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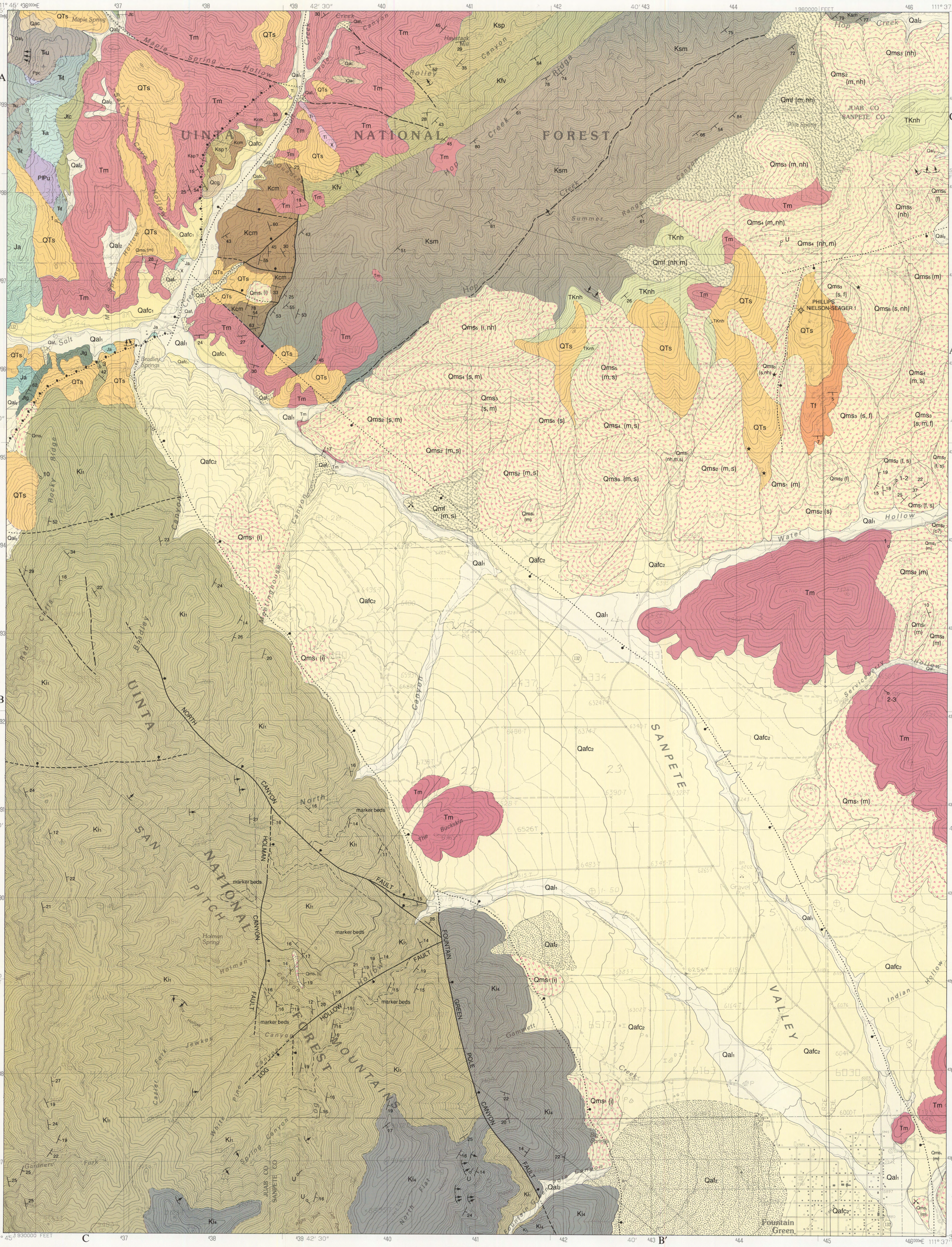

Base map from U.S. Geological Survey,
Fountain Green North Provisional Quadrangle, 1983

Malcolm P. Weiss, Thesis Advisor

SCALE 1:24 000

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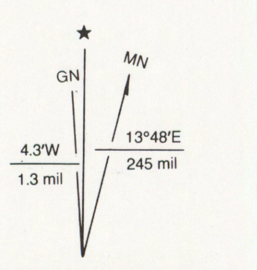
METERS: 1000 0 1000 2000

CONTOUR INTERVAL 40 FEET



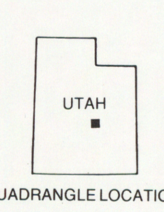
UTM GRID AND 1991 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

PROVISIONAL GEOLOGIC MAP OF THE FOUNTAIN GREEN NORTH QUADRANGLE, JUAB AND SANPETE COUNTIES, UTAH

by

Raymond L. Banks

1991



QUADRANGLE LOCATION

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DESCRIPTION OF MAP UNITS

QUATERNARY

Qal_1 — Younger alluvial deposits — *Dark-brown, reddish-brown or gray, unconsolidated, poorly sorted, poorly to moderately stratified, clay- to cobble-sized material. Occurs in channels and on canyon floors. Usually less than 50 feet (15 m) thick.*

Qcg — Colluvial gravel deposits — *Sand- to boulder-sized material derived entirely from the Indianola Group. Occurs in a cone at the base of a steep slope.*

Qac — Colluvial slopewash deposits — *Moderately consolidated, poorly sorted, locally derived, clay- to cobble-sized particles deposited in shallow gullies on hillslopes. Ranges up to 20 feet (6 m) thick.*

Qaf_1 — Younger alluvial-fan deposits — *Moderate reddish-brown to gray, poorly to moderately sorted, nonstratified, clay- to cobble-sized material deposited in fans at the mouths of smaller hollows. Rarely exceeds 50 feet (15 m) thick.*

$Qafc_1$ — Coalesced younger alluvial-fan deposits — *Coalesced moderate reddish-brown to gray poorly to moderately sorted, nonstratified, clay- to cobble-sized material deposited in fans at the mouths of smaller hollows. Rarely exceeds 50 feet (15 m) thick.*

Qal_2 — Older alluvial deposits — *Dark brown, reddish-brown, or gray, unconsolidated, poorly sorted, poorly to moderately stratified gravel, sand, silt, and clay. Occurs at higher elevations and in exposures incised by later drainages. Rarely exceeds 50 feet (15 m) thick.*

Qaf_2 — Older alluvial-fan deposits — *Moderate reddish-brown to gray, poorly to moderately sorted, nonstratified, clay- to boulder-sized material deposited in fans at the base of the Gunnison Plateau. Overlies coalesced alluvial fans. Isolated by downcutting of later drainages. Range from 40 to 100 feet (12-30 m) thick.*

$Qafc_2$ — Coalesced older alluvial-fan deposits — *Moderate reddish-brown to gray, poorly to moderately sorted, crudely bedded, clay- to boulder-sized material deposited in fans at the base of the Gunnison Plateau and Cedar Hills. Isolated by downcutting of later drainages. About 250 feet (76 m) thick.*

Qmf — Debris-flow deposits — *Poorly sorted, clay- to boulder-sized material that occurs as hummocky, sinuous deposits. Occur along Hop Creek Canyon.*

Qms — Landslide deposits — *Extremely poorly sorted, clay- to block-sized (up to about 20 feet or 6 m in average diameter) material deposited in hummocky to terrace-like mounds and lobes. The landslides are differentiated according to relative age (Qms_1 -youngest; Qms_5 - oldest). Where possible, multiple formations involved in a single slide movement are differentiated (s-Salt Creek Fanglomerate, m-Moroni Formation, c-Colton (?) Formation, f-Flagstaff Formation, nh-North Horn Formation, i-Indianola Group).*

QUATERNARY/TERTIARY

QTs — Salt Creek Fanglomerate — *Consolidated to unconsolidated pebbles, cobbles, and boulders in a reddish-brown, clay- to sand-sized matrix. Thickness is highly variable; locally may exceed 500 feet (152 m).*

TERTIARY

Tm — Moroni Formation — *Light-gray to dark-gray, waterlaid volcanic conglomerate and tuffaceous sandstone. Ranges up to about 1000 feet (305 m) thick.*

Tf — Flagstaff Limestone — *Yellowish-gray to light-gray, arenaceous, interclastic limestone with dark chert and mudstone. Pebbly near base. Probably about 300 to 750 feet (91-230 m) thick.*

TERTIARY/CRETACEOUS

TKnh — North Horn Formation — *Poorly exposed, yellowish-gray conglomerate, pink sandstone, and red mudstone. Up to about 2600 feet (792 m) thick.*

CRETACEOUS

Indianola Group

Cedar Hills nomenclature

Ksm — Sixmile Canyon Equivalent — *Massive, grayish-orange to yellowish-gray, clast-supported conglomerate with interbedded sandstone and sandstone lenses. Probably more than 7100 feet (2165 m) thick.*

Kfv — Funk Valley Equivalent — *Light-gray to yellowish-gray, pebble sand- with conglomeratic lenses. About 1600 feet (488 m) thick.*

Ksp — Sanpete Equivalent — *Massive, yellowish-gray to pale-red conglomerate with interbedded sandstone and sandstone lenses. Approximately 1300 to 1400 feet (396-427 m) thick.*

Gunnison Plateau nomenclature

Ki_4 — Member 4 — *Massive, yellowish-gray to light-gray, clast-supported conglomerate overlain by yellowish-orange sandstone with abundant ironstone concretions and liesegange banding. Ranges up to at least 1500 feet (457 m) thick.*

Ki_1 — Member 1 — *Massive, yellowish-gray to pale red, clast-supported conglomerate with interbedded sandstone, sandstone lenses, and reddish-orange arenaceous limestone. About 3700 feet (1128 m) thick.*

Kcm — Cedar Mountain Formation — *Interbedded, bright reddish-orange, calcareous mudstone, pink sandstone, yellowish-gray conglomerate, and gray, oncolitic limestone; 1300 to 1600 feet (396-488 m) thick.*

JURASSIC

Jtg — Twist Gulch Formation — *Interbedded, light-brown, calcareous siltstone, mudstone, gritstone, and light-gray sandstone. Probably 1200 to 1900 feet (366-579 m) thick.*

Ja — Arapien Shale — *Interbedded, greenish-gray to red, argillaceous limestone, sandstone, siltstone, and mudstone. Locally salt-bearing. Probably about 5500 feet (1676 m) thick, but locally much thicker and thinner due to structural deformation.*

PALEOZOIC AND MESOZOIC — *Material ranging from Pennsylvanian to Early Jurassic occurs in a landslide or detachment block complex in the northwest corner of the quadrangle. The landslide or detachment complex is of post-Middle Jurassic to pre-Oligocene age. Since most of the material maintains original bedding and can be identified by formation, it is mapped by original formation.*

Jtc — Jurassic Twin Creek Limestone — *Red to gray silty shale, siltstone, argillaceous limestone, and dense oolitic limestone. Contains* Pentacrinites.

TRa — Triassic Ankareh Formation — *Pale-red to moderate-reddish-brown calcareous shale, siltstone, sandstone, and brecciated sandstone.*

TRt — Triassic Thaynes Formation — *Gray and tan fossiliferous micrite, arenaceous, sparse biomicrite, and dolomitic limestone.*

TRu — Triassic deposits, undifferentiated — *Light-brown to pale-brown (weathered color), grayish-red to grayish-yellow-green (fresh color) siltstone and very fine-grained sandstone. May be derived from the Woodside, Thaynes, or Ankareh Formations.*

Ppc — Permian Park City Formation — *Light-gray to medium-dark-gray biomicritic limestone. Contains abundant bryozoans and crinoid fragments.*

PPu — Pennsylvanian-Permian deposits, undifferentiated — *Medium-light-gray to olive-black fossiliferous biomicritic and pelmicritic limestone. Contains abundant foraminifer, fusulinid, brachiopod and pelycepod fragments, and lesser crinoid and bryozoan fragments. Derived from either the Oquirrh Formation or the Kirkman Limestone.*

INTRUSIVE IGNEOUS ROCKS (TERTIARY)

Ti — Salt Creek dike — *Pale-brown to grayish-red andesite porphyry containing plagioclase, polycrystalline phenocrysts containing sanadine, and biotite in an aphanitic groundmass. 33.6 ± 1.4 Ma K-Ar age. Where exposed it is 30 feet (9 m) thick and about 2000 feet (610 m) long.*

Ksf — South Flat Formation — *On cross section only.*

Ju — Undifferentiated Jurassic deposits — *On cross section only.*

Note: For lithologic column, see map booklet.

MAP SYMBOLS

CONTACT — *dashed where approximate.*

NORMAL FAULT — *dashed where approximate, dotted where inferred; bar and ball on downthrown side.*

INFERRED THRUST FAULT — *teeth on upper plate*

REVERSE FAULT — *dashed where approximate, teeth on upthrown side.*

PHOTOGEOLOGIC LINEAMENT

LANDSLIDE COMPLEX BOUNDARY, *approximate*

SELECTED LOCATION OF WELL-EXPOSED OUTCROP

PROSPECT PIT — GRAVEL PIT

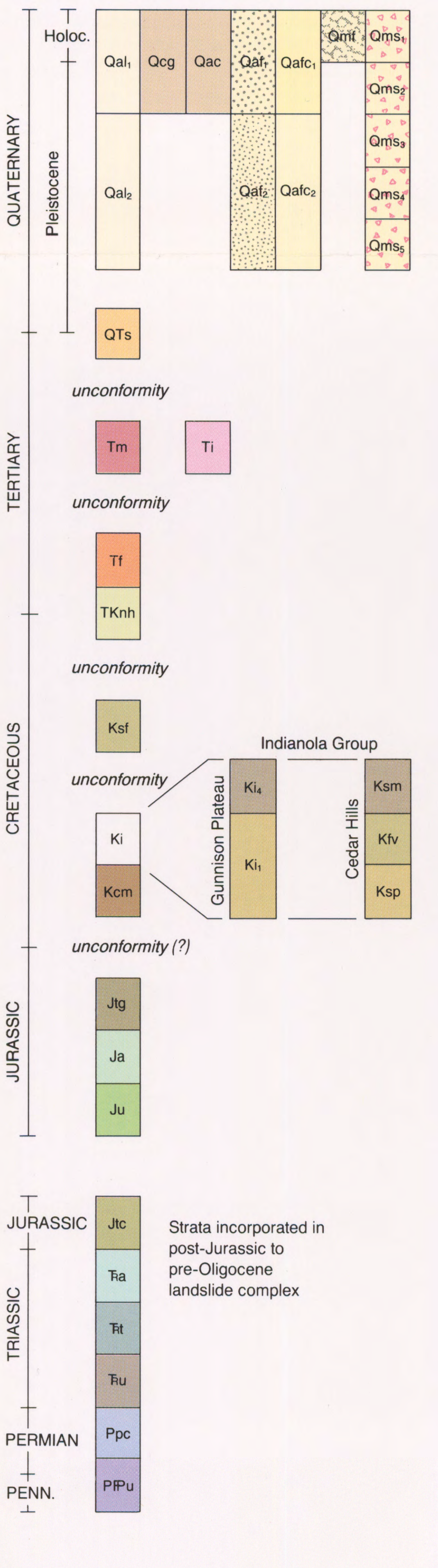
STRIKE AND DIP OF BEDDING

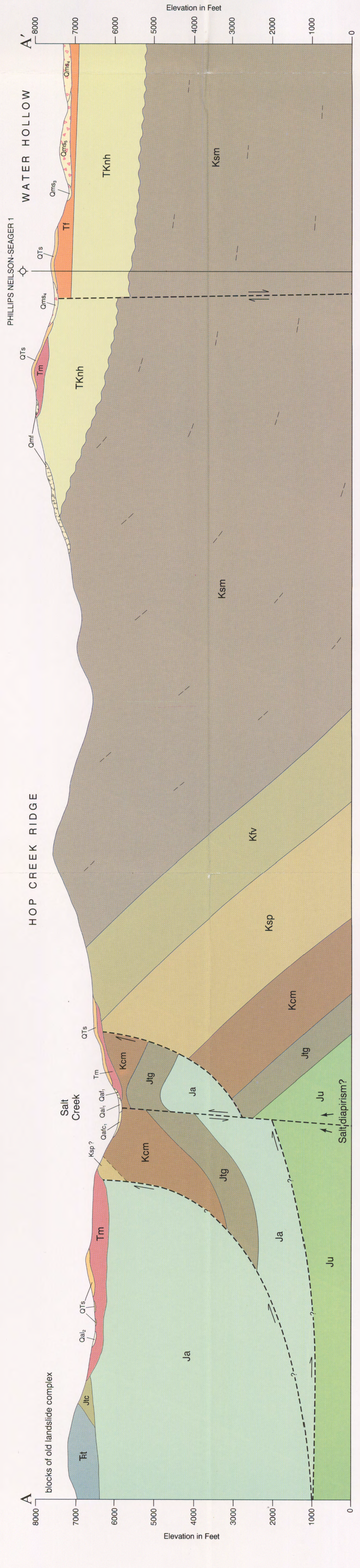
SPRING — *number indicates approximate output in gals/min. U = unmeasured or flow too small to measure.*

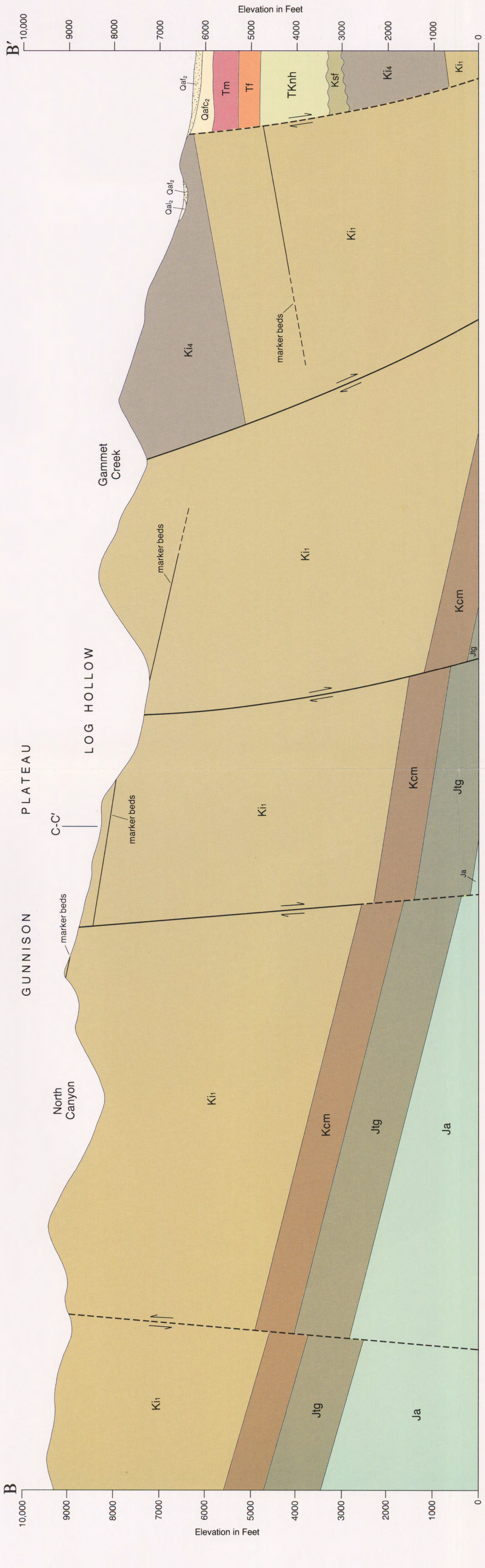
EXPLORATION WELL — *Phillips Neilson-Seager #1*

LANDSLIDE OR SLUMP — *associated with 1983-85 wet cycle*

CORRELATION OF MAP UNITS

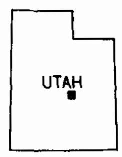






PROVISIONAL GEOLOGIC MAP OF THE FOUNTAIN GREEN NORTH QUADRANGLE, SANPETE AND JUAB COUNTIES, UTAH

by
Raymond L. Banks



MAP 134 **1991**

UTAH GEOLOGICAL SURVEY
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R.L. Banks PROVISIONAL GEOLOGIC MAP OF THE FOUNTAIN GREEN NORTH QUADRANGLE
U G S Map 134

PROVISIONAL GEOLOGIC MAP OF THE FOUNTAIN GREEN NORTH QUADRANGLE, SANPETE AND JUAB COUNTIES, UTAH

by
Raymond L. Banks

MAP 134 **1991**

UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

UTAH GEOLOGICAL SURVEY
2363 Foothill Drive
Salt Lake City, Utah 84109-1491

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PROVISIONAL GEOLOGIC MAP OF THE FOUNTAIN GREEN NORTH QUADRANGLE, SANPETE AND JUAB COUNTIES, UTAH

by
Raymond L. Banks
Northern Illinois University

ABSTRACT

The Fountain Green North quadrangle lies in an area of transition between three physiographic provinces in central Utah: the Middle Rocky Mountains, the Basin and Range, and the Colorado Plateau. Strata range from Middle Jurassic to Quaternary in age, though mappable blocks derived from older units occur in landslide masses. The Late Cretaceous Indianola Group dominates the map area. The Jurassic Arapien Shale and Twist Gulch Formation and Early Cretaceous Cedar Mountain Formation are exposed in small areas. The latest Cretaceous or early Tertiary North Horn Formation and Tertiary Flagstaff and Moroni Formations unconformably overlie older strata in the area. The only igneous intrusion in the map area, herein named the Salt Creek dike, has yielded an age of approximately 33.6 ± 1.4 million years.

Structural deformation of the area is mostly the result of eastward migration of Sevier orogenic thrusting, especially the emplacement of the Nebo allochthon. Salt diapirism has only locally modified structure within the quadrangle. In the study area, the frontal fault system along the northeast margin of the Gunnison Plateau is believed to be younger than the frontal fault system to the south. This implies that the portion of Sanpete Valley in the study area is younger than the main valley to the south. Numerous historic and prehistoric landslides occur in the area. Some threaten highways and other cultural features. Sand and gravel for construction use, and salt are the primary economic resources of the area. Exploration for oil and gas continues. The quadrangle contains an important watershed and numerous springs and streams.

INTRODUCTION

The Fountain Green North 7.5′ quadrangle lies 45 miles (72 km) south of Provo in central Utah. The quadrangle includes the junction of the northeastern portion of the Gunnison Plateau, the southeastern tip of the southern Wasatch Range, and a western portion of the Cedar Hills. They are separated by Salt Creek and the west arm of Sanpete Valley. The quadrangle includes most of the town of Fountain Green, and most of the outlying area is part of the Uinta National Forest. Utah State Highway 132 runs northwest to southeast through Salt Creek Canyon and Sanpete Valley.

The first substantial geologic work in the area, which was begun in the early 1920s by Spieker and Reeside (1925), resulted in the regional stratigraphic framework. Subsequent work by Spieker and his graduate students resulted in a number of fundamental publications (Spieker, 1930, 1936, 1946, 1949a, 1949b). Other studies within the quadrangle include those by Eardley (1933, 1934) and Black (1965) in the Mt. Nebo area, Schoff (1937, 1951) and Jefferson (1982) in the Cedar Hills, Hunt (1950), Thomas (1960), Hays (1960), and Weiss (1982) in the Gunnison Plateau, and regional studies by Lawton (1982, 1985) and Le Vot (1984). The prevailing poor outcrop quality and landsliding prevented measurement of stratigraphic sections within the map area. Thicknesses and stratigraphic position of the strata were determined using sections measured in nearby locations by myself and other workers.

STRATIGRAPHY

Strata in the Fountain Green North quadrangle range from Middle Jurassic to Quaternary in age. Material of Pennsylvanian-Permian to Middle Jurassic age exists in the northwest corner of the study area, but this older material is part of an ancient slide or detachment complex. Strata of the Jurassic System are the oldest rocks in place within the quadrangle and are represented by the Middle Jurassic Arapien Shale and the Late Jurassic Twist Gulch Formation. Cretaceous rocks include the Cedar Mountain Formation and the Indianola Group. Overlying the Indianola Group, with angular unconformity, is the Cretaceous-Tertiary North Horn Formation. Tertiary strata also include the Flagstaff and Moroni Formations. A small igneous intrusion in the quadrangle has been dated as Oligocene. The Salt Creek Fanglomerate of Tertiary-Quaternary age overlaps all older units. Quaternary units include several types and ages of alluvial fans, stream alluvium, colluvium, and mass-movement deposits. Mass-movement depostis are widespread throughout the area, and an effort was made to divide them according to their formational content and relative age.

PALEOZOIC AND MESOZOIC ROCKS IN LANDSLIDE DEPOSITS

Material ranging from Pennsylvanian-Permian to Early Jurassic, in the extreme northwest corner of the quadrangle, rests on the Middle Jurassic Arapien Shale and was interpreted by Black (1965) to have been emplaced by a series of imbricate thrust splays from the Nebo Overthrust. Le Vot (1984) interpreted the entire mass as a series of old landslides. Exposures of the formations involved are extremely poor and commonly occur as rubble-covered slopes. Attitudes, obtained where possible, are inconsistent, and no proper stratigraphic sequence can be observed. Given the chaotic nature of the material, the author agrees with Le Vot's interpretation and suggests that the material represents a series of detachments which broke away from the overthrust plate. The author, however, does not agree with the consistency of attitudes or the formational identification of some of the material shown on Le Vot's map. Grant Willis of the Utah Geological and Mineral Survey (personal communication, 1985) suggests that the material may have broken away from the overthrust plate and settled in a topographic low eroded into the less-resistant Arapien Shale. Although the true nature of the contacts is difficult to determine, it is probable that the sliding event produced transgressive, thrust-like contacts within the slide complex.

The timing of the sliding event can be best bracketed as post-Middle Jurassic to pre-Oligocene. The slide material rests on the Middle Jurassic Arapien Shale and is overlapped on its eastern margin by the Oligocene Moroni Formation. The material is not considered part of the proper stratigraphic column of the quadrangle, however, since most of the rocks can be identified as belonging to certain formations, they are herein described by formation. For a more detailed description of these formations, the reader is referred to Eardley (1933), Black (1965), and Biek (in press). Biek has visited the locality and assisted with the identification of these units, all of which are well developed in the adjacent Nephi quadrangle.

Pennsylvanian-Permian Undifferentiated (PℙPu)

A portion of the landslide complex was mapped as Pennsylvanian-Permian undifferentiated. The material belongs to either the Oquirrh Formation or the Kirkman Limestone. Definite identification was not possible because of the similarity between the two formations coupled with poor exposure and lack of proper stratigraphic sequence. The lithology is all limestone and can be classified as packed biomicrite and pelmicrite. Color ranges from medium-light gray on weathered surfaces to olive black on fresh surfaces. Caliche rinds are common on exposed surfaces. Fossils and fossil fragments account for approximately 40 percent of the rock with the remaining 60 percent being micritic mud. Foraminifera are the most abundant of the fossil constituents. Fusulinids, ranging in size from 0.12 to 0.24 in. (3-6 mm), are common. Shell fragments, mostly brachiopods and pelycepods, are the next most abundant fossil constituent. Crinoid fragments and bryozoans are present in lesser amounts. Black and white chert is abundant on the rubble-covered slope, but only a small amount was observed in thin sections. Fresh breaks of the rock have a fetid smell.

Permian Park City Formation (Ppc)

Only particles of the Franson Member of the Park City Formation were found in the slide complex. Again, the exposures are poor, but the material appears to be more cohesive than the previously discussed Oquirrh or Kirkman material. The exposures are entirely limestone and can be classified as a sparse biomicrite. Color ranges from light gray when weathered to medium-dark gray when fresh. Large bryozoans are common and have a pinkish gray color. The rock is approximately 70 percent micrite; fossils and fossil fragments constitute approximately 30 percent. Large bryozoans (up to 1.5 in or 38 mm) are the most abundant fossils (80%). Crinoid fragments represent the remaining 20 percent. General porosity is poor, and fractures are irregular.

Triassic Undifferentiated (T̄Ru)

Due to poor exposures, a portion of the slide complex was mapped as Triassic undifferentiated. Parts of the outcrops can be identified as Woodside Shale, Thaynes Formation, or Ankareh Formation but, because scattered outcrops of redbeds could belong to any of the three formations, the exposures were undifferentiated. The questionable red beds are composed of siltstone and very fine sandstone. Color ranges from light brown to pale brown when weathered and grayish-red to grayish-yellow-green when fresh. Grains constitute greater than 75 percent of the rock with the remainder being clay matrix. Pieces of platy float have small-scale cross bedding and are thinly laminated.

Thaynes Formation (T̄Rt)

Material identified as belonging to the Thaynes Formation forms the best exposures within this part of the slide complex. It generally occurs as widespread, disoriented, and highly fractured exposures up to 15 feet (4.6 m) across. The dominant rock types are gray and tan fossiliferous micrite, arenaceous sparse biomicrite, and dolomitic siltstone. The tan siltstone can be easily recognized by the brown, freckled appearance caused by limonite staining around iron oxide mineral grains. Iron oxide heavy minerals make up 3 to 5 percent of all samples collected. The gray limestone is commonly fossiliferous; the most abundant fossils are shell fragments replaced with coarse sparite. The presence of fossil ammonoids up to 4 inches (10 cm) in size within the float-covered slopes also serve to identify the formation. Black (1965) mentioned the presence of the ammonoid *Meekoceras,* which is indicative of the Early Triassic; however, the specimens found in this study were not preserved well enough to identify to species.

Ankareh Formation (T̄Ra)

Material identified as belonging to the Ankareh Formation consists of pale-red to moderate-reddish-brown shale, siltstone, sandstone, and brecciated sandstone. The exposures are extremely poor and commonly heavily vegetated where shale and siltstone predominate. The larger blocks (up to 2 ft or 0.6 m) of sandstone have medium to thick bedding and are cross bedded. Fragments in the brecciated sandstone are no larger than 0.75 inches (1.9 cm) and the fractures have been filled with secondary calcite. All of the rocks are calcareous and react strongly when tested with mild HCl. Porosity ranges from poor to high, and fracturing is irregular.

Jurassic Twin Creek Limestone (Jtc)

Material belonging to the Twin Creek Limestone occurs within the slide complex along its eastern margin. The material was previously assigned to the Jurassic Arapien Shale by Black (1965) and Le Vot (1984). The dominant rocks are red to gray silty shale, siltstone, argillaceous limestone, and dense oolitic limestone. The gray argillaceous limestone is thinly laminated, and thin platy chips often litter the slopes near exposures. The dense oolitic limestone forms good exposures up to 9 feet (2.7 m) thick. It has a pinkish-gray color and is highly fractured. The fractures are slightly conchoidal. The limestone is fossiliferous and contains the crinoid *Pentacrinites*, indicative of Jurassic-age rocks in central Utah and useful in distinguishing limestones of the Twin Creek from those of the Thaynes Formation (Hellmut Doelling, personal communication, 1985).

JURASSIC SYSTEM

The Jurassic System is represented in the quadrangle by the Arapien Shale and the Twist Gulch Formation. The Arapien Shale, as originally defined by Spieker (1946), was divided into two members, a lower Twelvemile Canyon Member and an upper Twist Gulch Member. Based on its regional extent, Hardy (1952) suggested that the Twist Gulch Member be elevated to formational status and the name Arapien Shale be used to refer to the Twelvemile Canyon Member. Since both conventions can be found in the literature, the uses suggested by Hardy (1952) and outlined by Witkind and Hardy (1984) will be used in this study.

Arapien Shale (Ja)

Exposures of the Arapien Shale occur along the west edge of the Fountain Green North quadrangle in Salt Creek Canyon. The largest exposure occurs north of Utah State Highway 132 with smaller discontinuous exposures to the south. A salt-bearing exposure is located on the west side of the Nebo Scenic Loop Road approximately one-half mile (0.8 km) north of Highway 132.

In the quadrangle, the Arapien Shale consists of interbedded greenish-gray argillaceous limestone (50%), sandstone (30%), siltstone (10%), and greenish-gray to red mudstone (10%). The limestone is arenaceous in part but is dominantly argillaceous micrite and thickly laminated to very thinly bedded. Regionally, the thin limestone beds contain fragments of *Pentacrinites*. The sandstone is calcareous, very fine to fine grained, very thin to thinly bedded, and contains small (up to 0.5 in or 12 mm) green clay inclusions. The sandstone contains more than 95 percent quartz and some glauconite and ilmenite. Much of the ilmenite is partially oxidized to hematite giving the rock a brown, freckled appearance. The glauconite helps establish the Arapien Shale's marine origin and is responsible for the greenish hue. The red mudstone is arenaceous, thickly laminated to very thinly bedded, and calcareous; it contains small (less than 0.5 in or 1.3 cm), gray siltstone inclusions and bears salt in one location.

Determining the stratigraphic position and thickness of the exposures in the quadrangle is difficult because of the discontinuous outcrop pattern and structural complexity. Based on lithology, the beds coincide well with Spieker's (1946) units 2 and 4, and Hardy's (1952) units C and E. The largest continuous outcrop exposes nearly 800 feet (244 m) of strata along the western edge of the mapped area in Salt Creek Canyon. Estimates of the entire thickness of the Arapien Shale range from 3000 to 11,000 feet (914 -3353 m) (Eardley, 1933; Spieker, 1946; Hardy, 1952). Standlee (1982) put the thickness of undeformed Arapien Shale in the Gunnison Plateau region at approximately 5500 feet (1676 m). The lower contact of the Arapien Shale does not occur in the quadrangle. The upper contact is exposed at one location just south of Highway 132 in the north end of the Gunnison Plateau. The contact between the greenish-gray beds of the Arapien Shale and the reddish-brown beds of the overlying Twist Gulch Formation is sharp and apparently conformable.

Wells drilled in the Juab Valley area have shown the Arapien Shale to be separated from the Navajo Sandstone by some 1500 feet (457 m) of carbonate beds. The carbonate beds have been correlated with the lower five members of the Twin Creek Limestone: the Watton Canyon, Boundary Ridge, Rich, Sliderock, and Gypsum Springs Members successively (Sprinkel, 1982). Sprinkel stated that, since the Arapien Shale lies between the Watton Canyon Member of the Twin Creek Limestone and the Twist Gulch Formation, it is correlative with the Leeds Creek and Giraffe Creek Members of the Twin Creek Limestone and is approximately of lower Callovian (Middle Jurassic) age.

Twist Gulch Formation (Jtg)

The Twist Gulch Formation is widespread in central Utah. Exposures within the mapped area occur at the north end of the Gunnison Plateau just south of Salt Creek, and approximately one-half mile (0.8 km) northeast of the junction between Highway 132 and the Nebo Scenic Loop Road. The latter exposure has since been covered by construction.

In the Fountain Green North quadrangle the Twist Gulch Formation consists of interbedded light-brown calcareous siltstone (60%), mudstone (7%), gritstone (3%), and light-gray sandstone (30%). Siltstone in the Twist Gulch is generally thickly laminated to very thinly bedded, blocky, slightly ripple marked, and moderately cemented. It is composed almost entirely of quartz grains with a small amount of ilmenite, which is commonly altered to hematite. The sandstone is generally medium bedded and friable, fine to medium grained and very porous. The mudstone is commonly arenaceous and structureless. Where intensely deformed, the mudstone contains loose calcareous stringers up to 0.5 inches (1.27 cm) wide. The gritstone is thick bedded, friable, and contains particles up to 0.3 inches (7 mm) in size.

A complete section of the Twist Gulch Formation is not exposed within the quadrangle. At the largest exposure, the north end of the Gunnison Plateau, approximately 450 feet (137 m) of strata are present. Thickness of the Twist Gulch in the Gunnison Plateau is reported to range from approximately 1200 feet (366 m) (Auby, in press) to 1900 feet (579 m) (Hunt, 1950).

The Twist Gulch Formation is overlain by the Cedar Mountain Formation. Jefferson (1982) reported no "... conclusive evidence of depositional disconformity ..." between the Twist Gulch and Cedar Mountain Formation. Just east of Rees Flat and north of Salt Creek the contact was seen as conformable. Northeast of the junction between Highway 132 and the Nebo Scenic Loop Road, the Twist Gulch is in fault contact with the Cedar Mountain and inferred to be in fault contact with the Indianola Group. The Twist Gulch Formation is unconformably overlain locally by the Salt Creek Fanglomerate. Imlay (1980) considers the Twist Gulch Formation as upper-lower Callovian to lower-middle Callovian in age.

CRETACEOUS SYSTEM

The Cretaceous System is represented by the Early Cretaceous Cedar Mountain Formation and the Late Cretaceous Indianola Group within the mapped area. Sediments deposited during the Cretaceous Period were derived from the Sevier orogenic belt to the west (Armstrong, 1968). The sediments were deposited as an eastward-thinning, eastward-fining clastic wedge in an asymmetric, marine foreland basin (Lawton, 1982; Fouch and others, 1983).

Cedar Mountain Formation (Kcm)

The strata now recognized as belonging to the Cedar Mountain Formation in central Utah were originally called Morrison (?) Formation by Spieker (1946) because of their lithologic and stratigraphic resemblance to the Morrison Formation of the eastern Colorado Plateau. Stuecheli (1984) and Roche (1985) have assigned these strata to the Cedar Mountain Formation based on lithologic, petrographic, and paleontologic evidence.

In the quadrangle, the Cedar Mountain Formation is exposed for approximately one and one-quarter mile (2 km) on the east side of the Nebo Scenic Loop Road, north of Utah State Highway 132. Smaller exposures can be seen on the west side of the road. The exposures are easily recognized by the orange color of the mudstones.

The Cedar Mountain Formation consists of interbedded, calcareous mudstone (55%), sandstone (20%), conglomerate (20%), and freshwater limestone (5%). The mudstone is the most conspicuous lithology because of its bright, fluorescent, moderate-reddish-orange color. It is structureless, arenaceous, and contains white calcareous nodules and highly polished reddish-brown chert pebbles that represent less than 1 percent of the unit. The chert pebbles are commonly referred to as gastroliths.

The sandstone is generally medium gray to grayish orange-pink and contains medium to coarse grains which are moderately sorted; it may contain pebbles up to 1 inch (2.5 cm). Quartz is the dominant constituent in the sandstone and usually comprises more than 95 percent of the unit. Lithic fragments are present in small amounts (less than 2%), and the rock is generally moderately cemented with calcite. The sandstone is thin to thickly bedded, cross bedded, and forms resistant planar ledges.

The freshwater limestone ranges in color from white to medium-light gray to light-brownish gray. It is very fine crystalline micrite and contains abundant oncolites. The oncolites are so abundant in places that, from a distance, beds appear to be conglomerates. Oncolites in place range up to 2.5 inches (6.4 cm) in diameter, however, some found in float are as large as 5 inches (12.7 cm). The limestone is medium to thickly bedded and forms resistant planar ledges.

Conglomerate of the Cedar Mountain Formation is, in general, thick bedded, and clast supported with a medium to coarse-grained matrix. It occurs as resistant planar ledges. Its matrix ranges in color from reddish orange to pinkish gray. Clasts range in size up to 10 inches (25 cm), and Roche (1985) reports clasts up to 3 feet (0.9 m) in the southeastern Gunnison Plateau. Clasts are composed of limestone, dolomite, and quartzite, with minor amounts of sandstone and chert. The carbonate clasts are blue-gray and were derived from Paleozoic formations. The quartzite clasts are variously colored (mostly white and maroon) and commonly banded. The quartzite is similar to Precambrian quartzites of the thrusted terrane to the west (Stuecheli, 1984; Roche, 1985).

Determining the thickness of the Cedar Mountain Formation in Salt Creek is difficult because of the intense deformation caused by thrusting and normal faulting, and by possible periodic salt diapirism. It is estimated that 1300 to 1600 feet (396-488 m) are present in the quadrangle.

The upper contact of the Cedar Mountain Formation with the overlying Indianola Group is possibly exposed at one location on the west side of the Nebo Scenic Loop Road approximately 1.3 miles (2 km) north of the junction with Utah State Highway 132. There a conglomerate bed of uncertain affinity is exposed. Conglomerate beds in the Cedar Mountain Formation are similar to those of the overlying Indianola Group and can be difficult to distinguish. I tentatively assigned the conglomerates to the Indianola Group based on color and the absence of chert pebbles; they are shown on the map as Indianola (?). Auby (in press), Biek (in press), and McDermott (in preparation) report no signs of angular discordance or disconformity at the upper contact along the northwestern margin of the Gunnison Plateau. Jefferson (1982) also reported no evidence for a disconformity in the Cedar Hills. However, he tentatively regards the upper contact as disconformable because of the Cedar Mountain's Early Cretaceous Age.

No biostratigraphic control exists for the Cedar Mountain Formation in the study area. Standlee (1982) reported that palynomorphs recovered from the basal Indianola along the western margin of the Gunnison Plateau have yielded Early Cretaceous dates (Upper Albian). Steucheli (1984) and Roche (1985) both suggested an Early Cretaceous age for the Cedar Mountain Formation.

Indianola Group

The Indianola Group was separated by Spieker (1946) into four formations: the Sanpete, the Allen Valley, the Funk Valley, and the Sixmile Canyon. Because of facies changes, that scheme did not work for exposures in the Gunnison Plateau and Cedar Hills, so the term "Indianola Group undifferentiated" was applied in those areas. Hunt (1950) made the first attempt at differentiating the Indianola Group and defined the South Flat Formation. Thomas (1960) and Hays (1960) later divided the Indianola into four members and revised the South Flat Formation. Schoff (1951) divided Indianola strata in the Cedar Hills into three units. Jefferson (1982) and Lawton (1982) revised Schoff's work and divided the same strata into four equivalents of Spieker's original four formations but did not give the four units formational status. Jefferson's (1982) Allen Valley equivalent is not distinguishable in the map area, and the contacts of the Funk Valley equivalent are questionable. The differences between the Indianola Group in the Cedar Hills and the Gunnison Plateau have resulted in two methods of differentiation (Thomas, 1960; Jefferson, 1982). Neither method works well in both places and, because of this, each is used in its respective place.

Gunnison Plateau

Only Members 1 and 4 of the Indianola Group, as defined by Thomas (1960), are present in the study area, although Members 2 and 3 lie not far south in the Fountain Green South quadrangle.

Member 1 (Ki_1) — Member 1 consists of interbedded conglomerate (70%), sandstone (20%), freshwater limestone (5%), and shale (5%). The conglomerate is polymictic, polymodal, and clast-supported. Clasts are generally well rounded and moderately to highly spheroidal; they constitute approximately 80 percent of the rock. Clast size ranges up to 2 feet (0.6 m) with a mode closer to 1 to 4 inches (2.5-10 cm). Three types of clasts are present: quartzite (greater than 60%), carbonate (35%), and sandstone (less than 5%). Zones exist where only quartzite or only carbonate clasts are present, however, they do not extend much farther than 20 feet (6 m) either laterally or vertically. The quartzite clasts range in color (white, maroon, pink, and green) but most are white and maroon; green clasts are rare. The quartzite clasts are commonly banded and conglomeratic as well. The carbonate clasts are light gray to blue gray, fossiliferous limestone and dolomite. The minor sandstone clasts are pale yellowish brown and fine to medium grained. As in the underlying Cedar Mountain Formation, the composition of clasts contained in the Indianola Group closely resembles the strata in the thrust terrane to the north and west from which they are believed to have been derived. The matrix (20%) ranges in color from yellowish gray to pale red. It is almost entirely medium- to coarse-grained quartz sand with abundant quartzite pebbles.

Sandstone beds occur as lenses within the conglomerate in Member 1. They range from pale red to moderate reddish orange. Medium grains constitute approximately 80 percent of such rock. They are well sorted, frosted to highly polished, angular to subangular, and have poor to moderate sphericity. Fine matrix makes up approximately 17 percent, and the remaining 3 percent is calcite and hematite cement. The sandstone is poorly to moderately cemented and is generally friable. The dominant mineral constituent, quartz, makes up approximately 90 percent of the rock. Rock fragments are present at approximately 5 percent, and the remaining 5 percent is calcite and iron oxides. Porosity is low, and cross bedding is common.

Approximately 1400 feet (427 m) below the contact with the overlying Member 4, about 30 feet (9 m) of limestone with interbedded shale and mudstone crops out. The 30-foot (9 m) unit is quite prominent in the Log Hollow area, so much so that it has been mapped wherever possible as a marker bed. The marker bed is helpful in identifying faults in the massive conglomerates of the northern plateau. The marker bed could not be found north of North Canyon or south of Spring Canyon. The limestone ranges from pale yellowish-orange to moderate reddish-orange when weathered and moderate red to medium-light gray when fresh. It is very dense micrite and arenaceous micrite. Where the rock is sandy, cross bedding is common. Bedding ranges from thick laminae to thick beds and is highly contorted in places. The exposures occur as steep cliffs.

Thin shales and mudstones occur throughout Member 1. The shales vary in color: where weathered they are light gray and pale red-purple, and where fresh they are medium-dark gray, black, and grayish red-purple. Bedding ranges from thickly laminated to very thinly bedded. The mudstone is usually moderate reddish orange, structureless, and commonly silty or sandy.

Bedding in Member 1 is poorly defined and is thick to massive. It is usually made apparent by the sandstone lenses. The conglomerate locally forms pinnacles, but generally Member 1 occurs as extensive, high, steep cliffs. A thickness of approximately 3700 feet (1127 m) of Member 1 is exposed in the quadrangle. The total thickness of Member 1 in the northern Gunnison Plateau is about 7150 feet (2179 m) (Banks, 1986).

Member 4 (Ki_4) — The rocks in the basal portion of Member 4 are similar to those in Member 1. Member 4 consists of interbedded conglomerate (60%) and sandstone (40%). The conglomerate is polymodal, bimictic, and clast-supported. The clasts constitute approximately 75 percent of the rock and range in size up to 12 inches (30 cm). They are well rounded and moderately to highly spheroidal. Two types of clasts are present, carbonate (60%) and quartzite (40%). The carbonate clasts are fossiliferous limestone and dolomite, ranging in color from light-bluish gray to medium-dark gray. The quartzite clasts are white, pink, maroon, and commonly banded. Green quartzite clasts are also present but rare. Matrix accounts for the remaining 25 percent of the rock. Color varies from yellowish gray where weathered, to very light gray where fresh. The matrix consists of medium to coarse quartz sand grains with occasional quartzite pebbles. The grains are moderately sorted, slightly frosted, angular to subangular, and have poor to moderate sphericity. Quartz is the dominant mineral constituent and accounts for 92 percent of the matrix. Lithic fragments account for approximately 5 percent, and the remaining 3 percent is calcite cement. Bedding in the conglomerates is crude and usually very thick to massive. As in Member 1, weathering produces pinnacles, and the conglomerates form bold cliffs. They represent the lower 250 to 300 feet (76-91 m) of the exposure flanking North Flat.

Sandstone makes up the upper 200 feet (61 m) of Member 4 flanking North Flat. The sandstone is dark-yellowish orange where weathered and grayish orange-pink to light-olive gray where fresh. It is almost entirely medium to coarse grained and gritty locally. The grains are well sorted, highly polished, angular to subangular, and have poor to moderate sphericity. The grains are generally moderately to well cemented with calcite (± 3%). The gritty zones are poorly cemented and extremely friable. Quartz and smoky quartz constitute approximately 87 percent of the rock. A black iron oxide mineral, believed to be ilmenite, makes up about 10 percent of the matrix, and alters to hematite and limonite. Calcite constitutes the remainder of the sandstone. Specific porosity is poor. Bedding ranges from very thin to medium, and cross bedding is common. The sandstone contains abundant ironstone concretions which are iron stained and have liesegange banding. Plant fragments were found on bedding planes at the mouth of Fountain Green Pole Canyon but could not be identified because of poor preservation. The sandstone forms continuous planar ledges. A complete section of Member 4 is not present in the study area, although about 450 to 500 feet (137-152 m) of it is exposed at North Flat. The thickness of Member 4 east of the East Gunnison Fault is less certain but at least 1500 feet (457 m). Thomas (1960) reported a total thickness of 1427 feet (435 m) of Member 4 in Fourmile Creek, approximately 2 miles (3.2 km) south of the southern boundary of the quadrangle.

Correlations of Members 1 and 4 — The contact between Members 1 and 4, despite the absence of Members 2 and 3, shows no evidence of angular unconformity or disconformity but is highly gradational and does not represent a distinct lithologic change. The contact was traced laterally into the study area and represents a zone which is better defined to the south by the presence of Members 2 and 3. Thomas (1960) noted that Member 2, which consists of sandstone, siltstone, carbonaceous shale, limestone, and a possible coal unit, disappears approximately 1 mile (1.6 km) south of the Fountain Green North quadrangle. Thomas (1960) extended Member 3 tentatively into the extreme southwest corner of the Fountain Green North quadrangle based on a rubble zone "...devoid of gray limestone pebbles and red, clayey stains" (p. 40). The presence of the rubble zone could not be verified and, therefore, Member 3 was not mapped. I feel that Member 2 was probably the result of local lacustrine conditions which may have existed during periods of relative quiescence, but it did not extend into the Fountain Green North quadrangle. The absence of Member 3 in the study area appears to be the result of a facies change. Beds equivalent to unit 3 are probably included within Member 1.

An upper contact with any overlying unit is not present within the quadrangle. South of the map area the Indianola Group is overlain in angular unconformity by the South Flat Formation and elsewhere by the Price River Formation (North Horn of some authors).

Cedar Hills

Using Jefferson's (1982) criteria for subdivision of the Indianola Group in the Cedar Hills, three informal units were mapped: the Sanpete equivalent, Funk Valley equivalent, and the Sixmile Canyon equivalent.

Sanpete Formation Equivalent (Ksp) — The Sanpete equivalent is exposed in the extreme north-central portion of the quadrangle in Haystack Hill and Rolley Canyon. Like Member 1 in the Gunnison Plateau, the Sanpete equivalent is composed of conglomerate (85%) and sandstone (15%) with minor amounts of mudstone. The lithology of the Sanpete equivalent is similar in most aspects to that of Member 1 just discussed, however, subtle differences do exist. The clast-to-matrix ratio is larger for the conglomerates in the Sanpete equivalent. Clasts generally account for 85 to 90 percent of the conglomerates, and the remaining 10 to 15 percent is matrix. Jefferson recognized quartzite clasts from upper Precambrian formations; limestone, dolomite, chert, and quartzite clasts from Paleozoic sourches; and sandstone and siltstone clasts derived from lower Mesozoic strata.

The gray to black and reddish-purple shale which occurs in Member 1 in the Gunnison Plateau is absent in the Sanpete equivalent in the Cedar Hills. However, the Indianola strata are intensely folded in the Cedar Hills (cross section A-A') and the absence of shale units could be the result of squeezing during deformation. However, the absence of shales is more likely the result of facies changes because shale is present in the Allen Valley equivalent northeast, along strike, of the quadrangle. The Allen Valley equivalent undergoes a rapid facies change to the southwest along Hop Creek Ridge from dark shale and fine sandstone to coarser pebbly sandstone, and it is not mappable in this quadrangle (Jefferson, 1982).

The intense deformation of the Indianola Group in the Cedar Hills has also produced a different outcrop pattern (figure 1). The steeply southeast-dipping strata generally occur as discontinuous ledges on moderate to steep slopes, rather than the bold, well-exposed cliffs of the northern Gunnison Plateau. The Sanpete equivalent was interpreted as a conglomeratic braided fluvial facies of a proximal braid plain, and the sandstone as a nearshore marine facies (Jefferson, 1982).

A complete section of the Sanpete equivalent is not exposed in this quadrangle. The lower portion of the unit is overlapped by the Tertiary Moroni Formation. Approximately 1300 to 1400 feet (396-427 m) of strata are present. Jefferson (1982) reported a total thickness of 2214 feet (675 m) for the Sanpete equivalent farther northeast along strike.

Funk Valley Formation Equivalent (Kfv) — The Funk Valley equivalent occurs along the northwestern flank of Hop Creek Ridge. Exposures are generally poor due to heavy vegetation which is common on most north-facing slopes in the area. It consists of interbedded sandstone and pebbly sandstone (60%), and conglomeratic sandstone (40%). Two different facies are recognized in the Funk Valley equivalent: a conglomeratic braided fluvial facies (proximal braid plain), and a nearshore marine sandstone facies (Jefferson, 1982; Lawton, 1982). The sandstone ranges from medium-light gray to dark-yellowish orange where weathered, and very pale orange to moderate orange pink where fresh. It is approximately 90 percent medium to coarse grained and moderately sorted. The grains are subangular and moderately spheroidal. A fine, silty matrix accounts for approximately 7 percent of the total. The grains are moderately to well cemented with about 3 percent calcite cement. Conglomeratic layers occur in the sandstone with clasts, mostly carbonate, that rarely exceed 4 inches (10 cm) in diameter. Quartz is the dominant mineral constituent and accounts for approximately 87 percent of the rock. Lithic fragments account for 10 percent, and the remaining 3 percent is calcite. Bedding is medium to thick, and cross bedding and graded bedding are common. Porosity is moderate to high and fractures are irregular. The sandstone forms discontinuous planar ledges. The Funk Valley equivalent undergoes a facies change to the southwest within the study area. The sandstone becomes coarser and more conglomeratic to the southwest and loses its light-gray color, approaching that of the underlying Sanpete equivalent.

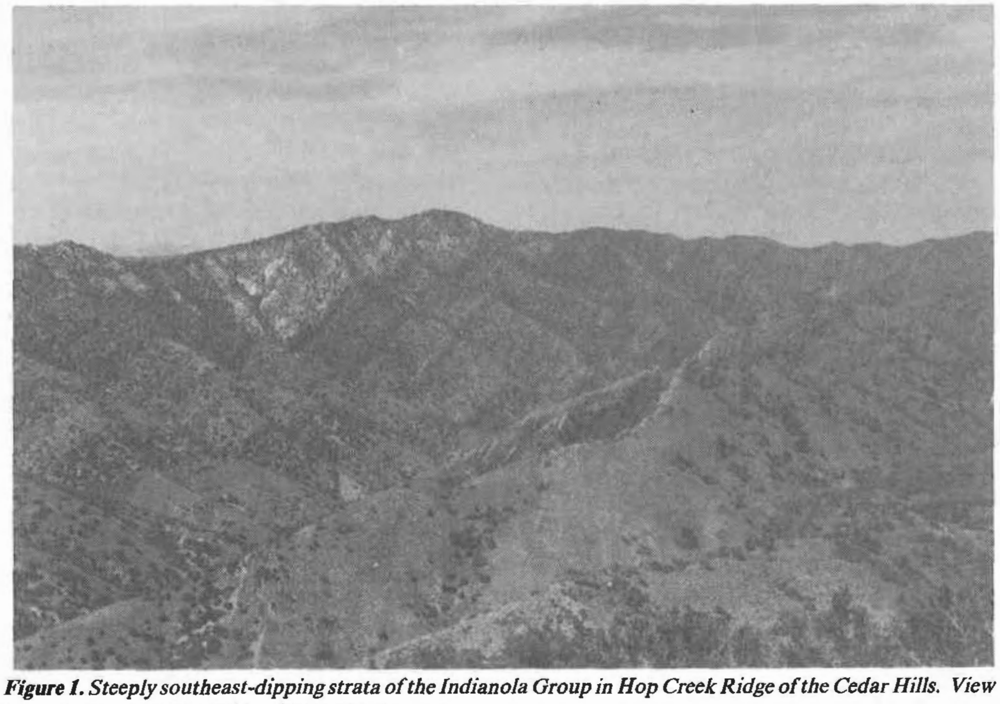

Figure 1. *Steeply southeast-dipping strata of the Indianola Group in Hop Creek Ridge of the Cedar Hills. View is north from southeast side of Hop Creek.*

The Funk Valley equivalent may be correlative with the 1400 feet (427 m) of strata above the carbonate marker beds in the Gunnison Plateau. Approximately 1600 feet (488 m) of Funk Valley equivalent are present in the study area. Schoff (1951) and Jefferson (1982) reported thicknesses of 2530 and 2952 feet (771-900 m) respectively to the northeast along strike. The relatively thin section reported here results from facies changes and selection of a different mappable contact.

Sixmile Canyon Formation Equivalent (Ksm) — The Sixmile Canyon equivalent consists of interbedded conglomerate (55%) and pebbly sandstone (45%). Three different facies are recognized in the Sixmile Canyon equivalent: an alluvial-fan facies, a conglomeratic braided fluvial facies (proximal braid plain), and a sandy/pebbly fluvial facies (distal braid plain) (Jefferson, 1982; Lawton, 1982). The conglomerates are polymodal, polymictic, and clast-supported. Clasts account for approximately 80 percent of the rock and range in size up to 12 inches (30 cm). Three lithologic types of clasts are present: quartzite, carbonate, and minor amounts of sandstone. The relative abundance of each clast type varies throughout the Sixmile Canyon equivalent, but certain patterns can be seen. Carbonate clasts dominate the basal portion of the unit much as they do in Member 4 in the Gunnison Plateau. Quartzite clasts increase in relative abundance up the section but rarely account for more than 60 percent of the total clasts. Sandstone clasts are minor throughout the section. Matrix constitutes 20 percent of the conglomerate. The conglomerate is generally yellowish gray both where weathered and fresh. The matrix is approximately 97 percent medium to coarse grains; the grains are moderately to well sorted, subangular, and moderately spherical. They are moderately to well cemented with calcite, which makes up 3 percent of the matrix. The matrix is composed of quartz and smoky quartz (80-90%), lithic fragments (10-15%), and calcite (3-5%). The conglomerate is crudely bedded and forms both continuous and discontinuous ledges.

Sandstone in the Sixmile Canyon equivalent ranges from grayish orange to yellowish gray where weathered and pale red to yellowish gray where fresh. It is 80 to 97 percent fine to coarse grains with occasional pebbly layers. The grains are poorly to well sorted, angular to subrounded, and have poor to moderate sphericity. Very fine matrix is present from 0 to 10 percent, and calcite cement constitutes approximately 3 percent of the rock. The sandstone is moderately to well cemented. Quartz is the dominant mineral and accounts for 85 to 97 percent of the rock. The coarser sandstone contains approximately 10 percent lithic fragments and less than 2 percent chert. An iron oxide, believed to be ilmenite, occurs in amounts ranging from 0 to 5 percent. Calcite is present at approximately 3 to 5 percent. The sandstone is generally thin to medium bedded and commonly cross bedded. Porosity ranges from low to high depending on the amount of matrix and cementation.

The exact thickness of the Sixmile Canyon equivalent in the quadrangle is difficult to determine because of overlap by the younger North Horn Formation, however, it must be at least 7100 feet (2164 m). I believe that the Sixmile Canyon equivalent of the Cedar Hills is correlative with Member 4 in the northern Gunnison Plateau.

The upper contact with the North Horn Formation is marked by an angular unconformity. The contact occurs along the southeast flank of Hop Creek Canyon but is poorly exposed. Although reliable attitudes are difficult to obtain, I estimate an angular discordance of approximately 30 degrees.

Age and Correlation

The abrupt lateral facies changes and lack of fossil evidence in the Indianola Group in the Gunnison Plateau make correlation of specific stratigraphic horizons difficult. A tentative correlation between the Gunnison Plateau and the Cedar Hills is proposed in figure 2. The correlation is based on lithologic similarity and stratigraphic position.

That portion of Member 1 below the carbonate marker beds in the Gunnison Plateau is probably correlative with the Sanpete equivalent in the Cedar Hills. The thicknesses of Member 1 and the Sanpete equivalent differ by nearly 3500 feet (1067 m), but this can be attributed to different proximity to the front of the source highlands.

Member 2, south of the study area, and the carbonate marker beds in the northern Gunnison Plateau are considered directly correlative. There is a difference of about 90 feet (27 m) between their relative positions in the Indianola sequence. Representative lithologies of both suggest a lacustrine and/or lagoonal setting. The carbonate marker beds may also correlate with the marine Allen Valley Shale equivalent in the Cedar Hills north of the quadrangle. The two zones are at comparable levels in the group and may represent correlative embayments of the Mancos sea.

Member 3 south of the quadrangle, the portion of Member 1 above the marker beds in the northern plateau, and the Funk Valley equivalent of the Cedar Hills are considered correlative. I find it inappropriate to designate the upper portion of Member 1 as Member 3 since the criteria which characterize Member 3 farther south are not present in the quadrangle.

Member 4 and the South Flat Formation (as redefined by Thomas, 1960) in the Gunnison Plateau are believed to be correlative with the Sixmile Canyon equivalent in the Cedar Hills. Basal sections of both Member 4 and the Sixmile Canyon equivalent are characterized by a relative abundance of Paleozoic carbonate clasts. There is a drastic difference in thickness between the Sixmile Canyon equivalent and the combined thickness of Member 4 and the South Flat Formation. A possible explanation is a shift in the locus of thrusting, and consequently of volume of sediment released, from the south to the north in the Sevier orogenic belt. Fossils found by Hunt (1950), Schoff (1951), and Jefferson (1982) indicate a Turonian and possible Cenomanian to Coniacian age for the Sanpete, Allen Valley, and Funk Valley equivalents. The age of the Sixmile Canyon equivalent is less certain. Jefferson (1982), based on lithostratigraphic grounds only, considered the Sixmile Canyon equivalent as Santonian-Campanian in age.

LATE CRETACEOUS TO MIDDLE TERTIARY SYSTEMS

North Horn Formation (TKnh)

Within the quadrangle the North Horn Formation occurs along the southeast flank of Hop Creek Canyon and the northern slopes of Water Hollow. Exposures of the North Horn Formation are extremely poor in the area due to heavy vegetation. It is often involved in Quaternary mass movements in this area because the unit dips parallel to the topographic slope. Deep red soil suggests the presence of the formation.

The North Horn Formation consists of four lithologic types within the quadrangle: conglomerate (70%), mudstone (20%),

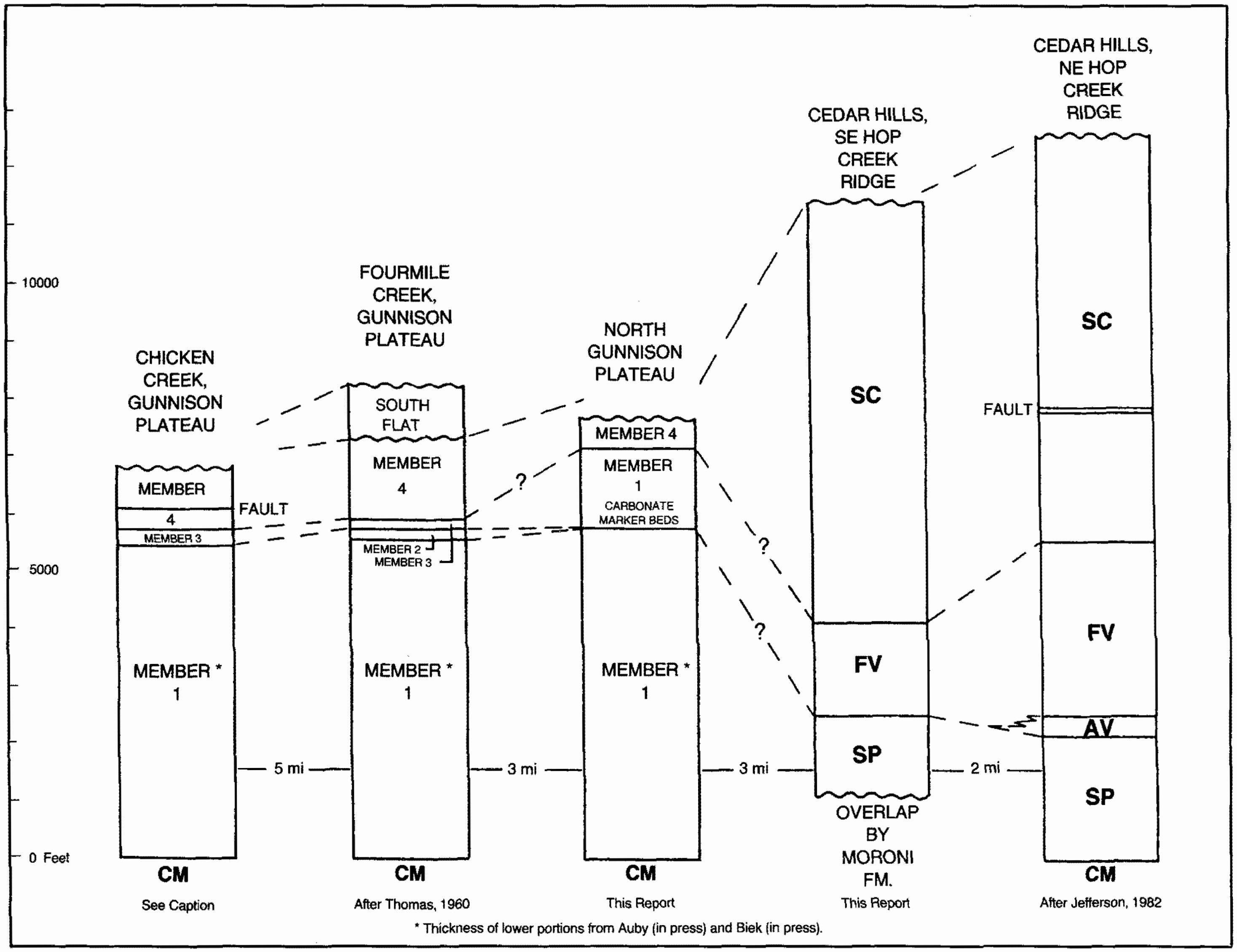

Figure 2. *Generalized correlation of the Indianola Group within and between the Gunnison Plateau and the Cedar Hills. Chicken Creek section constructed using data from this study, Hunt (1950), Weiss, (1979, unpublished data), and Lawton (1982, 1985). Member 3 has a lenticular outcrop pattern and reaches its maximum thickness of 1390 feet (424m) (Thomas, 1960) between Chicken and Fourmile Creeks. CM=Cedar Mountain Formation, SP=Sanpete equivalent, AV=Allen Valley equivalent, FV = Funk Valley equivalent, and SC = Sixmile Canyon equivalent.*

sandstone (7%), and limestone (3%). The conglomerate beds are of alluvial-fan facies (Jefferson, 1982). They are polymictic, polymodal, and clast supported. Clasts within the conglomerate (85-90%) are generally less coarse than those of the underlying Indianola Group. The clasts are moderately sorted, well rounded, have moderate sphericity, and rarely exceed 4 inches (10 cm) in size. Three distinct lithologic types of clasts are present in the conglomerates: carbonate (55%), quartzite (greater than 40%), and sandstone (less than 5%). The carbonate clasts are blue-gray and tan Paleozoic limestone and dolomite derived from the Nebo allochthon (Jefferson, 1982; Lawton, 1985). The minor sandstone clasts are reddish brown to tan and are believed to have been derived from Triassic and Jurassic units of the Nebo allochthon. Quartzite clasts are dominantly white and commonly banded; pink to maroon quartzites are also present. The quartzite source is most likely the underlying Indianola Group (Lawton, 1985). Matrix constitutes 10 to 15 percent of the conglomerates, and grains which make up the matrix are generally medium to very coarse and pebbly. Color ranges from pale yellowish orange to yellowish gray. The grains are poorly sorted, subangular to subrounded, and have moderate sphericity. Quartz is the dominant mineral constituent and comprises approximately 70 to 80 percent of the matrix. Lithic fragments make up about 20 to 30 percent, and calcite in the form of cement accounts for 3 to 5 percent. Poor exposures limit the determination of sedimentary structures. Bedding is crude at best.

Sandstone in the North Horn Formation ranges from pinkish gray where weathered to grayish-orange pink where fresh. It is composed of 85 to 90 percent medium to coarse grains which are poorly to moderately sorted, subangular to subrounded, with poor to moderate sphericity. A fine, silty matrix accounts for approximately 10 to 15 percent of the rock, and calcite cement about 3 to 5 percent. The sandstone is poorly to moderately cemented and commonly friable. Generally 60 to 70 percent of the grains are quartz, and lithic fragments account for approximately 30 to 40 percent. The sandstone is medium bedded, and its porosity is moderate.

Mudstone in the North Horn Formation is moderate red and arenaceous. It is generally structureless and prone to frequent slumping and sliding. Limestone occurs in only one location, on the southeast flank of Hop Creek Canyon (west-central portion of Section 2, T. 13 S., R. 2 E.). It is dense, medium gray to white, fine to medium crystalline, with common vugs and calcite stringers. The outcrops are highly fractured and bedding is indeterminate.

Thickness of the North Horn Formation could not be determined from the poor exposures in the quadrangle. Jefferson (1982) reported a thickness of approximately 2624 feet (800 m) in the southeast flank of the Cedar Hills, presumably to the northeast of the map area. Approximately 1500 feet (457 m) of North Horn strata were reported in the Phillips Petroleum, Neilson-Seager #1 unit, within the map area.

Contact of the North Horn Formation with the overlying Flagstaff Formation was only seen in one location in the northeast corner of the quadrangle where it is part of a large slide block. There the contact appears to be gradational.

Fouch and others (1982, 1983) considered the North Horn Formation to be as young as early Eocene in Sanpete Valley, based on interpreted ages of palynomorphs, but no direct paleontologic evidence is reported. The palynomorphs were recovered from beds which closely overlie the intertonguing boundary of the North Horn and Flagstaff Formations. Until more data are obtained, the North Horn Formation in Sanpete Valley should be considered Late Cretaceous (Maastrichtian) to Paleocene.

The North Horn Formation was deposited in a foreland basin near the end of the Sevier orogeny. Sediments of the North Horn Formation were derived from local sources which the formation overlaps. Lawton (1985) states "... that the conglomerates were deposited in strike valleys adjacent to the thrust uplifts and graded a landscape of high relief ...."

Flagstaff Limestone (Tf)

Within the quadrangle, the Flagstaff Limestone is poorly exposed on the north flank of Water Hollow. The best exposures occur in roadcuts north of Water Hollow where the unit is involved in mass movements. The Flagstaff Limestone consists of arenaceous mudstone (10%). The sandy limestone ranges from yellowish gray where weathered to very light gray where fresh. Intraclasts up to 4 inches (10 cm) are common and in places constitute approximately 70 percent of the rock. The limestone is dominantly micrite (85-100%) but may contain as much as 15 percent fine to medium quartz grains. Chert and iron staining are common and, near the contact with the underlying North Horn Formation, siliceous pebbles up to 1 inch (2.5 cm) are abundant. Bedding ranges from thin to thick, and exposures are highly fractured. Schoff (1951) attributed the fractures to proximity to faults in Water Hollow. Mudstone is the same color as the limestone and is structureless with a popcorn-weathering surface.

Thickness of the Flagstaff Limestone in the quadrangle is unknown due to poor exposure, faulting, and mass movements. Schoff (1951) estimated a thickness of approximately 300 to 750 feet (91-229 m) in the Cedar Hills. An approximate thickness of 500 feet (152 m) was reported in the Phillips Petroleum, Neilson-Seager #1 unit. Within the study area the Flagstaff Limestone is unconformably overlain by the Moroni Formation or the Salt Creek Fanglomerate. Fouch and others (1982, 1983) suggested an early Eocene age for the Flagstaff Limestone west of the Wasatch Plateau based on the interpreted ages of palynomorphs. No fossil evidence was found during this study in Flagstaff exposures in the quadrangle.

The Flagstaff Limestone was deposited in the Paleocene and early Eocene Lake Flagstaff and "... represents the final phase of subsidence and infilling of a forelandbasin east of the Sevier thrust belt (Stanley and Collinson, 1979, p. 312)."

Moroni Formation (Tm)

Controversy exists with respect to the naming of this unit. Some workers (Black, 1965; Jefferson, 1982; LeVot, 1984) refer to it as the Goldens Ranch Formation as defined by Muessig (1951) in Long Ridge and the West Hills. Schoff (1937) informally assigned "Moroni Formation" to the volcaniclastic rocks of waterlaid origin in the Cedar Hills. He later abandoned the name and simply referred to them as pyroclastic rocks (Schoff, 1951). Cooper (1956) informally reestablished the Moroni Formation for the Tertiary volcanics in the southern Cedar Hills, and that is the name used here. Other studies have referred to the rocks as the Moroni Formation or simply Tertiary volcanics (Hawks, 1980; Witkind and Weiss, 1985).

The Moroni Formation within the study area consists of crudely interbedded, waterlaid volcanic conglomerate (65%) and tuffaceous sandstone (35%). The best exposures occur near Salt Creek along Utah State Highway 132 and the Nebo Scenic Loop Road. The volcanic conglomerates contain up to 60 percent clasts and vary from clast- to matrix-supported. The clasts range in size up to

16 inches (41 cm), with a mode closer to 4 inches (10 cm). The clasts are subangular to subrounded, moderately spherical, and are poorly sorted. They are composed of black welded tuff, red andesite porphyry, maroon quartzite, blue-gray Paleozoic limestone, and minor amounts of scoria. The relative abundance of each clast type varies greatly throughout the quadrangle, however, the welded tuffs dominate in most places. The matrix (up to 40%) ranges from very light gray to pinkish gray and is similar in lithology to the tuffaceous sandstone. Along the Nebo Scenic Loop Road, approximately 2 miles (3.2 km) north of the junction with Utah State Highway 132, a dark gray to grayish-black volcanic conglomerate occurs. The clasts are almost entirely welded tuff, and the matrix consists dominantly of feldspar grains in a vitreous groundmass. The clasts are angular to subangular and account for approximately 70 to 80 percent of the rock. This is the only location where this type of conglomerate occurs in the quadrangle, and its origin is uncertain. Eardley (1933) suggested that it may have been a volcanic mudflow deposit.

The tuffaceous sandstone ranges from grayish orange pink to light gray; exposures in Pole Creek Canyon are light-greenish gray. The rock has been discolored in some locations by reddish surface staining from the overlying Salt Creek Fanglomerate.

The tuffaceous sandstone is composed of approximately 70 to 80 percent fine to medium grains which are angular to well rounded, and moderately to well sorted. Volcanic and sedimentary rock fragments up to 0.25 inches (0.64 cm) in size commonly account for 20 to 30 percent of the rock. Glass shards account for as much as 40 to 50 percent of the samples collected in Pole Creek Canyon. Altered feldspar crystals up to 1 inch (2.5 cm) are common. The tuffaceous sandstone is poorly to moderately cemented. Micrite is not uncommon (1-2%), but the cement is usually a vitreous material with extremely fine crystals. The dominant mineral constituents are feldspar (20-40%) and quartz (up to 30%). Volcanic rock fragments account for up to 40 percent. Magnetite is present in amounts up to 5 percent, and trace amounts of biotite are also present. Bedding in the Moroni Formation is crude and usually defined by conglomeratic layers or lenses. The tuffaceous sandstone is occasionally cross bedded, which helps to establish the waterlaid character.

The thickness of the Moroni Formation is highly variable throughout the quadrangle and the surrounding region as well. The variable thickness is due to surface erosion and irregularities on the unconformable surface onto which it was deposited (Eardley, 1933; Schoff, 1951). Schoff (1951) reported a maximum thickness of approximately 1560 feet (475 m), and Jefferson (1982) reported more than 1640 feet (500 m). A maximum thickness of approximately 1000 feet (305 m) occurs in this study area.

The Moroni Formation unconformably overlies strata from Jurassic to Eocene in age within the study area. Unconformably overlying the Moroni Formation is the Tertiary-Quaternary Salt Creek Fanglomerate. The Moroni Formation is extensively involved in Quaternary mass movements.

Radiometric dates from U.S. Geological Survey work in progress indicate an age between 35 and 39 Ma. Caution must be used, however, in the interpretation of these dates because of the reworked nature of the sedimentary fraction of the formation. Schoff (1951) believed the Moroni Formation to be equivalent to Tertiary volcaniclastic rocks of the Wasatch Plateau and the Strawberry Valley area. Muessig (1951) suggested correlation with the Goldens Ranch Formation of Long Ridge and the West Hills, based on lithologic similarity and stratigraphic position. The Moroni Formation may be correlative with the "Formation of Aurora" and as yet unnamed sandstone, mudstone, and conglomerate beds of volcanic origin reported by Willis (1986) in the Salina quadrangle.

The volcanic source of the Moroni Formation is uncertain. The large and subangular nature of the clasts within the conglomerate suggests a nearby source. Runyon (1977) proposed a source near Wanrhodes Canyon northwest of Thistle, Utah.

LATE TERTIARY AND QUATERNARY SYSTEMS

Salt Creek Fanglomerate (QTs)

The Salt Creek Fanglomerate was originally defined by Eardley (1933) for a thin formation overlying the Jurassic shales and waterlaid volcaniclastic deposits in Salt Creek Canyon. Eardley assigned the name to the poorly cemented mixture of large and small angular rock fragments in a matrix of red earthy material. Later workers have referred to these deposits as stream gravels (Hawks, 1980), boulder conglomerate (Jefferson, 1982), older alluvium (Le Vot, 1984), and pediment mantle (Witkind and Weiss, 1985).

The Salt Creek Fanglomerate occurs throughout the Salt Creek area; good exposures can be seen from Utah State Highway 132 and the Nebo Scenic Loop Road. It is also extensive to the west and thins to the south (Auby, in press; Biek, in press). The Salt Creek Fanglomerate is widespread in the Cedar Hills north of Water Hollow within the quadrangle, where it is involved in Quaternary mass movements in the Cedar Hills.

Most outcrops of the Salt Creek Fanglomerate are unconsolidated, but consolidated material occurs at two locations within the quadrangle. Just north of the highway along the western edge of the study area, a consolidated gravel caps the Moroni Formation at the top of the slope. Consolidated gravel also occurs at the mouth of Hop Creek.

The Salt Creek Fanglomerate consists of granules, pebbles, cobbles, and boulders contained within a clayey to sandy matrix. The clasts consist of Precambrian quartzite, Paleozoic carbonates, and minor amounts of sandstone and igneous material. Most of the clasts have been reworked from the Indianola Group, the North Horn Formation, and the Moroni Formation. A quartzite clast 5 feet (1.5 m) in diameter was found within the unit in the Cedar Hills. The relative abundance of each clast type differs widely throughout the quadrangle, but quartzite usually dominates. There is a crude pattern of increased angularity to the northwest in the quadrangle, suggesting a source in that direction.

The matrix is composed of clay, silt, and sand particles and is slightly calcareous. It ranges from pale yellowish-brown to pale reddish-brown except at the mouth of Hop Creek, where it is very pale orange to pale-yellowish orange.

The thickness of the Salt Creek Fanglomerate is highly variable but is greatest in Water Hollow, where it may exceed 500 feet (152 m). The Salt Creek Fanglomerate unconformably overlies strata of Jurassic to Tertiary age throughout the area. The age of the Salt Creek Fanglomerate is not well established; however, its partially consolidated nature, its presence at relatively high elevations (to 8000 feet or 2438 m), its accordance with the underlying Moroni Formation at the mouth of Hop Creek, and its extensive involvement in Quaternary mass movements suggest a late Tertiary to Quaternary age. The Salt Creek Fanglomerate is probably equivalent to the Axtell Formation as defined by Spieker (1949a), and also to gravel deposits of the Redmond Hills area as defined by Willis (1986).

Mass-Movement Deposits

Landslide Deposits (Qms1-5 (-s, -m, -c, -f, -nh, -i)) — Landslides occur along the eastern margin of the Gunnison Plateau and in the Cedar Hills. The landslides along the margin of the Gunnison Plateau consist of nonoriented blocks up to 20 feet (6 m) long of Members 1 and 4 of the Indianola Group. The surfaces of the landslides are commonly hummocky and covered with black soil. They extend as far as 1500 feet (457 m) from the base of the plateau.

Large complex landslides dominate the landscape in the Cedar Hills north of Water Hollow and along the east edge of Sanpete Valley. The landslides involve the North Horn, Flagstaff, and Moroni Formations, and the Salt Creek Fanglomerate. The landslides are differentiated according to relative age (Qms_1 = youngest; Qms_5 = oldest) and formational content. Where multiple formations are involved in a single slide movement, and where possible, the author has differentiated the material.

The mass movements are complex, and most are combinations of landslide and debris-flow material. The upper portions contain large pieces of rock material, are commonly hummocky, show remnant scars, and have successive benches or terraces. It is the terraces or benches which enabled determination of relative ages from aerial photographs. The terraces have been deeply incised by streams.

The lower portions of the landslides are more characteristic of debris flows. Material near the base of the landslides is finer than that of the upper portions. Crudely stratified layers, seen in a gravel pit, suggest a viscous transport. The lower portions have well-developed toes rising as much as 20 feet (6 m) above the valley floor in Water Hollow.

The cause of the large landslides in the Cedar Hills and Gunnision Plateau is not well understood. Hawks (1980) suggested that those in the Cedar Hills are the result of large (up to 5 miles or 8 km in diameter) collapsed salt diapirs. Schumm (in Mattox, 1986) suggested that a large increase in precipitation during Pleistocene glaciation created conditions favoring mass movement. The recent wet climate cycle (1983-1985), for example, markedly increased landslide activity.

Debris-Flow Deposits (Qmf) — Debris flows (Qmf) involving the North Horn and Moroni Formations occur along the southeast flank of Hop Creek Canyon. The surfaces of these debris flows are very hummocky, however, they are poorly exposed because of a thick layer of rich, dark soil. The courses of these debris flows are controlled by the existing topography.

Alluvial fans, containing numerous debris flows, occur along the eastern margin of the Gunnison Plateau, west of Fountain Green, and along the eastern margin of Sanpete Valley. These deposits were mapped as fans because of their overall morphology. These fans contain clay- to boulder-size material and their surfaces are littered with boulders up to 4 feet (1.2 m) in diameter. The lower portions usually have well-developed toes which suggests more viscuous, unified movement.

Alluvial-Fan Deposits (Qaf_1, Qaf_2, $Qafc_1$, $Qafc_2$)

Older, higher, coalesced alluvial fans ($Qafc_2$) form a sloping apron away from the foot of both the Gunnison Plateau and the Cedar Hills in Sanpete Valley. The sediments vary in color from moderate-reddish brown to gray. The fans are composed of clay- to boulder-size material which is poorly to moderately consolidated and crudely bedded. The coalesced fans are formed by overlap and interfingering of adjacent debris flows which emanate from the deep canyons along the margin of the valley. The thickness of the coalesced fans in the study area is uncertain. Robinson (1971) reports a thickness of approximately 250 feet (76 m) in a water well drilled near the town of Wales, approximately 9 miles (14 km) south of Fountain Green.

Older, solitary fans (Qaf_2) occur at the base of the Gunnison Plateau, west of Fountain Green. They were deposited over the older coalesced fans, and range in approximate thickness from 40 to 100 feet (12-30 m).

Younger, solitary fans (Qaf_1) and coalesced fans ($Qafc_1$) occur in Salt Creek and generally emanate from smaller hollows. They are similar in composition and color to the older coalesced fans, but clasts rarely exceed cobble size. Consolidation is poor to nonexistent, as is stratification. The thickness of the younger fans rarely exceeds 50 feet (15 m).

Colluvial Slopewash Deposits (Qac)

Colluvial slopewash consists of locally derived colluvium which has been loosened by weathering and deposited in shallow gullies on hillslopes. The color and composition reflect the local source, and the material generally consists of clay- to cobble-size particles. The sediments are poorly to moderately consolidated and poorly sorted. Its thickness ranges up to 20 feet (6 m).

Colluvial-Gravel Deposits (Qcg)

Colluvial gravel consists of locally derived material deposited at the base of steep slopes. Only one such deposit occurs in the study area, on the west side of the Nebo Scenic Loop Road approximately 1 mile (1.6 km) north of the junction with Utah State Highway 132. A large colluvial cone has formed at the base of the steep Indianola exposure. The cone is composed of sand- to boulder-size material wholly derived from the Indianola exposure.

Alluvial Deposits (Qal_1, Qal_2)

Older alluvium (Qal_2) occurs at higher elevations north and west of Salt Creek, in upper Hop Creek, and in Fountain Green Pole Canyon. Younger alluvium (Qal_1) occupies channels and canyon floors in Salt Creek, Sanpete Valley, and Water Hollow, and forms even surfaces of low relief. It also occupies channels which have been deeply incised in the older coalesced fans east of the Gunnison Plateau. The alluvium consists of unconsolidated clay- to cobble-size material. The color varies throughout the quadrangle, usually dependant on the surrounding bedrock and organic content. Common colors are dark brown, reddish brown, and gray. The materials are poorly sorted and poorly to moderately stratified. Thickness varies throughout the area, but probably does not exceed 50 feet (15 m).

TERTIARY INTRUSIVE IGNEOUS ROCKS

Salt Creek Dike (Ti)

The Salt Creek dike, composed of andesite porphyry, is located approximately 2 miles (3.2 km) north of Utah State Highway 132 along the Nebo Scenic Loop Road. A small east-west-trending exposure occurs on the west side of the road, and a large northwest-southeast-trending exposure occurs on the east side. On the east side the dike is approximately 30 feet (9 m) thick and 40 feet (12 m) high, and it cuts the Tertiary Moroni Formation. It is exposed for a total length of approximately 2000 feet (610 m). The dike is pale brown where weathered and grayish-red where fresh. Fractures contain secondary chalcedony. Plagioclase phenocrysts up to 0.13 inches (0.33 cm) constitute 35 percent of the porphyry. Unidentifiable polycrystalline phenocrysts containing sanidine account for 20 percent of the rock. Biotite is an accessory mineral and the remainder is aphanitic groundmass.

Potassium-argon dating of the biotite concentrate yielded an age of approximately 33.6 ± 1.4 Ma (see appendix). Given an age of 35 to 39 million years for the Moroni Formation, the date appears to be reliable. The date is consistent with those of other intrusions in central Utah.

STRUCTURE

The structural geology of central Utah has spawned many controversies. The complex structural and stratigraphic relationships, which change over short distances, are the result of the superposition of no fewer than three structural events: Mesozoic compression, mid-Cenozoic extension, and possible Mesozoic to Holocene salt diapirism (Spieker, 1949a; Armstrong, 1968; Standlee, 1982; Stokes, 1982; Witkind, 1982; Lawton,1985).

Two principal structural models have emerged to explain the complex deformation in central Utah: eastward-directed thrusting (Jefferson, 1982; Standlee,1982; Villien, 1984; Lawton, 1985), and repeated growth and collapse of salt diapirs (Baer, 1976; Runyon, 1977; Hawks, 1980; Stokes, 1952, 1982; Witkind, 1982). Proponents of thrusting offer various models which differ in the eastward extent of thrusting and its effect on the rocks. Standlee (1982) and Villien (1984) proposed that thrusting occurred as far east as the Wasatch Plateau, and that westward-directed back thrusting was a major force acting on Sanpete Valley and the eastern margin of the Gunnison Plateau. Lawton (1985) proposed that thrusting occurred as far east as western Sanpete Valley, and that folding was "...a direct result of the thrusting that affected rocks further west." Proponents of salt diapirism have suggested that most or all of the structural complexity in the region can be explained by the repeated growth and collapse of salt diapirs.

I agree with Mattox (1986) that "... a combination of thrusting and local salt diapirism may ultimately explain the region's complex structure.

FOLDING

Gunnison Plateau

Weiss (1982) described the Gunnison Plateau as two south-plunging synclines with parallel axes. Within the Fountain Green North quadrangle, strata of the Indianola Group, which dip gently (15-25 degrees) to the east-southeast, represent the west limb of the older syncline. Standlee (1982) believes that, based on seismic data, the structure is not a syncline but that the east-dipping beds continue to dip eastward beneath Sanpete Valley where they are terminated by listric, normal faults believed to be reactivated back-thrusts.

Both of the principal models, thrusting and diapirism, have been used to explain the folding in the Gunnison Plateau. Although the dynamic processes are arguable, the timing of events is reasonably constrained by the stratigraphic and structural relationships exposed along the east-central margin of the plateau. Both models indicate that deformation began in the Late Cretaceous, but differ with respect to the time at which deformation was complete. Proponents of compression and thrusting believe that deformation was complete by the early Paleocene (Lawton, 1985; Standlee, 1982), whereas proponents of salt diapirism suggest multiple episodes of growth and collapse which may have lasted into the Pliocene or Pleistocene (Witkind, 1982).

Cedar Hills

The Cretaceous strata have been folded and steeply tilted in the Cedar Hills. The Indianola Group in Hop Creek Ridge represents the steeply dipping west limb of a syncline, believed by Lawton (1985) to be the continuation of the Gunnison syncline. The Indianola strata in Hop Creek Ridge dip steeply to the southeast. The dip increases along strike from approximately 50 degrees in the southwest to 80 degrees in the northeast within the quadrangle. The increase in dip continues northeast of the map area until the strata eventually become overturned, dipping steeply to the northwest (Jefferson, 1982; Le Vot, 1984).

Dips of Indianola strata in part of the Cedar Hills within the quadrangle also show a moderate shallowing from northwest to southeast. This relationship appears to be better defined northeast of the quadrangle (Jefferson, 1982). Jefferson (1982, p. 78) attributed the shallowing of dips to the southeast to synorogenic sedimentation, and stated "... that the Indianola section was being concurrently uplifted and folded from west to east during deposition ...." Deformation during Indianola time (Late Cretaceous) culminated with emplacement of the Nebo allochthon along the Nebo thrust system. Mount Nebo, approximately 1.5 miles (2.4 km) NNW of the quadrangle, is the eastern overturned limb of the fold nappe. Alluvial-fan deposition in the upper Sixmile Canyon equivalent marks the initiation of emplacement of the Nebo allochthon and further substantiates synorogenic sedimentation (Jefferson, 1982).

The North Horn Formation, which overlies the Indianola Group with angular unconformity, dips approximately 25 to 30 degrees to the southeast. Jefferson (1982) attributed this to Laramide monoclinal flexure. The amount of flexure decreases along strike to the southwest as indicated by the shallowing of dips in that direction, and it is minimal within the study area. He projected the hinge of the monocline above the upper Hop Creek drainage basin, trending approximately northeast. Jefferson's placement of the hinge is based on the nearly horizontal North Horn strata which occur northwest of Hop Creek Ridge, approximately 2 miles (3.2 km) north of the map area, in the upper reaches of Salt Creek. Development of the monocline is believed to have occurred "... prior to the onlap of the Flagstaff Limestone ..." (late Paleocene to early Eocene) (Jefferson, 1982, p. 77). Jefferson based the timing on an unconformable relationship between the Flagstaff and North Horn; however, this relationship could not be confirmed within the study area.

FAULTS

Reverse and thrust faults represent the oldest faulting within the quadrangle. They occur in the Salt Creek area and are believed to be splays from the Nebo thrust system. The proposed thrust faults are only inferred because of Tertiary and Quaternary cover, but I feel that sufficient evidence exists to justify their existence.

Normal faults throughout the study area are the result of Miocene to recent Basin and Range extension. They trend in two general directions, northwest-southeast and east-northeast. The largest of the normal faults forms the eastern margin of the Gunnison Plateau. Locating faults in the Gunnison Plateau is difficult because the massive conglomerates have few correlatable intervals and are heavily vegetated. There is a strong probability that faults exist in addition to those shown on the map.

Reverse and Inferred Thrust Faults

One high-angle reverse and two inferred thrust faults occur in the Salt Creek area. The reverse fault is located approximately 4000 feet (1219 m) east of the Nebo Scenic Loop Road and extends for approximately 1 mile (1.6 km) from the junction with Utah State Highway 132. It is terminated on the south by a normal fault and passes beneath Tertiary cover just north of Quadrat Hollow. The fault juxtaposes the Cedar Mountain Formation and the Sixmile Canyon equivalent of the Indianola Group. It strikes north to just west of north, and dips approximately 45 to 60 degrees east. Strata of the Indianola Group, east of the fault, strike between 35 to 45 degrees east of north, and dip approximately 45 to 55 degrees to the southeast. The strike of the Indianola strata east of the fault is approximately 10 to 20 degrees different than the general trend of the strata in Hop Creek Ridge (N. 55° E.). This change in strike at the southwest end of Hop Creek Ridge is probably the result of the same compressive forces that generated the reverse fault. The bend also implies that the fault occurred after the larger force which initially deformed the Indianola Group in Hop Creek Ridge.

Determining amounts of displacement along the fault is difficult because of internal deformation in the Cedar Mountain Formation. I estimate displacement up to 2500 feet (762 m) and, because of this large displacement, have shown the fault to shallow at depth into a thrust fault (cross section A-A'). However, its high-angle surface expression requires that it be classified as a reverse fault.

A thrust fault has been inferred just west of the Nebo Scenic Loop Road. The extent of the fault is not known because it is completely concealed by Tertiary and Quaternary cover. A thrust fault is proposed for several reasons. The Moroni Formation, which conceals the fault, unconformably overlies the Jurassic Arapien Shale along the western margin of the quadrangle, north of Salt Creek. In the north arm of Salt Creek, the Moroni Formation again overlies the Arapien Shale at an isolated outcrop west of the Nebo Scenic Loop Road, approximately 2000 feet (610 m) north of the junction with Highway 132. It is therefore reasonable to assume that Twist Gulch through Indianola strata are absent beneath the Moroni north and west of Salt Creek. The Indianola and Cedar Mountain exposures which occur approximately 2500 feet (762 m) north of the Arapien outcrop along the Nebo Scenic Loop Road, and which dip steeply to the west-southwest, must therefore be fault-terminated at shallow depth (cross section A-A'). A high-angle contact occurs between the Moroni Formation and the Indianola Group at the south end of the Indianola exposure. However, this contact is interpreted as an angular unconformity because the Moroni Formation also overlaps the Indianola at this location (figure 3). The Indianola and Moroni dip approximately 54 and 20 degrees respectively along parallel strikes. The Indianola outcrop probably stood as an island during the deposition of the Moroni Formation because of its resistant nature relative to the Arapien Shale.

The remaining question is whether the Indianola and Cedar Mountain were down-faulted against the Arapien, or whether the Arapien was thrust up against the Indianola and the Cedar Mountain. Since a normal fault of that magnitude would most likely be part of basin-and-range extension, it would be expected to cut the Moroni Formation. This not being the case, it is probably a thrust fault. Displacement along the fault is uncertain but must be at least 4000 feet (1220 m).

A second concealed thrust fault has been inferred at the north end of the Gunnison Plateau. The fault is proposed because of the absence of the Cedar Mountain Formation at this location. Although a large amount of Quaternary cover exists, the proximity of the steeply dipping Twist Gulch Formation to the Indianola Group suggests that the Cedar Mountain is missing, or very nearly so. The extent of the thrust fault west of the study area is not certain. Biek (in press), Auby (in press), and McDermott (in

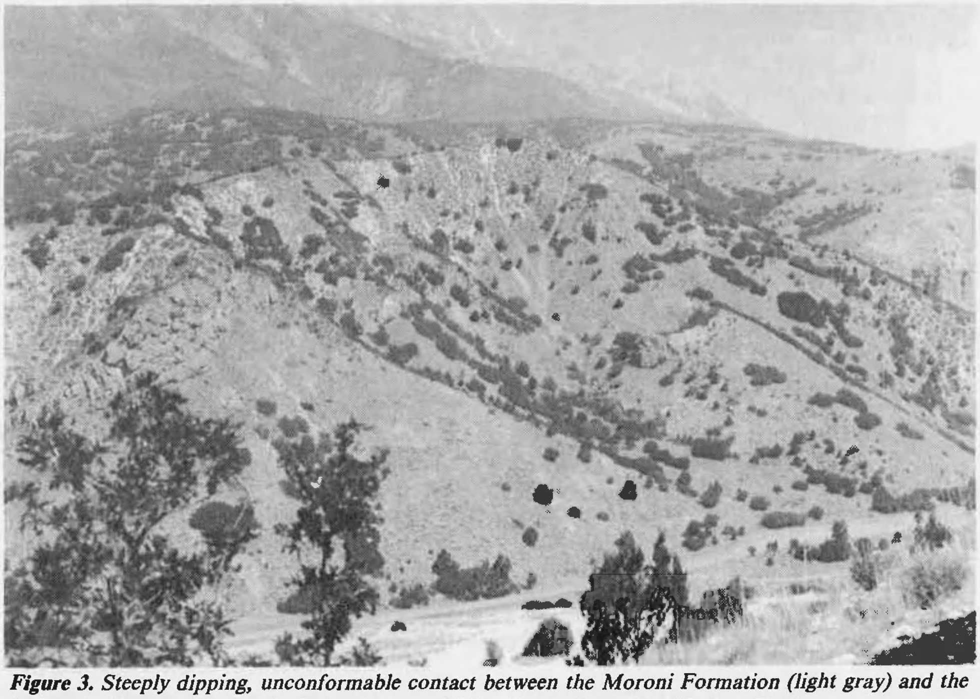

Figure 3. Steeply dipping, unconformable contact between the Moroni Formation (light gray) and the Indianola Group (cliffs at left of photo), west of Nebo Scenic Loop Road in Salt Creek.

preparation), report a continuous sequence of Arapien, Twist Gulch, Cedar Mountain, and Indianola, in upward succession, along the west margin of the Gunnison Plateau. This being the case, the thrust may extend into the intensely deformed Arapien Shale along the northwestern margin of the Gunnison Plateau, where thrusting has been documented (Hunt, 1950; Villien, 1984).

Normal Faults

East Gunnison Plateau Frontal Fault System — Two faults or zones of faults lie at or near the east front of the Gunnison Plateau. One extends along the entire foot of the mountain but is buried by Quaternary deposits. It is down to the east, it forms the mountain, and it has been called the "valley fault" (VF) in older reports. The total throw on this fault is on the order of 8000 to 9000 feet (2438-2743 m) near the north end of the plateau. The second is a fault trending SSE from the mouth of Log Hollow to and across Fountain Green Pole Canyon and out to the VF in the Fountain Green South quadrangle. This fault is offset down to the east about 1500 feet (457 m) and is called the Fountain Green Pole Canyon fault (FGPCF). Although the sense on the VF is always down to the east, there is, a few miles south of this quadrangle, a large down to the west fault near the edge of the plateau, named the East Gunnison fault (EGF) by Thomas (1960). Thomas considered the EGF normal and west dipping, however, Weiss (1982) determined the true nature to be that of a high-angle reverse fault, dipping steeply to the east.

Any explanation of the relationship between the VF, FGPCF, and the EGF must recognize that the east edge of the plateau is not a single, simple cliff. A narrow "foothill belt" of lower elevation lies low on the mountain face from Fountain Green Pole Canyon, at the south edge of the Fountain Green North quadrangle, to approximately Petes Canyon in the Wales Quadrangle, 12 miles (19.2 km) south of the quadrangle. This belt, south of Birch Canyon, about 3 miles (4.8 km) south of the quadrangle, consists largely of broken and poorly exposed beds of the Twist Gulch Formation and the Indianola Group, mapped as Indianola undifferentiated by Weiss (1982) and Thomas (1960). The outcrop of the Twist Gulch Formation terminates at Birch Canyon, as does the EGF. The foothill belt, south of Birch Canyon, is a horst 0.75 miles (1.2 km) wide between the EFG and the VF. Still to be explained are the termination of the foothill belt horst and the EFG, and the fact that the plateau margin west of the town of Fountain Green has two faults down to the east.

It is also important to the explanation that Member 4, mapped east of the FGPCF, exposes orderly bedding and is clearly down with respect to the main body of the plateau. Hunt (1950) recognized the same down to the east relationship, but he mapped the strata east of the FGPCF as South Flat Formation, as they were then defined. Thus, the mountain front here is not like the foothill belt south of Birch Canyon and is not a horst, but a structural terrace between the plateau and the VF.

Study of the structural relations along the front, and the dynamics required to produce them (Weiss, 1982), as far south as Wales (about 10 miles or 16 km south of Fountain Green) shows that the main body of the plateau has a different structural history south of the Fountain Green North quadrangle. The following hypothesis is proposed to explain the differences.

The strong upward and west-directed fault that produced the steeply overturned folds and the high-angle reverse EGF, as reported by Weiss (1982) in Maple and Wales Canyons (4 and 10 miles or 6.4-16 km south of Fountain Green, respectively), is truncated at Birch Canyon. Further, it is truncated by both the FGPCF and VF expressed west of the town of Fountain Green, both of which lie at an oblique angle (about 30 degrees) to the EGF, the foothill belt horst, and the VF south of Birch Canyon. This requires that the FGPCF be younger than those three structural features, and that the VF north of Birch Creek be younger than the trend of the VF south of that location. The northern element (strike N. 30° W.) is therefore, from this point on, referred to as VF2, and the older element to the south (strike north-south) as VF1. VF2 lies entirely within the Fountain Green North quadrangle, and the area of junction of VF1 and VF2 is near Fountain Green Pole Canyon.

The valley faults, once formed, have permitted the plateau to be elevated with respect to Sanpete Valley. However, the streams which emanate from all of the major canyons north of Fountain Green Pole Canyon have deeply incised the alluvial fans at the base of the plateau. At least two terraces can be seen in most of the channels. The deepest and widest channel emanates from Log Hollow; it is approximately 80 to 100 feet (24-30 m) deep and ranges in width from 400 to 1500 feet (122-457 m). The channels are box-shaped which indicate that they are relatively young. The incised channels may be the result of recent movement along VF2 or changes in climate. A tectonic origin is favored, however, since the fans in front of the canyons south of an including Fountain Green Pole Canyon do not show such deeply incised channels. This suggests that motion on VF1 and VF2 has not been coincident or equal.

Other Normal Faults — A northeast-southwest-trending normal fault in Log Hollow is here referred to as the Log Hollow fault. The fault is terminated to the northeast by the FGPCF and is lost by decreasing throw to the southwest in White Pine Canyon. The fault is nearly vertical and drops the strata on the southeast. Displacement of the carbonate marker beds is approximately 300 feet (91 m).

A northwest-southeast-trending fault extends for about 3 miles (4.8 km) from the mouth of Log Hollow, through North Canyon, to the upper portion of Bradley Canyon and is here referred to as the North Canyon fault. The North Canyon fault is nearly vertical and displaces the carbonate marker beds about 400 feet (122 m) down to the northeast.

The fault here referred to as the Holman Canyon fault trends north-south for approximately 1.5 miles (2.4 km) between Jewkes Canyon and North Canyon. The fault is nearly vertical and displaces the carbonate marker beds approximately 200 feet (61 m) down to the east. The Holman Canyon fault is terminated to the north by the North Canyon fault. To the south it is lost west of Jewkes Canyon, but it may extend up the unnamed canyon between Jewkes and White Pine Canyons.

A valley fault must exist along the eastern margin of the west arm of Sanpete Valley. It will be referred to as the West Cedar Hills fault (WCHF) hereafter. The WCHF is exposed between Hop Creek and the northern arm of Salt Creek. The fault, as seen at this location, drops the Tertiary Moroni Formation against the Sixmile Canyon equivalent of the Indianola Group. The Moroni strata, southwest of the fault, dip 25 to 30 degrees to the south, while the Indianola strata, northeast of the fault, dip 45 to 55 degrees to the southeast. South of Hop Creek, the fault is inferred beneath Quaternary cover.

Although evidence for the WCHF is poor farther to the south, geometric constraints necessitate some type of westward termination of the strong southwest trend of the strata in the Cedar

Hills. The fault may represent a middle Tertiary reactivation of a zone of weakness produced during the intense deformation of the Cedar Hills during the Late Cretaceous.

STRUCTURAL DISCONTINUITY OF INDIANOLA GROUP

Conspicuous structural discontinuity exists between the Indianola strata in the Gunnison Plateau and the Cedar Hills. Indianola strata in the Gunnison Plateau generally strike from N. 15° W. to N. 15° E. and dip gently (15-25 degrees) east. Indianola strata in the Cedar Hills generally strike approximately N. 55° E. and dip steeply (45-80 degrees) southeast. Jefferson (1982) attributed the substantial folding and tilting of the Indianola Group in the Cedar Hills to the emplacement of the Nebo allochthon. In addition to contemporaneous folding and sedimentation discussed previously, he added two more lines of evidence suggesting deformation by emplacement of the Nebo Allochthon: "... (1) northeast-trending, steep to overturned Jurassic and Cretaceous strata in the Cedar Hills are sub-parallel to the upper plate strata of the Nebo Allochthon to the west, and (2) all Pennsylvanian-Permian through Upper Cretaceous strata are unconformably overlain by the overlap assemblage" (p. 77). If thrusting of the Indianola section in the Cedar Hills occurs at depth, displacement is not believed to be more than 3.2 miles (5 km) (Jefferson, 1982).

SALT DIAPIRISM

There is good evidence to support localized salt diapirism at one location in the map area. At the entrance to the north arm of Salt Creek, just north of Highway 132, strata on both sides of the Nebo Scenic Loop Road are intensely deformed. Strata along the west side of the road dip to the west, and strata on the east side of the road dip to the east. The effects of thrust faulting in this area were discussed previously, but thrust faulting is inadequate to explain the westward dips of the Tertiary Moroni strata west of the road. The best evidence for salt diapirism, however, is the exposed salt plug within the isolated Arapien outcrop near the west side of the road. The diapirism probably does not extend much farther north than Quadrat Hollow, for dips of Moroni strata on either side of the canyon past this point are consistently to the northwest. Extensive faulting in this area (cross section A-A') may have provided a weakened area conducive to salt diapirism.

Hawks (1980) proposed the collapse of extremely large diapirs (up to 5 miles or 8 km in diameter) as the cause of the extensive landsliding in the Cedar Hills. Hawks based the diapirs on circular depressions in Water Hollow and Big Hollow, and on seismic interpretations. The author disagrees with this diapir model as applied in the Cedar Hills because of the extremely large volume of diapiric material that would be required. Even if the mudstones and shales of the Arapien Shale are included with the evaporites in the diapir, it would require mobilization of nearly the entire formation for about 15 square miles (38 km^2) (Banks, 1986). Regional gravity surveys (Cook and Berg, 1961; Brown and Cook, 1982; Zoback, 1983), which should indicate a structure of that size, show no evidence to indicate salt diapirs in the Cedar Hills.

GEOLOGIC HAZARDS

EARTHQUAKES

The Intermountain seismic belt is coincident with the transitional boundary between the Basin and Range and the Colorado Plateau-Middle Rocky Mountain physiographic provinces in central Utah (Smith and Sbar, 1974; Smith, 1978). The proximity to the Wasatch fault zone, which borders the west edge of the Gunnison Plateau, and the valley fault bordering its east edge within the quadrangle, make part of the quadrangle area a zone of high seismic risk.

Historical earthquakes of magnitude 4.4 occurred 12.5 miles (20 km) to the southwest (1963) and 25 miles (40 km) to the northwest (1980) of Fountain Green; however, most earthquakes in the vicinity are less than or equal to magnitude 2.8 (Cook and Smith, 1967; McKee and Arabasz, 1982). Focal depths computed for earthquakes in the area by McKee and Arabasz (1982) are less than 49,400 feet (15,057 m), and the depths of half were less than 13,200 feet (4023 m). Although most earthquakes in recent times in the area are small, the potential for larger ones is reason for concern.

MASS MOVEMENTS

Mass movements are a major problem in central Utah. Three types of mass movements occur within the map area: landslides, slumps, and debris flows. Most landslides and slumps are small and can be attributed to the wet climatic cycles such as the 1983-1985 cycle. Larger, older, and more complex landslides are common at the base of the Gunnison Plateau and in the Cedar Hills between Hop Creek and Water Hollow. None of these slides shows evidence of recent movement. Alluvial fans, resulting from the numerous debris flows, occur along the base of the Gunnison Plateau and the Cedar Hills. Debris flows also occur along the southeast flank of Hop Creek Canyon; the most striking is located in the very northeast corner of the map area. At the time the flow occurred, it must have dammed Hop Creek as indicated by the large alluvial mass just upstream behind the flow. Member 4 of the Indianola Group, the North Horn Formation, the Moroni Formation, and the Salt Creek Fanglomerate are all prone to mass-movement activity.

Several landslides and fans of debris-flow origin involve Member 4 of the Indianola Group at the base of the Gunnison Plateau just west of Fountain Green. Large boulders up to 4 feet (1.2 m) in diameter litter the surface of the fan which emanates from Fountain Green Pole Canyon, attesting to its debris-flow origin. South of Fountain Green, in the Fountain Green South quadrangle, large amounts of slide material derived from the Gunnison Plateau cover portions of the valley floor as far as 2 miles (3.2 km) from the plateau margin. Boulders the size of automobiles are common and attest to the magnitude of those rock slides. Fresh scars from smaller (approximately 4-5 acres or 1.6-2 hm^2), more recent (as late as 1983-1985), slides occur high on the face of the plateau west of Fountain Green. The recent slides are shallow and long, and they occur on steep slopes.

The North Horn Formation, Moroni Formation, and Salt Creek Fanglomerate produce many landslides and debris flows in the Cedar Hills, but no evidence of recent (post-1983) movement was observed with the exception of a few small slides. Unconsolidated portions of the Salt Creek Fanglomerate are prone to sliding and slumping when they overlie impervious units such as the Arapien Shale.

Immediate threat to man-made structures from mass movements in the map area is low, in part because little development has occurred. There are, however, areas which deserve concern. The Salt Creek Fanglomerate overlying the Arapien Shale is especially susceptible, particularly during periods of prolonged rain or thunderstorms. Also of concern is the Holiday Oaks recreational housing development, approximately 2 miles (3.2 km) southeast of the

Nebo Scenic Loop Road on Utah State Highway 132, which is located in an area that has experienced Quaternary landslide activity. Finally, the face of the Gunnison Plateau just west of Fountain Green has had much landslide and debris-flow activity.

ECONOMIC GEOLOGY

SAND AND GRAVEL

The most plentiful economic resource within the area of study is sand and gravel. Most of the sand and gravel occurs in the alluvial apron which borders the base of the Gunnison Plateau in Sanpete Valley. The coalesced alluvial fans are mostly sand, silt, and gravel, and are poorly sorted and stratified, with the finer constituents near the top. Coarser constituents are seen in stream cuts in lower portions of the fans. Overall, sand and silt make up approximately 60 percent of the deposits, while gravel, containing large boulders, comprises 40 percent. Pratt and Callaghan (1970) describe this type of material as being of fair quality to use as fill.

Good fill material occurs in the modern stream-channel deposits at the mouths of canyons along the east edge of the Gunnison Plateau. Large deposits are located at the mouths of Log Hollow, Worth Canyon, Meetinghouse Canyon, and Bradley Canyon. The gravels in these channels range up to boulder size and consist of approximately 60 to 70 percent quartzite and 30 to 40 percent limestone.

To date, none of the stream-channel deposits have been worked, but several borrow pits in the coalesced alluvial fans were used in the construction of Utah State Highway 132. Secondary sources of sand and gravel in the study area include the Quaternary-Tertiary Salt Creek Fanglomerate, the conglomeratic layers of the Tertiary Moroni Formation, and Quaternary mass-movement deposits involving these formations.

SALT

Salt deposits in the Arapien Shale have been exploited in central Utah since the arrival of the earliest settlers. One exposure occurs in the Fountain Green North quadrangle at the junction of Utah State Highway 132 and the Nebo Scenic Loop Road. A pit has been dug at the exposure, but it does not appear to have been worked appreciably, nor recently. The salt is contained in the reddish-brown calcareous mudstones of the Arapien Shale. The exposure of salt within the pit is approximately 15 by 10 feet, (4.5 by 3 m) but the full extent of the deposit cannot be observed. Salt was once mined underground approximately 3 miles (4.8 km) farther north along Salt Spring Creek and was processed at a small plant which stood near the junction of Highway 132 and the Nebo Scenic Loop Road (Witkind and Weiss, 1985). The remains of the plant can be seen near Utah State Highway 132, 5 miles (8 km) east of Nephi.

OIL AND GAS

Oil and gas exploration in the area has occurred in the past and will probably continue. Several wells have been drilled, including the Phillips Petroleum Company's Neilson-Seager #1, which is in the map area. No appreciable shows of oil or gas were discovered; however, gas and very slight shows of oil were recovered by drill stem tests in the Tennessee Gas Transmission #1 J.W. Irons unit just south of Moroni, approximately 7 miles (11 km) south-southeast of Fountain Green (Ritzma, 1972). These shows occurred in the Ferron and Tununk Sandstone Members of the Mancos Shale, which are correlative to the Funk Valley and Allen Valley Formations of the Indianola Group respectively (Fouch and others, 1983). Shows such as these, and the fact that the Ferron and Dakota (equivalent to the Sanpete Valley Formation of the Indianola Group) members are gas producers in eastern Sanpete County, leave open the possibilities for oil and gas in the study area (Pratt and Callaghan, 1970).

WATER RESOURCES

Springs

Numerous springs occur throughout the Fountain Green North quadrangle. For a more comprehensive look at springs in Sanpete County the reader is referred to Pratt and Callaghan (1970). Field work occurred in the third year of an unusual wet climatic stage, so many more springs were active and were mapped than might be expected to persist in drier parts of the cycle. A great number of springs in the quadrangle, particularly in the Gunnison Plateau, are fracture or fault controlled.

The two largest springs, Big Springs and Bradley Spring, are located along the east and northeast margin of the Plateau, respectively. Both of these springs issue from Cretaceous Indianola conglomerates and are related to the Gunnison fault zone (VF2) which forms the eastern margin of the Gunnison Plateau (Hunt, 1950; Thomas, 1960). Big Springs, the larger of the two, is used as the municipal supply for the town of Fountain Green. It is also used for irrigation and for the Fountain Green Fish Hatchery. It has a reported discharge of 4 to 17.5 cfs (1800-79,000 gpm) (Mundorff, 1971). The magnitude of its output has made Big Springs suitable for the generation of power, and a small hydroelectric plant has been constructed at the discharge area.

Bradley Spring is the principal municipal supply for the town of Nephi. The spring has been sealed, and water is piped to the mouth of the canyon. Bradley Spring has a reported average discharge of 4 cfs (1800 gpm). Discharge from both of these springs varies throughout the year, with the greatest flow occurring during the months of July and August. In addition to the data presented here, chemical analyses and other data can be obtained from Mundorff (1971).

Other springs occurring in the area are those described as pocket springs by Hunt (1950). These springs are usually small and have erratic flow. They generally issue from contacts where unconsolidated soils and gravels overlie less pervious units. Pocket springs are numerous throughout the area and are usually used for the watering of livestock; many are intermittent.

Surface Water

Three continuous sources of surface water exist within the study area: they are Salt Creek and two of its tributaries, Pole Creek, and the unnamed creek which flows west through Water Hollow and northwest through Sanpete Valley. In addition, most of the smaller drainages flow intermittently. Salt Creek has a drainage area of approximately 95.6 square miles (247 km^2) and an average annual discharge of approximately 19,560 acre-feet (24.1 hm^3) (Gates, 1982; Price, 1984). The main source for Salt Creek is snow-melt, springs, and ground-water infiltration.

Ground Water

Based on previous studies (Pratt and Callaghan, 1970; Robinson, 1971; Gates, 1982), the potential for ground water in the northwest arm of Sanpete Valley is good. Underflow from the canyons and possible leakage from the Gunnison fault augment the ground water in the valley alluvium. While both water-table and artesian conditions exist farther south (Robinson, 1971), no evidence of artesian conditions was observed within the study area. The water table can usually be reached at less than 60 feet (18 m) in the valley lowlands, and between 60 and 100 feet (18-30 m) on higher alluvial fans at the base of the Gunnison Plateau (Robinson, 1971). The water table in Sanpete Valley slopes to the southeast.

Water-table fluctuations occur on a seasonal basis in the Fountain Green area and have resulted in septic tank and basement flooding. Water levels decline in the months from March to about October and rise again fromOctober to March of the following year (Robinson, 1971). The decline is due mostly to pumping of irrigation wells, down-valley drainage, and evapotranspiration.

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REFERENCES

Armstrong, R.L., 1968, Sevier orogenic belt in Nevada and Utah: Geological Society of America Bulletin, v. 79, p. 429-458.

Auby, W.L., in press, Provisional geologic map of the Levan quadrangle, Juab County, Utah: Utah Geological and Mineral Survey, 1:24,000.

Baer, J.L., 1976, Structural evolution of central Utah-Late Permian to Recent, *in* Hill, J.G., editor, Symposium on Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists, p. 37-45.

Banks, R.L., 1986, Geology of the Fountain Green North quadrangle, Sanpete and Juab Counties, Utah: M.S. thesis, Northern Illinois University, 246 p.

Biek, R.F., in press, Provisional geologic map of the Nephi quadrangle, Juab County, Utah: Utah Geological and Mineral Survey, 1:24,000.

Black, B.A., 1965, Nebo overthrust, southern Wasatch Mountains, Utah: Brigham Young University Geology Studies, v. 12, p. 55-89.

Brown, R.P., and Cook, K.L., 1982, A regional gravity survey of the Sanpete-Sevier Valley and adjacent areas in Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 127-136.

Cook, K.L., and Berg, J.W., Jr., 1961, Regional gravity survey along the central and southern Wasatch Front, Utah: U.S. Geological Survey Professional Paper 316-E, 89 p.

Cook, K.L., and Smith, R.B., 1967, Seismicity in Utah, 1850 through June 1965: Bulletin of the Seismological Society of America, v. 57, p. 689-718.

Cooper, J.E., 1956, Petrology of Moroni Formation, southern Cedar Hills, Utah: M.S. thesis, Ohio State University.

Eardley, A.J., 1933, Stratigraphy of the southern Wasatch Mountains, Utah: Papers of the Michigan Academy of Science, Arts and Letters, v. 18, p. 307-344.

Eardley A.J., 1934, Structure and physiography of the southern Wasatch Range, Utah: Papers of the Michigan Academy of Science, Arts and Letters, v. 19, p. 377-400.

Fouch, T.D., Lawton, T.F., Nichols, D.J., Cashion, W.B., and Cobban, W.A., 1982, Chart showing preliminary correlation of major Albian to Middle Socene rock units from Sanpete Valley in central Utah to the Book Cliffs in eastern Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 267-272.

Fouch, T.D., Lawton, T.F., Nichols, D.J., Cashion, W.B., and Cobban, W.A., 1983, Patterns and timing of synorogenic sedimentation in Upper Cretaceous rocks of central Utah and northeast Utah, *in* Reynolds, M.W., and Dolley, E.D., editors, Mesozoic Paleogeography of the West-central United States, Rocky Mountain Paleogeography Symposium 2: Society of Economic Paleontologists and Mineralogists, p. 305-330.

Gates, J.S., 1982, Hydrogeology of the Gunnison-Fairview-Nephi area, central Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 151-162.

Hardy, C.T., 1952, Eastern Sevier Valley, Sevier and Sanpete Counties, Utah with reference to formations of Jurassic age: Utah Geological and Mineral Survey Bulletin 43, 98 p.

Hawks, R.L., Jr., 1980, The stratigraphy and structure of the Cedar Hills, Sanpete County, Utah: Brigham Young University Geology Studies, v. 27, pt. 1, p. 67-80.

Hays, J.D., 1960, A study of the South Flat and related formations of central Utah: part 1 petrology, part 2 palynology: M.S. thesis, Ohio State University, 147 p.

Hunt, R.E., 1950, The geology of the northern part of the Gunnison Plateau, Utah: Ph.D. dissertation, Ohio State University, 267 p.

Imlay, R.W., 1980, Jurassic paleogeography of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

Jefferson, W.S., 1982, Structural and stratigraphic relations of Upper Cretaceous to lower Tertiary orogenic sediments of the Cedar Hills, Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 65-80.

Lawton, T.F., 1982, Lithofacies correlations within the Upper Cretaceous Indianola Group, central Utah: *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 199-213.

Lawton, T. F., 1985, Style and timing of frontal structures, thrust belt, central Utah: American Association of Petroleum Geologists Bulletin, v. 69, no. 7, p. 1145-1159.

Le Vot, Michel, 1984, L'Overthrust Belt Face Aux Uinta Mountains (Utah, U.S.A.): Thèse de doctorate de 3ème Cycle, Université de Bretagne Occidentale, Brest - SNEA(P), 310 p., various scales.

Mattox, S.R., 1986, Geology of the Hells Kitchen Canyon SE quadrangle, Sanpete County, Utah: M.S. thesis, Northern Illinois University, 448 p.

McDermott, J.G., in preparation, Geology of the Chriss Canyon quadrangle, Juab County, Utah: M.S. thesis, Northern Illinois University.

McKee, M.E., and Arabasz, W.J., 1982, Microearthquake studies across the Basin and Range - Colorado Plateau transition in central Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 137-150.

Muessig S. J., 1951, Geology of a part of Long Ridge, Utah: Ph. D. dissertation, Ohio State University, 213 p.

Mundorff, J.C., 1971, Nonthermal springs of Utah: Utah Geological and Mineral Survey Water-Resources Bulletin 16, 70 p.

Pratt, A.R., and Callaghan, Eugene, 1979, Land and mineral resources of Sanpete County, Utah: Utah Geological and Mineralogical Survey Bulletin 85, 69 p.

Price, Don, 1984, Map showing selected surface-water data for the Nephi 30 x 60-minute quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigation Series, Map I-1512.

Ritzma, H.R., 1972, Six Utah "hingeline" wells, *in* Baer, J.L., and Callaghan Eugene, editors, Plateau-Basin and Range Transition Zone, Central Utah, 1972: Utah Geological Association Publication 2, p. 75-80.

Robinson, G.B., Jr., 1971, Ground-water hydrology of the San Pitch River drainage basin, Sanpete County, Utah: U.S. Geological Survey Water-Supply Paper 1896, 80 p.

Roche, M.G., 1985, Morrison(?) Formation of central Utah reassigned: M.S. thesis, Northern Illinois University, 176 p.

Runyon, D.M., 1977, Structure, stratigraphy, and tectonic history of the Indianola quadrangle, central Utah: Brigham Young University Geology Studies, v. 24, pt. 2, p. 63-82.

Schoff, S.L., 1937, Geology of the Cedar Hills, Utah: Ph.D. dissertation, Ohio State University, 105 p.

Schoff, S.L., 1951, Geology of the Cedar Hills, Utah: Geological Society of America Bulletin, v. 62, p. 619-646

Smith, R.B., 1978, Seismicity, crustal structure, and intraplate tectonics of the interior of the western Cordillera, *in* Smith, R.B., and Eaton, G.P., editors, Cenozoic Tectonics and Regional Geophysics of the Western Cordillera: Geological Society of America Memoir 152, p. 111-144.

Smith, R.B., and Sbar, M.L., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the intermountain seismic belt: Geological Society of America Bulletin, v. 85, p. 1205-1218.

Spieker, E. M., 1930, Structure of the Manti-Salina area, Utah (abstract): Geological Society of America Bulletin, v. 41, p. 55-56.

Spieker, E.M., 1936, Orogenic history of central Utah: Science, v. 83, p. 62-63.

Spieker, E.M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geological Survey Professional Paper 205-D, p. 117-161.

Spieker, E.M., 1949a, The transition between the Colorado Plateau and the Great Basin in central Utah: Utah Geological Society Guidebook 4, 106 p.

Spieker, E.M., 1949b, Sedimentary facies and associated diastrophism in the Upper Cretaceous of central and eastern Utah; sedimentary facies in geologic history: Geological Society of America Memoir 39, p. 55-82.

Spieker, E.M., and Reeside, J.B., 1925, Cretaceous and Tertiary formations of the Wasatch Plateau: Geological Society of America Bulletin, v. 36,

p. 435-454.

Sprinkel, D.A., 1982, Twin Creek Limestone-Arapien Shale relations in central Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 169-179.

Standlee, L.A., 1982, Structure and stratigraphy of Jurassic rocks in central Utah: their influence on tectonic development of the Cordilleran foreland thrust belt, *in* Power, R.B., editor, Geologic Studies of the Cordilleran Thrust Belt: Rocky Mountain Association of Geologists, p. 357-382.

Stanley, K.O., and Collinson, J.W., 1979, Depositional history of Paleocene-Lower Eocene Flagstaff Limestone and coeval rocks, central Utah: American Association of Petroleum Geologists Bulletin, v. 63, p. 311-323.

Stokes, W.L., 1952, Salt-generated structures of the Colorado Plateau and possible analogies (abstract): American Association of Petroleum Geologists Bulletin, v. 36, p. 961.

Stokes, W.L., 1982, Geologic comparisons and contrasts, Paradox and Arapien basins, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 1-11.

Stuecheli, P.J., 1984, The sedimentology, age, and depositional setting of the Morrison (?) Formation in central Utah: M.S. thesis, Ohio State University, 137 p.

Thomas, G.E., 1960, The South Flat and related formations in the northern part of the Gunnison Plateau, Utah: M.S. thesis, Ohio State University, 137 p.

Villien, A., 1984, Central Utah deformation belt: Ph.D. dissertation, University of Colorado, 283 p.

Weiss, M.P., 1982, Structural variety on the east front of the Gunnison Plateau, central Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association 10, p. 49-63.

Willis, G.C., 1986, Geologic map of the Salina quadrangle, Sevier County, Utah: Utah Geological and Mineral Survey Map 83, 1:24,000.

Witkind, I.J., 1982, Salt diapirism in central Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah, 1982 Symposium and Field Conference: Utah Geological Association Publication 10, p. 13-30.

Witkind, I.J., and Hardy, C.T., 1984, The Arapien Shale of central Utah —A dilemma in stratigraphic nomenclature: U.S. Geological Survey Bulletin 1537-A, p. A5-A20.

Witkind, I.J., and Weiss, M.P., 1985, Preliminary geologic map of the Nephi 30 x 60-minute quadrangle, Carbon, Emery, Juab, Sanpete, and Wasatch Counties, Utah: U.S. Geological Survey Open-File Report 85-466, 47 p.

Zoback, M.L., 1983, Structure and Cenozoic tectonism along the Wasatch fault zone, Utah: Geological Society of America, Memoir 157, p. 3-27.

APPENDIX

Potassium-Argon Age Determination

Laboratory: Krueger Enterprises, Inc., Cambridge, MA
Date Reported: 1/23/86
Sample Number: B-7450
Sample Description: Andesite dike.
Location: SE ¼ of SW ¼ of SW ¼ of Section 28, T. 13 S., R. 2 E.

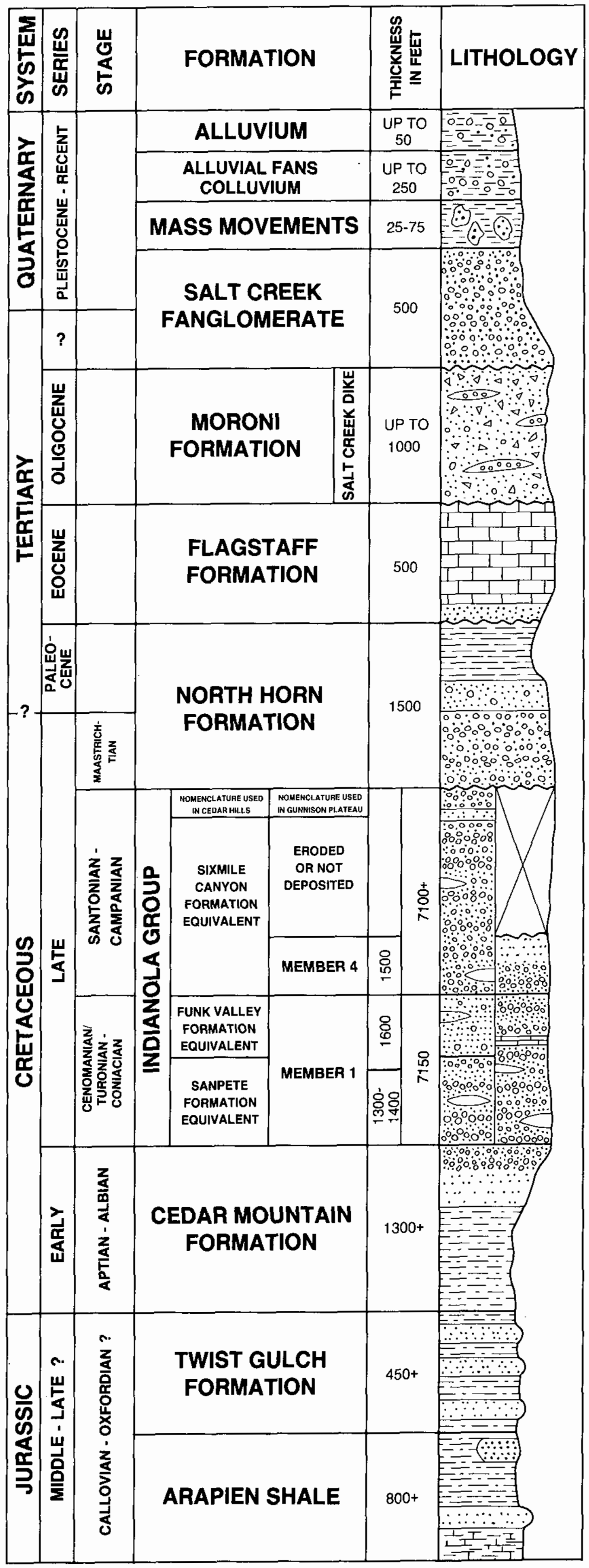
Material Analyzed: Biotite concentrate, -60/+200 mesh.
$^{40*}Ar/^{40}K = 0.001972$
Age: 33.6 ± 1.4 million years
Argon Analyses:

$^{40*}Ar$, ppm	$^{40*}Ar$/Total ^{40}Ar	^{40*}Ave. Ar, ppm
0.01210	0.373	0.01250
0.01289	0.594	

Potassium Analyses:

%K	Ave. %K	^{40}K, ppm
5.217	5.311	6.336
5.405		

Note: $^{40*}Ar$ refers to radiogenic ^{40}Ar.


SYSTEM
SERIES
STAGE
FORMATION
THICKNESS IN FEET
LITHOLOGY
QUATERNARY
PLEISTOCENE - RECENT
ALLUVIUM
UP TO 50
ALLUVIAL FANS COLLUVIUM
UP TO 250
MASS MOVEMENTS
25-75
SALT CREEK FANGLOMERATE
500
TERTIARY
?
OLIGOCENE
MORONI FORMATION
SALT CREEK DIKE
UP TO 1000
EOCENE
FLAGSTAFF FORMATION
500
PALEO-CENE
?
NORTH HORN FORMATION
1500
MAASTRICH-TIAN
CRETACEOUS
LATE
SANTONIAN - CAMPANIAN
INDIANOLA GROUP
NOMENCLATURE USED IN CEDAR HILLS
NOMENCLATURE USED IN GUNNISON PLATEAU
SIXMILE CANYON FORMATION EQUIVALENT
ERODED OR NOT DEPOSITED
MEMBER 4
1500
7100+
CENOMANIAN/ TURONIAN - CONIACIAN
FUNK VALLEY FORMATION EQUIVALENT
1600
SANPETE FORMATION EQUIVALENT
1300-1400
MEMBER 1
7150
EARLY
APTIAN - ALBIAN
CEDAR MOUNTAIN FORMATION
1300+
JURASSIC
MIDDLE - LATE ?
CALLOVIAN - OXFORDIAN ?
TWIST GULCH FORMATION
450+
ARAPIEN SHALE
800+