar sands have been mined locally for use as road pavement (Pinnell, 1972, p. 120). The tar is probably indigenous to the formation because it is bedded and restricted to a specific horizon.

Oil and Gas Possibilities.—The Diamond Creek anticline excited oil exploration in the late 1940's and early 1950's. Drilling yielded only a show from the middle Park City member (Neighbor, 1959, p. 178). The deepest test was 5,936 feet.

Possible source beds include Manning Canyon Shale, which underlies the Oquirrh Formation shale beds in the lower Oquirrh Formation, Kirkman Limestone, middle member of Park City Formation, and Twin Creek Limestone. If the deep-seated thrust is proven, Cretaceous beds in the autochthon could also be source beds. Reservoir rocks could include Oquirrh sandstone (probably tight), Kirkman Limestone, Diamond Creek Sandstone, Nugget Sandstone, Twin Creek Limestone, and Cretaceous sandstone.

Stratigraphic traps could occur in Park City Formation, Thaynes Formation, Twin Creek Limestone, and Cretaceous beds. Folded structures include Diamond Creek anticline, which appears to be part of the Thistle Dome (2,000 to 3,000 feet of closure), and a large unnamed anticline on the western edge of the mapped area (Text-fig. 9). Thrusting could develop traps at depth. Other faults may also prove significant. Oil exploration may yet produce significant results.

SUMMARY

Billies Mountain quadrangle offers one of the most complete exposures of stratigraphy and structure of the western edge of the Sevier Orogenic belt yet observed. The stratigraphy of this quadrangle comprises over 20,000 feet of well-exposed Permian to Oligocene strata. The structure within this quadrangle reflects Sevier and Laramide deformation modified by Basin-and-Range-type faulting. Possible future studies and conclusions are listed below.

Future Studies

A search for pollen and the accompanying classification of the pollen within the Cretaceous conglomerate and Red Narrows Conglomerate would give better age determination of these units. A study such as this would also serve as a key in delineating and correlating other clastic units along the eastern edge of the Sevier Orogenic belt.

Radiometric dating of the volcanic rock units within Billies Mountain quadrangle would define ages and show correlation of these units, one to another and regionally with other volcanic rock units in surrounding areas.

Conclusions

1. Truncations of the upper and middle members of the Park City Formation by the overlying Woodside shale is evidence for local deformation in the Late Permian time.
2. Uppermost Cretaceous and younger rocks were deposited on a series of paleocuestas or paleohogbacks. Ridge-forming formations are the Nugget Sandstone, Morrison Formation, and lower Upper Cretaceous sandstone. Soft Triassic and Jurassic shale underlaid the intervening paleovalleys.
3. Coarse clastic deposition within the mapped area was fairly continuous from Upper Cretaceous through Oligocene. During the deposition of the Flagstaff Limestone, this clastic deposition continued in the vicinity of Teat Mountain and graded laterally east and west into fresh-water limestone. Subsidence around the prograding alluvial fan deposits resulted in thick accumulations of Flagstaff Limestone near the fans.
4. A calcite-lined hot water conduit located midway up Wanrhodes Canyon may be evidence of a local source for some of the Oligocene volcanic rocks. Breccia deposits elsewhere in the mapped area may indi-

cate other source areas. Wanrhodes Basin, which is structurally low and filled with volcanic deposits, may be a collapsed caldera.

ACKNOWLEDGMENTS

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Greatest appreciation goes to my parents, who offered encouragement, assisted in manuscript preparation, and provided room and board while the project was undertaken.

APPENDIX

MEASURED SECTIONS

The Wentworth scale is used to measure grain and clast size. The McKee and Weir scale modified by Ingram (1954) is used for bedding size. Sections are measured in feet, while units are recorded to nearest whole foot. Sections are listed in descending order.

Tibble Formation Section

This incomplete(?) section is underlain conformably by the Uinta Formation and overlain unconformably by volcanic ash. Lower contact is covered, causing thickness of unit 1 to be estimated. This section was measured up Little Diamond Creek with base at SE¼, NW¼, NE¼, Section 35, T. 8 S, R. 4 E and top at NE¼, SE¼, SE¼, of Section 26. Tape and Brunton were used. The section forms rounded hills with some rounded cliffs.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
17	Pebble conglomerate, pale green matrix, thick bed; forms ledge. Pebbles are volcanic andesite and Paleozoic limestones and quartzites.	3	581
16	Ash fall, pumice fragments, medium to very coarse, angular, with fine-grained matrix, white to yellowish gray.	7	578
15	Covered slope.	10	571
14	Conglomerate similar to unit 17, but the clast size is up to 4 inches in diameter.	10	561
13	Ash, greenish gray to light olive gray, medium bedded; forms ledge; very calcareous and is combined with a coarse-grained sand; waterlain.	15	551
12	Covered slope.	14	536

11	Conglomerate, reds to grays, pebbles to boulders, very thick beds; forms rounded cliff. Cobbles composed of 70 percent Upper Paleozoic dark gray limestone and 30 percent volcanic andesite, dark reddish brown to grayish red, matrix, coarse to medium grains composed of limestone and volcanic rock plus some red silt; calcite cement.	36	522
10	Covered slope, probably ash or sand.	45	486
9	Conglomerate and subgraywacke. Conglomerates grayish red, thick-bedded Paleozoic limestone and volcanic rock with some quartzite cobbles. Subgraywacke, grayish red, very coarse grained, medium beds, grains composed of limestone, quartz, and volcanic fragments; cement is calcite. Sand matrix in conglomerate is about 40 percent.	27	441
8	Covered slope, believed to be sandstone and conglomerate.	16	414
7	Conglomerate, grayish blue to medium bluish gray cobbles with grayish red purple coarse-grained matrix. Cobbles, 80 percent Upper Paleozoic limestones which are mostly derived from the Mississippian Great Blue limestone, and 20 percent volcanic rock. Calcite present; forms rounded cliff.	69	398
6	Covered slope believed to be pebble conglomerate and coarse subgraywacke. Cobbles in float are quartzite and quartz sandstone, from Tintic or Oquirrh Formation, volcanic cobbles of grayish red and pale brown andesite.	88	329
5	Volcanic arenite, light green weathers grayish green, medium to coarse grained, thick beds, calcareous, fragments composed mainly of pumice chert and quartzite rock fragments; forms ledge-slope.	28	241
4	Conglomerate, mixed paleozoic and volcanic cobbles with grayish red coarse-grained matrix but grayish green matrix in upper 5 feet. Base has dirty grayish green sand about 5 feet thick, reacts with calcite. Volcanic cobbles are medium gray and dark reddish brown. The reddish brown andesites have 10 percent needle amphiboles plus a fine crystalline matrix; gray andesites have fewer amphiboles; forms rounded cliff.	47	213
3	Covered slope, probably volcanic ash.	30	166
2	Subgraywacke, greenish, very dirty, lots of ash, calcite reacts; forms slope.	36	136

1	Covered slope believed to be volcanic ash and sand with calcite matrix, grayish green changing to yellowish gray or pale greenish yellow when lots of calcite is present. Waterlain, thin to thick beds; forms slope.	100	100
	Total thickness of Tibble Formation	581	

Uinta Formation Section

The Uinta Formation section is underlain by the Colton-Green River Formation and is overlain locally with a disconformable contact by volcanic rocks and white quartzite cobbles. Elsewhere the Tibble Formation overlies it. Section is believed to be complete. Upper contact was covered and its position is estimated. The section was measured from base at NE¼, NW¼, SE¼, Section 23 to top at NW¼, NE¼, SW¼, Section 23, T. 9 S, R. 4 E. The formation forms rounded ridges with mostly covered slopes. The section was measured along the roadcut.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
15	Covered slope.	20	328
14	Conglomerate and shale, interbedded. Shale, moderate red. Conglomerate cobbles composed mostly Mississippian-age Paleozoic limestones and sandy limestones, not well consolidated; forms rounded hill.	10	308
13	Interbedded shale, siltstone, and limestone; gradational contacts between members. Shale and siltstone moderate reddish orange, calcareous, thin beds; forms crumbly slope. Limestone minor, grayish orange pink to grayish pink, thin beds; forms rounded slope.	66	298
12	Conglomerates, as in unit 14, rounded ledge.	4	232
11	Shale, light gray calcareous; forms crumbly slope.	4	228
10	Moderate red shale and interbedded light gray limestone as in unit 13.	11	224
9	Shale, sandstone, and conglomerate. Shale grayish green with some interbedded dusky red purple layers; greenish layers are very calcareous. Sandstone, medium gray, coarse grained, medium beds. Conglomerate, pebbles to cobbles, in beds 2 to 3 feet thick below the sandstones.	15	213
8	Mostly shale, strong reddish orange but with a 10-foot zone of greenish gray shale bounded by dusky red purple shale in upper half of unit. Thin limestone beds in the upper part give	35	198

	crumbly talus, not found in lower part; forms slope.		
7	Conglomerate cobbles with light gray sandstone matrix and calcite cement; forms rounded ledge.	10	163
6	Shale interbedded dusky red and moderate yellowish brown beds; forms slope.	15	153
5	Shale, greenish gray, very calcareous, some pale reddish purple shale interbedded with it; forms slope.	13	138
4	Sandstone, greenish gray, medium grained, medium to thick bedded, calcareous; forms ledge.	17	125
3	Interbedded dusky red shales and greenish gray shales, very calcareous, a few 1-inch-thick calcareous dusky yellow sandstone beds; unit erodes into a crumbly slope with little rock chips all over it.	45	108
2	Conglomerate, cobbles, possibly derived from Tintic or Humbug Formations, light gray sandstone matrix, calcite cement, not well indurated; forms rounded ledge.	5	63
1	Interbedded shales, dusky red, moderate reddish brown, dusky yellow and dusky yellow brown; forms slope.	58	58
	Total thickness of Uinta Formation	328	

Colton-Green River, Flagstaff Tongue, Colton Formation Section

The measured strata between the Flagstaff Formation and Uinta Formation is divided into three units: (1) Colton-Green River Formation; (2) Flagstaff Tongue; and (3) Colton Formation. The lower contact is gradational with the Flagstaff. The upper contact is conformable with the overlying Uinta Formation. The section continues from the Flagstaff Limestone section with basal contact on the northern edge of NE$\frac{1}{4}$, NE$\frac{1}{4}$, NE$\frac{1}{4}$, Section 26 and top in center of N$\frac{1}{2}$, of the SE$\frac{1}{4}$, NE$\frac{1}{4}$, Section 23, T. 9 S, R. 4 E. The section forms flatlands with rounded hills where the middle member occurs.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
Colton-Green River Formation			
25	Limestone, white, thick bedded, punky, believed to be partially volcanic ash, contains oncolites and gastropods; forms rounded ledge. There may be a few shales interbedded with the limestones. This unit makes a good maker bed.	46	868
24	Shale, moderate reddish brown; forms slope.	32	822
23	Limestone, white, punky, ashy; forms rounded ledge with blocky talus. May not be a continuous unit.	15	790

22	Shale, moderate reddish orange to grayish red; forms slope; poor exposure.	48	775
21	Limestone as in unit 23.	7	727
20	Shale as in unit 22.	40	720
19	Shale, grayish green interbedded with some moderate red shale. A couple of small limestone beds, white, punky, believed to contain ash.	34	680
18	Shale, grayish orange pink; forms slope.	17	646
17	Ashy shale and ashy limestone, white, very crumbly; forms slope.	10	629
16	Shale, moderate red, slope, covered.	24	619
15	Shale and ashy limestone, light pink to white; forms slope.	10	595
14	Shales, moderate red; forms covered slope. A few beds of oolitic limestone are interbedded, grayish orange, ledges 1 to 3 feet thick near the base of unit.	40	585
	Total thickness of Colton-Green River Section	323	
	Flagstaff Limestone Tongue		
13	Limestone, very pale orange, fine crystalline, some sandy limestone, thin beds fractured: forms slope.	10	545
12	Oolitic limestone, moderate brown, weathers grayish orange, oil smell, massive; forms cliff.	10	535
11	Sandy limestone, moderate yellow brown, thin to medium beds; forms ledge. Some sandstone and pebble conglomerate present.	50	525
10	Sandstone, dark gray, thick bedded; forms ledge.	5	475
9	Limestone and sandstone, pale yellowish brown, thin to thick beds; forms ledge.	10	470
8	Shale with interbedded limestone; shales moderate red; limestones grayish orange; limestones form ledges 1 to 5 feet thick with shales forming slopes.	30	460
7	Limestone, grayish orange, medium to thick beds; forms ledges. Contains ostracods.	20	430
6	Limestone, light gray weathering dark gray, massive; forms ledge. Some conglomerates present.	5	410
	Total thickness of Flagstaff Limestone Tongue	104	
	Colton Formation		
5	Interbedded moderately red shale and grayish olive shale and a few pale orange sandy lime-	70	405

	stones. Red shales dominate, approximately 80 percent. Forms covered slope.		
4	Interbedded light olive gray and grayish purple red shale; light olive gray shales dominate slightly; forms covered slope; thickness estimated.	100	335
3	Interbedded dusky red shale, grayish orange shaly limestone and grayish orange calcareous conglomerate. Shales dominate, shaly limestones thin to medium beds, one medium bed of pebble conglomerate with calcite cement; forms slope.	45	235
2	Interbedded grayish red to moderate pink shales with light gray to gray green shales; forms covered slope; outcrop poor. Some thin beds of shaly limestones.	40	190
1	Shale and limestone. Shale, grayish green, thin laminate; forms covered slope. Thin shaly limestone and oolitic limestone beds occur in zones about ten feet thick every 10 to 20 feet. These zones form slopes with shaly or slabby talus.	150	150
	Total thickness of Colton Formation	405	
	Total section thickness	868	

Flagstaff Formation Section

The Flagstaff Formation is underlain conformably by conglomerates of Red Narrows and overlain with an interfingering contact by Colton Formation. Contacts are well exposed. The section was measured from the mouth of Chicken Hollow with base in center of E$\frac{1}{2}$, NE$\frac{1}{4}$, SE$\frac{1}{4}$, of Section 26. The section was measured north with tape and Brunton to northern edge of NE$\frac{1}{4}$, NE$\frac{1}{4}$, NE$\frac{1}{4}$, Section 26, T. 9 S, R. 4 E. The formation is well exposed, forming prominent cliffs and ledges.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
31	Oolitic limestone, grayish orange, thin to thick bedded, thicker beds near base of units; forms ledge-cliff.	18	571
30	Oolitic limestone and calcareous shale, laminate to thin beds; forms ledge-slope.	11	553
29	Sandstone, pale brown weathering grayish orange; each grain coated with calcite as if oolites were starting; forms cliff.	5	542
28	Limestone, grayish orange, thin to thick beds; forms ledge-slope.	20	537

27	Shale and shaly limestone, light brown weathering pale yellowish orange, laminated.	22	517
26	Conglomerate, medium gray, cobbles around 1 inch diameter, well rounded; forms ledge.	3	495
25	Limestone, sandy, medium gray near base and grayish orange near top, thin to medium beds, gastropods in lower part, oolites in upper part; forms ledge.	49	492
24	Calcareous shale and shaly limestone, very pale orange, laminate to thin beds; forms slope with shaly talus.	21	443
23	Sandy limestone, grayish orange, slightly darker when fresh, thick beds; forms cliff. This unit grades into the conglomerate unit below.	12	422
22	Conglomerate, dark gray, calcite cement with a fine-grained matrix, very thick beds; forms cliff. Cobbles 2 inches at base, mostly granules in upper part. Clasts rounded, well sorted.	29	410
21	Limestone, oolitic and sandy, light brown, very thin to thin beds; forms ledge-slope with slabby talus.	20	381
20	Limestone, moderate brown, weathers medium gray to light gray, fractured, thick beds; forms cliff.	8	361
19	Silty limestone, moderate brown weathering pale yellowish orange to grayish orange, mottled; forms ledge.	10	353
18	Covered slope believed to be calcareous siltstone, pale yellowish orange, thin to medium beds, plus light gray shales; forms slope.	13	343
17	Conglomerate, calcareous cement, cobbles up to 2 inches diameter, dark gray, thick bed, ledge.	3	330
16	Quartz sandstone, dark yellowish orange, calcareous, medium beds; forms slope.	2	327
15	Covered slope, believed to be silty limestone and calcareous shales, light brown.	67	325
14	Limestone, basal limestone moderate brown, weathers medium gray, top limestone is grayish orange with blotches of white limestone, both thick bedded; forms cliff.	9	258
13	Limestone, light gray with upper portion slightly darker, medium to thick beds, highly fractured, fine crystalline; forms rounded ledge. Upper portion contains gastropods.	18	249
12	Covered slope, believed to be light gray to light brown limestone, medium beds, highly fractured. Some siltstone and shale beds may also be present.	25	231
11	Silty and shaly limestone, light gray, thin to medium beds; forms ledge.	15	206

10	Limestone, moderate brown weathering medium gray, very thick beds; forms cliff. Some gastropod hash.	13	191
9	Covered slope believed to be dark to medium gray limestone, highly fractured.	10	178
8	Limestone, light brownish gray weathering to yellowish gray, slightly sandy, medium to very thick beds; forms rounded cliff. Gastropods.	10	168
7	Covered slope believed to be limestone, medium gray, micrite to fine grained, highly fractured.	7	158
6	Limestone, dark gray weathering medium gray, thick bed. Oncolites.	3	151
5	Covered slope believed same as unit 7.	8	148
4	Limestone, pale yellowish brown weathering grayish orange, contains oolites which are white, thick beds which weather to 2 inch blocks of talus; forms cliff. Unit 4 contains large gastropods, one inch in diameter, which are not high spired.	24	140
3	Covered slope believed to be grayish orange shale or siltstone.	56	116
2	Limestone, grayish orange weathering white, very fine crystalline, very thick beds; forms cliff. In center of unit is a small 2-foot zone of shale or siltstone; forms short slope. Upper half mottled with white limestone and light gray limestone together. Some fossil hash present.	30	60
1	Limestone, grayish orange, medium crystalline, slightly silty; forms slope. Some slight ledges of thin to medium beds.	30	30
	Total thickness of Flagstaff Limestone	571	

Red Narrows Conglomerate Section (new formation)

Red Narrows Conglomerate is underlain with an angular unconformity by Cretaceous conglomerate. The upper portion of the measured section is a mountaintop; elsewhere the formation is overlain by the Flagstaff Limestone. The top of the type section begins 300 yards east of the summit of Teat Mountain (NW¼, SW¼, SW¼, Section 15, R. 5 E, T. 9 S). The type section follows the ridge crest on the east side of Rough Hollow down to U.S. Highway 50-6 (NE¼, SW¼, NW¼, Section 33, R. 5 E, T. 9 S). The type section spans the upper and middle members of the Red Narrows Conglomerate. A reference section for the lower member is at the west end of Red Narrows Canyon in Section 30. Top is in NE¼, NW¼, SE¼ and the bottom is in NE¼, SW¼, SE¼ of R. 5 E, T. 9 S. Overall thickness of the formation was obtained by graphic methods from topographic maps and aerial photographs. Unit thicknesses are field estimates. Descriptions were done in the field. This formation forms reddish cliffs, ledges, and slopes.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
Upper Member			
22	Conglomerate, white to grayish red, cobbles to pebbles, well rounded, dirty sandstone matrix, calcite cement, massive bedding; forms rounded ledge.	30	1470
21	Interbedded conglomerate and calcareous sandstone, forming a stairlike slope. Conglomerates, light gray to grayish pink, cobbles to pebbles, mostly Paleozoic limestone derived (Mississippian) and quartzite, well rounded, in a pale reddish brown sandstone matrix that is medium to fine grained, with calcite and silica cement; forms ledge. Sandstone, pale reddish brown, fine grained to siltstone, dirty sands also, all very calcareous, thin to medium beds; forms slope.	110	1440
20	Algal limestone, dark yellowish brown weathers pale yellowish brown, thick bedded; forms rounded ledge. Algal balls up to 4 inches in diameter.	15	1330
19	Conglomerate, light gray, cobbles quartzite and Paleozoic limestone with grayish red to moderate brown matrix. Cobbles to pebbles, well rounded; forms rounded ledge.	20	1315
18	Siltstone and sandstone, moderate reddish brown, calcareous; forms covered slope. Some thin beds of grayish pink limestone, very fine crystalline.	40	1295
17	Conglomerate as in unit 19.	20	1255
16	Algal limestone as in unit 20.	20	1235
15	Conglomerate as in unit 19.	20	1215
14	Siltstone and sandstone, some limestone. Siltstone and sandstone moderate reddish brown, calcareous; forms covered slope with occasional slight ledges of resistant sandstone. Limestone, pale red thin beds around 2 inches thick.	100	1195
13	Limestone, pale red weathers light gray with grayish pink splotches, very fine crystalline but not a micrite, slightly sandy at times, thick bed; forms rounded ledge.	5	1095
	Total thickness of upper member	380	

Middle Member			
12	Siltstone and sandstone, moderate reddish brown, some grayish purple, calcareous; forms slope with rounded sandstone ledges of medium-thick beds. Some conglomerates present. Unit 12 differs from unit 14 in having more and thicker sandstone beds.	125	1090
11	Conglomerates and sandstone, light brown to moderate brown, cobbles well rounded, lots of sand, grayish orange to light brown in lenses and in the matrix, calcareous; forms rounded cliff.	25	965
10	Sandstone, moderate orange pink, medium to fine grained, massive(?); forms steep slope.	60	940
9	Conglomerate as in unit 11.	20	880
8	Siltstone and mudstone, moderate red; forms covered slope.	125	860
7	Sandstone, light gray weathers pinkish gray, fine grained, calcareous, medium to thick beds; forms rounded ledge.	45	735
6	Interbedded conglomerates and sandstone. Conglomerates and sandstones appear in about equal amounts, moderate red to moderate reddish brown, thick beds less than 20 feet; forms a stairlike slope with conglomerates as rounded cliffs and ledges and sandstone slopes. Conglomerates channeled into underlying sandstones, cobbles and pebbles, quartzites and Paleozoic limestone, moderate red sand matrix and calcite cement. Sandstones, moderate red calcareous, thick and massive at base grading upward into siltstones and then mudstone.	290	690
	Total thickness of middle member	690	
Lower Member			
5	Conglomerate, white, light brown, and grayish red. The white beds are dominated by light-colored sandstone cobbles, the reddish beds dominated by grayish pink to pale red quartzite or hard sandstones (slightly calcareous) with some Paleozoic limestone cobbles. Sand matrix reflects color and composition of larger clasts. Calcite matrix in moderate red beds. The grayish red conglomerates dominate. There are lenticular, moderate red sandstone beds present; forms cliff.	150	400
4	Conglomerates, white to light brown with dusky brown water stain common on the surface, cobbles to pebbles ranging from 8 inches to 1 inch, white sandstone cobbles (Cretaceous or	76	250

	Jurassic sandstones) and grayish orange quartzites, sand matrix, coarse to fine grained, sandstone matrix to grayish orange pink, cement is silica with some calcite. These white sandstone conglomerates may be localized around the Cretaceous highs; forms cliff.		
3	Covered slope believed to be sandstone and siltstone, moderate red, possibly more of a bed than a lense as in unit 5.		
2	Conglomerate as in unit 4.	69	150
1	Covered slope as in unit 3.	81	81
	Total thickness of lower member	400	
	Total thickness of Red Narrows Conglomerate	1470	

Cretaceous Conglomerate Section

Cretaceous sandstone and conglomerate are underlain with a disconformity by Morrison Formation and are overlain with an angular unconformity by Cretaceous(?) and Tertiary age conglomerates of Red Narrows. The section is incomplete because the base is faulted and covered. The thickness of the basal unit was estimated. The thickness of the last cliff-forming unit was also estimated. The rest of the section is measured with tape and Brunton. Using graphic methods and topography, the minimum thickness is determined from the faulted base to the unconformity at the top. The section base is located in the center of SW¼, NW¼, Section 20, T. 9 S, R. 5 E. The section top is in NE¼, NE¼, NE¼, of Section 30. The section is fairly well exposed, with some covered slopes. The section forms cliffs, ledges, and slopes covered with sandstone cobbles.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
29	Conglomerate, very light gray to yellowish gray, boulders made of sandstone, matrix is sand; forms cliff.	100	1250
28	Covered slope believed to be sandstone.	30	1150
27	Conglomerate as in unit 29.	65	1120
26	Interbedded conglomerates and sandstone, yellowish gray to very light gray with a dark reddish brown crust on some of the conglomerates. Reddish crust may come from the overlying unconformity. From across the canyon, the top of this unit or the base of unit 26 has some dark reddish brown beds believed to be siltstone. These beds weather white or are covered where section was measured.	33	1055
25	Conglomerate, white, boulders of sandstone, matrix is sand; forms cliff.	15	1022
24	Covered slope.	19	1007

23	Sandstone, white to pale yellowish orange with some moderate yellowish brown iron stain, coarse grained to granules; forms cliff.	20	988
22	Covered slope.	48	968
21	Sandstone and conglomerate, white, sandstones are coarse grained, slightly calcareous.	10	920
20	Covered slope. Reddish color noted across canyon at about this vicinity.	10	910
19	Sandstones and conglomerates, white, thick bedded, fine grained to boulders, slightly calcareous; forms cliff.	13	900
18	Covered slope.	5	887
17	Sandstone with conglomerates in the middle of unit, white, thick bedded, slightly calcareous, fine- to coarse-grained sands; forms cliff.	20	882
16	Covered slope.	16	862
15	Conglomerate, white, pebbles to medium cobbles, all composed of white sandstone, thick bedded; forms cliff.	30	846
14	Covered slope believed to be coarse sandstone white.	9	816
13	Conglomerate as in unit 15.	22	807
12	Covered slope, probably sandstone.	57	785
11	Conglomerate, white, pebbles to small cobbles, clasts are white sandstone, sand in matrix; forms rounded cliff to ledge.	12	728
10	Covered slope believed to be sandstone, white, quartz grains, medium grained.	20	716
9	Conglomerate, white, massive; forms cliff. Clasts, boulders to pebble all made of white to pale yellowish brown sandstone, rounded, have a fused texture almost like pumice. Matrix of sand, cement of silica, a few lenses of grit and medium-grained sandstone present.	172	696
8	Covered slope.	27	524
7	Sandstone, white, quartz, no acid reaction, no fossils, very thick beds with minor lenses of pebble conglomerate about $\frac{1}{4}$ inch in size. Cross-bedding present; forms ledge.	28	497
6	Conglomerate and sandstone in about equal percentages, white; forms ledge-slope. Conglomerates, pebbles of 1 to 2 inches, some 1-foot diameter boulders, medium to thick beds. Sandstones, very pale orange to white, medium to fine grained, no acid reaction, no fossils, thick to thin beds.	25	469
5	Sandstone, white, fine grained, slight acid reaction, no fossils; forms cliff. Some pebble conglomerate lenses present. Pebbles $\frac{1}{4}$ to 2	50	444

	inches, large ones round, small ones angular and very soft. Frequency of pebble lenses increases upward.		
4	Dip slope, poor outcrop, composed of sandstone, dark yellowish orange, medium grained, small moderate yellowish brown iron spots, no acid reaction, no fossils.	60	394
3	Sandstone, pale yellow orange weathers white with dark yellow orange iron (limonitic) zones, some iron concretions noted at top of unit, fine grained, quartz, very thick beds, some thin beds noted, no acid reaction or very slight, because of possible leaching by ground water; forms cliff with slabby talus. One bivalve seen, burrows very common, unit believed to be marine.	65	334
2	Sandstone and limestone. Sandstone, medium gray weathers pale to moderate yellowish brown, fine grained; forms ledge. Limestone, medium gray weathers pale yellowish brown, sandy, many burrows and some bivalves. Bedding thin, 2 to 4 inches; forms ledge. This thickness approximated, location appears only (?) at NE¼, NW¼, SW¼, Section 20.	20	269
1	Covered slope, thickness determined from maps and aerial photographs.	249	249
	Total thickness of Cretaceous conglomerate	1250	

Section of Morrison, Summerville, Curtis, and Entrada Formations

This section encompasses the Morrison Formation, Summerville Formation, Curtis Formation, and Entrada Sandstone, all Jurassic age. Only the Morrison Formation is incomplete. The Entrada Sandstone interfingers slightly with the Twin Creek Limestone at the base and has gradational contact with the Curtis at the top. The Curtis grades upward into the Summerville, which grades into the Morrison. The Morrison Formation is overlain with a disconformable contact by Cretaceous conglomerates. The section was measured on the east side of Monks Hollow. The section base is located at SW¼, SE¼, NE¼ of Section 5, T. 9 S, R. 5 E. The section top is located at the center of NE¼, SW¼, Section 9. The formations are well exposed. This section was measured with a Jacob staff and hand level. The section forms low rounded hills and valleys.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
Morrison Formation			
18	Sandstone, very coarse grained, grayish pink to white, thick beds; forms cliffs with slabby talus, slightly calcareous, no fossils.	20	2135

17	Conglomerates, grayish pink to white, weathers pale red, thick beds. Cobbles to boulders, 80 percent of unit. Sandstone, thick beds and lenses, coarse grained, yellowish orange. Cobbles are 80 percent quartzite, 20 percent Paleozoic limestones and shaly limestone.	30	2115
16	Mudstone and siltstone, moderate reddish orange, thin beds; forms covered slope.	22	2085
15	Conglomerates and sandstone, grayish pink to pale reddish brown, calcareous, poor sorting, subround. Grain size, siltstone at very base, fine sand to very coarse sand and granules, coarse material channeled into siltstone base. Mud balls present.	11	2063
14	Micrite, shaly, grayish pink, weathers light gray; forms ledge with slabby rubble; no fossils.	5	2052
13	Mudstone and siltstone as in unit 16.	7	2047
12	Sandstone, grayish pink weathers medium gray, coarse grained, poorly sorted, calcareous, thick bed.	2	2040
11	Mudstone and siltstone as in unit 16.	25	2038
10	Covered slope.	63	2013
9	Mostly mudstone, dusky red to pale red, thin beds; forms slopes. Some interbedded shaly limestone and chert. Limestone is thin bedded, chert, medium gray, irregular nodules. Some sandstone, white, coarse, thin beds.	25	1950
8	Sandstone, grayish pink, weathers light gray, medium grained, thick beds; forms ledges.	5	1925
7	Mudstone, moderate reddish orange, thin beds; forms slopes.	14	1920
6	Sandstone, grayish pink, weathers light gray, cross-bedded, medium grained, thick bedded; forms ledges.	6	1906
5	Covered slope.	20	1900
4	Mudstone, dusky red, thin beds, crumbles, interbedded with silty limestone, 20 percent, light gray, thin beds; forms slopes.	75	1880
3	Siltstone, moderate reddish orange, interbedded with sandstone, grayish pink, weathers light gray; forms slope. There may be a thin conglomerate at very top.	25	1805
2	Covered slope. Measured 135 feet but believed to cross slump fault with displacement of around 100 feet.	35	1780
1	Mudstone, moderate red to dusky red, with some lenses of sandstone and pebble quartz con-	75	1745

	glomerate. Pebbles are well rounded and polished.		
	Total thickness of Morrison Formation	465	
Summerville Formation			
18	Sandstone, light pink to white, medium to very coarse grain, cross-bedded, thick to thin bedded. Color banding present; forms ledge.	5	1670
17	Mudstone and siltstone, moderate red orange, calcareous, laminate to thin beds, forms slope.	8	1665
16	Sandstone, very pale orange to moderate orange pink, fine grained, slightly channeled into unit below; forms ledge.	3	1657
15	Mudstone and siltstone as in unit 17.	54	1654
14	Sandstone, light brown to moderate orange pink, friable, calcareous, good sorting, very thin beds; forms slope. Base is less friable, forming small ledge.	20	1600
13	Shale, moderate reddish orange; forms slope.	60	1580
12	Same as sandstone in unit 14.	2	1520
11	Shale as in unit 13.	8	1518
10	Sandstone, light brown to grayish orange pink, medium to very coarse grained, laminate to thick beds, subround to subangular, calcareous; forms ledge.	20	1510
9	Mudstone, moderate reddish brown, forms slope.	28	1490
8	Sandstone as in unit 10. Weathers into slabby talus.	7	1462
7	Mudstone as in unit 9.	25	1455
6	Sandstone as in unit 10 only more massive, thick beds; forms ledge.	7	1430
5	Sandstone, fine grained, light brown to moderate orange pink, laminate to thin beds; forms slope.	2	1423
4	Sandstone as in unit 10.	6	1421
3	Mudstone as in unit 9.	120	1415
2	Mudstone and shale, grayish yellow green, laminate to thin beds; forms slope. Some grayish red beds in center of unit. Poor exposure.	15	1295
1	Sandstone, medium to fine grain, very thin beds, light brown; forms slope with slabby talus, fair exposure.	5	1280
	Total thickness of Summerville Formation	395	
Curtis Formation			
6	Mudstone and shale, greenish gray to light gray, laminate to very thin beds, calcareous;	13	1275

	forms slope. Some thin grayish red mudstone beds present.		
5	Sandstone, light brownish gray, medium grained; forms rounded ledge.	1	1262
4	Mudstone and shale, greenish gray to light gray, laminate to very thin beds, calcareous; forms slope.	41	1261
3	Mudstone, grayish red; forms slope.	15	1220
2	Mudstone, greenish gray to light gray; forms slope.	35	1205
1	Covered slope, believed to be mudstone, greenish gray to light gray, with two 15- to 20-foot beds of grayish red mudstone, one near center and one in upper half.	195	1170
	Total thickness of Curtis Formation	300	

Entrada Sandstone

57	Mudstone, grayish red; forms slope.	11	975
56	Sandstone, light brown to pale olive, fine to coarse grained, poorly sorted, thin to medium beds; forms ledge with slabby talus.	4	964
55	Siltstone to mudstone, pale red purple to grayish red purple, crumbly, fair exposure; forms slope. Some sandstone, medium grained, light brown to pale olive, beds about 2 feet thick, found only in upper third.	82	960
54	Mudstone and shale, grayish green, laminate, fissiled, poor exposure; forms slope.	5	878
53	Sandstone, light brown to pale olive, medium to very coarse grained, cross-bedded, thick bedded; forms rounded ledge.	3	873
52	Shale, pale reddish purple; forms slope.	27	870
51	Sandstone as in unit 53.	3	843
50	Shale as in unit 52.	15	840
49	Siltstone to fine sandstone, grayish pink, thin to thick bedded; forms rounded ledge-slope.	6	825
48	Mudstone pale red purple; forms slope.	9	819
47	Sandstone, medium to coarse grained, white to grayish pink, friable, calcareous, massive bed; forms slope.	5	810
46	Mudstone as in unit 48.	5	805
45	Silty mudstone, pale red to light brown with red or pink tint, some siltstone to fine sandstone, calcareous, thin beds; forms slope.	5	800
44	Siltstone to very fine sandstone, pale green, thin beds; forms slope.	5	795
43	Mudstone and siltstone, light red, calcareous, laminate to very thin beds, poor exposure; forms slope.	25	790

42	Sandstone, moderate orange pink, coarse grained, thick bed; forms ledge-slope.	3	765
41	Mudstone and siltstone as in unit 43.	87	762
40	Sandstone and siltstone, light brown, thick bed; forms slope.	3	675
39	Mudstone, pale red purple; forms slope	2	672
38	Sandstone, white, coarse grained, very friable, slightly calcareous, thick bed; forms slope.	5	670
37	Mudstone and shale, pale green, laminate, crumbles; forms slope.	10	665
36	Sandstone and siltstone, grayish red purple, weathers pale reddish purple, friable, cross-bedded, calcareous, sharp contact on bottom; forms slope.	5	655
35	Shale and mudstone, variegated, laminate; forms slope.	9	650
34	Sandstone, grayish red purple, weathers pale reddish purple, very fine grained, calcareous; forms slope.	1	641
33	Repetitive cycles of sandstone to variegated shale and siltstone. Cycles ten feet or less. Basal sandstone is approximately two feet thick, pale red, slightly calcareous, friable, coarse-grained medium beds which channel into cycle below. Basal sandstone grades upward into finer-grained sandstone then siltstone; thickness of latter two about equal thickness of basal sandstone. This siltstone sequence grades upward a calcareous, thin bedded, grayish reddish purple into a noncalcareous, very thin-bedded to laminate, grayish green or pale olive siltstone. Siltstones overlain by variegated sequence composed of shales and siltstones. Shales are pale reddish purple, calcareous, thin laminate. Siltstones are grayish green, laminate to very thin beds, noncalcareous. Basal sandstone occasionally absent. Entire sequence forms slope.	92	640
32	Sandstone, white to light greenish gray, coarse grained, cross bedded, friable; forms slope.	3	548
31	Repetitive cycles as in unit 33.	66	545
30	Sandstone, light brown gray to pale red, friable, graded bedding, coarse grained, thick beds, ledge-slope.	3	479
29	Sandstone as unit 30 except cross bedded, slightly channeled, very coarse grained.	2	476
28	Mudstone and sandstone, variegated as in unit 33.	4	474
27	Sandstone, pale red, medium grained, thick beds, ledge-slope.	3	470
26	Siltstone and some shale and mudstone al-	42	467

	ternating with sandstone. Sandstone three to five feet thick, cross bedded. Finer-grained units fissiled, thin bedded; forms slope.		
25	Sandstone, pale red, medium to coarse grained, massive base becoming thin bedded at top due to ripples or cross bedding; forms ledge.	5	425
24	Shale, grayish red purple, calcareous; forms slope.	2	420
23	Sandstone, pale reddish purple, medium to very coarse grained, calcareous, massive with internal laminate; forms slope-ledge.	4	418
22	Covered slope.	11	414
21	Sandstone, coarse grained, thick beds; forms cliff-ledge.	8	403
20	Sandstone, fine grained, siltstone and shale, coarser units at base, cross bedding in sandstones, thin beds, friable; forms ledge-slope.	45	395
19	Siltstones, pale reddish purple, and mudstones grayish red purple, laminate to thin beds; forms slope.	15	350
18	Sandstone, thick beds, friable; forms ledge-slope.	10	335
17	Siltstone and mudstone as in unit 19.	15	325
16	Sandstone, pale red, coarse to fine grained, cross beds, thick bedded; forms ledge-slope.	20	310
15	Siltstone, grayish red, crumbles; forms slope.	7	290
14	Siltstone and sandstone beds, medium to thick.	8	283
13	Sandstone, yellowish gray, coarse grained, slightly calcareous, cross bedded; forms ledge.	5	275
12	Siltstone and mudstone, grayish red purple, crumbles; forms slope.	30	270
11	Siltstone, grayish yellow green to yellowish gray, very thin bedded, mud cracks; forms slope with slabby talus.	5	240
10	Mudstone, grayish red purple, weathers pale red purple, crumbles; forms slope.	13	235
9	Sandstone, yellowish gray to light brown, coarse grained; forms rounded ledge.	2	222
8	Siltstone, slight shaly, dusky red, calcareous; forms ledge-slope. Distinct color band which is darker than grayish red purple mudstone above and below it. Contact gradational.	106	220
7	Siltstone and mudstone interbedded, dark grayish red, weathers pale red, some calcareous beds leached white. Siltstones form rounded ledges 2 to 3 feet thick, mudstones form slope.	36	114
6	Mudstone, grayish red purple, calcareous, similar to beds of mudstone in above unit.	28	78
5	Mostly mudstone, moderate red, laminate, crumbles; forms slope with dirt cover. Grades	27	50

	into unit above. Foot-thick zone of silty limestone, fissiled, pale green, very thin bedded; forms slope.		
4	Limestone, silty, fissiled, pale green, very thin beds; forms rounded ledge to slope.	3	23
3	Mudstone as in unit 5.	8	20
2	Siltstone and shale, moderate red to moderate reddish brown, laminate to paper shale, symmetrical ripple marks are very abundant; forms slope.	5	12
1	Mostly mudstone, moderate red, laminate, crumbly, forms slope. A six-inch zone of limestone, green, very thin bedded, is present near middle.	7	7
	Total thickness of Entrada Sandstone	975	
	Total thickness of section	2135	

Twin Creek Limestone Sections

The Twin Creek Limestone is measured in two parts: a partial section comprised of the upper 482 feet, called section A, and a complete section called section B. The upper 422 feet of section B is a covered slope, but section A had the same interval well exposed. Together the two sections form a compete description. The Twin Creek Limestone is underlain conformably (?) by the Nugget Sandstone. This contact is well exposed at the base of section B. Twin Creek Limestone is overlain conformably by the interfingering contact of the Entrada Sandstone. The upper contact is well exposed in section A but is covered in section B. The upper contact of section B is only approximated. Section A was measured on the east side of Monks Hollow with base in SW¼ and top in SE¼ of the NE¼, SE¼ of Section 32, T. 8 S, R. 5 E. Section B was measured in Sam's Canyon with base in SW¼, SE¼, SE¼ of Section 31, T. 8 S, R. 5 E and top in NE¼, NW¼, SW¼, of Section 5, T. 9 S, R. 5 E. The formation forms high hills with some rounded cliffs or ledges on the steeper slopes.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
Section A			
Giraffe Creek member			
45	Mudstone, greenish gray, weathers light greenish gray, very thin bedded, poor exposure; forms slope. Contains beds of sandstone, medium green to light green, medium bedded.	37	482
44	Shale and siltstone. Shale is pale red getting darker when becoming mudstone, laminate to thin bedded, fine exposure; forms slope. Siltstone, pale red to light greenish gray, thin bedded, ripple marked; forms slope.	17	435

43	Mudstone, shale and sandstone, light olive, weathers light greenish gray, laminate to very thin beds, crumbles, sharp contact with unit below; forms slope. Coarser material at base of unit.	18	428
42	Sandstone, yellowish gray, coarse grained, grains coated with calcite; forms ledge.	1	410
41	Mudstone and shale, moderate green, laminate crumbly, calcareous; forms slope.	3	409
40	Sandstone to siltstone, grayish yellow green to very pale orange, shaly, very thin to laminate beds, calcareous, ripple marks; forms ledge.	3	406
39	Mudstone to siltstone, light green, laminate; forms slope.	4	403
38	Mudstone and shale, moderate reddish brown to grayish red, thin laminate to laminate, papery and shaly; forms slope.	6	399
37	Sandstone to siltstone, silt size to very fine grained, some shaly areas, weathers light green to pale olive, darker when fresh, laminate to thin beds, ripple marks, mud cracks; forms ledge-slope. Ripple marks very abundant, interference, current and oscillatory. Gastropods seen in float.	7	393
36	Siltstone and sandstone, moderate yellowish green, weathers light green, silt to fine grained, laminate to very thin bedded, calcareous, poor exposure; forms slope.	38	386
35	Mudstone to shale, light green, weathers to pale green, laminate, some sandstone beds; forms slope. Poor exposure.	36	348
34	Sandstone, pale olive, very fine to fine grained, laminate; forms rounded ledge to slope with shaly talus.	2	312
33	Shaly mudstone to siltstone, pale olive, poor exposure; forms slope.	20	310
32	Siltstone and sandstone, pale olive, thin bedded, ripple marks; forms rounded ledge to slope with shaly talus.	8	290
31	Shale to mudstone, pale olive; forms slope.	12	282
30	Shale, mudstone and siltstone, pale red; forms slope. Siltstone forms shaly to thin slabs of talus.	5	270
29	Siltstone, shaly, pale olive, very thin bedded, ripple marks; forms slope.	8	265
28	Shale and mudstone, pale red; forms slope.	4	257
27	Siltstone as in unit 29.	8	253
26	Mudstone, grayish red purple, laminate; forms slope.	3	245

25	Siltstone and fine-grained sandstone, light brown to grayish green, laminate, ripple marks partings; forms rounded ledge to slope.	17	242
24	Shale and mudstone, pale olive, calcareous, laminate; forms slope.	17	225
23	Shaly mudstone, grayish red purple, laminate; forms slope.	3	208
22	Sandstone, grayish orange to pale olive, very thin beds; forms rounded ledge.	5	205
21	Sandstone, light green to light brown, thin bedded, cross bedded, asymmetrical ripples in cross beds; forms ledge with slabby float. Grades into unit below.	5	200
	Total thickness of Giraffe Creek Member	287	
Leeds Creek member			
20	Sandstone, light brown to pale olive, laminate bedding due to abundant ripples, rain imprints, calcareous, very fine to fine quartz grains; forms rounded ledge with shaly talus.	15	195
19	Shale and shaly mudstone, grayish green to pale olive, laminate, poor exposure; forms slope.	7	180
18	Sandstone as in unit 20.	5	173
17	Shale as in unit 19.	5	168
16	Sandstone as in unit 20.	3	163
15	Shale as in unit 19.	3	160
14	Sandstone as in unit 20.	3	157
13	Shale as in unit 19.	7	154
12	Sandstone as in unit 20.	7	147
11	Shale as in unit 19.	15	140
10	Sandstone as in unit 20.	1	125
9	Shale as in unit 19.	28	124
8	Sandstone, light olive gray, weathers light brown, fine grained, thick bedded, cross bedded, well sorted, dense; forms ledge with slabby talus.	3	96
7	Shale as in unit 19.	22	93
6	Sandstone as in unit 8.	3	71
5	Shale as in unit 19.	28	68
4	Sandstone as in unit 8.	5	40
3	Shale with a few beds of ripple marked siltstone, greenish gray to light olive gray, laminate, poor exposure; forms slope.	15	35
2	Sandstone, light gray, weathers light brown, ripple marked, fine grained thin to medium bedded, softer than upper sandstone units; forms rounded ledge.	5	20

1	Same as unit 3.	15	15
	Partial thickness of Leeds Creek member	195	
	Total section thickness	482	

Section B

Giraffe Creek member

43a	Covered slope, thickness of member taken from section A.	287	1842
	Total thickness of Giraffe Creek member	287	

Leeds Creek member

43b	Covered slope.	135	1555
42	Sandstone, very pale orange to light brown interbedded with gray shale and siltstone, thin beds, calcareous; forms slope with slabby talus.	70	1420
41	Shale, light gray with some interbedded thin limestone beds.	27	1350
40	Sandstone, calcareous, thin to medium beds; forms slope with slabby float.	20	1323
39	Covered slope. Probably shale, light gray, with thin occasional limestone beds. About forty feet from top was a 4-inch-thick float with grit, one-eighth inch, cemented in limestone.	194	1303
38	Shale and sandstone. Shale, light gray, calcareous. Sandstone, grayish orange, very thin bedded; forms slope.	38	1109
37	Shale, light gray, with minor interbedded limestone, grayish green, very thin bedded; forms slope.	50	1071
	Total thickness of Leeds Creek member	534	

Watton Canyon member

36	Shale, moderate reddish brown, poor exposure; forms slope.	7	1021
35	Sandstone, light green, weathers yellowish gray, medium-grained quartz, ripple marks; forms ledge.	10	1014
34	Covered slope, probably moderate reddish brown shale.	10	1004
33	Limestone, grayish green, weathered pale yellowish green; forms ledge with splintery talus.	23	994
32	Sandstone, calcareous to sandy limestone, light gray, weathers light brownish gray, laminate to thin beds, ripple marks common; forms ledge-slope with shaly talus. Quartz grains fine to medium.	55	971

31	Shale, grayish green; forms covered slope.	27	916
30	Micrite, medium gray, weathers pale yellowish.	22	889
29	Covered slope, probably shale, light gray.	23	867
28	Micrite as in unit 30.	40	844
27	Shale and siltstone, moderate reddish brown; forms slope.	14	804
26	Limestone and shaly limestone, grayish green, weathers pale yellowish green, thin to thick beds, interbedded shale units; forms ledge.	12	790
25	Micrite, light brown weathers pale greenish yellow, thin to thick beds; forms cliff with slabby talus.	21	778
24	Limestone to shaly limestone, medium gray green weathers light greenish gray, fine crystalline, thin to medium beds; forms ledge with slabby talus.	45	757
23	Micrite, greenish gray, weathers light greenish gray, thin to thick beds; forms cliff with shaly to slabby talus.	57	712
	Total thickness of Watton Canyon member	366	
Boundary Ridge member			
22	Shale, light gray to greenish gray; forms slope with blocky talus cover caused by thin to very thin limestone beds near base.	121	655
21	Shale and siltstone, moderate reddish brown; forms slope containing some very thin limestone beds, grayish green.	25	534
20	Limestone, grayish green, weathers pale yellowish green, thin to very thin beds; forms ledge with splintery talus. Some shale partings.	16	509
19	Shale, moderate red to moderate pink; forms slope.	5	493
18	Micrite, medium grayish green, dense, massive; forms cliff.	6	488
17	Limestone, pale yellowish green, laminate, splintery, ripple marks; forms ledge-slope.	4	482
16	Shale, pale red to moderate pink; forms covered slope.	23	478
	Total thickness of Boundary Ridge member	200	
Rich member			
15	Limestone and shale, grayish green, very thin laminate to paper shale, ripple marks, strongly fissiled; forms ledge-slope.	35	455
14	Limestone, grayish green, laminate, splintery; forms ledge.	24	420

13	Covered slope, probably shale, grayish green.	10	396
12	Shaly limestone, grayish green, weathers pale green, laminate, splintery; forms ledge.	25	386
11	Shale, grayish green, and limestone, grayish green, both thin laminate to laminate; forms slope with splintery talus. Near base is limestone, light brown, weathers moderate yellowish brown, medium beds, contains bivalve fragments.	105	361
10	Limestone, light brown, weathers grayish green, laminate; forms ledge-slope with splintery talus. Some shale partings.	17	256
9	Shale, greenish gray with some siltstone and very thin beds of limestone, very pale orange; forms covered slope.	135	239
	Total thickness of Rich member	351	
Sliderock member			
8	Micrite, moderate brown, weathers light brown, medium beds, horizontal beds; forms rounded ledge.	19	104
7	Coquina, dark yellowish brown, gastropod hash.	1	85
6	Limestone, light brown, weathers pale greenish yellow, medium beds to thick beds, dense, fine crystalline; forms cliff to ledge with splintery talus. Some silt in the limestone.	15	84
5	Limestone, moderate brown, weathers light brown, contains oolites, thin bedded; forms ledge.	5	69
4	Limestone, shale and some siltstone, moderate brown to moderate olive brown, weathers pale olive with greenish cast; forms slope. Siltstone forms thin ledges.	16	64
3	Sandy limestone to calcareous sandstone, light brown, weathers grayish orange, thin beds at base to very thin beds at top, calcite content increases upward; forms ledge to rounded cliff.	9	48
	Total thickness of Sliderock member	65	
Gypsum Spring member			
2	Shales, moderate reddish brown with siltstone, moderate orange pink. Shales are calcareous, about 80 percent of unit; forms slope. Siltstones, slightly calcareous, well cemented; forms ledge. Siltstones similar to unit 1. Possible crinoids in float.	25	39
1	Sandstone, moderate orange pink, weathers grayish orange pink, thick beds, slightly cal-	14	14

citic; forms cliff with blocky talus and slabby talus. Grains medium size, well rounded. No fossils seen.

Total thickness of Gypsum Spring Member	39
Total thickness of section B.	1842

Ankareh Formation Section

The Ankareh Formation is underlain conformably by the Thaynes Formation and overlain conformably by the Nugget Sandstone. The complete section was measured along Spanish Fork Canyon road and foothills. The base, which is covered, is approximately located at NW¼, SE¼, SE¼, Section 17, T. 9 S, R. 4 E. The top is located at NE¼, SW¼, NW¼, Section 21. The formation is well exposed in the road cuts, but is generally lowlands with some rolling hills.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
31	Covered slope composed of siltstone and sandstone, moderate reddish orange; forms slope.	74	1399
30	Sandstone, moderate pink to grayish pink, thin to thick cross-bedding sets and horizontal beds. Quartz grains thin to coarse, some calcite cement, rock fairly well indurated. Some ripple marks; forms cliff.	40	1325
29	Sandstone and siltstone interbedded, pale yellowish orange to pinkish gray, predominantly sandstone, thin to thick bedded, cross bedding and ripple marks present, slightly calcareous; forms ledge.	75	1285
28	Sandstone, pale olive, weathers yellowish gray, slightly calcareous, medium to thick bedded, coarse grained, cross bedding; forms rounded cliff.	20	1210
27	Sandstone and siltstone, moderate red to moderate reddish orange, thin to thick bedded; forms rounded ledge to slope.	40	1190
26	Sandstone, yellowish gray to light greenish gray, coarse to medium grained, thick bedded, large scale cross bedding; forms ledge.	20	1150
25	Sandstone and siltstone as in unit 27.	20	1130
24	Covered slope.	30	1110
23	Sandstone, yellowish gray, medium grained, very thick bedded; forms rounded ledge.	10	1080
22	Interbedded siltstone and sandstone, moderate reddish orange, very thin bedded; forms slope, mostly covered.	230	1070

21	Siltstone and sandstone, moderate reddish orange, laminate to medium beds; forms rounded ledges to slope.	50	840
20	Sandstone, pinkish gray, weathers grayish pink, thick bedded; forms rounded cliff.	10	790
19	Interbedded sandstone, siltstone and shale, coarse-grained beds are grayish yellow green when fresh, fine-grained beds are pale red purple, laminate to very thin bedding; forms slope. Unit is calcareous.	20	780
18	Sandstone as in unit 20.	8	760
17	Siltstone and shale as in unit 19.	4	752
16	Sandstone as in unit 20.	3	748
15	Interbedded sandstone and siltstone, moderate reddish orange, laminate to medium beds; forms slope with blocky talus.	25	745
14	Sandstone, siltstone, and shale; pale red sands are pale olive when fresh; forms ledge.	12	720
13	Sandstone, grayish orange pink, weathers moderate orange pink, thick bedded; forms rounded ledge.	5	708
12	Interbedded sandstone, siltstone, and shale; sandstone is light olive gray when fresh, finer-grained units light brownish gray; forms ledge-slope. Calcareous.	5	703
11	Shale, reddish purple, thin laminate beds; forms slope.	4	698
10	Siltstone, grayish red purple, thin laminate, micro-cross bedding; forms slope.	4	694
9	Sandstone, light brownish gray to grayish red, weathers pale red with grayish yellow green mottling, medium- to fine-grained quartz, very thick beds grading to thin beds at the unit's boundaries; forms cliff with blocky talus.	64	690
8	Shale and siltstone, grayish red to dark reddish brown, laminate; forms slope.	156	626
7	Sandstone interbedded with siltstone. Sandstone, light brownish gray, weathers pale reddish brown to pale red, fine grained, calcareous, cross bedded, thin to thick bedded. Siltstone orangish red, slightly shaly, calcareous, laminate to thin irregular beds; forms ledge.	10	470
6	Siltstone, moderate reddish orange, interbedded with shale and sandstone. Laminate to very thin beds, calcareous, ripple marks; forms slope.	76	460
5	Sandstone, moderate pink, thick bedded, calcareous, cross bedded; forms ledge.	4	384
4	Partially covered slope of siltstone and shale. Siltstones, moderate reddish orange, dominate. Shales, purple red, laminate; forms slope.	150	380

3	Sandstone, moderate reddish brown, very thin to medium bedded, cross-bedded, ripple marks present; forms slope. Interbedded laminate of siltstone present.	14	230
2	Siltstone, moderate reddish brown, laminate; forms slope. Shale beds present. Calcareous.	40	216
1	Interbedded shale, siltstone, and sandstone. Shale, dusky red, some grayish yellow green splotches along fractures believed caused by leaching of ground water, thin laminate, calcareous; forms slope. Siltstone, moderate reddish brown with grayish yellow green splotches present, thin laminate to laminate, bedding becomes irregular near sandstone beds suggesting ripples; forms slope. Sandstone, minor, grayish pink to light greenish gray, very thin to thin bedded, calcareous, very fine to fine grained; forms slope with slabby talus. No fossils.	176	176
	Total thickness of Ankareh Formation	1399	

Thaynes Formation Section

The Thaynes Formation is underlain conformably by the Woodside Shale and overlain conformably by the Ankareh Formation. The lower contact is obscured by a covered slope, folding and possible faulting making the lower contact only approximate. The upper contact was drawn at the last calcareous sandstone, which is believed to be the top, but erosion and covered slopes make this uncertain. The section was measured along roadcuts in Spanish Fork and Diamond Fork canyons. The section base is located at SE¼, SW¼, NW¼, of Section 17, T. 9 S, R. 4 E. The top of the section was at NW¼, SW¼, NW¼, Section 16, T. 9 S, R. 4 E. The section was measured using a tape and Brunton. The outcrop is moderately well exposed but is folded and may be faulted at the lower end. The formation forms rounded hills with occasional ledges.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
44	Sandstone, calcareous cement, pale olive both fresh and weathered, fine to medium grained, well cemented, thin reddish partitions common, thin bedded; forms ledge.	5	1140
43	Sandstone, calcareous, pale olive to weathered yellowish gray, medium grained, thick bedded, quartz grains; forms cliff. No fossils.	4	1135
42	Sandy limestone to calcareous quartz sandstone, pale olive, weathers yellowish gray, thin to medium bedded; forms ledge. Shale, very pale orange, laminate present. No fossils.	7	1131

41	Interbedded sandstone, siltstone, and shale. Fine-grained units are pale red, coarser units moderate pink to pale olive when weathered, laminate to thin beds, some cross bedding in the sandstone beds. All beds are slightly calcareous; forms rounded ledge to slope.	14	1124
40	Sandstone, moderate pink, well-cemented quartz grains, not calcareous to a very slight reaction, thick bedded, massive; forms cliff.	2	1110
39	Shale, grayish red to dusky red, thin laminate to laminate; forms slope. No fossils, calcareous. Siltstone partitions are interbedded with it.	3	1108
38	Covered slope.	154	1105
37	Calcareous sandstone, fine-grained quartz, and calcareous shale, both grayish red, weathers pale red to grayish pink, laminate to very thin beds; forms rounded slope. Bivalve molds were seen at top of unit.	41	951
36	Calcareous sandstone and sandy limestone, light gray to grayish orange pink, weathers yellowish gray. Sandy beds dominate at top, limestone beds on bottom. Thin to thick beds; forms ledge with slabby talus. Some bivalve molds.	15	910
35	Shale, grayish red; forms slope.	10	895
34	Sandstone and sandy limestone as in unit 36. Crinoid stems and bivalve molds present.	11	885
33	Shale and siltstone, grayish red, laminate to very thin beds; forms rounded slope.	5	874
32	Shale and siltstone, pale green, laminate to very thin beds; forms rounded slope.	4	869
31	Sandy limestone, moderate pink, weathers grayish orange pink, medium beds, mottled surface indicating burrowings (?); forms ledge.	7	865
30	Covered slope.	135	858
29	Sandy limestone, greenish gray, weathers light greenish gray, thin to medium beds; forms ledge with slabby to shaly talus. Some siltstone and shale partitions. No fossils.	24	723
28	Interbedded calcareous sandstone, siltstone, and shale; grayish red to moderate pink; forms rounded slope with sandstones giving a slabby talus.	24	699
27	Sandstone, calcareous, greenish gray, weathers light brownish gray, medium to thick bedded; forms ledge. Some reddish shale partitions and limestone beds.	24	675
26	Interbedded moderate red shales with sandy limestone and calcareous sandstone; shales form slopes. Resistant sandstones and limestones are medium to thick bedded, grouped	83	651

	into units 10 to 15 feet thick; forms ledge with slabby talus.		
25	Limestone and sandy limestone, medium gray to pinkish gray when weathered, thick bedded, fossil hash common slightly above the middle; forms ledge.	17	568
24	Calcareous quartz sandstone, moderate red to moderate reddish orange, medium beds; fine to medium grained, lots of burrows; forms ledge-slope.	5	551
23	Limestone, dark gray, weathers moderate brown, thick bed; forms resistant ledge, bivalve hash on surface.	5	546
22	Covered slope believed to be same as unit 21.	36	541
21	Shale, siltstone with interbedded sandy limestone beds 6 inches to 1 foot thick. Shale and siltstone are moderate reddish brown, limestones grayish orange pink; forms slope with slabby talus. Location is at junction of Spanish Fork and Diamond Fork canyons.	15	505
20	Shale, moderate red to grayish red, very thin beds to laminate; forms slope.	25	490
19	Limestone, pale red with chert nodules common, very thick beds with horizontal to slightly irregular bedding. Thinner beds with fossil hash near top; forms cliff. Fossil bivalves, crinoids, sponges, and burrows.	13	465
18	Shale, grayish green; forms slope.	1	452
17	Shale, moderate red; forms slope.	11	451
16	Shale, grayish green, weathers pale green, thin laminate; forms slope.	10	440
15	Limestone, pale red, weathers moderate pink, fossil hash and mottled look are common. Similar to unit 19; forms cliff.	10	430
14	Interbedded grayish green and grayish red shales. Grayish green shales appear at top and bottom of unit, laminate, some siltstone present, small brachiopods present. Grayish red shales in middle, laminates; forms slope. The grayish green shales appear above and below the resistant limestone units.	13	420
13	Limestone, greenish gray, thin to thick bedded, irregular bedding common, some shale and siltstone partings present; forms cliff.	10	407
12	Limestone and shales interbedded. Limestones, pale olive to yellowish gray, weathers lighter, brachiopods, some sandy limestone beds; forms ledges. Shales and some siltstones, yellowish gray laminate beds that are cross bedded in places; forms covered slope.	27	397

11	Shale, yellowish gray to gray orange pink; forms slope.	15	370
10	Sandy limestone, dusky red, weathers moderate reddish brown, thin to thick beds; forms cliff. Some laminated shale and siltstone present. Chert blebs, fossil hash, and mottled bedding common.	15	355
9	Interbedded limestones, sandstones, and shales. Limestones, light green, sandy, weather pale greenish yellow, contain brachiopods. Sandstone, moderate pink to light olive gray, thick bedded. Shale, mostly moderate red, some pale green and moderate reddish orange near base; forms ledge-slope.	30	340
8	Covered slope believed to be moderate red shales with a few sandy limestone and calcareous sandstone beds.	50	310
7	Sandy limestone to fine- to medium-grained calcareous sandstone, light green, weathers to grayish yellow, abundant bivalves; forms ledge-cliff.	30	260
6	Limestone, dark gray, weathers medium gray, thick bedded, irregular bedding, some lenses of crinoid hash; forms cliff.	10	230
5	Shale, siltstone, and some sandstones. Shales are dusky red and light gray to pale olive. Siltstones are grayish yellow, dusky yellow, and pale green. Unit grades from laminated shales to thin to medium beds of calcareous sandstone; forms slope.	50	220
4	Covered slope, thickness estimated.	100	170
3	Sandy limestone, grayish green, medium bedded; forms ledge.	8	70
2	Interbedded calcareous sandstone and shale. Sandstone is grayish pink, thin to thick bedded; forms ledge. Shale is pale green and pale red; forms slope.	20	62
1	Shale, dusky red, laminate; forms slope.	42	42
	Total thickness of Thaynes Formation	1140	

Park City Formation Section

The Park City Formation is underlain conformably by Diamond Creek Sandstone and overlain with an angular unconformity by Tertiary (?) conglomerates of Red Narrows. The lower, middle, and upper members were measured separately. The sections were measured on the right side of the Right Fork of Little Diamond Creek. The lower and middle members are complete, upper member incomplete. The lower member, with its base located at NE$\frac{1}{4}$, NE$\frac{1}{4}$, SW$\frac{1}{4}$, of Section 22, T. 8 S, R. 4 E, is measured east through the lower phosphate bed of the middle member to its top at NE¼, NW¼, SE¼, of Section 22. The upper 18 feet of the lower member is a covered slope and its description was obtained from the northeast side of the next hill 100 yards to the north. The middle member has its base located at SW¼, NE¼, SE¼ of Section 22, T. 8 S, R. 4 E, near the phosphate mine. This member was measured ENE along the road to its top at NW¼, NE¼, SE¼, of Section 22. The upper member was measured from its base located at NW¼, SW¼, SW¼, of Section 14, southeast to where it contacts Tertiary conglomerates of Red Narrows in the SE¼, SW¼, SW¼, of Section 14, T. 8 S, R. 4 E. The Park City Formation is well exposed although some folding does occur. The lower and upper contacts are covered and their positions are approximately located. This formation forms high hills with cliffs, ledges, and rounded ledges. This section was measured with a tape and Brunton.

Unit No.	*Description*	*Thickness* *Unit*	*Thickness* *Cumulative Section*
Upper member			
23	Covered slope believed to be shale or siltstone, moderate reddish brown.	99	1642
22	Limestone, light gray, weathers light gray to very pale orange, thin bedded; forms ledge with slabby slope. Limestone is medium crystalline and occasionally sandy. Fossil hash of brachiopods and crinoids.	26	1543
21	Limestone and sandy limestone, light gray, weathers light gray to very pale orange to grayish pink, medium to thick bedded, slabby talus over rounded ledges and slope. Fossil brachiopods are replaced by sparry white calcite resembling popcorn in the rocks. Limestone is medium crystalline.	100	1517
20	Limestone and fossiliferous limestone, light gray becoming very pale orange as they become a sandy limestone, very thin to thin bedded; forms ledge-slope, shaly to slabby talus. Brachiopods, productids (?) common. A few beds of calcareous sandstone, dark yellowish orange; forms ledge.	51	1417
	Total thickness of Park City Upper member	276	
Middle member			
19	Cherty limestone, medium gray brown, weathers moderate yellowish brown, thick bedded, highly fractured; forms ledge. Chert is in modules, medium gray, very abundant.	6	1366
18	Mostly black shale, weathers to medium greenish gray, interbedded with thin beds of oolitic	30	1360

	phosphate and dark gray cherty limestone; forms slope.		
17	Cherty limestone, dark gray with black chert nodules, thick bedded; forms ledge.	5	1330
16	Mostly shale, black weathers light gray thin laminate interbedded with dark gray cherty limestone which is thin bedded; forms slope.	40	1325
15	Limestone, dark gray, weathers light gray, contains chert nodules, black, abundant, thin to medium bedded. Contact with unit above and below is very irregular; forms thick ledge.	18	1285
14	Covered slope believed to be shales, black and dark greenish gray, interbedded with thin beds of calcareous sandstone, pale yellowish orange to moderate reddish brown. May contain some dolomite in the sandstone beds.	52	1267
13	Interbedded dolomite and shale. Dolomite silty, moderate brown, weathers pale yellowish orange, thin bedded; forms ledge. Shale medium gray, weathers greenish gray, thin laminate; forms slope.	40	1215
12	Oolitic phosphate, black to medium light gray, thin to medium bedded; forms slope with shaly talus. Burrowed.	10	1175
	Total thickness of Park City middle member	201	

Lower member

11	Limestone, dark gray, weathers light gray, medium bedded with fractures perpendicular to bedding; forms ledge, contains large sperifers (?).	6	1165
10	Limestone, light brown to grayish orange, weathers moderately orange pink, medium bedded; forms ledges. Productid brachiopods abundant. Well preserved.	12	1159
9	Limestone and sandy limestone, grayish orange pink, thin to thick bedded, forms rounded cliffs to steep ledges with slabby and shaly talus. Chert nodules, gray, common in lower part, upper part silicic limestone bed present. Brachiopods present.	167	1147
8	Limestone and sandy limestone, light gray to dark yellowish orange, thin to medium bedded; forms ledges with slabby talus. Limestones are fine crystalline with some beds of coarse bioclastic limestones, light brown to dark-yellowish orange. Bioclastic debris is brachiopods and crinoids; these beds form slopes. Gray chert at 910 feet.	229	980

7	Sandy limestone to calcareous sandstone, pale yellowish orange to pale yellowish brown, thin bedded; forms slope. Brachiopod hash common.	21	751
6	Fine-grain limestones, sandy limestones, and silicic limestones; gray to light brown with increase of sand content; forms ledge. Thin cross bedding in medium to thick sets noted. Vugs filled with white calcite common. Light brownish gray chert nodules at about 700-foot level.	30	730
5	Same as unit 6 minus the calcite-filled vugs and chert.	100	700
4	Limestone, light gray, medium beds; forms ledge. Light gray to white chert and gray silicic limestones common.	39	600
3	Limestone, light brownish gray grading to a slightly sandy limestone, brownish gray near the top. Thin to thick bedded, forms a rounded cliff with blocky talus. White-bedded chert in laminate to thin beds very common. At about 400-foot level is a 3-foot bed of white chert.	221	561
2	Limestone, sandy limestone, and cherty limestone; brownish gray to light gray, weathering light gray, grayish orange to nearly white. Sandy limestone is brownish gray. Limestone containing chert is light gray to light brownish gray. The chert is white, laminate to thin beds, or isolated nodules. Beds are thin to thick; form ledges with slabby talus. No fossils seen. Sand in the limestone is in thin beds to laminate and forms small cross beds.	177	340
1	Covered slope believed to be calcareous sandstone and sandy limestone, moderate orange pink to grayish orange, thin bedded, interbedded with siltstone partings.	163	163
	Total thickness of Park City Lower member	1165	
	Total thickness of Park City Formation	1642	

Diamond Creek Sandstone Section

The Diamond Creek Sandstone is underlain conformably (?) by the Kirkman Limestone and is overlain conformably by the Park City Formation. The complete section is measured near the head of the Right Fork of Little Diamond Creek. The section base is located in the SW¼, NE¼, NW¼, of Section 22, T. 8 S, R. 4 E, with the section top in the SW½, NW¼, NE¼, of Section 22. A tape and Brunton were used. The outcrop is well exposed except at the formation contacts, which are both covered. The position of the contacts is approximated and is believed to be nearly correct. This formation generally forms cliffs or steep ledges.

Unit No.	Description	Thickness Unit	Thickness Cumulative Section
10	Sandstone, moderate orange pink and white, fine to medium quartz grains, thin to medium beds; forms ledge to slope, partially covered.	137	901
9	Sandstone, moderate pink to pale red and white, thin to thick beds, small cross-bed sets of ripple marks to thick sets, fine- to very coarse-grained quartz, good sorting; forms cliff.	129	764
8	Sandstone, grayish pink to white, medium to thick cross-bed sets composed of thin bedding, calcareous, parallel beds also present; forms cliff to steep ledge. No fossils. Fine-grained quartz. Pebble conglomerate seen in float, believed to come from top of unit. About midway up a dark purple gray sandy limestone was noted in a one foot bed.	30	635
7	Sandstone, moderate orange pink to moderate reddish orange, fine- to medium-grained quartz, cross-bedded; forms massive cliff. Honeycomb weathering in places.	100	605
6	Calcareous quartz sandstone, moderate orange pink to white occurs as minor beds or splotches, medium to thick cross-bed sets which are composed of thin beds, some parallel beds present; forms cliff to ledge with some slopes. Softer units made of very fine- to fine-grained quartz forming micro-ripple marks; more resistant units are fine to coarse grained and form larger cross-beds. Fractures parallel to bedding plane noted.	268	505
5	Interbedded sandstone, sandy limestone. The sandstone is white and moderate pink, fine to medium grained, calcareous, thin to thick bedded limestone is minor, white, medium to thick bedded; medium-grained quartz common in it.	20	237
4	Sandstone, white and moderate pink when fresh or weathered, fine grained, calcareous, massive bed; forms cliff. No fossils, grains are well sorted, well rounded, all clean quartz. Some calcite cement which increases in the pinker units. White color more common in upper half.	44	217
3	Covered slope.	103	173

2	Sandy limestone to calcareous sandstone, dark gray, weathers very light gray; forms ledge.	10	70
1	Covered slope.	60	60
	Total thickness of Diamond Creek Sandstone	901	

Kirkman Limestone Section

The Kirkman Limestone is underlain disconformably (?) by the Oquirrh Formation and is overlain conformably (?) by the Diamond Creek Sandstone. The complete section was measured from a base at NE¼, NW¼, SW¼, or Section 21, T. 8 S, R. 4 E, north to the top at SE¼, SW¼, NE¼, of Section 21. A tape and Brunton were used. The outcrop is poor and is partially covered with brush and soil. The upper contact is good, but the lower contact is covered and its position was approximated. The formation usually forms a strike valley, but rounded ledges and slopes are found at the head of Little Diamond Creek Canyon.

		Thickness	
Unit No.	*Description*	*Unit*	*Cumulative Section*
7	Limestone, medium and dark gray, weathers slightly lighter, thin laminate; forms rounded ledge to small cliff. Some beds of intraformational breccia and some beds of limestone, pinkish gray, weathering yellowish gray, sandy, laminate. No fossils observed at this locality; however, Kirkman outcrop on hill to the NE contains brachiopods and bryozoans.	22	292
6	Intraformational breccia composed of limestone, dark to medium gray, weathering medium to light gray, thick bedded, the breccia blocks made of thin laminate, with alternating layers of light and dark limestone and shaly limestone giving a mosaic, edge-of-book-like pattern. Basal 5 feet has a pinkish cast; forms rounded ledges.	52	270
5	Covered slope.	93	218
4	Limestone, dark gray, weathering medium gray with occasional pinkish cast, medium to thick beds; forms rounded ledge to slope. Gray limestones are either uniform medium crystalline or breccias composed of thin laminated material as in unit 6.	35	125
3	Sandy limestone and calcareous quartz sandstone, grayish orange, weathering grayish orange pink or pale yellowish orange, thin to medium beds; forms ledge. No fossils.	15	90
2	Covered slope.	22	75
1	Intraformational breccia, matrix composed of limestone, possibly some sandy limestone, coarse	53	53

crystalline, massive beds, some thin beds of breccia, grayish orange pink, weathering to grayish orange, moderate orange pink to grayish pink. Breccia blocks are either the coarse limestones and sandy limestones from above or dark gray, thin laminate limestone. Blocks are 1 to 6 inches across, subsquare; forms rounded cliff.

Total thickness of Kirkman Limestone 292

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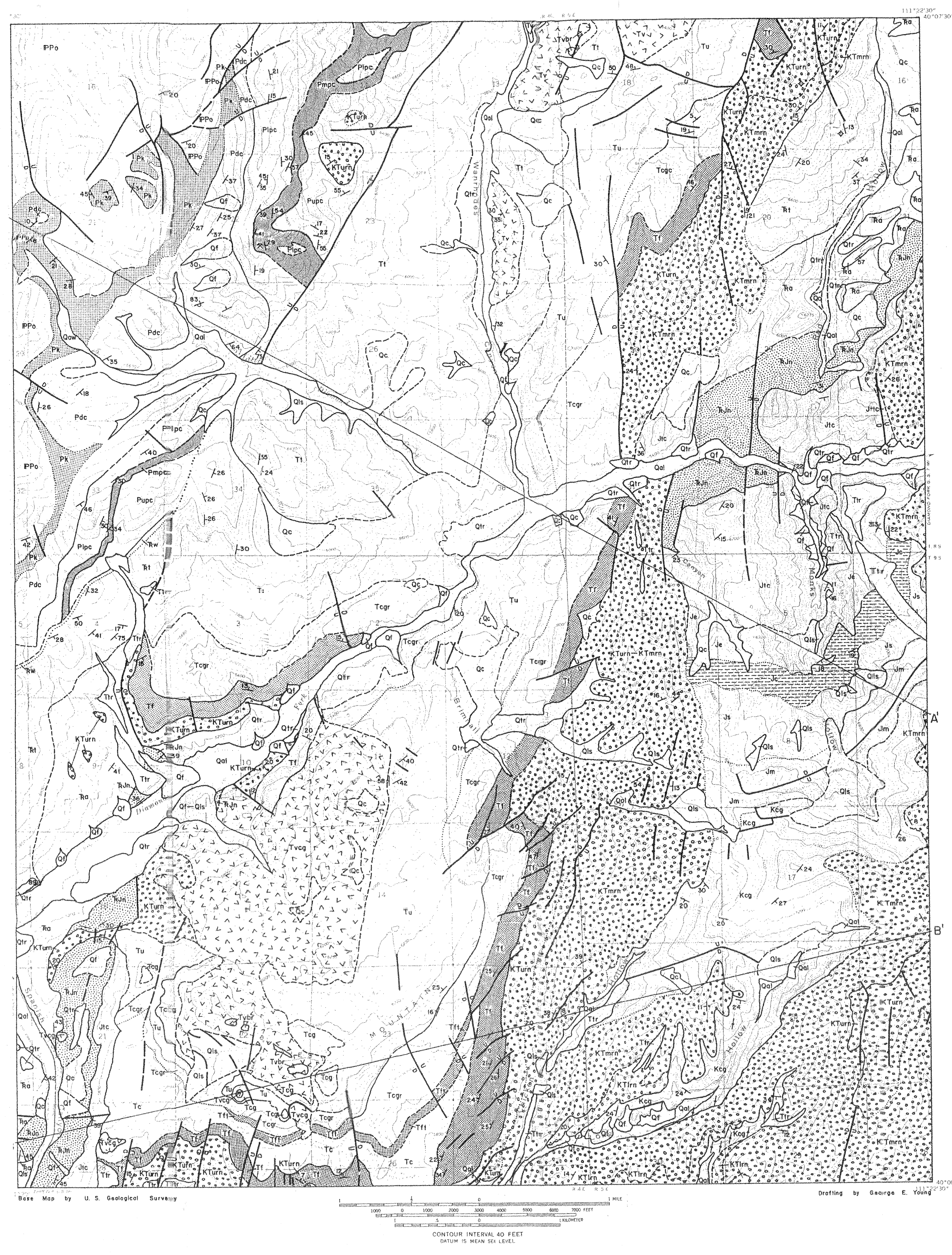

GEOLOGY AND SECTIONS OF BILLIES MOUNTAIN QUADRANGLE

by

George E. Young

1975

SEDIMENTARY ROCKS

QUATERNARY

- Qal — Alluvium
- Qc — Alluvium and colluvium
- Qf — Alluvial fan or talus cone
- Qls — Landslide or slump
- Qow — Glacial outwash
- Qtr — Quaternary terrace

TERTIARY

- Ttr — Tertiary terrace
- Tcg — Pediment gravel
- Tt — Tibble Formation
- Tu — Uinta Formation
- Tcgr — Colton—Green River Formations (undifferentiated)
- Tc — Colton Formation
- Tft — Flagstaff Limestone tongue
- Tf — Flagstaff Limestone
- KTurn — Upper Red Narrows Congl.

CRETACEOUS

- KTmrn — Middle Red Narrows Cg.
- KTlrn — Lower Red Narrows Congl.
- Kcg — Cretaceous conglomerate (Price River? — Indianola?)

JURASSIC

- Jm — Morrison Formation
- Js — Summerville Formation
- Curtis Formation
- Je — Entrada Sandstone
- Jtc — Twin Creek Limestone

TRIASSIC

- ŦRJn — Nugget Sandstone
- ŦRa — Ankareh Shale
- ŦRt — Thaynes Formation
- ŦRw — Woodside Shale

PERMIAN

- Pupc — Upper Park City Formation (Franson Member)
- Pmpc — Middle Park City Formation (Meade Peak Tongue)
- Plpc — Lower Park City Formation (Grandeur Member)
- Pdc — Diamond Creek Sandstone
- Pk — Kirkman Limestone
- PPo — Oquirrh Formation

VOLCANIC ROCKS

TERTIARY

- Tvcg — Volcanic conglomerate
- Tv — Volcanic tuff
- Tvbr — Volcanic breccia

Contact
Dashed where approximate, dotted where inferred

Fault showing upthrown and downthrown sides

Strike and dip of beds
Normal, Overturned, Horizontal

Joints
Normal, Vertical

Hot water conduit

Mine

Well drilled for oil or gas, dry

Syncline

Anticline

Approximate Declination $16\frac{1}{2}°$