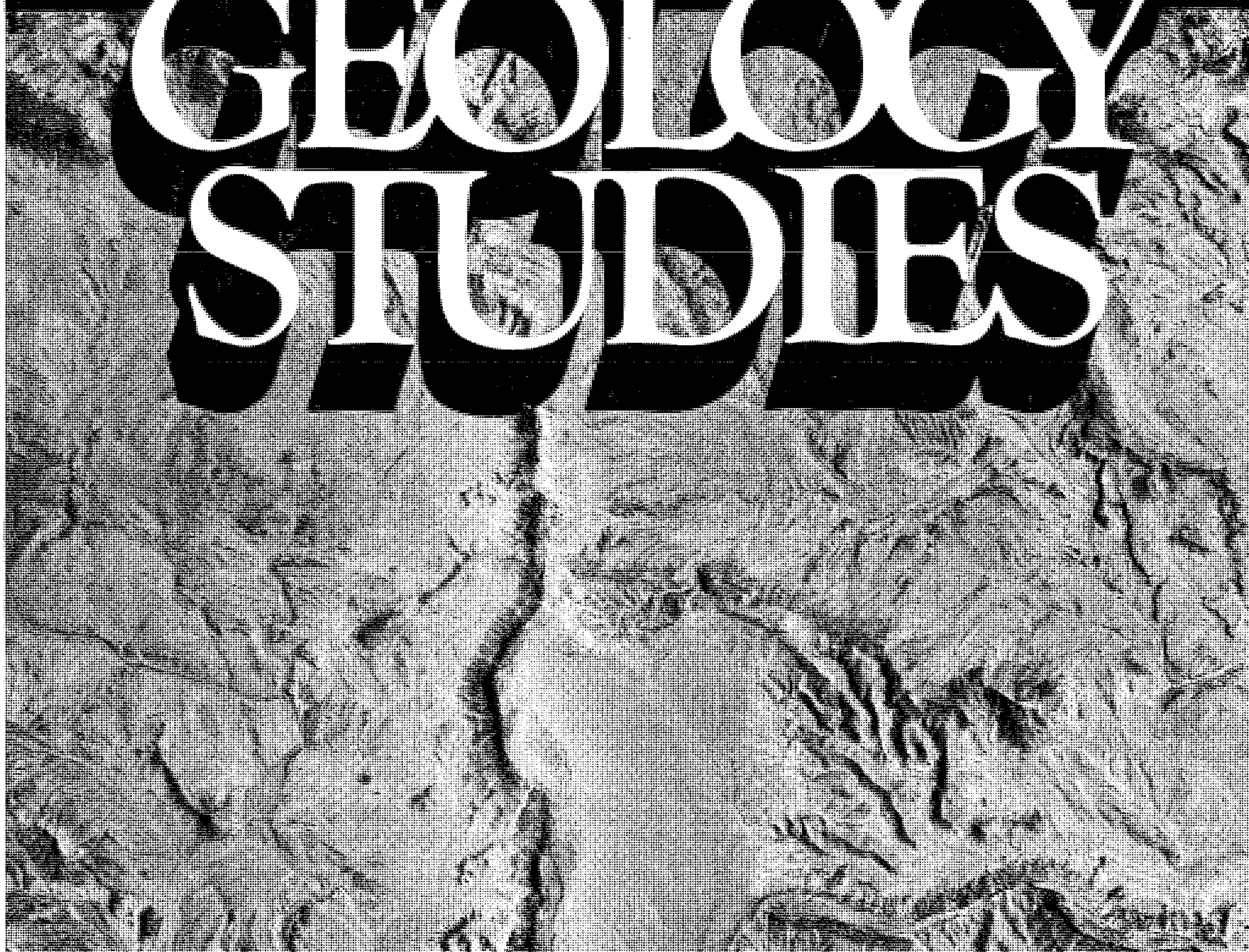
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



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THE GLORY OF GOD IS INTELLIGENCE

Cover: Aerial photograph showing exhumed stream paleochannels in the Cedar Mountain Formation near Green River, Utah. Courtesy Daniel R. Harris.

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The Stratigraphy and Structure of the Cedar Hills, Sanpete County, Utah*

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ABSTRACT.—Two salt diapirs dominate the geology of the Cedar Hills of northern Sanpete County. Intermittent ascension of these piercement structures and their collapse produced local unconformities: doming, faulting, and a variety of potential hydrocarbon traps. Groundwater has dissolved the upper portions of the diapirs, resulting in collapse of the surface. The dissolved evaporites are suspected to have been deposited in the Great Salt Lake drainage basin.

The stratigraphy has been disrupted by the piercement of the diapirs and their collapse. Landslide and slumps are commonly seen around the oval-shaped depressions which outline the collapse structures.

The boundary faults associated with the piercement and collapse of the diapirs are normal faults. Additional faults are seen around the collapse features and are associated with the landslides and slumps in the depressions or in the Sanpete Valley itself.

This area has been involved in the development of the Cordilleran and Rocky Mountain geosynclines. Physiographically the study area is located near the intersection of the Basin and Range Province, the Colorado Plateau Province, and the Central Rocky Mountain Province. Geophysical data indicates the close proximity of the tectonic hinge line of the craton beneath the Cedar Hills and the possibility of a Jurassic rift zone.

The Sevier and Laramide orogenies and the basin and range faulting have had a distinct influence on the structural and stratigraphic expressions of central Utah.

INTRODUCTION

The purpose of this study is to map the northwest quarter of the Moroni, Utah, 15-minute quadrangle and to provide information on the stratigraphy and geologic structure of the area. The area lies within the overthrust belt of central Utah and encompasses most of the southern part of the Cedar Hills of northern Sanpete County (fig. 1). The Cedar Hills are 96.5 km south of Provo, Utah, situated between the Wasatch Plateau to the east and the Gunnison Plateau (San Pitch Mountains) and Wasatch Mountains to the west. The Sanpete Valley is south of the area. The Cedar Hills, as defined by Schoff (1937), are approximately 48 km long and have a maximum width of 25 km.

The acquisition of new data allows for new interpretations of the geologic history of central Utah. These interpretations are based on regional tectonic studies by numerous investigators. The regional studies provide insight into the geologic setting of the tectonic hinge line, but when such a small area is involved, the need arises to separate reality from the far-reaching conclusions drawn from a plate tectonic model.

PREVIOUS WORK

For years central Utah has attracted the attention of geologists, but in early reports the Cedar Hills received only brief treatment. The Wheeler Survey (1875) referred to this area as extrusive igneous rocks. Dutton (1880) called it a "medley of low hills." Richardson (1907), while doing a groundwater survey of the Sanpete and Sevier Valleys, produced a general reconnaissance map but did not discuss the Cedar Hills. Regional geologic analyses of the southern Wasatch Mountains have been done by Eardley (1933, 1934) and Hintze (1962). Spieker (1946, 1949) and Spieker and Reeside (1925) have done detailed work in specific areas.

Schoff (1937, 1951) studied the Cedar Hills in detail. Studies of areas adjacent to the Cedar Hills include Harris (1953) in the Birdseye Quadrangle; Khin (1956), Mase (1957), and Runyon (1976) in the Indianola Quadrangle; Pinnell (1972) in the Thistle Quadrangle; Young (1976) in the Billies Mountain Quadrangle; Hunt (1950) worked in the northern Gunnison Plateau; McGookey (1960) in central Utah; Gilliland (1949) in the Gunnison Quadrangle; and Hardy (1952) in the Sevier Valley.

With the use of more adequate topographic base maps and aerial photographs, together with increased information from recently drilled petroleum exploration wells, it was possible to examine this part of the Cedar Hills in detail. Well data, with newly acquired geophysical data, allow for a better interpretation of the geology of the study area.

ACKNOWLEDGMENTS

I would like to express my appreciation to Professors James L. Baer, who served as thesis chairman, J. Keith Rigby, a committee member, Harold J. Bissell, Lehi F. Hintze, and Jess R. Bushman for their suggestions, assistance, and encouragement. R. Brigham Young was very helpful with the Landsat and ERTS imagery. H. W. Peace II of the Union Oil Company of California in Casper was kind enough to provide data from

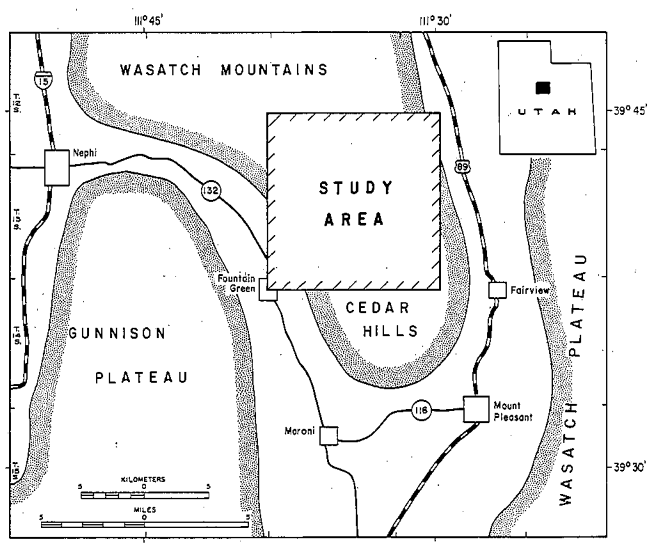

FIGURE 1.—Index map.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, December 1979. Thesis chairman: James L. Baer.

Union Oil's well at Indianola. The Stan Simmons family of Manti, Utah, were very gracious in allowing me to stay in their home while I was doing fieldwork. Randy Chamberlain and Steve Sperry provided stimulating discussions and encouragement. Financial assistance received from Amoco Production Company and Cities Service Company is gratefully appreciated.

GEOLOGIC SETTING

Eocambrian to Jurassic

The Cordilleran miogeosyncline existed from Eocambrian to Triassic at the western edge of the craton in what is now western Utah and southeastern Nevada. According to Armstrong (1968a), the stratigraphy during this time in the eastern Great Basin was relatively simple with the miogeosynclinal rocks subsequently thrust over rocks that represent the thin shelf facies of the craton. Except for some local disturbances, the Cordilleran miogeosyncline was relatively stable from the Eocambrian to the Triassic, with resultant sedimentation of predominantly clean carbonates and sandstones.

Rocks of Triassic or earliest Jurassic age were the last deposits in the Cordilleran miogeosyncline (Armstrong 1968b). Prior to this time, sediment transport had been from the east and southeast from the craton.

Marine waters invaded from the north during the Jurassic, and the area may have contained some enclosed basins and tidal flat environments in which were deposited the mud and salt of the Arapien Shale and the silt of the Twist Gulch Formation (Runyon 1976). Hintze (1973) noted that, because of the plasticity and mobility of the Jurassic salt and gypsum, the depositional thickness is not known. It is likely many of the structural features of Sanpete Valley may have resulted from movement of the evaporites.

Jurassic to Cretaceous

As noted by Runyon (1976), the Nevadan orogeny in the Early to Middle Jurassic produced a gradual shift to the west in the depositional pattern which marked the beginning of the orogenic history of this area. The Sevier orogenic belt, as defined by Armstrong (1968a), was a highland in the miogeosyncline from which a fluviatile system was built from west to east. From the Upper Jurassic to the Lower Cretaceous, continental clastic deposits derived from this western highland spread across the eastern edge of the Paleozoic miogeosyncline and the Colorado Plateau.

Armstrong (1968a) observed that the Sevier orogeny was not a single event but a series of pulses which occurred from Late Jurassic to Early Cretaceous. McGookey and others (1972) noted, on a regional scale, that the Sevier orogenic belt extended from Nevada to Alaska. It had a transition in tectonic pattern from the Late Jurassic to Early Cretaceous intense overthrusting and mountain building in the Cordilleran miogeosyncline, to the Eocene continuous pulses of localized thrusting along the miogeosyncline-craton boundary. These eastward migrating pulses produced a clastic wedge on the western flank of a mobile foredeep, with part of the material being recycled into a multigeneration clastic wedge (Armstrong 1968a). He observed that this orogenic belt was the source for the fragments of Eocambrian and Paleozoic quartzite and carbonate clasts derived from the Cordilleran miogeosyncline.

Hintze (1973) visualized that by the Early Cretaceous the Sevier orogenic belt was characterized by compressional folds and overthrusts which were moving thick miogeosynclinal sections onto the thin sedimentary rocks of the craton. The rapid sedimentation east of the orogenic highland led to the creation of the Cretaceous Rocky Mountain geosyncline (Dietz 1972) and brought an end to the Cordilleran geosyncline.

Armstrong (1968a) noted that Eocambrian rocks occur almost exclusively in the sole of the thrusts, as do those in the eastern Canadian Rockies. The major thrusts appear to flatten out at depth in the Eocambrian quartzite-shale sequence. He accounted for the gravity sliding to be thin allochthonous blocks, 1 to 3 km thick and generally unmetamorphosed at their bases. Listric faults, older fault planes folded by the younger structurally lower faults, also support the idea of gravity sliding (Runyon 1976).

Crustal shortening has been discussed by several investigators, and most agree that the regional average for the Sevier orogenic belt is on the order of 65 to 95 km although in the Mt. Nebo area, northwest of the Cedar Hills, the estimate is more on the order of 15 to 25 km (Hintze 1962).

Runyon (1976) noted that this orogenic belt was approximately 150 to 250 km wide and contained several localized structural styles. These may have resulted from different rates of uplift as well as from local disturbances of different ages.

Cretaceous to Eocene

The Laramide orogeny overlapped the Sevier orogeny although its structural style was significantly different. The Laramide orogeny began in the Late Cretaceous and continued through the Eocene. It was characterized by vertical uplifts that formed the present-day Rocky Mountains. It extended from Mexico to Canada east of the Sevier highland and brought an end to the Rocky Mountain geosyncline. During this time two large freshwater lakes dominated central and eastern Utah, the Paleocene Lake Flagstaff and the Eocene Lake Green River (Hintze 1973).

Oligocene

In the Oligocene, silicic volcanism dominated the landscape, with centers in the Bingham and Tintic districts, as well as in several localities in southwestern Utah (Hintze 1973). This volcanism serves as a useful reference because it predates basin and range block faulting and postdates the Sevier and Laramide orogenies (Hintze 1973). The block faulting and volcanism are believed to be associated with extension or rifting due to changes in the West Coast plate tectonic relationships (Atwater 1970). Morris (1957) believes the vents located in the Tintic mining district could be a source for the volcanic rock of central Utah. Young (1976) recognized hot water vents in the Thistle area, which indicate a possible more northern source for the Tertiary volcanics of central Utah.

Miocene to Recent

The basin and range structure is a result of tension which began in the Early Miocene and continues to the present. It resulted in a system of steep normal faults that produced horsts and grabens oriented north-south. Eardley (1963) noted that the explosive silicic volcanism of the Oligocene changed to dominantly basaltic extrusive flows in the Miocene.

The last major tectonic event was the regional uplift of the eastern Great Basin and adjacent areas, producing the Colorado Plateau and its spectacular scenery.

Present-Day Setting

The Cedar Hills (fig. 1) lie in a unique physiographic position, according to Fenneman (1931), with the Colorado

Plateau Province to the east, the Basin and Range Province to the west, and the southern Central Rocky Mountain Province to the north. Dietz (1972) indicated that two geosynclines have existed in or near the Cedar Hills, the Cordilleran and Rocky Mountain geosynclines.

Moulton (1976) discussed the existence of the Middle Jurassic Sanpete-Sevier rift, a downwarp filled with a sequence of evaporites, carbonates, and shale and thin sandstone in the Carmel-Arapien Formations. He indicated that the Cedar Hills lie in this rift and that the salt may be more than 2,440 m thick in some areas.

Topography of the Cedar Hills ranges from flat, cultivated valleys to pasture land and low rolling hills with scattered cedar trees to forested slopes and basalt-capped cliffs. The elevation ranges from 1,081 m near Fountain Green to 2,513 m in the north central part. Topography is controlled by normal faults, collapsed salt diapirs, and Tertiary volcanic rocks, all affected by several large landslides.

STRATIGRAPHY

Beginning with the Late Cretaceous, when the Cedar Hills area was removed from any marine influence, it was subjected to continental orogenic and sedimentary processes. It is the continental sediments (fig. 2) which indicate the recurrent effects of the Sevier and Laramide orogenies in central Utah. The result is a sedimentary system dominated by continental clastics, fluvial and lacustrine environments, and subaerial erosion—a system which produced numerous lateral facies changes with transitional and gradational boundaries. Confusion frequently occurs in distinguishing one formation from another on the

QUATERNARY		Alluvium	?	*Landslide debris, colluvium, soil and valley fill.*
TERTIARY	PLIOCENE	Stream Gravels	?	*Red, purple, green, olive green, brown, pink, white, banded red and purple and banded tan and gray-green quartzite pebbles, cobbles and boulders.*
TERTIARY	MIO-OLIG.	Volcanics (*unnamed*)	655 m	*Volcanic conglomerate; volcanic ash; tuff breccia; red and black welded tuff.*
TERTIARY	EOCENE	Green River Formation	107-214 m	*Basal-massive, white limestone with quartzite and dark gray limestone pebbles; ostracods; thin-bedded gray micrite.*
TERTIARY	EOCENE	Colton Formation	177 m	*Red sandstone and conglomerate; pebbles are quartzite and gray limestone*
TERTIARY	PALEOCENE	Flagstaff Formation	229 m (?)	*Yellow-buff, massively bedded, fresh-water limestone with pink and white quartzite pebbles. Hard, dense, gray limestone; medium to coarse grained, thin to massive bedded calcareous gray sandstone*
CRETACEOUS		North Horn Formation	1281-2043 m	*Red or yellowish brown conglomerate with quartzite (white), sandstone (brown, red or gray) and dark gray limestone pebbles*

~~FIGURE 2.—Stratigraphic column of rocks exposed in study area. Thicknesses from Schoff and Cooper.~~

basis of color and rock type alone. Lack of fossils makes age determination difficult, and, when found, they are frequently useful only for determining the depositional environment.

The quality of the exposures depends on the lithic character of the unit being examined. Volcanic rocks have the best exposures since they are the youngest and are more resistant to weathering. The North Horn, Flagstaff, Colton, and Green River Formations produce very poor exposures and are commonly badly brecciated in the landslides. Because the landslide debris produces a thick soil, vegetation is copious, especially on the east- and north-facing slopes. Figure 3 is a bedrock geologic map and will assist the reader in understanding the interpreted bedrock relationships in spite of the poor exposures.

Cretaceous-Tertiary

North Horn Formation

The North Horn Formation of central Utah was originally included in the Wasatch Formation as the lowest member (Spieker and Reeside 1925, p. 448). Spieker (1946, p. 132) later raised it to formational rank when dinosaur and Paleocene mammals were discovered in it. The type section for the North Horn Formation is on North Horn Mountain east of Manti, Utah, on the Wasatch Plateau (Spieker 1946). He described four main units consisting mostly of variegated shale with sandstone, conglomerate, and some freshwater limestones. The type section is 500 m thick and represents alternating fluviatile and lacustrine conditions.

Spieker (1946, p. 135) correlated the North Horn Formation with the Lance and Fort Union Formations of Wyoming and the Ojo Alamo, Puerco, and Torrejon Formations of the San Juan Basin of Colorado and New Mexico. The transition from Cretaceous to Paleocene occurs within this strata. He also pointed out that the boundary between Cretaceous and Paleocene cannot be mapped because no physical basis for regional subdivision of the North Horn Formation has been recognized.

In the study area Schoff (1951, p. 629) mapped the North Horn Formation in the Hop Creek drainage along the south ridge. He described the lithology as varied, with coarse to fine, gray and white through brown, pink, and red sandstones and conglomerates; red and gray shales; and dense and hard, gray or pink limestone, some of which is algal or sandy.

In the present study area the North Horn Formation was seen in the northwest corner along a ridge which strikes southwest-northeast and forms the southern ridge of Hop Creek. On the north side of this ridge landslide debris produces hummocky slopes that are heavily vegetated. Beds on the south side of the ridge, overlooking Water Hollow, dip approximately 52° to the southeast. Exposures are poor because of vegetation and slumping or sliding. To the west in the Phillips Petroleum Nelson-Sieger #1 well (section 1, T. 13 S, R. 2 E) approximately 451 m of North Horn beds were logged. Other well data in the Moroni area shows that the North Horn Formation has thinned southward to 233–263 m thick.

On the ridge on the north side of Water Hollow numerous slumps and slides have disturbed the bedding and mixed the red North Horn sediments with the overlying white to buff Flagstaff Formation. The topography is very irregular and hummocky, which is typical of sliding and slumping. As a result outcrops are brecciated with irregular orientation, making attitudes difficult to determine and of questionable value.

The North Horn Formation in the area is red or yellowish brown conglomerate (fig. 4) with pebbles of white quartzite; of brown, pink, and gray sandstone; and a few of dark gray limestone. The soil is red or brown. The clasts vary in size up to approximately 5 cm. Exposures seen in the area under investigation (fig. 5) are conglomeratic although Schoff (1951) described some limestone, sandstone, and shale units to the north. In the Phillips Nelson-Sieger #1 well the upper 220 m are predominantly a white to gray or pink sandstone and conglomerate. The lower unit of about 259 m is a light gray to black shale with some coal beds and a few sandstone units. No thicknesses were determined because of the poor exposures and vegetation cover although farther north Schoff (1951) noted that the thickness of the North Horn Formation ranges between 1,281 and 2,044 m.

Tertiary

Flagstaff Formation

The Flagstaff Formation was originally defined by Spieker and Reeside (1925, p. 448) as the "Flagstaff limestone member of the Wasatch Formation." It is a freshwater, white limestone which consistently appears between units previously called "upper and lower members of the Wasatch Formation." Later Spieker (1946, p. 135–6) raised it to formation rank and called it the Flagstaff Limestone.

Other writers from different localities have noted a vastly different lithology. Gilliland (1949, p. 70) reported a considerable amount of sandstone and conglomerate in the Gunnison

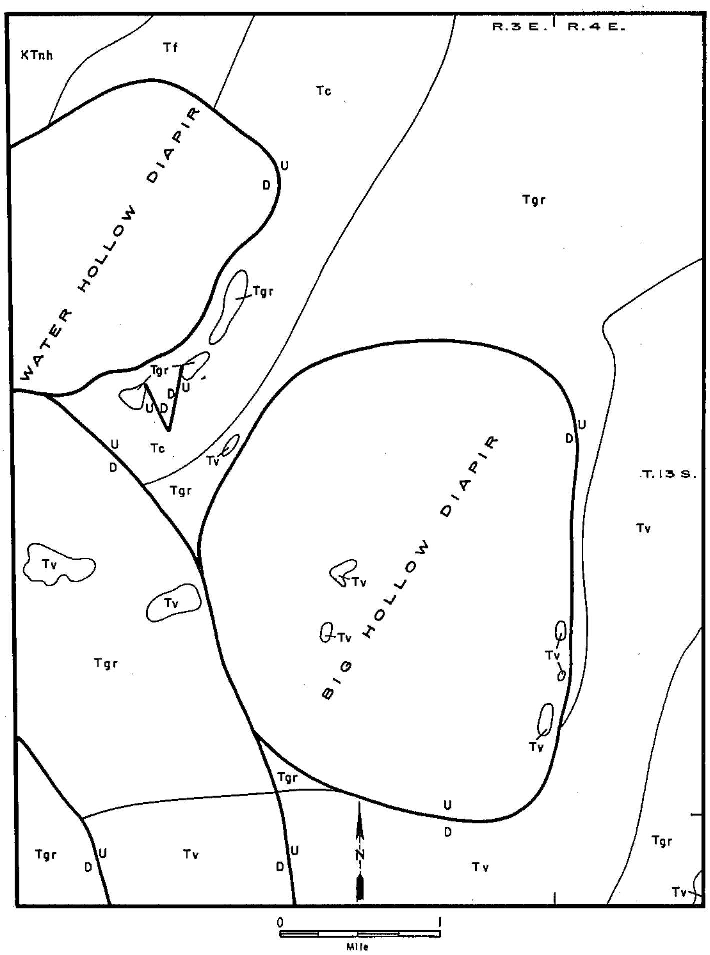

FIGURE 3.–Bedrock geology map with alluvium, stream gravels, and landslide material removed.

Plateau. Gilliland substituted the term *formation* because he felt the term *limestone* inappropriate. Stolle (1978) reported a similar lithology in the Canyon Range, southwest of Levan, Utah. McGookey (1960, p. 595) and LaRocque (1951, 1960) also employed the term *formation* rather than the term *limestone*. Runyon (1976, p. 72) applied the name Flagstaff Formation in the Indianola Quadrangle, and the same nomenclature is used in this study because of the dominantly clastic nature of the exposures.

In the type section at Flagstaff Peak on the southern Wasatch Plateau, the Flagstaff Limestone is a white to buff weathering, lacustrine limestone with interbedded, gray, calcareous shales.

Schoff (1951, p. 631) described the Flagstaff Formation in the Cedar Hills as a succession of light gray and white strata, including some limestone, which overlies the North Horn Formation. These outcrops are in the northwest corner of the study area and in Water Hollow. Schoff (1951) noted that this unit is in the same stratigraphic position as the Flagstaff Limestone on the Wasatch Plateau but here contains more clastic material. The only exposures of the Flagstaff Formation in the study area are located along the northeast-southwest striking ridge on the north side of Water Hollow. These beds dip 56° to the southeast (fig. 6). Poor exposures and vegetation make thickness determination impractical. Along this ridge the exposure is approximately 15.3 m wide before it is disrupted by slides and slumps in Water Hollow.

The Flagstaff Formation as mapped by Schoff (1937, 1951) in Water Hollow is the result of collapse of the units above a diapir and the subsequent sliding and slumping of the surrounding sides of the diapir. The result has been a mixing of Flagstaff and North Horn rocks in the northwest part of Water Hollow and a mixing of the Flagstaff and Colton rocks in the eastern and southern areas of Water Hollow.

The exposures of the Flagstaff Formation in Water Hollow are brecciated, with random bedding making it difficult to obtain meaningful dips and strikes. On the north ridge of Water Hollow the Flagstaff Formation is a yellowish buff, massively bedded, freshwater limestone containing pink and white quartzite pebbles. In the slide areas of Water Hollow, the Flagstaff Formation varies from a hard, dense, gray limestone to a medium- to coarse-grained, thin- to massive-bedded, calcareous, gray sandstone. The Flagstaff Formation in the Phillips Nelson-Sieger #1 well, 1.6 km west of the study area is a light gray to tan, dense limestone with some gray to white sandstone beds. The upper part contains chert and quartzite fragments in the limestone.

Schoff (1951) described the Flagstaff Formation as also present in the southwest corner of Big Hollow, as a result of a fault. These rocks are mapped is the Green River Formation and their stratigraphic position is above the Colton Formation. The fault mapped by Schoff is associated with the boundary fault of the Big Hollow diapir.

The thickness of the Flagstaff Formation in Water Hollow was indicated by Schoff as being about 229 m, with the total thickness unknown because of a fault cutting the beds. The thickness was not determined in this study because the sliding and slumping have so altered the area as to prevent the obtaining of a valid thickness. The fault noted by Schoff is one of several possible faults associated with the diapir. To the south in several wells drilled in the Moroni area, the Flagstaff Formation ranges from 61 to 122 m thick. The Flagstaff Formation is approximately 198 m thick in the Phillips Nelson-Sieger #1 well to the west.

Schoff (1951, p. 632) noted that the Flagstaff Formation of the Cedar Hills is thought to correlate with the Flagstaff Limestone of the Wasatch Plateau. Spieker (1946) considered the Flagstaff Formation to be Late Paleocene or Early Eocene age,

FIGURE 5.–Exposure of steeply dipping North Horn Formation.

FIGURE 4.–North Horn Formation: yellowish brown conglomerate with quartzite and dark limestone pebbles.

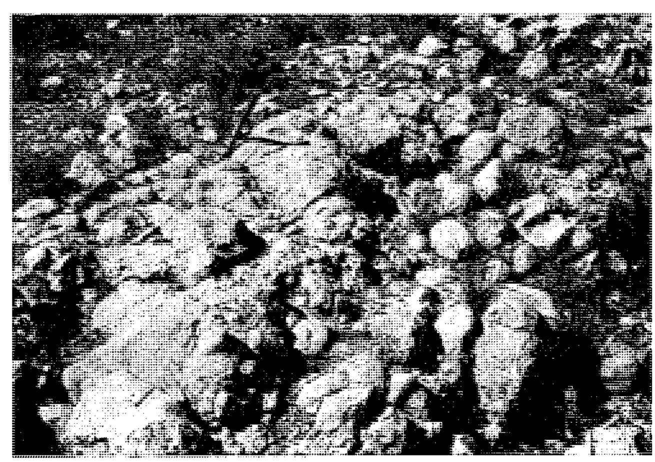

FIGURE 6.–Steeply dipping (parallel to hammer) Flagstaff Formation on north side of Water Hollow.

with no great lapse of time between deposition of the North Horn and Flagstaff Formations.

Colton Formation

Spieker (1946, p. 120–21, 137–39) applied the term Colton Formation to what was called the upper member of the Wasatch Formation of central Utah. The type section is located north of Colton, Utah, in Price Canyon, and lies between the Flagstaff and Green River Formations. In the type locality the contacts are clearly defined, and the Colton Formation is a "gray, pepper-and-salt sandstone, greenish-buff sandstone, and siltstone that weathers golden brown, and shale ranging from deep red to variegated and gray in color" (Spieker 1946).

The Colton Formation is irregular and discontinuous in outcrop, and Spieker (1946) indicated that it represents a fluvial environment while the enclosing Flagstaff and Green River Formations represent a lacustrine environment. To the west of the type section the Colton Formation grades into Green River-type rocks. Such a gradation appears to be a regional characteristic.

The thickness of the Colton Formation is uncertain because of erosion and the exposed base. Davis (1967, p. 25) indicated that Colton beds are absent in an extensive area from Indianola along the northeast-trending Diamond Fork Anticline in Spanish Fork Canyon

Schoff (1951) reported the Colton Formation from the study area along the Big Hollow–Water Hollow divide where it consists of red strata, nine-tenths of which are variegated shale and the rest, sandstone and conglomerate. It has a thickness of about 177 m. He noted that the contact is conformable on the Flagstaff Formation and that, because of intervening alluvium and pyroclastic rocks, correlation with the type section was based on lithology and stratigraphic position.

The thickness of the Colton Formation may be greater than originally noted by Schoff (1951) because slides and slumps have disrupted the bedding. Along the Big Hollow–Water Hollow divide the base of the formation is concealed by the slide material, although the upper part is exposed. The dip of the Colton Formation along this face is about 10° to the southeast. The rocks are dominantly a red sandstone and conglomerate. The conglomerate beds (fig. 7) contain pebbles, cobbles, and boulders of quartzite, up to 25 cm in diameter, and pebbles of dark gray limestone. The matrix is a gray or red, medium- to coarse-grained sandstone. The few shale beds seen are usually red although some are gray or greenish gray.

In the wells drilled around Moroni, the Colton ranges from 106.8 to 213.5 m. The difficulty with using these well thicknesses is that different individuals have recorded the information and used varying criteria for establishing the boundaries.

The southwestern extent of the Colton Formation is defined by a fault-line escarpment (section 7, T. 13 S, R. 3 E) which has elevated the Colton beds. This fault appears to be related to an overall arcuate pattern which extends from just north of Moroni to Salt Creek Canyon. This pattern may represent a large slump block which has slid into the Sanpete Valley. North of the Big Hollow–Water Hollow divide, the Colton Formation is poorly exposed and heavily vegetated, and landslides have formed on the east and west side.

To the northeast, in Uinta Gulch the Colton Formation mapped by Fograscher (1956) is found in landslide deposits and is mixed with Green River rocks. Along the east side of Big Hollow he mapped a fault contact between the Colton and Green River beds, which extends into Uinta Gulch. This fault follows the present road from section 13 to section 1 (T. 13 S, R. 3 E) before turning northeast into Uinta Gulch. In the present study no fault was recognized in this area because of the landslide debris. The Colton beds are slide material from the west which has been mixed with the Green River sediments. The collapse of the Big Hollow diapir has produced slumps of Colton sediments along the northwest and northern side of Big Hollow, which have mixed with debris from the overlying Green River Formation, as well as with some of the Tertiary volcanic rocks and Tertiary-Quaternary stream gravels.

Spieker (1949, p. 34) considers the Colton Formation to be Eocene since no Paleocene fossils have been found. Peterson (1976) indicates the Colton Formation is a small, freshwater deltaic sequence which developed in Lake Flagstaff during late Paleocene and early Eocene.

Green River Formation

The Green River Formation was named by Hayden (1869, p. 90) from exposures near Green River, Wyoming. It was deposited in two basins, separated by the Uinta Mountains. The basin to the north includes the oil shale deposits of Goshiute Lake (King 1878) of southwestern Wyoming. The southern basin of Utah and Colorado in which Uinta Lake (Bradley 1930, p. 88) was located demonstrated lithologies from environments of higher energy. As a result the study area includes more clastic sediment than the northern basin.

Runyon (1976) noted that in the Indianola Quadrangle the formation is characterized by numerous conglomerate units 6 to 9 m thick. The clasts are predominantly pink and white quartzites with some dark limestones. Streams in the Indianola area demonstrated tremendous carrying capacity in draining the highlands immediately adjacent to the basin (Mase 1957, p. 40). In areas adjacent to the town of Indianola, where the Green River Formation is present, it is in contact with either the Flagstaff or the Colton Formation (Runyon 1976). The contact is gradational and represents a change in environment from the fluvial Colton to the lacustrine Green River Formation. According to Fograscher (1956, p. 25) the nature of the contact with the overlying Crazy Hollow Formation is not exposed. The Crazy Hollow Formation was not seen in the present study. He also noted that a disconformity is visible elsewhere in the Sanpete-Sevier Valleys when the contact is exposed.

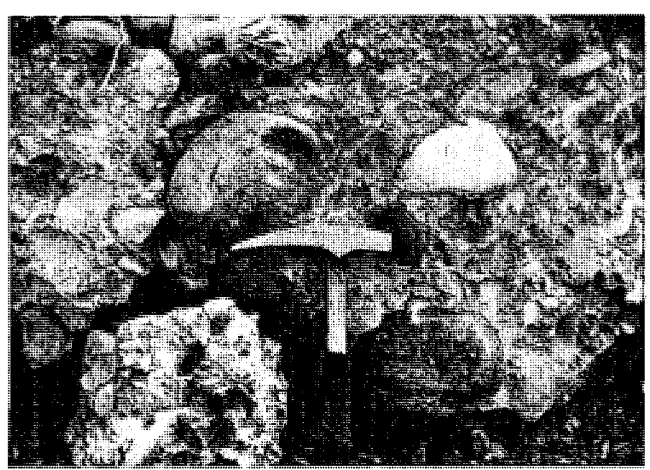

FIGURE 7.–Conglomerate from Colton Formation with clasts of quartzite and dark gray limestone.

In the study area Schoff (1951) reported the Green River Formation to underlie the Big Hollow and Uinta Gulch, with a small outlier capping the Big Hollow–Water Hollow divide. Here the preserved thickness of the Green River beds was reported to be only 52 m. This thickness is not representative because of erosion.

In the current study outcrops of the Green River Formation were found in the Big Hollow and Uinta Gulch areas. Exposures in Big Hollow have been subjected to landslides and slumps. On the Big Hollow–Water Hollow divide three small outliers of Green River beds, approximately 49 m thick, were seen. The contact is gradational with the underlying Colton beds. The beds dip 14° to the southeast.

In the southwestern part of Big Hollow there are a few outcrops of Green River beds, but they are brecciated and covered by slump material. The distinguishing feature is the white color of the soil which can be seen all around Big Hollow. In Big Hollow the Green River Formation has been largely affected by collapse and subsequent slumping. Along the east side of Big Hollow the few outcrops of undisturbed Green River rocks have a dip of 6° to the southeast.

To the north in the Uinta Gulch area, the Green River appears to have been subjected to some slumping, which suggests a possible collapse feature to the northeast. The beds dip 4° to 8° to the southeast in the area north of Uinta Gulch. This area has been subjected to landslides which have involved the Colton Formation from the ridge to the west and the Green River Formation, mixing the red Colton debris with the white to greenish-gray Green River debris. On the Big Hollow–Water Hollow divide the basal Green River Formation is a massive, white limestone with pebbles of quartzite and dark gray limestone. Along the road from Big Hollow to Uinta Gulch, section 12, T. 13 S, R. 3 E, is a massive white ledge of Green River beds (fig. 8) about 9 m thick, which contains quartzite clasts.

Along the east side of Big Hollow the Green River Formation is frequently covered by Tertiary volcanic rocks and Tertiary-Quaternary stream gravels. In sections 14, 15, 22, 23, 26, and 27, in T. 13 S, R. 3 E is a large tongue of debris approximately 4 km long (fig. 9) of intermixed Green River beds and volcanic rocks in the southern part, and a mixture of Colton and Green River debris to the north. The source area is to the northwest on the Big Hollow–Water Hollow divide. The slide may have developed when the oversteepened sides of the depression were saturated, resulting in a debris flow or slurry. It is not uncommon to see small outcrops of volcanic rocks which are generally at the higher elevations exposed in Big Hollow on a debris flow. The volcanic rock outcrops composed of the welded tuff generally have remained a single unit and are not brecciated.

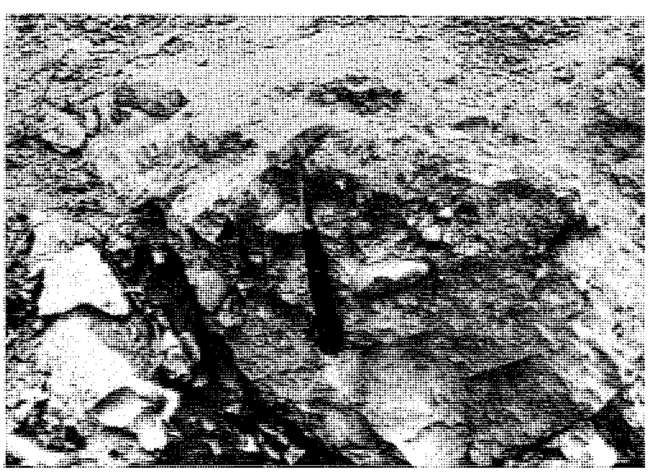

FIGURE 8.–Quartzite pebbles and cobbles in Green River Formation along Big Hollow–Uinta Gulch divide.

The Green River Formation is thought to be Middle Eocene in age, although Spieker (Schoff 1951) considered the Green River-type rocks of central Utah to range in age from Late Paleocene to Middle Eocene.

Tertiary Volcanic Rocks

The volcanic rocks of the Cedar Hills represent a drastic change in the geologic history of the area. During the Oligocene large quantities of pyroclastic volcanic rocks were extruded from several vents. Hintze (1973) reported volcanic centers in the Tintic, Crystal Peak, Marysvale, and Little Cottonwood areas and in the Needle Range. He indicated these were generally silicic and intermediate types (rhyolite-andesite-dacite) and were extruded as ash falls, tuffs, and latite flows. Runyon (1976) noted that in many cases the volcanic rocks have filled valleys in the Oligocene topography. In the Indianola Quadrangle these volcanic rocks do not occupy their original depositional site but have been eroded and redeposited by streams (Runyon 1976). He also noted a crude bedding and, in some cases, even cross-bedding, with several of the units consisting of clasts up to 40 cm in diameter. This material was unconsolidated, commonly containing algal balls mixed with unsorted matrix.

Hintze (1973, p. 83) considered the volcanic rocks to be a valuable reference datum because they postdate the Sevier and Laramide orogenies and predate the basin and range block faulting. In the Little Clear Creek area of the Indianola Quadrangle, Runyon (1976, p. 74) indicated the volcanic rocks help date recurrent movement of an adjacent diapir.

The source of the volcanic rocks is unknown although various authors have suggested several source areas. Morris (1957) and Hintze (1973) suggested the Tintic area. A. A. Baker (in Schoff 1951) indicated that the volcanic rocks of the Cedar Hills may have come from vents in the Strawberry Valley, but Schoff rules this possibility out because the largest boulders reported by Baker are smaller than some of those seen in the Cedar Hills. Khin (1956, p. 104) did some petrographic work on the volcanic rocks near Little Clear Creek in the Indianola Quadrangle and speculated on a possible source area in Park City. Young (1976) indicated that the Wanrhodes Basin at the head of Wanrhodes Canyon, northwest of Thistle, Utah, may be a volcanic caldera and the source of some of the volcanic rocks of central Utah. Runyon (1976) indicated that in the Oligocene the net effective transportation of sediment was east and south. It is possible the Wanrhodes Canyon Caldera is the source of the volcanic rocks of the Cedar Hills.

Spieker (1949, p. 38) merely guessed at the age of the volcanic rocks of central Utah as being mid-Tertiary. Schoff (1951) considered a range of Late Eocene to Quaternary for the volcanic rocks of the Cedar Hills. Runyon (1976) reported the age dates range from Eocene to Miocene. Most writers believe them to be Oligocene.

Schoff (1937, p. 105) originally called the Tertiary volcanic rocks the Moroni Formation but later (1951, p. 634) abandoned that name and merely referred to them as "pyroclastic rocks." He described them as varied pyroclastic rocks, believed to be primarily water laid, consisting of a metamorphosed tuff, breccia, volcanic conglomerate (fig. 10), green sandstones, and conglomerates with a maximum thickness of about 457 m. Schoff reported the metamorphism was due to a sill, but that the Moroni Formation did not include the sill. Cooper (1956) did not describe the tuff as being metamorphosed and indicated that the sill mentioned by Schoff is a unit of welded tuff which should be included in the Moroni Formation. Fograscher (1956) described the Moroni Formation in the eastern part of the study area as a dark gray and red brown welded tuff with grains of feldspar and pumice in a black glassy groundmass, all overlying a conglomerate. Schoff (1951) described four distinct units of the Moroni Formation in descending order:

4. tuff breccia
3. tuff
2. volcanic conglomerate
1. green sands, sandstone, and minor conglomerate

In the present study the Tertiary volcanic rocks are preserved in the southern and eastern part of the area. The thickest volcanic rocks appear to be found in the southeast corner. The thickness noted by Schoff is a maximum and may be in actuality less because the volcanic rocks slid and slumped, or they were deposited on a surface of varied relief. The youngest volcanic unit is the black and red welded tuff which is extremely hard and preserves the ridge tops. David Runyon (pers. comm. 1979) indicated there were no welded tuffs in his area. The volcanic rocks he mapped were predominantly volcanic conglomerates. The source area may be related to fissures below these massive units of silicic welded tuff. When the welded tuffs are involved in the sliding or the slumping (fig. 11), they retain their competency and will preserve the slide feature. In Big Hollow there are several outliers of volcanic rocks which have been brought down by the debris flows or are a result of collapse. These outcrops may be solid units of welded tuff which produce a sharp topographic change from the surrounding units, or they may be rounded hills with volcanic boulders on top.

As indicated earlier, a number of authors have speculated on the source area of the volcanic rocks. The welded tuffs demonstrate no flow structure, and the massiveness of the exposures along the east side of Big Hollow and their homogeneity perhaps indicate a nearby source from fissure eruptions. David Runyon (pers. comm. 1979) indicated the mobility of salt is associated with the temperature and suggested the possibility of the diapirism being related to the heat from the volcanics. Further study is needed to determine the origin of the volcanic rocks.

Tertiary Quaternary

The present topography of the Cedar Hills is produced by valley fill, alluvium, landslide debris, and the continuing uplift of the surrounding plateaus.

Stream Gravels

Stream gravels of quartzite pebbles, cobbles, boulders, and a small number of dark gray limestone pebbles were found throughout the study area. The quartzites range from red, purple, green, olive green, tan, brown, pink, and white to banded red and purple and banded tan and gray green. Clast size is quite variable, ranging from gravel and small pebbles to boulders (fig. 12) 1.2 m across.

The stream gravels have been affected by the collapse of the diapir and are frequently involved in the landsliding. There are a few hills which appear to be actual depositional features, but, for the most part, the stream gravels frequently have a steplike, terrace appearance (fig. 13). This feature is most common along the southern side of Big Hollow where the volcanic rocks form the topographic high points. The gravels have covered any indication of faults of the diapir but the steplike, hummocky appearance is common throughout the study area, especially where gravels are involved.

In the southwest corner of the quadrangle near Fountain Green, there is a fault contact between the volcanic rocks and the stream gravels. It appears to be the result of movement along a large slump block into the Sanpete Valley.

No thickness was determined for the gravels because of the extensive sliding and slumping.

Harold J. Bissell (pers. comm. 1979) indicated the source of these multicolored quartzite stream gravels is the Canyon Range, 56.4 km to the southwest, where Eocambrian quartzites are exposed. These quartzites were involved in the Sevier thrusting and are presently visible because of basin and range block faulting.

Landslides

Big Hollow (fig. 14) and Water Hollow (fig. 15) are oval-shaped depressions. Big Hollow is approximately 7.2 km in a north-south direction and 5.6 km in an east-west direction.

FIGURE 9.–Large landslide mass in Big Hollow involving Green River and Colton debris. Source of slide was from northwest (upper left).

Water Hollow is about 5.6 km in a northeast-southwest direction and 4.0 km in a northwest-southeast direction. Around the sides of these depressions can be seen hummocky topography, disturbed bedding, and irregular strikes and dips. The circular pattern of these depressions can be seen on the conventional aerial photos and the ERTS and Landsat imagery.

During the initial period of fieldwork the extent of landsliding and slumping was not recognized. As a result the phenomenon producing such a feature was not comprehended. Once the extent of the landsliding and the circular pattern emphasized by the depressions was realized, the origin was suggested to be the collapse of salt diapirs.

The possibility that these depressions were of volcanic origin was ruled out because this area is not known for its volcanism although there are some volcanic rocks on the east and south side of Big Hollow. Diapirs have been studied at the mouth of Salt Creek Canyon near Nephi, Utah, and in Chicken Creek Canyon on the west side of the Gunnison Plateau near Levan, Utah. Three small diapirs were studied by Runyon (1976) in the Indianola Quadrangle to the northeast.

Arnold West of the Phillips Petroleum Company (pers. comm. 1979) indicated that their seismic data suggest the presence of a salt diapir in Water Hollow in the position shown in figure 17.

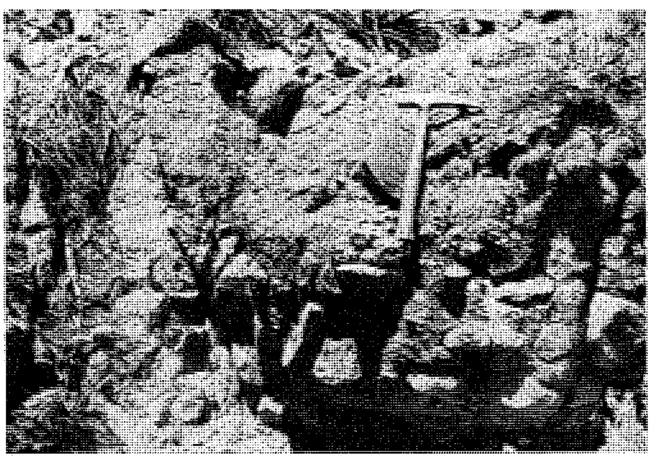

FIGURE 10.–Rounded cobbles of water-laid volcanic conglomerate.

Quaternary

Alluvium

The central parts of Big Hollow and Water Hollow are covered by alluvium to depths of up to 15 m in some areas. The alluvium of Big Hollow is most extensive and allows for irrigated cultivation.

The stream system which drains Big Hollow has done the most extensive erosion in the study area and is still quite active, especially in the northern and northwestern parts of Big Hollow where landslides continue (fig. 16).

The alluvium is predominantly soil, with some rocks. Its great thickness is a result of the landsliding and slumping initiated by the collapse of the diapirs.

STRUCTURE

Faults in the area under investigation are normal faults. They were located by fieldwork, conventional aerial photos, stream drainage patterns, and Landsat and ERTS imagery. The latter was particularly useful in determining regional trends not seen by mapping on a scale of 1:24,000. The large faults in the area are related to diapirism or the slumping associated with the collapse of the diapirs.

From the ERTS imagery a linear feature can be seen which begins just east of Moroni and extends north into the study area in sections 2 and 3, T. 14 S, R 3 E; along the west sides of Big Hollow, including the Big Hollow–Water Hollow divide; and leaves the area in section 27, T. 12 S, R. 3 E, just south of Mt. Baldy. The linear feature continues northward and includes Mt. Baldy and the east side of Spencer Canyon and enters the valley at Pines. It forms the west side of the Big Hollow collapse diapir within the study area and is probably older than the diapir. It may account for the fact that such units as the Green River Formation are present only east of it.

In the southwest corner of the study area are two normal faults that may be associated with sliding or slumping into the Sanpete Valley. The westernmost fault appears to run along the western edge of the Cedar Hills. The result is that the Tertiary-Quarternary stream gravels are in contact with the alluvium on the Sanpete Valley. Stream gravels are in contact with exposures of welded tuff on the ridge in section 5, T. 14 S, R. 3 E. On the ridge to the south the contact is delineated by a saddle. About 2.8 km to the east, in Big Hollow, a parallel fault appears to begin at the north end of Moroni and to extend northward along the west side of the Cedar Hills. The fault enters the present study area in section 3, T. 14 S, R. 3 E in the

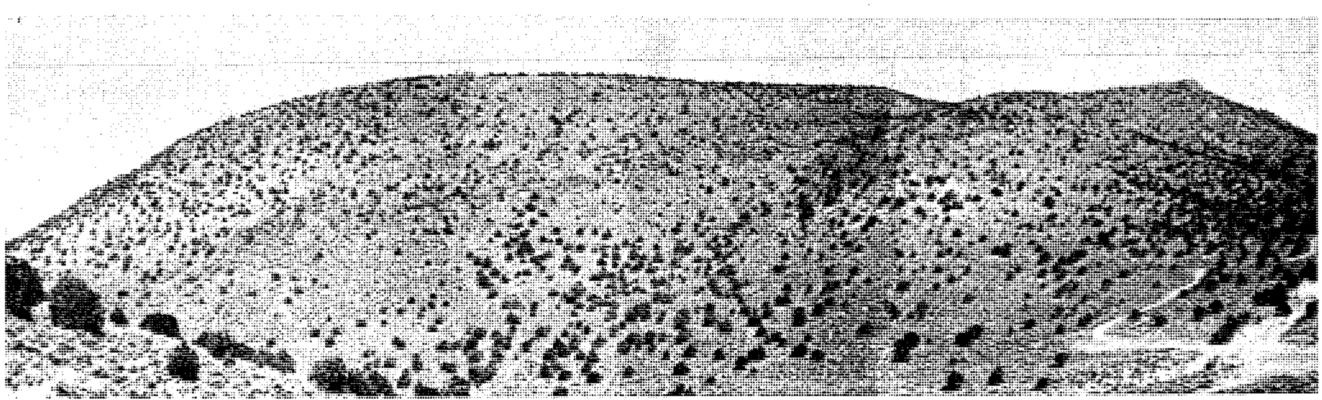

FIGURE 11.–Youngest unit of Tertiary volcanic rocks is black and red welded tuff exposed at top of ridge. Subsequent sliding has produced a series of benches capped by welded tuff at levels A and B.

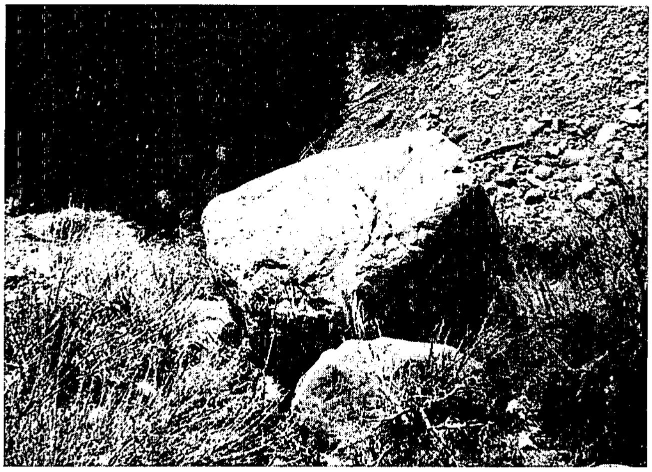

FIGURE 12.—Large pink quartzite boulder of Tintic Quartzite lag from probable Oligocene conglomerate. Boulder is approximately 1.2 m across and found in Wood Hollow.

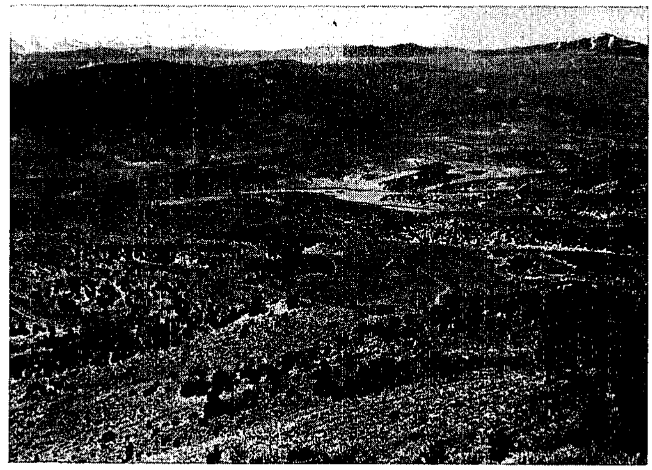

FIGURE 14.—View of Big Hollow looking north. Steplike terraces of stream gravels in foreground and light colored Green River sediments involved in landsliding.

vicinity of the previously mentioned linear feature. This fault also follows the west side of Big Hollow and in section 16, T. 13 S, R. 3 E turns northwestward. There it produces an escarpment of the Colton Formation, and enters Water Hollow at the approximate boundary of the Water Hollow diapir. The fault crosses Water Hollow and leaves the study area. There is a break in the topography as a result of the fault in the area north of Water Hollow. On the northeast side of the fault, the bedding is visible in the rock units. Southwest of the fault the topography has a hummocky appearance, similar to that seen in Big Hollow and Water Hollow. This hummocky, disrupted terrain continues to the northwest and disappears where the fault enters Salt Creek Canyon at the Nebo Loop Road.

Two small normal faults are seen in section 9 and 16, T. 13 S, R. 3 E and form a downdropped wedge within the Colton Formation.

Differential movement of the diapirs has produced a variety of slumps or slides around the edges of the diapirs, and collapse of entire units into the diapirs. These slumps and collapse features obscure the boundary faults of the diapirs, which may be a series of faults. Because of lack of surface exposure, however, only one fault has been mapped. The faults directly associated with the diapirs in Big Hollow and Water Hollow have been mapped as normal faults and are best explained by reference to the map and cross section (fig. 17, A-A'). Faults and contacts are dashed on the map because of poor exposures.

In section 35, T. 13 S, R. 3 E a ridge has a saddle with a contact of volcanic rocks and stream gravels which is visible down the north side until it disappears below the alluvium of Big Hollow. To the south it disappears under the alluvium of Wood Hollow. Because of slumping and sliding, it is not seen on the south side of Wood Hollow. The topographic expression of the volcanic rocks on the ridge indicates this fault may continue to the south. Another possibility is that this fault may be related to the boundary fault of the Big Hollow diapir which passes along the north side of the ridge in section 35.

FIGURE 13.—Series of five steplike terraces (third terrace out of view) involving stream gravels produced by slumping associated with collapse of diapir. Black welded tuff caps ridge.

FIGURE 15.—Aerial view of Water Hollow and large landslide involving Colton and Green River Formations.

Because of differential movement of the diapirs, slumping, and sliding, it is very difficult to accurately determine the displacement along these faults. In some cases the displaced units are not exposed, although there is a possibility of displacement of upwards of 305 m.

From the Landsat and ERTS imagery a series of southwest-northeast arcuate features can be seen. Their origin is not known although they may be related to possible imbricate thrust slices associated with the Nebo Thrust and may influence the placement of the diapirs in this area. These arcuate features are found in Pole Canyon, on the Nebo Loop Road; Hop Creek Canyon; Water Hollow; Serviceberry Hollow; Big Hollow; and Wood Hollow. The author believes they may be part of the key to fully understanding the structure of the area.

TECTONIC HISTORY

The tectonic development of central Utah and, in particular, of the Cedar Hills area (fig. 18), has resulted from the complex interaction of the Cordilleran miogeosyncline, the Nevadan orogeny, the Sevier orogeny, the Flagstaff and Green River lakes, Tertiary volcanism, basin and range uplift, and the sporadic, intermittent ascension and collapse of salt diapirs.

With such an interesting list of geologic events affecting the study area, it is understandable why the geology of the Cedar Hills has been misunderstood and incomplete for so long.

The following outline of the tectonic history is intended as a generalized chronologic review of events which have affected the surficial geology:

1. Eocambrian to Jurassic: Paleozoic deposition in Cordilleran miogeosyncline.
2. Jurassic: Development of Sevier Arch and regional drainage shifts by Nevadan orogeny.
3. Late Jurassic to Early Cretaceous: Sevier orogeny, a major thrust belt from Nevada to Alaska.
4. Middle Cretaceous to Paleocene: Rocky Mountain geosyncline which produced "inverted" stratigraphy shed from Sevier highland to west.
5. Late Cretaceous to Eocene: Laramide orogeny produced by vertical uplifts and minor thrusting resulting in localized gravity sliding. This may have initiated ascension of salt diapirs.

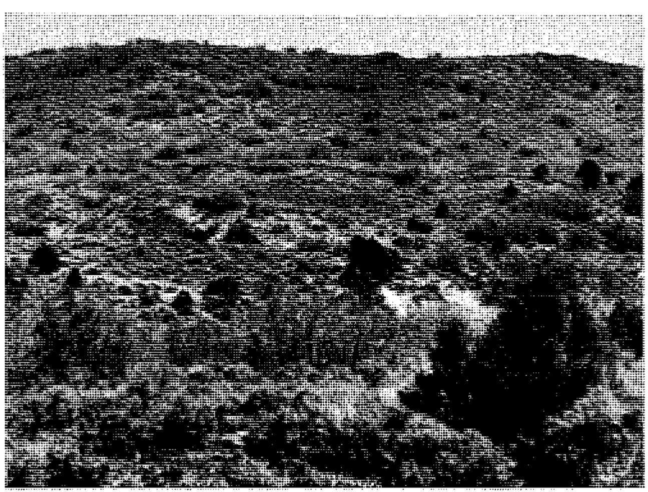

FIGURE 16.—A recent slide in Green River debris in Big Hollow. Tertiary volcanic rocks are on top.

6. Paleocene: Lake Flagstaff in existence during waning stages of Laramide orogeny, probably producing North Horn Formation. Lacustrine sediments of Lake Flagstaff may have been from a series of intermountain lakes rather than a single large body of water. Fluvial sediments of Colton Formation may be the transition area between these lakes.
7. Eocene: Lake Green River in this area, influenced by close proximity of highlands to west, which may account for abundance of coarse clastics in lacustrine sediments.
8. Oligocene to Miocene: Tertiary volcanism produced ash falls, tuff breccias, welded tuffs, and volcanic conglomerates which may have been reworked by streams. Volcanism changes from explosive, silicic type of Oliogocene to basaltic in Miocene.
9. Miocene to Recent: Basin and range block faulting and regional uplift from tensional plate tectonic forces.
10. Jurassic(?) to Recent: Intermittent diapiric movement resulting from faulting, folding, regional uplift, and sediment loading. Collapsed diapirs are produced by solution activity of groundwater. These salt diapirs are possible source areas for evaporites of Great Salt Lake.

ECONOMIC GEOLOGY

The study area has economic resources that could be developed without much interference of ranching and farming. The exception is quarrying of gravel deposits, which would be restricted because of access and limited quantities.

Runyon (1976) noted that an unsuccessful mining operation for bitter halides was undertaken in the Indianola area to the northeast. Such an operation is unlikely in this area because no source of bitter halides is close enough to the surface to be economically feasible.

In other areas of the United States openings in salt domes are used as underground storage facilities for hydrocarbons and radioactive wastes. Although this is a sensitive subject because of the environmental and safety implications, further study of the stability of these diapirs may reveal their potential as a storage facility. In the near future such an investigation may be warranted.

Presently petroleum exploration has the greatest economic potential in the study area because the salt diapirs may provide structural reservoirs for oil and gas. The reservoirs would most likely be in the Upper Jurassic clastic sequence around the diapir with the reservoir created by a combination of stratigraphic and structural traps. For a number of years Christiansen (1963) emphasized the importance of these diapirs in Utah and their economic significance for oil and gas accumulation. During the past few years noncommercial shows have been reported. Runyon (1976) indicated that in the studies by David Kupfer and others on the Louisiana Gulf Coast the rise of low-density evaporites by isostatic adjustment produces an anticline or uplifted dome beneath the diapir which acts as a trap for petroleum.

Isostatic uplift of evaporites in the map area and effects of the tectonics may have combined to form potential traps. A potential source for the hydrocarbons may be in the Paleozoic miogeosynclinal and the Mesozoic sediments. The Jurassic Navajo Sandstone has been found to be an excellent reservoir in other areas of Utah and could be here also. Runyon (1976) noted warm springs near Indianola as a potential heat source for maturation of the hydrocarbons. With the possibility of a nearby heat source due to volcanic activity, an adequate temperature regime may have been established.

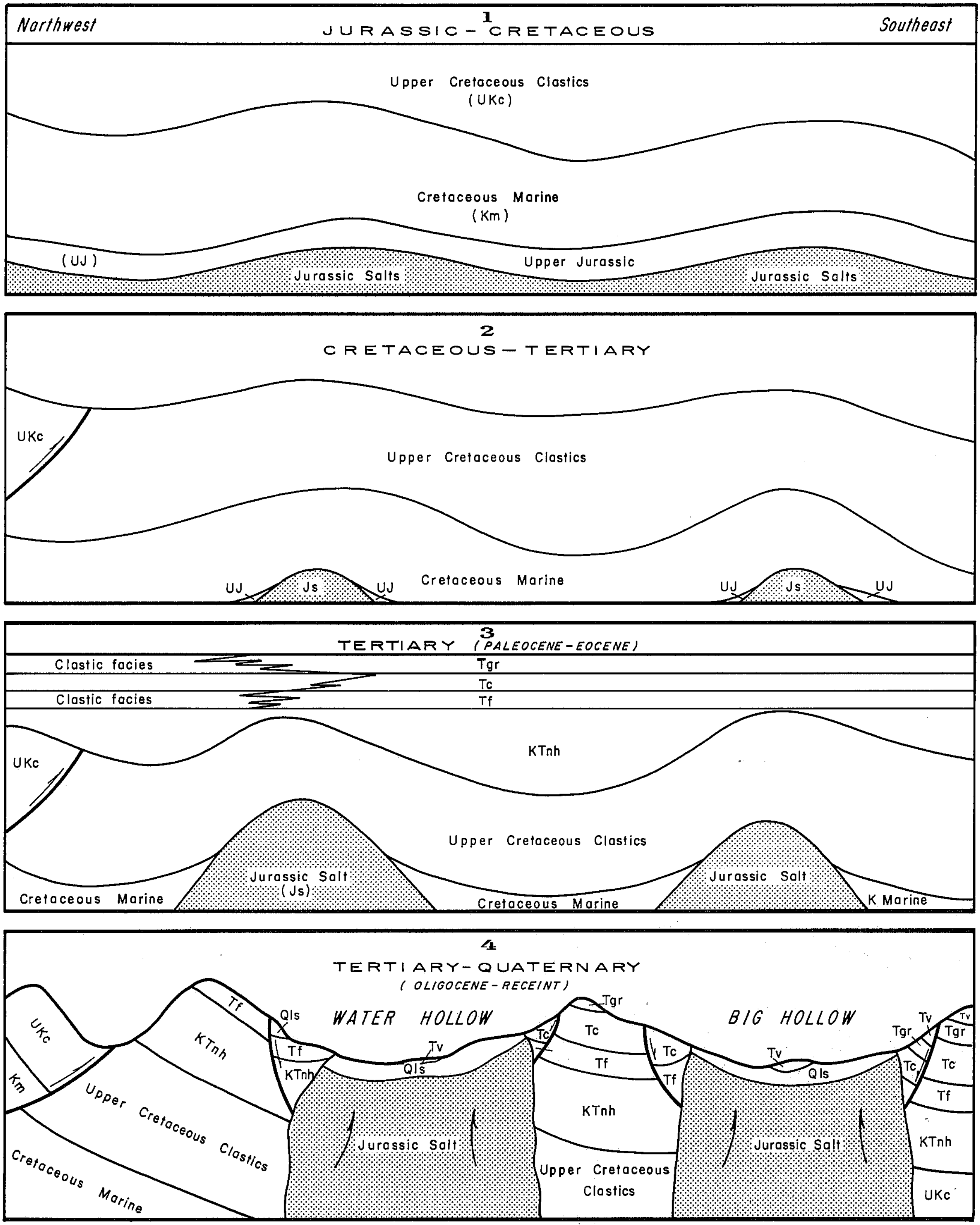

FIGURE 18.–Orogenic evolution of study area. Refer to figure 17 for stratigraphic abbreviations. 1 Deposition of Jurassic salt, Upper Jurassic carbonates and clastics, and Cretaceous marine and clastic sediments. 2 Laramide orogeny with some thrusting and movement of salt diapirs. 3 Deposition of Flagstaff, Colton, and Green River Formations, with clastic facies to west. Diapirs continue intermittent intrusion into overlying strata. 4 Deposition of volcanic rocks and stream gravels and collapse of diapirs due to groundwater erosion, resulting in creation of Big Hollow and Water Hollow.

Salt diapirs in Big Hollow should be examined further for petroleum possibilities.

SUMMARY

With increasing emphasis on the search for petroleum there is renewed interest in the Cedar Hills. The result has been an attempt to more precisely define the geology of this area.

The recognition of the role salt tectonics has played in this area is now being seriously considered. Moulton (1976) indicated the Sanpete-Sevier rift may have accumulated Jurassic salt, evaporites, and shale which locally may exceed 3,355 m in thickness. With compressive forces from the west the development of broad diapirs may have resulted. As previously noted, the Water Hollow and Big Hollow diapirs appear to be located along a series of arcuate features which appear to begin in the area of the Nebo Thrust and proceed to the southeast. Further examination of the area to the north and northwest of the present study area is needed to determine the origin of these trends and their influence, if any, on the placement of the diapirs. With the recognition of diapirism both in this area and in the Indianola Quadrangle, further examination of nearby areas is needed to determine the extent of salt diapirs and their effect on petroleum generation. For example, Landsat and ERTS imagery show a circular feature which extends from Hilltop Station to Indianola, to the northeast of the study area and occupies part of the present study area in Uinta Gulch. There has been extensive landsliding or slumping in the Hilltop Station-Indianola area. The previously mentioned circular feature lies in the same arcuate trend as the Big Hollow diapir. Is the origin of this feature in the Hilltop-Indianola area and elsewhere similar to the origin of Water Hollow and Big Hollow?

From the Landsat and ERTS imagery a variety of linear and circular features can be seen. What is their importance in understanding the geologic evolution of this area? A combination of fieldwork, satellite-imagery analysis, and well-data analysis is needed to better understand the complexities of the northern Sanpete Valley.

Of interest are the origin and composition of the volcanic rocks. The uppermost unit of red and black welded tuffs does not show any flow characteristics. Does this indicate a nearby source? What effect has the proximity of the volcanism had on petroleum maturation? Does the Tertiary volcanism represent an abortive attempt at subduction? Are the collapse features more related to volcanism than to diapirism?

This area has been referred to as the Sanpete-Sevier rift by Moulton (1977). Is it possible the Jurassic sea occupied such a rift? If so, was such a Jurassic rift related to the present basin and range rifting, or was it an earlier attempt at rifting? What is the significance of the location of the salt diapirs at the junction of the Colorado Plateau Province, the Basin and Range Province, and the Central Rocky Mountain Province?

What is the origin of the quartzite gravels? Could the North Horn, Flagstaff, Colton, or possibly the Green River Formation be a facies change?

These are only a few of the problems dealing with the geology of this area. The future offers many challenges to any student studying the Cedar Hills and Sanpete Valley.

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