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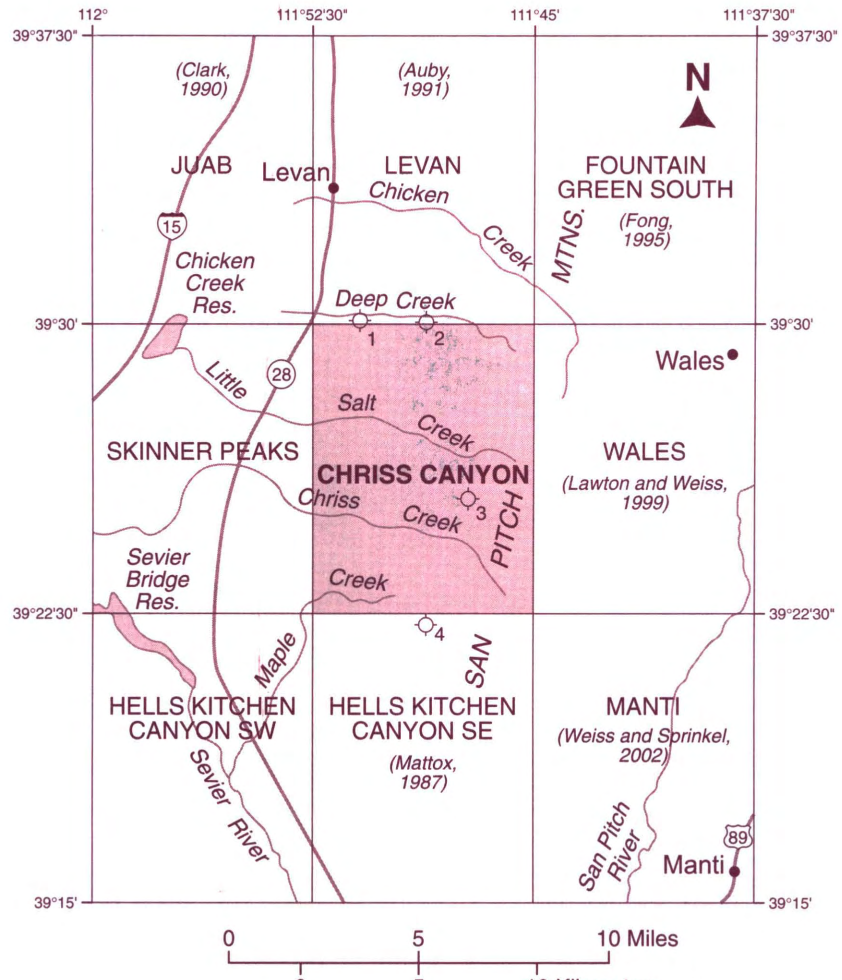

MAP 185
UTAH GEOLOGICAL SURVEY
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2003 **Utah Department of Natural Resources**

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ABSTRACT

The Chriss Canyon quadrangle lies in a region of structural transition between the extended lithosphere of the Basin and Range Province and the moderately deformed Colorado Plateau. In Late Cretaceous time this region was the leading edge of the Sevier orogenic belt. Bedrock strata exposed within the quadrangle are from Middle Jurassic (Callovian) through late Eocene in age. Minor intrusive rocks are Miocene in age. A transect across this quadrangle and the Wales quadrangle just to the east shows the sedimentary and structural record of the region prior to and during the Sevier orogeny, the effects of early and late Laramide movements, and the consequences – still preserved as geomorphic features – of subsequent Basin and Range extension.

Jurassic strata antedate the Sevier orogeny in central Utah and lie in a great southwest-plunging antiformal welt across the northwestern quadrant of the Chriss Canyon quadrangle. The base of the oldest exposed unit, Arapien Shale, is not exposed. The Arapien is severely distorted and undoubtedly much thickened by structural repetition of beds; the stratigraphic thickness of the exposed part is about 2,000 feet (610 m). The relatively undisturbed thickness of the whole unit is 3,668 feet (1,118 m) in the interior of the Gunnison Plateau. Subsurface data in the region show the Arapien Shale to range between 2,700 and 7,000 feet (823-2,134 m) thick. The Twist Gulch Formation is much less disturbed and ranges from 1,420 to 1,837 feet (433-560 m) thick. Cretaceous strata deposited in a foreland basin associated with the Sevier orogenic belt are here classified into four major lithostratigraphic units: the Cedar Mountain Formation, the San Pitch Formation (basal unit of the Indianola Group), the undifferentiated remainder of the Indianola Group, and the North Horn Formation. These units were deposited during the Sevier orogeny, and have an aggregate thickness of 5,826 to 7,143 feet (1,777-2,177 m). The North Horn was deposited during later stages of the orogeny, and its upper part is Paleocene and Eocene in age. The North Horn is overlain in succession by beds accumulated in a Laramide basin. These strata include 0 to 500 feet (0-152 m) of the lower Eocene Flagstaff Limestone, 0 to 480 feet (0-146 m) of the lower Eocene Colton Formation, 735 to 1,617 feet (224-492 m) of the upper Eocene Green River Formation, and about 400 feet (122 m) of the upper Eocene Crazy Hollow Formation.

A number of stocks, sills, and dikes of several lower Miocene monzonites intrude the Arapien Shale and Twist Gulch Formation. In 1991, Auby dubbed them the Levan monzonite suite. Upper Tertiary and Quaternary sedimentary deposits occupy only a small part of the Chriss Canyon quadrangle. Except for mass-wasting deposits, they are better represented in the Skinner Peaks quadrangle adjacent on the west.

The rocks of the quadrangle make up the west-central part of the Gunnison Plateau horst, a great structural block that stands high between the Wasatch fault and Juab Valley on the west and a range-bounding fault zone marking Sanpete Valley on the east. Highest at its northern end, the horst plunges gently southward and disappears beneath the valley fill of Sevier Valley. The horst block contains an anticline-syncline pair; an eastward overturned anticline on the west, and a tight asymmetric syncline in Jurassic and older Cretaceous rocks to the east. A shallow, more open syncline in the younger Cretaceous and Tertiary rocks of the plateau is superimposed on the structurally deeper and older asymmetric syncline. The stacked synclines occupy the high country of the central and eastern parts of the quadrangle. A north-

east-trending culmination of highly contorted Arapien Shale in the foothills of the west side of the plateau occupies the northwest quadrant of the quadrangle, and plunges southward beneath the West Gunnison monocline, which occupies the southwest quadrant of the quadrangle. Both the synclinal and monoclinal parts of the area are cut by many normal faults. The faults having the greatest length and displacement are related to two large grabens – the Divide and Chriss/Mellor grabens – that enter the south edge of the quadrangle from the Hells Kitchen Canyon Southeast quadrangle; both grabens die out near the middle of the Chriss Canyon quadrangle.

Economic resources of the Chriss Canyon quadrangle are not numerous, and agriculture – ranching and grazing – is the principal use. The area also serves as an important watershed for both surface and subsurface water that supports agriculture in Juab Valley. Exploration for petroleum has so far failed to pay off. Gypsum has been extracted from several sites in the Arapien Shale over many years, and large reserves still remain. What was apparently the first extraction of oil from oil shale in Utah was carried out in the quadrangle about 140 years ago, but the deposits of oil shale are insignificant when compared to others in the state.

The Chriss Canyon quadrangle lies in the Intermountain seismic belt, and the Wasatch fault crosses the northwest and southwest corners of the quadrangle. Although the likelihood of earthquakes is moderately high, there has been little earthquake-related damage in this part of Utah, and there is little development in the quadrangle that could be damaged from seismic events. Landsliding and rock fall are more serious threats to development in the quadrangle, and are ongoing processes in the area even without seismic disturbances. Weak rock, particularly in the North Horn and Colton Formations and the shale member of the Green River Formation, is readily displaced on steep slopes when saturated with water, as during snowmelt and in wet periods such as the one that occurred in 1983-84. Flooding of the major streams is an annual event during snowmelt, but the damage from floods is more serious downstream, out of the quadrangle. Within the quadrangle, floods will disrupt the road net, but there are at present no structures to be harmed by floods. Although problem soils, which shrink and swell during drying and wetting, are a potential threat, damage from such soils is mostly to foundations and other fixed structures not now present in the quadrangle. The Chriss Canyon quadrangle as a whole has a moderate to high potential hazard from radon, a natural, poisonous gas found in most rocks. Potential danger, however, comes from accumulation of radon gas in buildings, which are not now present in the quadrangle.

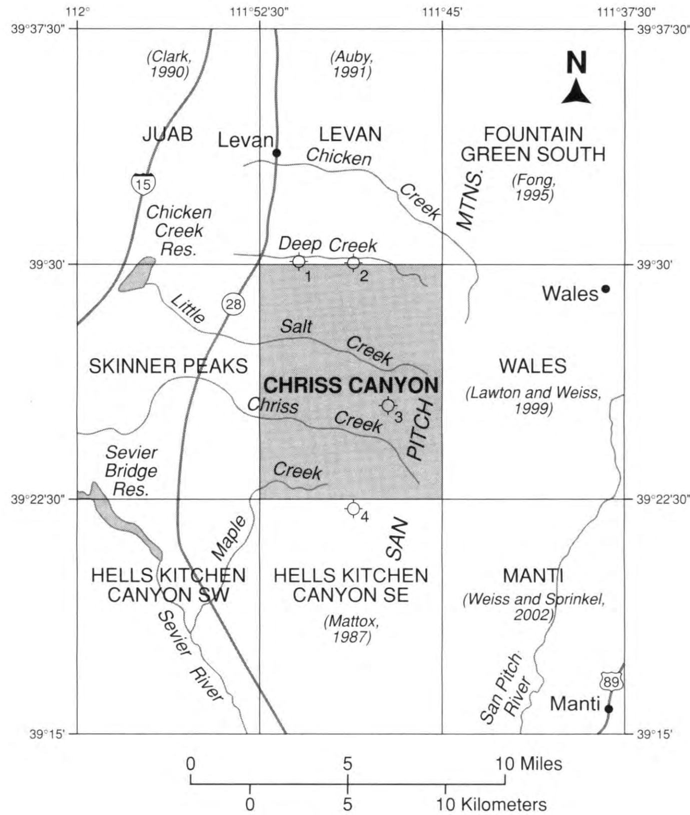

Figure 1. *Location of the Chriss Canyon and surrounding quadrangles, with major geographic and geologic features. Oil and gas exploration wells are labeled: 1 = No. 1 Levan, 2 = American Quasar 16-34 Chicken Creek, 3 = Dixel Resources #1, and 4 = Chevron USA #1. Published geologic map references in italics.*

INTRODUCTION

The name Chriss Canyon is possessive, but the appropriate punctuation (Chris's) is not used in geographic names; Chriss is pronounced in two syllables. The quadrangle forms the west-central part of the Gunnison Plateau (San Pitch Mountains), the northwesternmost of the High Plateaus section of the Colorado Plateau physiographic province (figure 1). The crest of the Gunnison Plateau lies at the east edge of the quadrangle, and a part of the east edge of Juab Valley lies in the northwest corner of the quadrangle. Juab Valley trends north-northeast, parallel to the strike of the beds in the Chriss Canyon quadrangle, so the valley edge is several miles west of the quadrangle at the latitude of Chriss Creek. There are no permanent inhabitants of the quadrangle. Two ranch homes at the mouth of Chriss Creek and two abandoned ranch homes in the Flat Canyon area are all in the Skinner Peaks quadrangle.

The lowest elevation in the quadrangle is about 5,320 feet (1,622 m), in the intermittent drainage at the northwest corner of the quadrangle. The highest elevation, 8,775 feet (2,675 m), is at the Ephraim triangulation station on Big Baldy, near the southeastern corner of the quadrangle. The total relief is thus about 3,455 feet (1,053 m) in the area. The highlands face west-northwest to Juab Valley and most of the drainage is to that valley.

Four perennial streams drain the area. From north to south they are Deep, Little Salt, Chriss, and Maple Creeks. Deep Creek Canyon is in the Levan quadrangle (adjacent on the north), parallel to and within a half mile (0.8 km) of the common boundary of the quadrangles, but the headwaters of Deep Creek are in the northeast corner of the Chriss Canyon quadrangle. The first three streams drain into Juab Valley, but Maple Creek drains to Sevier Valley via Flat Canyon. Although each is mapped as a perennial stream, only Chriss Creek discharges much water in the dry season. The dry-season discharge of the other three is trivial in normal years. These facts and the rugged terrain account for the lack of permanent human habitation in the area. The alluvial flats of Flat Canyon, in the southwest corner of the quadrangle, are dry farmed, but the remainder of the area is used only for summer grazing. In common with most of the southern half of the Gunnison Plateau, most of the land is privately owned. National Forest land lies only in the north and northeastern parts of the quadrangle.

The geology of the Chriss Canyon quadrangle has been mapped previously. The first geologic map was by Zeller (1949), before a topographic map was available and at a time when our knowledge of the stratigraphy of the rocks in the Gunnison Plateau was primitive. Zeller's map was combined by C. T. Hardy with the adjacent one to the south and published (Hardy and Zeller, 1953). Witkind and others (1987) published a map of the Manti 30' x 60' quadrangle, compiled at a scale of 1:100,000, which includes the Chriss Canyon quadrangle.

This map and report have been made by a committee, but with better success, we think, than the proverbial camel. The original field work was carried out in 1985 and 1986 by McDermott, under Weiss's direction. McDermott measured and sampled a number of sections and completed a pencil-drawn map of most of the quadrangle. Banks described those samples and summarized the descriptions of several formations from the measured sections. Subsequent to McDermott's field work, the North Horn Formation has been divided into several units (Lawton and others, 1993), and a new formation – the San Pitch – has been defined from the lower beds of the Indianola Group (Sprinkel and others, 1999). This required that the newly defined units be mapped, in addition to completing the mapping that McDermott had begun. Both of these objectives were carried out at intervals: 1994 and 1995 (Banks, Sprinkel, and Weiss), 1996 (Banks, Biek, Sprinkel, and Weiss), and 1998 and 2000 (Biek and Sprinkel). The map was inked by Weiss, and he also prepared three drafts of the report. Sprinkel prepared the cross sections. The final form of the report was prepared by Sprinkel and Weiss, with the assistance of Banks and Biek.

To aid the location of geologic features discussed in the text, the 7.5-minute quadrangle is divided into nine rectangles with intervals of 2.5 minutes of latitude and longitude (figure 2). The rectangles are referred to as northeast rectangle (NER) and so on throughout this report.

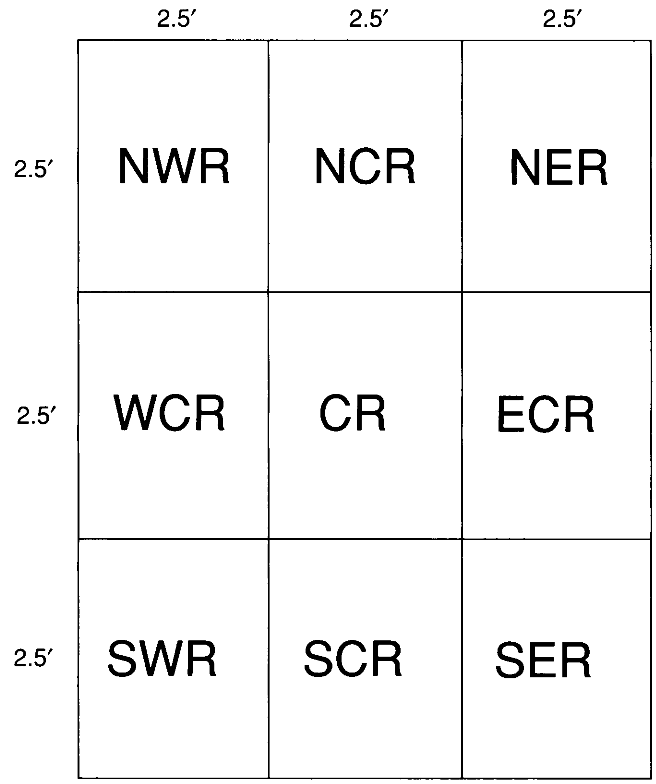

Figure 2. *A 7.5′ quadrangle may be divided into nine rectangles. These are used throughout the text. For example, WCR means the west-central rectangle.*

STRATIGRAPHY

Geologic Setting

Sedimentary rock formations exposed in the Chriss Canyon quadrangle are from Middle Jurassic to Eocene in age. Unconsolidated deposits of Pliocene(?), Pleistocene, and Holocene age locally overlie the bedrock units. A suite of Miocene monzonitic rocks intrudes the bedrock formations as small plugs, sills, and dikes, all north of Little Salt Creek. As will become apparent, each of the several bedrock units is associated with particular structures and landforms within the quadrangle.

The Gunnison Plateau (San Pitch Mountains) as a whole is fronted on the east side by great cliffs throughout its length. The same is true of the northern half of its west side; imposing cliffs of the older Cretaceous rocks – the San Pitch Formation and the undifferentiated Indianola Group – face Juab Valley and loom over lower hills formed by a doubly plunging antiformal mass of complexly folded and faulted Arapien Shale called the Levan anticline by Auby (1991). Between the tall cliffs and the Levan anticline are foothills and strike valleys in the softer Twist Gulch and Cedar Mountain Formations. The southern half of the west side of the Gunnison Plateau is faced by a west-dipping monocline – the West Gunnison monocline of Felger (1991) – formed of the younger Cretaceous and Eocene beds of the North Horn, Flagstaff, Colton, and Green River Formations. The regional relations of the major stratigraphic units of the Chriss Canyon quadrangle were illustrated by Sprinkel (1994).

The transition southward from the cliffs to the monocline is possible because the great antiformal mass of Arapien Shale (Levan anticline) plunges south-southwest in the Chriss Canyon quadrangle. From its culmination at Hill 8360 in section 20, NCR, the mass decreases in elevation and then disappears beneath the surface between Little Salt and Chriss Creeks. Thus, it is at about the middle of this quadrangle that the aspect of the west front of the plateau changes from bold, west-facing high cliffs to the bordering monocline that dips under both Juab and Sevier Valleys. Small remnants of the West Gunnison monocline remain near the north end of the west edge of the quadrangle, and in the adjacent part of the Skinner Peaks quadrangle (Felger, 1991), where beds of the limestone member of the Green River Formation dip steeply into a branch of the Wasatch fault at the edge of Juab Valley. The monocline is clearly expressed south of Little Salt Creek, but is complicated by subparallel grabens farther south, in the Hells Kitchen Canyon Southeast quadrangle. So, we see that certain formations lie in certain preferred locations in the quadrangle, as follows:

(1) The Arapien Shale lies like a great whale – the Levan anticline – at the foot of the plateau, from near the north edge of the Levan quadrangle (Auby, 1991) to about the middle of the Chriss Canyon quadrangle. It plunges beneath younger rocks at both its north and southwest ends. The "anticline" is complicated by a number of tight folds and some faults parallel to its strike, so that it is better called a culmination than an anticline. Beds of limestone like those of the upper Twin Creek Limestone (a northern lithofacies equivalent, in part, of the Arapien) are in the Levan quadrangle just to the north (Auby, 1991), but are not conspicuous in the Chriss Canyon quadrangle.

(2) The easily weathered Twist Gulch and Cedar Mountain Formations form foothills and strike valleys east of the welt of Arapien Shale. Strata of both formations dip southeast under great cliffs in the northern part of the quadrangle and plunge beneath Maastrichtian and Eocene beds of the West Gunnison monocline in the south half of the quadrangle.

(3) The bulk of the plateau is formed by the thick, resistant conglomeratic beds of the San Pitch Formation and the undifferentiated Indianola Group. These are well exposed in the tall cliffs that cap the northern part of the plateau, including the NER of the Chriss Canyon quadrangle. Together with the Jurassic rocks below them, these thick clastic units are tilted to the southeast; in the eastern part of the quadrangle they dip into a syncline beneath Eocene beds that cap the plateau. The same southeast dip lowers the Jurassic and older Cretaceous beds southward, so that south of Little Salt Creek they plunge beneath the same succession of younger Cretaceous and Eocene formations in the West Gunnison monocline.

(4) Only remnants of the Cretaceous and Tertiary North Horn Formation are exposed in the northwest part of the plateau and in the Levan quadrangle (Auby, 1991), but the formation is present on the southeast flank of the Levan culmination and above the undifferentiated Indianola Group along Little Salt Creek. It lies unconformably there on the Indianola and dips southeasterly. Thus, the North Horn Formation is at the tops of the cliffs in the northeast corner of the quadrangle, but is also part of the monocline in the southwestern area.

(5) The North Horn is succeeded concordantly by the Flagstaff Limestone, Colton Formation, and Green River Formation, which together cap the main body of the plateau and descend in the monocline into Juab Valley. The Crazy Hollow Formation lies locally upon Green River strata, but occupies only a small part of the quadrangle.

Jurassic

Arapien Shale (Ja)

The Arapien Shale actually contains rather little shale, although it weathers like shale, and forms steep, bare slopes covered with small bits and chips of rock. It is mostly micritic limestone with some salt (in the subsurface) and gypsum beds and pods. Local, large volumes of gypsum are indicated on the map by special symbols. In the Levan quadrangle, Auby (1991) found that the formation consists of light-gray micrite (80 percent), gray sparite (13 percent), sandstone and sandy siltstone (5 percent), and lenses and pods of gypsum and the red and gray mudstone locally associated with them (2 percent). Actually, Auby's "micrite beds" are not all limestone, but are interbedded with thin-bedded calcareous mudstone. The formation is more fully exposed along the big creeks that cut across it in the Levan quadrangle (Auby, 1991), but those percentages may be taken to apply also in the Chriss Canyon quadrangle, where such long cross sections are not so well exposed. One difference in the formation between the two quadrangles is apparent, however; very few of the large lenses or pods of gypsum that Auby (1991) found farther north, which are up to 200 feet (61 m) thick and several hundred feet long, are present in the Chriss Canyon quadrangle.

The micrite and calcareous mudstone beds are mostly thin bedded, but some thick beds are present. They are very light yellowish gray or light olive gray and weather to very light gray or white. Ripple marks are present, particularly on the sandy siltstone and sandstone beds scattered throughout. The siltstones are yellowish or greenish gray and locally cross-laminated. Fine-grained friable sandstone is in thin to very thick (1 to 15 feet [0.3-4 m]) beds. These clastic beds are weakly cemented with calcite, and the sandstone contains disarticulated crinoid stems regionally. Red or red-purple siliceous mudstone is present in small amounts, typically close to gypsum beds.

The base of the Arapien Shale is exposed at very few places in the region, but it is exposed on Miners Ridge in the Nephi quadrangle (about 18 miles [29 km] north of the Chriss Canyon quadrangle), where it lies on the Watton Canyon Member of the Twin Creek Limestone (Biek, 1991). In the vicinity of the Chriss Canyon quadrangle, the base of the Arapien also lies on the Twin Creek Limestone in the subsurface (Sprinkel, 1982, 1994). In the normal succession it is overlain by the Twist Gulch Formation, whose dark red color contrasts conspicuously with the pale Arapien Shale. The Arapien-Twist Gulch contact is mostly conformable, but is disconformable locally in the quadrangle and also in the Manti quadrangle (Weiss and Sprinkel, 2002). The Arapien Shale is overlain unconformably – mostly in angular unconformity – by several of the younger rock units in the quadrangle, including the North Horn Formation, and both the shale and limestone members of the Green River Formation. The many faults and tight folds in the relatively weak Arapien Shale allowed it to be intruded at many places by dikes, sills, plugs, and small stocks of early Miocene igneous rock (John, 1972; Witkind and Marvin, 1989).

The thickness of the Arapien Shale is always a difficult matter to deal with because of the number and variety of folds and faults in the mass. The fact that it has welled up slowly by local diapiric action has added to the already disordered structure, and accounts for the variety of younger units deposited unconformably upon it. In the longer sections exposed on Pigeon and Chicken Creeks in the Levan quadrangle, Auby (1991) found that the thickness of a maximum package of orderly beds is 1,600 feet (488 m). We estimate an exposed thickness of Arapien strata in the Chriss Canyon quadrangle of about 2,000 feet (610 m). The best measures of the thickness of the Arapien are the thicknesses of flat-lying sections in two wells atop the Gunnison Plateau.

It is 3,668 feet (1,118 m) thick in the Dixel Resources No. 1 Gunnison State well in the NE1/4 section 15, ECR, and includes two beds of salt, 14 and 74 feet (4 and 23 m) thick (Sprinkel, 1994). Standlee (1982) cited different values of thickness of the formation and of the salt, but he also used an Arapien Twist Gulch contact that does not accord with usage on the surface. The Chevron U.S.A. No. 1 Chriss Canyon well lies only 600 feet (183 m) south of the south edge of the quadrangle (section 33, SCR); Standlee (1982) cited a thickness for the Arapien of 5,690 feet (1,734 m) and 790 feet (241 m) of salt there. These values are uncertain because, as we shall see in the description of the Twist Gulch Formation, Standlee (1982) reported much thinner Twist Gulch than we have measured on the surface. He used a different Arapien/Twist Gulch contact than we have, such that the Arapien Shale may be thinner than stated above from Standlee's work.

The Arapien was deposited in a narrow, north-trending marine basin in central Utah, and displays many qualities indicative of an arid environment. Massive gypsum and selenite are common in many of the different rock types in the formation. The anhydrite and halite that are so conspicuous in the subsurface are also indicative of a restricted, arid marine basin. Halite crops out or is at a shallow depth near the northeast and southeast corners of the Gunnison Plateau (Banks, 1991; Weiss, 1994), and has been mined from a shallow depth for many decades in the Sevier Valley. At the north end of the Wasatch Plateau and in the Nephi quadrangle (Biek, 1991), and in the subsurface throughout central Utah (Sprinkel, 1982, 1994), the Arapien Shale lies conformably on the Watton Canyon Member of the Twin Creek Limestone. The abundance of limestone beds of various types – particularly in the Levan quadrangle – suggests that the local Arapien Shale expresses northward changes of lithofacies from the more highly clastic units of the northern Sevier Valley to the Twin Creek Limestone itself. Sprinkel (1982) and Sprinkel and Waanders (1984) correlated the Arapien Shale with the upper two members – Leeds Creek and Giraffe Creek – of the Twin Creek Limestone.

Both Auby (1991) and Biek (1991) suggested correlations of the Arapien beds displayed along the northwest face of the Gunnison Plateau with the formation in Arapien Valley, its type area. Biek (1991) believed that he could recognize equivalents of members A, B, C, and D of Hardy (1952) in the Nephi quadrangle, but elected to describe the formation in three parts without definite correlation to Hardy's members. Auby (1991) believed that Hardy's members A and C can be identified in the Levan quadrangle, and this correlation may stand the test of time. The problem is that the whole formation in southern Sanpete County, where Hardy worked, is less limy and more clastic than here on the northwest flank of the Gunnison Plateau. All in all, it appears that most of the Arapien Shale in the Chriss Canyon quadrangle may belong to member C.

The age of the Arapien is generally regarded as Middle Jurassic. Using dinoflagellates, Sprinkel and Waanders (1984) found that the lower part of the formation is Bathonian and the upper part Callovian. Villien and Kligfield (1986) placed it somewhat higher in the Jurassic section, but serious errors in some of their sample locations make that conclusion uncertain. The part of the Arapien that is exposed in the Chriss Canyon quadrangle is likely entirely Callovian in age.

Twist Gulch Formation (Jt)

The Twist Gulch Formation is a thick succession of marine and marginal marine mudstones, siltstones, and sandstones that are very evenly bedded and weakly cemented. This unit and the overlying Cedar Mountain Formation form lowlands between the more resistant Arapien Shale and the conglomerate beds of the San Pitch Formation. That, and the formation's distinctive brownish-red or reddish-chocolate color, make it rather easy to map. The mudstones of the overlying Cedar Mountain are both red – of a distinct orange cast – and lavender, and almost fluorescent in luster.

Auby (1991) recorded the fractions of the different rock types: sandstone [fine to very fine] 54 percent, siltstone 30 percent, mudstone 15 percent, and fine conglomerate [gritstone] 1 percent. Sandstone beds are light brownish orange because they contain little of the red mud. They may weather to even lighter shades because of the feldspar (3 to 9 percent, averaging 7 percent) that has gone to clay (Auby, 1991; Biek, 1991). The conglomerates, or gritstones, are formed of granules or small pebbles of chert and quartz, have a sandy matrix, and are cemented by iron oxides and calcite. These coarser materials lie mostly in the basal parts of the sandstone beds, some of which are medium or thick beds. Planar cross-laminae are present in some of the sandstone beds, and lamination or thin bedding is characteristic of the siltstone and mudstone beds. The mudstones and the siltstones are mostly red of various shades, but some are gray.

The Twist Gulch overlies the Arapien concordantly, but the very marked change in rock type may represent a disconformity; a basal bed of grit is present locally, as about mile (0.8 km) northwest of Little Red Hill, and a similar basal grit is present locally in the Manti quadrangle (Weiss and Sprinkel, 2002). It is overlain disconformably by the Cedar Mountain Formation in the normal succession, in a belt from Little Red Hill (CR) toward the northeast corner of the quadrangle. Both the North Horn Formation and Flagstaff Limestone overlie the Twist Gulch in angular unconformity on Little Salt Creek, where the Tertiary beds in the West Gunnison monocline dip west over the east-dipping Mesozoic beds.

The Twist Gulch Formation is 1,420 feet (433 m) thick north of Little Red Hill and 1,837 feet (560 m) thick near the north edge of the quadrangle. These values are of the same order of magnitude found in the Nephi quadrangle – 1,200 feet (366 m) (Biek, 1991) – and in the Levan quadrangle – 1,667 feet (508 m) (Auby, 1991). Sprinkel (1994) reported similar thicknesses under the plateau top: 1,162 feet (354 m) in the Dixel well and 1,230 feet (375 m) in the Chevron well. From the same two wells, Standlee (1982) recorded thicknesses less than half of these, showing that he used a different Arapien/Twist Gulch contact than we have on the outcrop.

The pale-colored sandstone beds in the Twist Gulch Formation have the look of the Curtis Formation of the San Rafael Swell. Willis (1986) found that these sandstone beds – most abundant in the middle of the formation – become more like the Curtis from Sanpete Valley into Salina Canyon, and he correlated the Twist Gulch with the Entrada, Curtis, and Summerville Formations. The age of the Twist Gulch is Callovian, and Imlay (1980) correlated it with the Preuss Sandstone of northern Utah.

Cretaceous

The Cedar Mountain Formation and the Indianola Group – Introduction

A great succession of conglomerates with sandstone, mudstone, and some limestone makes up most of the volume of the northern and central Gunnison Plateau and forms the bold cliffs that are so conspicuous on its west face as far south as Little Salt Creek. These strata were called Indianola Group by two of E.M. Spieker's students who pioneered the mapping of the west side of the plateau (Zeller, 1949; Hunt, 1950). They adopted that name because of the similarity of the rocks and the stratigraphic position of this mass to those of the Indianola Group of the Wasatch Plateau, which is the next of the High Plateaus to the east of the Gunnison.

Spieker (1946) named the group from exposures east of the village of Indianola, in the northern part of the Wasatch Plateau, and defined four formations within the group from the area of Sixmile Canyon, east of Sterling, Utah, and near the middle of the west side of the Wasatch Plateau. Those four formations, in ascending order, are the Sanpete Sandstone, the Allen Valley Shale, the Funk Valley Formation, and the Sixmile Canyon Formation. In both the Wasatch and Gunnison Plateaus, the Indianola Group was regarded as early Late Cretaceous in age and as lying between the Upper Jurassic(?) Morrison(?) Formation and the younger Upper Cretaceous Price River and North Horn Formations (Spieker, 1946, 1949). Hardy (1948) took a different view in the Hells Kitchen Canyon Southeast quadrangle, and mapped these same bold conglomerates on the west side of the Gunnison Plateau as Price River Formation. In Hardy and Zeller (1953), which Hardy prepared, the same beds are mapped as undifferentiated Indianola Group in the north half of the map (Zeller's area, now the Chriss Canyon quadrangle) and as Price River Formation in the south half of the map (Hardy's area, now the Hells Kitchen Canyon Southeast quadrangle)!

The compiling of maps of central Utah for the U.S. Geological Survey (Witkind and others, 1987), and continued work by students of J.W. Collinson at the Ohio State University, led to new views of the section between the Twist Gulch Formation and the Sanpete Sandstone in the Gunnison Plateau. No Upper Jurassic rocks – that is, no Morrison Formation – are in this interval in central Utah (Standlee, 1982; Stuecheli, 1984; Witkind and others, 1986; Schwans, 1988b). What had earlier been thought to be a hiatus between Upper Jurassic and Upper Cretaceous rocks (for example, Spieker, 1946, 1949) was really a hiatus between Middle Jurassic rocks and the upper part of the Lower Cretaceous section (Stuecheli, 1984; Witkind and others, 1986; Schwans, 1988a; Weiss and Roche, 1988; Weiss, 1994). The former Morrison(?) unit used by Spieker (1946, 1949), which was subsumed into the Twist Gulch Formation by Hardy and Zeller (1953), is now divided into two lithostratigraphic units. Schwans (1988a) called them the lower and upper members of his Pigeon Creek Formation. The lower is also recognized as the Cedar Mountain Formation (Auby, 1991; Biek, 1991; Weiss, 1994). The upper was called the basal unit of the Indianola Group, a fifth formation inserted under the Sanpete Sandstone (Weiss and Roche, 1988; Weiss, 1994). It is now recognized as the San Pitch Formation (Sprinkel and others, 1999), and regarded as the basal one of five formations that make up the Indianola Group.

Cedar Mountain Formation (Kcm)

In its type area in the northwestern part of the San Rafael Swell, the Cedar Mountain Formation lies between the Upper Jurassic Morrison Formation and the Upper Cretaceous Dakota Sandstone (Stokes, 1944, 1952; Yingling, 1987). Its upper, unnamed member consists mostly of variegated mudstone with calcareous nodules and highly polished pebbles of chert and quartzite believed to be gastroliths. This is the main body of the formation and the part that reaches into central Utah; the lower member, the Buckhorn Conglomerate, does not extend into central Utah. In the Gunnison Plateau and in Salina Canyon, at the south end of the Wasatch Plateau, the Cedar Mountain Formation is more like the main body of the deposit in its type area. The formation mapped in the Chriss Canyon quadrangle is approximately equal to the lower part of the Cedar Mountain Formation revised by Witkind and others (1986) and the lower part of what Schwans (1988a) called the Pigeon Creek Formation (see Sprinkel and others, 1999).

In the Chriss Canyon quadrangle the Cedar Mountain Formation forms low, unstable slopes that are covered in many places by mass-wasted material (Qc or Qms) derived from the overlying San Pitch Formation. Where exposed it shows its characteristic qualities: variegated red, reddish-orange, and lavender mudstone or siltstone, thin beds or lenses of conglomerate and sandstone, and thin beds of micritic limestone. Lumpy, angular nodules of micrite and chalcedony are present in the mudstones, and gastroliths are commonly associated with the limy nodules. In the southern part of the plateau the formation contains beds of pedogenic carbonate that weather to form limy nodules (Sprinkel and others, 1999). Such may also be the source of the limy nodules elsewhere on the plateau.

The Cedar Mountain Formation lies unconformably on the marine mudstones and siltstones of the Twist Gulch Formation throughout the Gunnison Plateau, but the contact is better exposed to the north (Auby, 1991; Biek, 1991) and to the south (Weiss, 1994; Sprinkel and others, 1999). Low on the west face of Little Red Hill, SE1/4 section 32, NCR, in this quadrangle, the contact is an angular unconformity having a discordance of about 20 degrees, but such has not been observed elsewhere. The Twist Gulch is typically better exposed, more uniform in texture and bedding, and is a brick red color; the reds of the Cedar Mountain are quite orange, so that the contrast between the two is apparent even at poor exposures. The upper contact with the San Pitch Formation (Indianola of Auby, 1991; and Biek, 1991) is conformable and apparently gradational through a short interval. But on the western side of the Gunnison Plateau the basal bed of the San Pitch is a persistent, massive, clast-supported, cobble conglomerate about 50 feet (15 m) thick. Because the Cedar Mountain is covered by debris at so many places, that thick ledge of conglomerate serves as a good guide for mapping. The Cedar Mountain thins southward from the north end of the plateau. It is 680 feet (207 m) thick there (Biek, 1991); thins to 305 feet (93 m) in Chicken Creek Canyon, 2.5 miles (4 km) north of this quadrangle (Auby, 1991); and thins further to an exposed thickness of about 270 feet (82 m) in this quadrangle; Cedar Mountain strata may thicken eastward in the subsurface to about 600 feet (183 m). The Cedar Mountain disappears beneath younger rocks at Little Salt Creek, and is not exposed farther south on the west side of the Gunnison Plateau.

The Cedar Mountain Formation was deposited in a mixed fluviatile and minor lacustrine environment (Yingling, 1987; Schwans, 1988a). It was frequently exposed to the atmosphere and underwent brief periods of soil formation. It is composed of soil, regolith, and rock shed from the rising Sevier orogenic belt during the early stages of that orogeny. As the elevation differential increased, erosion cut deeper into the hinterland and eroded bedrock units; that coarser debris was delivered to what is now central Utah to form the San Pitch Formation and the undifferentiated Indianola Group. The age of the Cedar Mountain in central Utah derives from palynomorph and radiometric data that come mostly from the upper half of the formation. In the San Rafael Swell, the Cedar Mountain Formation is Barremian to late Albian-early Cenomanian (Tschudy and others, 1984; Kirkland and others, 1997; Kirkland and others, 1999). In the Gunnison Plateau it is considered to be Aptian to middle Albian in age (Weiss and Sprinkel, 2002).

San Pitch Formation

The San Pitch Formation, as mapped in the Chriss Canyon quadrangle and described here, is the lower part of what was mapped on the west side of the Gunnison Plateau as the Indianola Group by Zeller (1949), Hunt (1950), Auby (1991), and Biek (1991). It is also what Schwans (1988a) called the upper part of the Pigeon Creek Formation. Without being named, it was designated as a new, basal formation (the lowest of five) of the Indianola Group at the southern end of the plateau (Weiss and Roche, 1988; Weiss, 1994). It has since been named the San Pitch Formation and assigned to the basal part of the Indianola Group (Sprinkel and others, 1999). The formation is divisible into three informal members, A, B, and C, that can be traced throughout the Gunnison Plateau, the southern Wasatch Plateau, and in the subsurface of the associated valleys (Sprinkel, 1994). The members are mapped herein, and the formation is described, part by part, following Sprinkel and others (1999).

The Cedar Mountain and San Pitch Formations together form an upward-coarsening clastic sequence that represents the increase of durable weathered rock from the heights of the hinterland of the Sevier orogenic belt. As the orogenic belt began to rise, it shed sediment that formed the rather fine-grained Cedar Mountain Formation. As the intensity of the crustal movements and elevation differential increased the sediment delivered to the basin was coarser and deposited as the San Pitch Formation. Both the Cedar Mountain and the San Pitch Formations become finer grained eastward toward Salina Canyon and the San Rafael Swell.

Member A (Kspa): Member A consists of cobble and pebble clast-supported conglomerate interbedded with both calcareous and non-calcareous mudstone. Conglomerate ledges are thick to medium bedded and have channel-form geometry. The mudstones are red and reddish brown, as is the muddy matrix of the conglomerates. Pebbles and cobbles are of rounded to subrounded quartzite and carbonates, in about equal proportions, plus a few of sandstone and siltstone. The quartzite clasts came from Proterozoic and Cambrian formations in western Utah. White and light-gray varieties are from the Caddy Canyon Quartzite (Late Proterozoic), purple or red ones – plain or banded – are from the Mutual Formation (Late Proterozoic), and pale-orange to pinkish ones are from the Tintic Quartzite (Cambrian). Sparse pale-green quartzite and grayish-green (fresh colors) quartzose sandstone pebbles are from the Dutch Peak Formation (Late Proterozoic) and the Ophir Formation (Cambrian), respectively. Carbonate clasts are of various Paleozoic dolomite formations. Sandstone and siltstone clasts are probably from Triassic and Jurassic formations.

The change from the mostly mudstone Cedar Mountain Formation to the conspicuously coarser San Pitch Formation was described previously. In this quadrangle the base of the San Pitch and its member A is the great, bold cliff about 50 feet (15 m) thick at the top of the mudstones in the back valley and at the base of the series of step-like cliffs in the mountain front. Contacts of the members within the formation are based on changes in grain size, clast composition, matrix color, and bed geometry. The reddish-brown, channel-form conglomerates of member A give way to the lighter colored, tabular conglomerate, sandstone and calcareous mudstone beds of member B. Whereas the conglomerates of member A are dominated by quartzite in this area, carbonate cobbles and pebbles dominate the basal part and much of the remainder of member B.

The San Pitch Formation thins generally south- and southeastward from the area of the northwestern Gunnison Plateau, and the members generally thin concordantly with the whole. Member A is 495 feet (151 m) thick on Chicken Creek, 2.5 miles (4 km) north of this quadrangle, but is only 168 feet (51 m) thick at Little Salt Creek. Within the Chriss Canyon quadrangle, however, member A thickens to about 918 feet (280 m) at Deep Creek (NER), and thins to 193 feet (59 m) on Little Red Hill (NCR).

Member B (Kspb): Member B consists of distinctive stacked tabular beds of cobble and boulder conglomerate and sandstone, interbedded with mudstone. Because some conglomerate beds are composed of mostly carbonate clasts they are lighter and grayer in color that those of member A. Mixed-clast conglomerate beds, having about equal quantities of quartzite and carbonate clasts, are more prevalent. The carbonate clasts are mostly dolomite. The sandstone beds are light pinkish orange to light gray, fine to medium grained, and display trough cross-beds, asymmetrical ripples, flute casts, and tool and groove marks. Burrows, root casts, a few gastropods, and rare leaf impressions are also found in the sandstone beds. The two distinctive clast types of member A – grayish-green quartzose sandstone and pale-green quartzite – are also found in member B. The sources of these and other identifiable cobbles and pebbles are the same in this member as described for member A.

Member B is 2,200 feet (671 m) thick on Chicken Creek, 2.5 miles (4 km) north of this quadrangle, and an incomplete section at Little Salt Creek is 2,110 feet (643 m) thick (Sprinkel and others, 1999). Thicknesses computed from the map are 2,667 feet (813 m) just northeast of Little Red Hill (CR) and 2,880 feet (878 m) on upper Deep Creek (NER).

The gradational contact between member B and member C is marked at most exposures by a change from the abundantly conglomeratic member B to a conspicuous thickness of mudstone with sandstone and some conglomerate in the lower part of member C. The latter member contains abundant coarse sandstone and conglomerate, as we shall see, but a considerable thickness of mudstone lies in its lower part.

Member C (Kspc): Member C consists mostly of mudstone, but with large thicknesses of boulder and cobble conglomerate locally. In the NER and adjacent parts of the Levan quadrangle, it consists of reddish-brown or gray mudstone and sandstone interbedded with thick tabular beds of cobble conglomerate. In this quadrangle especially, the conglomerates are very light gray or yellowish gray, with numerous limonite nodules. The clasts in conglomerate beds are mostly quartzite, plus a few lithic clasts, cemented in a calcareous sandy mudstone matrix.

The top of member C is the top of the San Pitch Formation. At the south end of the plateau, member C clearly underlies the Sanpete Sandstone of the Indianola Group unconformably. The contact selected elsewhere in the plateau is considered correlative to that exposure. The base of the Sanpete contains light-colored quartzite boulder conglomerate – thin at the south, but locally thick. It is weakly cemented and indurated when fresh, but weathers readily and scatters loose boulders about the slopes. The boulders are mostly from the Tintic Quartzite, but some are from the Caddy Canyon Formation and the Eureka Quartzite. The colored clasts (except green) that are so conspicuous in members A and B of the San Pitch Formation are also locally in the basal Sanpete.

Member C is less regular in thickness than the other two members. At Chicken Creek it is 967 feet (295 m) thick, and 1,453 feet (443 m) thick on upper Deep Creek near the northeast corner of the Chriss Canyon quadrangle. From there it thins southward through the plateau.

The age of the San Pitch Formation ranges from middle to late Albian, but the data points are not well distributed among the members. The middle Albian age of member A is determined from palynomorphs collected near the base of the member at Chicken Creek (Sprinkel and others, 1999). The late Albian age of member C derives from palynomorphs collected from near the top the member (Sprinkel and others, 1999). Those palynomorphs are comparable to late Albian palynomorphs in the top 66 feet (20 m) of the Cedar Mountain Formation in the San Rafael Swell (Tschudy and others, 1984). The whole Lower Cretaceous section in that deeper part of the foreland basin may be taken to be older than the lithofacies in central Utah. A sample from the upper part of member C in Salina Canyon (at the south end of the Wasatch Plateau) contained palynomorphs of middle to late Albian age (Sprinkel and others, 1999). It thus seems reasonable that member C is of late Albian age and that the San Pitch Formation as a whole is middle through late Albian in age.

Indianola Group undifferentiated (Kiu)

The bold, ragged cliffs of the northwest flank of the Gunnison Plateau were mapped as Indianola Group by Hunt (1950), Auby (1991), and Biek (1991). The San Pitch Formation just described is the lower part of that great thickness of conglomerate, sandstone, and mudstone. As the San Pitch Formation of this report underlies the classic four formations (Sanpete, Allen Valley, Funk Valley, and Sixmile Canyon) of the Indianola Group at the south end of the plateau and in the Wasatch Plateau, this remaining upper part on the northwest flank of the Gunnison Plateau must be equivalent to those formations. Even so, the equivalence has not been demonstrated, and the four formations have not yet been recognized in this area. Several informal names have been given to parts of this section, but none has been proposed formally and published. Thus the remaining upper part of the former, whole Indianola Group is mapped here as Indianola Group undifferentiated. This part of the group ranges in age from Cenomanian or Turonian at the base to Campanian at the top.

Most exposures of this undifferentiated upper part of the Indianola Group are found north and northeast of the Chriss Canyon quadrangle, but one large exposure lies on the north side of Bear Creek, mostly in section 34 (NER). The rocks there consist of a succession of cobble- and boulder-conglomerate, sandstone, and mudstone beds. The mudstone and sandstone beds are mostly red or red-brown in color. In the vicinity, the unit lies on member C of the San Pitch Formation and unconformably below the calcareous siltstone unit of the North Horn Formation, but at this particular spot the contacts are faults – down against member C and up against the North Horn beds. The undifferentiated Indianola beds in that exposure are about 1,800 feet (549 m) thick, less than the thickness of the unit in the Levan quadrangle.

Cretaceous and Tertiary

North Horn Formation

The North Horn Formation regionally is a thick succession of terrestrial sediments – fluvial, flood plain, lacustrine, and deltaic – that ranges in age from the late Campanian into the Eocene. It is unconformable on all older formations in the region. Although it spans the Mesozoic-Cenozoic boundary, there is nowhere any conspicuous physical feature that marks the K-T boundary. Evidence of intermittent sedimentation persists throughout its thickness, for there are many disconformities and even angular unconformities within the formation. Though Spieker (1946, 1949) divided the North Horn roughly into two mostly fluviatile and two mostly lacustrine packages in the Wasatch Plateau, it is only through the work of T.F. Lawton (Lawton and Trexler, 1991; Lawton and others, 1993; Lawton and Weiss, 1999) that a specific lithostratigraphy and sedimentary history of the North Horn have been developed.

Working on the east face of the Gunnison Plateau in the Wales quadrangle (directly east of the Chriss Canyon quadrangle), where the thickest exposures of the North Horn are found, Lawton divided the formation into eight mappable units (Lawton and others, 1993). Working both north and south from Big Mountain (a bold escarpment on the east side of the plateau), Lawton and Weiss (1999) mapped the extent and facies changes of each of the eight units across the Wales quadrangle. Only a minority of the eight units exposed in Big Mountain extend into the Manti and Chriss Canyon quadrangles, for Big Mountain seems to lie in what was once a major axis of transport and sedimentation from the Sevier highland during the late stages of the Sevier orogeny. Weiss and Sprinkel (2002) were able subsequently to map the four units that extend into the Manti quadrangle, and two of the eight are mappable in the Chriss Canyon quadrangle as well. The extent of the units north of the Wales quadrangle has not been tested.

The two uppermost units of the North Horn Formation, the calcareous siltstone unit and the upper redbed unit, are separated from each other over part of the plateau by the

Wales Tongue of the Flagstaff Limestone. This tongue joins the main body of the Flagstaff near the north edge of the Wales quadrangle, but thins southward and westward in the Chriss Canyon quadrangle. These three lithic bodies, the calcareous siltstone and upper redbed units of the North Horn Formation and the Wales Tongue of the Flagstaff Limestone, are exposed and mapped in the Chriss Canyon quadrangle.

Calcareous Siltstone Unit (TKn): The calcareous siltstone unit contains the largest volume of rock of any of the eight units of the North Horn Formation. East of here its thickness varies widely, for it has complex facies relationships with several other units of the North Horn Formation (Lawton and others, 1993; Lawton and Weiss, 1999). It is a great, thick sheet of calcareous siltstone and sandstone in the Chriss Canyon quadrangle, but thins to a feather edge over the Mesozoic beds of the Levan culmination.

The unit consists mostly of red and reddish-brown calcareous siltstone and mudstone that weather to slopes between ledges. Gray or olive-gray blocky ledges of well-cemented siltstone may be pedogenic layers. The massive sandy siltstone beds are much more red and contain calcareous nodules of micrite. Micrite nodules, pisolites (indicative of paleosols), and rootlet traces are common in the siltstone beds. Light-yellowish-gray, medium- and thick-bedded sandstone ledges, some of them pebbly, are bioturbated and contain fossil snails and ostracodes. Some of the pebbly sandstone beds in the Chriss Canyon quadrangle contain small cobbles as well, because they were deposited near the upturned Mesozoic beds at the edge of the basin. The sandstone beds are thin or medium in thickness and tabular where associated with blocky siltstone beds; they are thick and lensing to tabular in the massive siltstone slopes. The sand is fine to very coarse grained, highly quartzose, and tends to fine upward in the beds.

Where its base is exposed in the quadrangle, the calcareous siltstone unit is unconformable on older rocks – the Arapien, Twist Gulch, Cedar Mountain, and San Pitch Formations, and the undifferentiated Indianola Group. The unit thins northward in the Chriss Canyon quadrangle and pinches out on the flank of the Levan culmination. Locally it is overstepped by the Flagstaff Formation. The unit is overlain typically by the Wales Tongue of the Flagstaff Limestone, into which it grades locally or interfingers on a small scale. Across Little Salt Creek from Little Red Hill the unit is only 282 feet (86 m) thick (T.F. Lawton, written communication, 1998), and it thins somewhat west from there before it goes into the subsurface. Upstream from Little Red Hill it is about 310 feet (94 m) thick in the ECR, and as much as 440 feet (134 m) in the SCR.

Where the upper redbed unit of the North Horn Formation is pinched out, the Wales Tongue becomes the base of the main body of the Flagstaff Limestone, and the upper contact of the calcareous siltstone is with the main body of the Flagstaff. This condition exists in two areas within the Chriss Canyon quadrangle. West of Cold Spring Flat (NER) the upper redbed unit pinches out and the Wales Tongue joins the main body of the Flagstaff Limestone, which lies on the calcareous siltstone unit; farther on, the Flagstaff oversteps the calcareous siltstone to rest directly on the San Pitch Formation. The upper redbed unit also pinches out eastward in Chriss Creek, in NE1/4 section 21, SCR, where the Wales Tongue is not separately distinguishable. Thus the calcareous siltstone unit again lies directly under the main body of the Flagstaff Limestone in the upper reaches of Chriss Creek. The calcareous siltstone unit is 0 to 480 feet (146 m) thick in the NER, about 200 feet (61 m) thick in lower Chriss Creek (SW1/4, section 17, SWR), and up to 680 feet (207 m) thick in upper Chriss Creek (sections 21 and 22, SER). The calcareous siltstone unit thickens eastward under the Gunnison Plateau and may be up to 2,900 feet (885 m) thick along the line of cross section B-B'.

The unit was deposited in a mixture of lacustrine, lake margin, fluvial, and flood-plain environments. The lake margin and flood plain areas were where soils developed that are now paleosols in the rock section (Lawton and Weiss, 1999). The calcareous siltstone unit ranges from latest Cretaceous to Paleocene age in the Wales quadrangle, where it occupies about half of the thickness of the North Horn Formation (Lawton and Weiss, 1999, figure 2). Only the younger, upper part of the unit is exposed in the Chriss Canyon quadrangle, as is true also in the Manti quadrangle. Although its age has not been measured in the Chriss Canyon quadrangle, it is probably all Tertiary in age. Because of the lack of the certainty, however, it is labeled as TKn in the Chriss Canyon quadrangle.

Upper Redbed Unit (Tnu): Although the Wales Tongue of the Flagstaff Limestone directly overlies the calcareous siltstone unit over most of the area, the upper redbed unit is described here because it is part of the North Horn Formation. It is a reddish-brown mottled siltstone farther east, where named, but more varied here. Red-brown mottled sandstone forms some thin ledges in the unit, and the few claystone beds are orange-red. Where close to the Jurassic strata the unit gained red mud from the Twist Gulch Formation in addition to being oxidized when exposed subaerially. It is less red in the southern part of the quadrangle, farther from the Jurassic redbeds. All the rock types are calcareous. Some sandstone beds have the form of channel or splay sands, in beds 1 to 6 feet (0.3-2 m) thick. Thin red beds beneath overstepping Flagstaff beds in the central and north-central rectangles (CR, NCR) are mapped as the upper redbed unit, although the patch on Little Red Hill has abnormal lithofacies because of the conglomeratic beds.

The upper redbed unit generally overlies the Wales Tongue by gradation through a very short interval, and may be disconformable locally. The contact with the main body of the Flagstaff Limestone is also rather sharp, but it is difficult to imagine that surface as a disconformity. The unit is from 0 to 112 feet (0-34 m) thick in the central and northern part of the quadrangle, but is only about 80 feet (24 m) thick in the SCR, in that great headland that reaches toward Chriss Creek, from section 28 into section 21, like the prow of a great battleship. East of the "battleship" the upper redbed unit pinches out, so that the Wales Tongue is not mappable separately from the main body of the Flagstaff southeast of there, in the upper reaches of Chriss Creek. A similar pinch-out in section 34, NER, also joins the Wales Tongue to the Flagstaff main body, which lies on and oversteps the calcareous siltstone unit there.

These redbeds were deposited on a flood plain of low gradient and exposed to the air and oxidized from time to time. The upper redbed unit is early Eocene in age in the Wales quadrangle (Hobbs, 1989; Lawton and others, 1993; Talling and others, 1994) and probably of the same age in the

Chriss Canyon quadrangle.

Flagstaff Limestone

Wales Tongue of Flagstaff Limestone (Tfw): The Wales Tongue is mostly light gray or light-yellowish-gray dolomite and dolomitic limestone, much of it muddy, and dark-gray fossiliferous wackestone. It lies in medium and thick beds, parted by sandy mudstone and siltstone, that tend to form square ledges that are conspicuous between the reddish slopes of the calcareous siltstone and upper redbed units of the North Horn Formation. Gastropod fossils are common in the carbonate beds. Where the tongue is thinner, away from the Wales quadrangle, it weathers to somewhat orange ledges of muddy dolomitic limestone and wackestone; the color and the square (jointed) ledges make it easily mappable.

The Wales Tongue interfingers through a short interval with the calcareous siltstone unit of the North Horn Formation, but is rather sharply succeeded by the upper redbed unit. In the NER and SER of the Chriss Canyon quadrangle, where the upper redbed unit of the North Horn Formation is pinched out, the tongue becomes the basal part of the main body of the Flagstaff Limestone. The Wales Tongue is rather thin everywhere west of the axis of the plateau. Where too thin to map as a band with two contacts, it is mapped herein with a single dashed line marked with the same label. Across Little Salt Creek from Little Red Hill, it is only 26 feet (8 m) thick (T.F. Lawton, written communication, 1998). It is as much as 50 feet (15 m) thick in the northeastern part of the quadrangle, but only 20 feet (6 m) or less thick in the western districts. From there it melds southeastward into the base of the main body of the Flagstaff, where the upper redbed unit is absent.

The Wales Tongue was deposited in open lacustrine and lake-margin environments (Lawton and others, 1993). Like the main body of the Flagstaff Limestone, much of the tongue may have formed on lake-marginal flats that were only intermittently wet, and covered with wetland vegetation at other times. Such an environment has been called palustrine (Platt and Wright, 1992). The Wales Tongue is late Paleocene in age (Lawton and others, 1993; Talling and others, 1994).

Flagstaff Limestone (main body) (Tf): The Flagstaff is a thick coherent body of rock regionally, although a body of red limestone and mudstone lies in its middle in the southern Wasatch Plateau. Here in the middle and southern part of the Gunnison Plateau it makes better historical sense to recognize the Wales Tongue as part of the whole formation locally. Doing so requires that the principal thickness of the formation be named separately, and "main body" describes that part. Unpublished maps made prior to Lawton's partition of the North Horn Formation (Lawton and others, 1993) included the Wales Tongue with the main body of the Flagstaff near and north of Wales, where the intervening tongue of red mudstone (now called the upper redbed unit of the North Horn Formation) is thin. Farther south, the carbonate tongue was regarded locally as a limy unit in the North Horn Formation. Locally, as in South Maple Canyon in the Manti quadrangle, the Flagstaff was considered to have a red unit within it, similar to the much thicker one of the same sort in the southern Wasatch Plateau. That "red unit," of course, was the upper redbed unit of current usage. The increase of named units makes for a busier map, but Lawton's initiative has led to a more rational assignment of those two tongues and a better understanding of the sedimentary and structural history of the region. Godo (1979) described the main body of the Flagstaff Limestone in detail, but most of his sections are from sites farther south than the Chriss Canyon quadrangle. He was perhaps the first to recognize the abundance of pedogenic horizons in the unit.

Although Spieker (1946, 1949) and all earlier workers called the formation "limestone," it is known to contain dolomite and dolomitic limestone – to nearly half the volume of the whole (Weiss, unpublished data, 1965-67; Godo, 1979). With reference to the main body where it is fully developed in the eastern and southern parts of the quadrangle, the Flagstaff consists of thin and medium beds of carbonate rock separated by shaly partings and thin beds of limy mudstone. Medium and thick intervals of irregularly bedded limy mudstone weather to slopes covered with angular chips, and separate the cliffy carbonate beds. The limestone, mostly with subordinate dolomite, is light-gray or yellowish-gray micrite and fine sparite, with locally abundant gastropod fossils. Most dolomite beds are limy dolomicrite, with spar-filled cavities and local pseudomorphs of bladed gypsum, as well as fragments of gastropods. Much of the dolomicrite is mottled, contains micrite intraclasts, and weathers faintly orange, in contrast to the lighter gray of the weathered limestone. Beds of fine- to medium-grained sandstone are rare in the formation and grade into calcareous siltstone.

The formation changes markedly as it thins westward from the plateau top into the West Gunnsion monocline, because the Flagstaff Limestone laps onto the Levan culmination, as does the North Horn Formation, and it even oversteps the feather edge of the North Horn. In these western zones the formation lies in angular unconformity on the Arapien Shale; the Twist Gulch, Cedar Mountain, and San Pitch Formations; and, just north of the quadrangle, on the undifferentiated Indianola Group. Near its western margin the Flagstaff is much more muddy and the mudstone interbeds are thicker. Where the Flagstaff lies in angular unconformity on the San Pitch Formation and the undifferentiated Indianola Group, near the northeast corner of the quadrangle, it is very sandy and pebbly. It is colored red locally by subjacent Mesozoic muds, and elsewhere is a hard, gray limestone full of sand, pebbles, and small cobbles. Godo (1979) found gastropod fossils in this type of rock.

Away from that edge of the basin the Flagstaff Limestone is generally concordant with the upper redbed unit of the North Horn Formation, and overlies it sharply. Locally, as described above, it lies on the calcareous siltstone unit of the North Horn Formation where the upper redbed unit is absent; at those sites the Wales Tongue becomes the basal bed of the main body of the Flagstaff. The upper contact with the Colton Formation is gradational regionally, for the uppermost Flagstaff is mostly gray limy mudstone. The base of the Colton is considered to begin with the oxidized, colorful beds of shale and mudstone (Marcantel and Weiss, 1968). The Colton is absent over a few square miles in the WCR, and there the shale member of the Green River Formation lies directly on the Flagstaff beds. In the NER the Flagstaff is 0 to 100 feet (0-30 m) thick. Where patches of it lie on Jurassic beds in the NCR it reaches 400 to 500 feet (122-152 m) of maximum thickness. On the south wall of Little Salt

Creek, near where it dips beneath the surface, the Flagstaff is about 150 feet (46 m) thick. From there it thickens eastward to about 480 feet (146 m), and is somewhat thicker in the Wales quadrangle (Lawton and Weiss, 1999). The same eastward thickening is seen in Chriss Creek, where it thickens to about 400 feet (122 m) thick in the "battleship" in section 21, SCR. A measured section of the Flagstaff Limestone in Timber Canyon that topped out in SW1/4 section 33, just off the south edge of the quadrangle, is 781 feet (238 m) thick (Godo, 1979). The formation thickens southward in the plateau but, more important, the Timber Canyon section is farther east of the Levan culmination.

The Flagstaff Limestone was deposited in a large lake and bordering marshes that spread over much of central Utah (Stanley and Collinson, 1979). Usually called Lake Flagstaff (La Rocque, 1960; Weiss, 1969), the lake fluctuated between a shallow lake and a broad marsh. The sedimentary features, the fossils, and the abundance of dolomite attest to the shallowness of the lake and to the intermittent exposure of large areas of lacustrine or marsh (paludal) muds (Lawton and Weiss, 1999). Platt and Wright (1992) suggested the term palustrine for freshwater carbonate deposits formed under alternating subaqueous and subaerial conditions. They also suggested that the carbonate marsh produced most of the sediment, as opposed to pedogenic modification of lake-margin facies.

The Flagstaff Limestone of the Gunnison Plateau has traditionally been correlated with the upper part of the much thicker Flagstaff Limestone on the Wasatch Plateau (La Rocque, 1960; Stanley and Collinson, 1979). Because the biostratigraphy is not definite on this point, Lawton and Weiss (1999) suggested that the main body of the Flagstaff here is correlative, at least in part, with the middle part of the formation on the Wasatch Plateau – the Cove Mountain Member of Stanley and Collinson (1979). This correlation is supported by features of desiccation, such as dolomite and pseudomorphs of evaporite minerals, that are common to the two bodies of rock. The age of the main body of the Flagstaff Limestone is early Eocene (Jacobson and Nichols, 1982; Rich and Collinson, 1973).

Colton Formation (Tc)

Like the main body of the Flagstaff Limestone, the Colton Formation is widespread on the high surface of the southern two-thirds of the Gunnison Plateau. In contrast to the Flagstaff, however, it is soft, weathers readily to slopes, and is almost everywhere well covered by vegetation. It consists mostly of mudstone and claystone of many colors, including reddish brown, red, purple or violet, light gray, greenish gray, and very light gray. Many thin beds of glassy micritic limestone and fine sparite are interbedded with the mudstone and claystone beds. They exhibit a similar variety of colors, but most are some shade of gray, suggesting a lower oxidation state than that of the fine clastic beds. Mollusks and ostracodes are common in some limestone beds. Intraclasts are common in most of the beds; about half of the limestones are micrites and half are intrasparites and intrarudites (Volkert, 1980).

Weakly cemented yellowish-brown siltstone and silty sandstone beds are also present. The sandstone beds are feldspathic and either sheet-like or channel-form in shape, and they comprise only a few percent of the thickness of the Colton. Grains of weathered feldspar (subequal plagioclase and K-feldspar) are next most abundant to quartz sand grains; 7 to 12 percent of the grains are feldspar in most samples, but may reach as high as 27 percent in some beds (Volkert, 1980). The feldspathic sandstone contrasts markedly with the highly quartzose and lithic sandstone of the Cretaceous formations and the Green River Formation. These sandstone beds support the hypothesis that the fluviatile clastics that overrode the lacustrine and palustrine Flagstaff Limestone came from the southeast (Stanley and Collinson, 1979; Dickinson and others, 1986).

The Colton Formation, regionally, lies concordantly on the Flagstaff Limestone and beneath the shale member of the Green River Formation. It grades from the Flagstaff by the more numerous oxidized beds and the fewer beds of carbonate rock; it grades to the lower Green River by loss of the bright colors of oxidation, the change to gray and greenish-gray mudstone, and a gain of carbonate in the form of many thin and medium beds of white-weathering limestone. Locally, however, the Colton Formation is absent and the shale member of the Green River Formation lies directly on the Flagstaff Limestone. At such places, the lacustrine-palustrine environment of Flagstaff Lake persisted without being overwhelmed by the fluviatile and oxidized Colton deposits. There is no evidence of the Colton having been deposited at such places and then removed; it simply was not deposited – probably those were high points on the basin floor, perhaps associated with the Levan culmination. The lacustrine-palustrine limy muds of the lower Green River Formation were then deposited directly upon undisturbed upper Flagstaff beds.

Zeller (1949) recognized the absence of the Colton Formation in this quadrangle, in sections 4 and 5, south of Little Salt Creek, but this was not mentioned in Hardy and Zeller (1953). The Colton appears again in section 17, just north of Chriss Creek. Thus, it may be presumed to be absent from about 4.5 square miles (11.7 km2) of the WCR of this quadrangle, and an unknown additional area to the west. Whether there are Colton beds on Skinner Peaks, just to the west of the SWR of this quadrangle, is uncertain because of changes of lithofacies (Felger, 1991). The Skinner Peaks area was not the regional depositional limit of the Colton Formation, however, for it is present farther west across Juab Valley in the West Hills (Clark, 1990).

The Colton Formation was formed under a variety of fluviatile and minor lacustrine conditions: wide areas of flood plain, channels, local overbank splays of sand or silt, and ponds or marshes wherein the limestones formed. Konowal and Wells (1998) gave an excellent short summary of the Colton Formation and its origin. The local channel deposits formed the lenses of weakly cross-bedded sandstone. Because of thinning toward the Levan culmination – and its absence on top of it – the Colton has a variety of thicknesses over the quadrangle. At Sage Flat in the NER it is 220 feet (67 m) thick, but 420 to 480 feet (128-146 m) in sections 10 and 1 of the ECR, respectively. It is about 370 feet (113 m) thick in the W1/2 of section 16 of the CR. In the SER the Colton ranges from 440 feet in section 26 to 480 feet (134-146 m) in sections 14 and 23. It ranges from 120 feet (37 m) in section 20 to 160 feet (49 m) thick in the SWR; this area is south of where the Colton was not deposited, and also somewhat westerly, close to the buried Levan culmination.

The Colton Formation is early Eocene in age, lying as it does between the early Eocene Flagstaff Limestone and the middle-and-upper Eocene Green River Formation. Although deposition of the Colton began in the Paleocene in the Uinta Basin, it did not develop in central Utah until the early Eocene (Fouch and others, 1983).

Green River Formation

The Green River Formation occupies the axial crest of the Gunnison Plateau, but also forms the outer layer of the West Gunnison monocline. North of Little Salt Creek the outcrops of the Green River in the monocline are trivial in area, but from Little Salt Creek to the south edge of the quadrangle, and in the nearby Skinner Peaks, the Green River forms most of the outer skin of the monocline. The formation was deposited in the southwestern arm of Lake Uinta and consists of two major unnamed rock units: a lower calcareous shale member and an upper limestone member. When these were deposited in Lake Uinta the shore of the lake was in the West Hills, not far west of the Chriss Canyon quadrangle. The lithofacies here are somewhat different from exposures farther east; the limestone member, particularly, contains much more clastic material here than it does regionally. The shale member is very thick within the plateau, where little of the limestone member remains. In the West Gunnison monocline, in the southwest quadrant of the Chriss Canyon quadrangle, the shale member is diminished in thickness and the upper limestone makes up most of the formation.

The shale member of the Green River Formation is middle Eocene in age, by comparison with known ages of the Flagstaff Limestone. Sheliga (1980) obtained two isotopic ages (43.34 ± 0.64 and 43.59 ± 0.49 Ma) 131 feet (40 m) below the top of the shale member and an age of 46.35 ± 1.12 Ma 472 feet (144 m) below the top of the shale member, by $^{40}Ar/^{39}Ar$ dating of biotite and other minerals from tuff beds in Sanpete Valley. He concluded that the Green River Formation was deposited over an interval of 4 to 5 million years. Tuffs in the Green River Formation at the north end of the Wasatch Plateau yielded ages of 42 to 45 million years by zircon fission-track dating (Bryant and others, 1989). The Goldens Ranch Formation that overlies the Green River west of the Chriss Canyon quadrangle is late Eocene to middle Oligocene by potassium-argon dating (Witkind and Marvin, 1989).

Shale member (Tgs): The shale member consists of light-gray and greenish-gray mudstone and shale with many thin beds of very light-gray, white-weathering limestone. It forms steep slopes of greenish-gray mud and soil, and is prone to landsliding. Medium beds of poorly cemented quartzose sandstone that weather to a dark brown are not common, but form conspicuous benches where the dips are low, as on the plateau top. The limestone beds are micritic, brittle, poorly fossiliferous (mollusks), and some are glassy. Some beds are dolomitic limestone or dolomite, and have a higher content of fine siliceous clastics than the limestones (Millen, 1982). Consistent with the increase of clastic materials westward, the shale member has less limestone in it in the western part of the quadrangle than it does near the east edge of the quadrangle.

The Colton-lower Green River contact is a transition from the highly oxidized Colton beds to the reduced lower Green River beds (Marcantel and Weiss, 1968). Although gradational, this contact is readily distinguished in outcrop or by soils. The change from the shale to the limestone member is also gradational; regionally, it is recognized by the increase of limestone and sandy limestone of a different color (light yellowish brown), the addition of a few clean limy sandstone beds of the same color, and by the addition of thin and medium beds of biotitic tuff. In the western parts of the Chriss Canyon quadrangle the change is even more marked because of the abundance of sandy limestone, sandstone, and even pebbly sandstone in the lower part of the limestone member.

The shale member is 911 feet (278 m) thick just east of the southeast corner of the quadrangle (Millen, 1982). It is only about 230 feet (70 m) thick in the NER, where it has been thinned by erosion. Even so, the whole Green River Formation thins northward on the plateau. The shale member ranges between 300 and 500 feet (91-152 m) thick in the CR and SWR, but is only 0 to 200 feet (0-61 m) thick in the WCR, where the limestone member overlaps the shale member onto the Arapien Shale. The shale member may thicken to about 800 feet (245 m) along the line of cross section B-B′. These data show the tendency for the limestone member to thicken westward at the expense of the lower shale member.

The shale member has generally been ascribed to deposition in Lake Uinta (for example, Stanley and Collinson, 1979), but the abundance of siliceous mud, silt, and some sand suggests that the prevailing environment may have been palustrine, the concept of Platt and Wright (1992). Ponds and shallow lakes did, however, cover large areas from time to time to deposit the limestone and dolomitic limestone. Whatever the case, the iron in the entire member is in a reduced state, which indicates that the environment was usually damp and always contained abundant biogenic sediment.

Limestone member including "Tawny facies or beds" (Tgl): A conspicuous change in the lithology of this member that takes place across the quadrangle has been mentioned already. In the east, and regionally, the limestone member consists of finely crystalline, yellowish, gray-weathering sparite in thin to thick beds, very light-gray micritic limestone, and pale-yellowish-gray micritic dolomite. The member forms a resistant cap and cliffs over the soft shale member. Some sparite beds containing abundant well-rounded, fine and medium quartz sand grains are weakly cross-bedded. Some of these grade to limy sandstone, but are not well cemented. Thin beds of shale and shaly limestone separate the carbonate beds. The member is oolitic locally, and thin stromatolite beds are present in a few locales, but very little of either is found in the Chriss Canyon area (Millen, 1982). Weiss (1982c) suggested that the Green River and Crazy Hollow Formations are closely related, always concordant, and locally gradational, and this has since been demonstrated (Norton, 1986; Mattox and Weiss, 1989; Weiss and Warner (2001).

Biotitic tuffs, white- and orange-weathering, are present in beds up to 3 feet (1 m) thick in the upper layers of the limestone member throughout the quadrangle, in both carbonate and clastic facies (Millen, 1982). The tuffs have a quartz-feldspar groundmass and a few percent of biotite and hornblende; the abundance of phenocrysts of the main minerals differs widely, to as high as 50 percent of the rock. Most beds contain some chips and flat pebbles of limy mudstone (Millen, 1982).

The limestone member of the Green River Formation was deposited as a delta plain and its proximal alluvial facies (Millen, 1982), and Felger (1991) endorsed the concept. The fan/delta system was formed by material from the west that was dumped into the southwest arm of Lake Uinta. Through time, the ratio of lacustrine to subaerial deposits decreased, and the more fully terrestrial deposits of the Crazy Hollow Formation prevailed in the region. Sundback and Wells (1998) described the development of the Green River Formation well.

Westward across the quadrangle the member loses most of its carbonate beds and gains mudstone, siltstone, sandstone, and even conglomeratic beds. The relationship is well illustrated by Millen (1982, plate 1) and, in the Hells Kitchen Canyon Southeast quadrangle, by Mattox (1987, figure 4). The change is believed to have taken place because of proximity to the western margin of the southwest arm of Lake Uinta, which lay little more than 8 miles (13 km) west of this quadrangle during the Eocene Epoch. Millen (1982) studied the Green River Formation over the central part of the Gunnison Plateau and discussed several sections within the western lithofacies of the limestone member of the Green River Formation. His sections and the one on Skinner Peaks by Felger (1991) detail this western facies best. Consideration of this facies requires a discussion of a concept originated by Zeller (1949) – the "Tawny facies" or "Tawny beds." These terms have had a checkered history since that time, and it may be possible to settle the matter here once and for all. The concept applies only in this quadrangle and part of the adjacent Skinner Peaks quadrangle. We describe the unit first, and then briefly summarize the history of this strange name.

"Tawny facies or beds": In the west half of section 7 (WCR) and on the north side of Chriss Creek, the shale member of the Green River is overlain by yellowish-brown siltstone and sandstone and light-greenish-gray beds of mudstone. Numerous pebbles are present in some of the sandstone beds; many of the pebbles are black chert, an indicator of the upper Green River beds and the Crazy Hollow Formation locally. A few percent of feldspar is mixed with the quartz in the sandstone. As the beds become more clastic, they become more brown and orange in color. Less than a mile (1 km) northwest of there, in the NE1/4 section 12, the upper and middle parts of the member contain an abundance of clastic material, much of it in dirty and sandy limestone beds. The proportions in that area are: muddy and sandy limestone, 60 percent; shale and mudstone, 26 percent; sandstone, 11.5 percent; and conglomerate 2.5 percent (Zeller, 1949; Millen, 1982). A mile and a half (2.4 km) south of the same starting point, in the NE1/4 section 13, the proportions are: muddy and sandy limestone, 4.3 percent; shale and mudstone, 26 percent; sandstone, 16 percent; limy siltstone and sandy siltstone, 5.8 percent; partly covered sandstone and siltstone, 31 percent; tuff, 0.85 percent; and covered intervals, 14.7 percent (Millen, 1982). Most beds of the principal rocks – sandstone, mudstone, and limestone – are medium to thick bedded. The average thickness of the sandstone beds is between 6 and 8.5 feet (1.9 2.6 m); the average of the mudstone beds is about 13 feet (4 m); that of the limestone beds north of Chriss Creek is about 19 feet (5.8 m) and south of Chriss Creek 7 to 8 feet (2.1 2.4 m) (Millen, 1982). The pebbles and small cobbles in the conglomerate and sandy beds include some from Proterozoic and Cambrian quartzites and Paleozoic dolomites, in addition to the black chert, also from Paleozoic formations. However, the abundant conglomerate of Millen's section No. 8, the Flat Canyon Road section that he adapted from Vogel (1957), is no longer considered part of the Green River Formation, but rather an equivalent of the Flagstaff Limestone and North Horn Formation below the Green River (Felger, 1991).

This unit of mixed clastics and carbonates is 1,117 feet (340 m) thick at the mouth of Deep Creek, just north of this quadrangle (Millen, 1982). Auby (1991) cites 1,420 feet (433 m) for that locality, but his figure includes both the shale and limestone members of the Green River. The part exposed in section 7, WCR, north of Chriss Creek is 379 feet (116 m) thick (Zeller, 1949; Millen, 1982). The Pierce Canyon section, in SW1/4 section 19, SWR, includes 735 feet (224 m) of the member (Millen, 1982). Measurements made in the Skinner Peaks area and attributed to the limestone member are excluded from this list in order to confine attention to Zeller's original concept and to avoid possible confusion with other application of the term "Tawny beds."

Zeller (1949) recognized these darker colored, more clastic beds in 1948, said that they were a western lithofacies of the upper part of the Green River Formation, and called them the "Tawny facies." They are about the color of a lion hiding in the tall grass; E. M. Spieker may have suggested the term, for the old USGS used strange words for colors – drab, somber, tawny. Hunt (1950) did his field work in 1948-49, picked up the concept from Zeller that first summer, and found beds of similar color in the western edge of the West Gunnison monocline as far north as the middle part of the Levan quadrangle (Tg of Auby, 1991). He called them "Tawny beds," denied that they were part of the Green River Formation because Zeller had not proved the facies relationship, made them a separate unit, and said that they were unconformable on Green River beds in the West Hills (the southern part of Long Ridge in those days, and outside of Hunt's area) (Hunt, 1950). The latter claim is not supported by Clark (1990). The next worker on the scene was Vogel (1957), who also had no topographic maps to aid him. Presuming Hunt's claim of unconformity to be accurate, he treated the "Tawny beds" as a separate formation lying on the Green River and beneath the Goldens Ranch Formation of volcaniclastics. He suspected that the "Tawny beds" might be the Crazy Hollow Formation, but noted that they contained fossils typical of the Green River Formation (La Rocque, 1956; Vogel, 1957).

Vogel (1957) included the conglomeratic Tertiary beds lying unconformably on the Arapien Shale on Skinner Peaks in his "Tawny beds." Millen (1982) denied that the "Tawny beds" of Hunt (1950) and Vogel (1957) were a separate formation, but instead are a western, clastic facies of the limestone member of the Green River Formation. While thus endorsing Zeller's original concept, Millen also followed Vogel's view of the conglomeratic beds on the Arapien Shale in Skinner Peaks, and put them in the limestone member of the Green River (Millen, 1982). Norton (1986) studied the Crazy Hollow Formation throughout central Utah, and concluded that the "Tawny beds" are the Crazy Hollow Formation. The resemblance is appealing for the two are intimately related, as we shall soon see, but even her table of comparative mineralogy of the three – Green River, "Tawny beds," and Crazy Hollow – suggests that the "Tawny beds" are an intermediate step between the upper Green River and the Crazy Hollow. A similar transition was shown by Weiss (1982c, table 1). Felger (1991) restudied the problem, called these beds the "Tawny facies or beds," and concluded that they are the western facies of the upper member of the Green River Formation. The present authors take the same view, and have included the contested section in Tgu on the map. We believe that the clastic western facies of the limestone member portended the deposition of the Crazy Hollow beds, but that they are not the same body of rock. If, as Norton (1986) did, we were to put all these clastic beds into the Crazy Hollow Formation, only a diminished thickness of lower Green River beds would remain to represent the great body of rock that the Green River Formation is regionally. We believe it is better to regard the clasticity of the upper Green River in the west as lake-marginal lithofacies of the Green River Formation, not the Crazy Hollow Formation.

One more problem remains. Bedding is inconspicuous in the upper part of the limestone member of the Green River Formation (the "Tawny facies"). Many beds are lenses or of very limited extent. In the middle and upper part of the member the rock is quite brownish or brownish orange, colors seen also in the much younger alluvial fan mapped as QTaf. The contact between the "Tawny facies" and the fan deposits is difficult to locate and to map, partly because the alluvial fan contains so much sediment that was derived from the limestone member of the Green River. In his early report on the Green River/Crazy Hollow relationship, Weiss (1982c) confused the attributes of the upper member (Tgu) and the old alluvial-fan deposit (QTaf) somewhat.

Crazy Hollow Formation (Tch)

Deposition of the Crazy Hollow Formation followed the drying of Lake Uinta, similarly as the Colton Formation followed Lake Flagstaff. Thick deposits of late Eocene and younger beds succeeded the Green River Formation in the Uinta Basin of northeastern Utah and the Gosiute Basin of southwestern Wyoming, but those are not connected to the Crazy Hollow Formation and resemble it only in that they are also clastic units spread into a former lake basin. The Crazy Hollow differs from the others also in that it did not cover the entire floor of the southwest arm of Lake Uinta, but was deposited only in patches, near bordering highlands that provided the sediment. Lithofacies of the Crazy Hollow are numerous, and differ over rather short distances. Except for Plio-Pleistocene deposits, the Crazy Hollow Formation is the youngest consolidated sedimentary unit in the region. In and west of Juab Valley, however, the Green River Formation is succeeded by the Goldens Ranch Formation, which includes both volcaniclastic and sedimentary members.

Regionally, the Crazy Hollow Formation contains red mudstone, light-gray sandstone, thin, gray pond limestone, and the "signature" rock type of the formation – "salt-and-pepper sandstone" (Weiss and Warner, 2001). That sandstone is dominated by grains and pebbles of black and light-gray chert, in addition to quartz, and contains nearly as much feldspar as does the Colton Formation (Norton, 1986). Beds of such sandstone lie atop the crest of the Gunnison Plateau not far south of this quadrangle (Mattox, 1987) and across Utah Highway 28 not far west of here (Norton, 1986). The one outcrop of the Crazy Hollow in this quadrangle is in a fault block west of the middle of the SCR. There the unit is composed of brownish-orange mudstone and conglomeratic sandstone – most of the numerous pebbles being black chert. No contact with the limestone member of the Green River Formation is exposed. We cannot be certain that that outcrop is not a part of the limestone member, but it is different from the paler colored and pebble-free Green River nearby, and it is very different from the thick development of the limestone member in the section measured in SW1/4 section 19, SWR (Millen, 1982).

The Crazy Hollow Formation ranges from 0 to 1,307 feet (0-398 m) in thickness over the region (Norton, 1986). The thickness exposed in this quadrangle is estimated at about 400 feet (122 m). The variety of lithofacies, erratic thicknesses, and patchy distribution of Crazy Hollow beds indicate a highly varied fluviatile environment, with local pond or paludal carbonate lenses. Fossils in the Crazy Hollow are like those in the Green River, and indicate a late Eocene age. Using published and unpublished radiometric dates of units lying above and below the Crazy Hollow, Norton (1986) concluded that it is late Eocene in age. Both methods give an age that accords nicely with the evidence about the close sedimentologic relationship between the limestone member of the Green River and Crazy Hollow, discussed above.

Tertiary Intrusive Rocks (Td, Tmp, Tbmp, Thmp, Tlm)

More than 40 small stocks, plugs, dikes, and sills intrude the Arapien Shale, the Twist Gulch Formation, and the Arapien-Green River contact in the Levan culmination between Pigeon Creek (east of Levan, Utah) and Little Salt Creek. The largest is the Water Hollow stock (John, 1972), which is a mile (1.6 km) in diameter and located 1.5 miles (2.4 km) north of the northwest corner of this quadrangle. About 20 small stocks, plugs, dikes, and sills lie in the Chriss Canyon quadrangle, and are labeled according to the rock type. Many of the intrusions in the Levan and Chriss Canyon quadrangles were studied by John (1972), who called the largest in the Chriss Canyon quadrangle the Broad Canyon stock (NCR). Auby (1991) discovered some additional examples, and named the swarm of intrusions the Levan monzonite suite.

Examples of five of the six rock varieties described by John (1972) are found in this quadrangle – all in the northwest (NW) and north-central (NC) rectangles. Nearly all of the intrusions penetrate the Arapien Shale, but a few cut other units. The Twist Gulch is cut by stocks of leucomonzonite porphyry in the NW1/4 section 22, NCR and in the NE1/4 section 32, NCR. The upper unit of the North Horn Formation is cut by a small plug of leucomonzonite in the SW1/4 section 32, NWR. The Flagstaff Formation is cut by plugs of diabase and hornblende monzonite porphyry in the NW1/4 section 28 and the NE1/4 section 29, NCR. The limestone member of the Green River Formation is cut by a small stock of hornblende monzonite porphyry in the W1/2 section 32, NWR. Each rock variety mapped is described briefly, following John (1972).

The porhyritic diabase (Td) is light greenish gray, but darkens on weathering. Large phenocryts of biotite, feldspar, and hornblende make up 10 percent of a sample. Inclusions of one diabase body are found in the hornblende monzonite porphyry that intruded it, and the other was cut by a body of leucomonzonite (Tlm).

The biotite-augite monzonite porphyry (Tbmp) stock in the N1/2 section 22 (NCR) is phaneritic and white with greenish-gray grains, but stains with limonite upon weathering. It differs from the monzonite porphyry (Tmp) in having conspicuous grains of biotite and augite. That and severe alteration near the contact with the younger leucomonzonite (Tlm) cause the stock to weather readily.

The monzonite porphyry (Tmp) in the Broad Canyon stock is pinkish gray to light gray and weathers to shades of yellow and brown. The groundmass is aphanitic, and phenocrysts of feldspar, hornblende, and biotite stand out. Both K-feldspar and andesine are present, and the latter is the major fraction of the rock.

The bodies of hornblende monzonite porphyry (Thmp) are distinguished by having 20 percent or more of hornblende, much of which is in large, bright, black phenocrysts. The fresh groundmass is mostly feldspar, and is light gray or greenish gray, but weathers to light olive gray or light brown.

The porphyritic leucomonzonite (Tlm) is very pale in color and darkens slightly to pale yellowish brown on weathering. It has a fine texture with few phenocrysts, and is even finer in the dikes and sills. The principal feldspar in the larger bodies is oligoclase, but andesine in the smaller ones. The light color is due to the fact that ferromagnesian minerals are 5 or less percent of the rock.

The most abundant rock type is the monzonite porphyry (Tmp) in what John (1972) called the Broad Canyon stock in the NCR. Nearly as abundant is the hornblende monzonite porphyry (Thmp) found in several small stocks and plugs between Little Red Hill and the northwest corner of the quadrangle. The biotite-augite monzonite porphyry (Tbmp) is in a small stock in section 22, NCR. The dikes and sills in the area are of either the diabase (Td), the monzonite porphyry (Tmp), or a porphyritic leucomonzonite (Tlm). The latter also forms a small stock in sections 29 and 32, NCR and a few small plugs. Two small pipes of porphyritic diabase (Td) are cut by larger bodies in section 29, NCR. The tiny outcrops of syenodiorite mentioned by John (1972) are not mapped.

Map relationships show that the diabase is the oldest intrusive rock and that the leucomonzonite is younger than the biotite-augite monzonite; it is probable, as John suggested, that the latter monzonite and the two other monzonite porphyrys are about the same age. Otherwise, he judged relative age by silica content; the intrusions toward the southeast are most basic, and silica content increases northwestward with decreasing age.

Having no age data, John (1972) was unable to discuss the age of the Levan monzonite suite, but he speculated that its intrusions may have been the conduits through which the extrusive materials in the Moroni Formation were delivered to the surface. The Moroni Formation is exposed north and east of the Gunnison Plateau. Greater confidence might have been had in calling the Levan monzonite suite the source for part of the Goldens Ranch Formation, which lies not far west of these intrusions. But small matter, for the igneous materials in the Moroni and Goldens Ranch Formations have since been demonstrated to be closely similar in age (Witkind and Marvin, 1989). However, de Vries (1990) found that they are not petrographically or geochemically "correlative."

Despite the uncertainties of potassium-argon dating, John's (1972) idea that the Levan monzonite intrusives fed the extrusive rocks in the Goldens Ranch and Moroni Formations may not be correct. Witkind and Marvin (1989) discussed radiometric and paleobotanical ages from many units in those two formations and came to the conclusion that both the Goldens Ranch and Moroni Formations are from late Eocene to middle Oligocene in age. Auby (1991) had two samples from the Levan monzonite suite dated by the potassium-argon method; they yielded ages of 23.5 ± 1 Ma and 23.3 ± 1.3 Ma, or early Miocene. Witkind and Marvin (1989) also dated some samples from the Levan monzonite suite and got ages similar to those reported by Auby (1991).

Tertiary and Quaternary

Almost all of the area of the Chriss Canyon quadrangle is steep upland that yields sediment rather than accumulating it. Thus, only a few types of unconsolidated deposits are found in the quadrangle. However, mass-wasting and colluvial deposits associated with steep slopes are common. Only one deposit (QTaf) is believed to be partly Tertiary in age.

Alluvial Deposits (Qal_1, Qal_2)

Alluvial deposits consist of light-yellowish-gray or pale-yellowish-brown, uncemented, stratified, moderately sorted mud, sand, and gravel of many sizes deposited by streams. The pebbles and larger clasts are typically well rounded from churning and tumbling in the streams. The deposits include small alluvial fans of similar sediment dumped onto the flood-plain surfaces from tributary gulches; such fans are too small to differentiate at the 1:24,000 scale.

Modern deposits of alluvium are of only trivial size in this quadrangle. Significant modern deposits are only found farther downstream, outside of this quadrangle, for stream alluvium here is being mostly eroded and exported rather than added to. The transition from erosion to deposition takes place on Chriss Creek, for example, in the Skinner Peaks quadrangle, close to the mouth of the creek at the apex of the Chriss Creek fan.

Except for Pierce Creek, in the SWR, the drainageways from the highlands in the quadrangle cross over the Levan culmination – the welt of Arapien Shale that plunges below younger beds just south of Little Salt Creek. We believe that local diapirism of the labile mudstones and evaporites of the Arapien Shale may have elevated the Levan culmination in both Pleistocene and Holocene times. Some elevation of these deposits was surely also due to rises of the plateau block on the east side of the Wasatch fault. Thus the formerly aggrading alluvial deposits in the creeks have been slowly elevated so that those deposits are now incised by their creeks, and their surfaces stand a few tens of feet above the average gradient of their streams. Thus no modern alluvium is mapped in the quadrangle, and the youngest alluvial deposits are labeled Qal_1.

All Qal_1 deposits closely flank the stream that is now dissecting them. The surfaces of these deposits still receive a little sediment from slopewash or storm discharges from tributary gulches, but the stream deposits are entrenched 20 feet (7 m) or more by their master streams. The material eroded is carried to Juab Valley and redeposited there, perhaps as alluvial fans. These stream deposits are 20 to 30 feet (6-9 m) thick at most, and are considered early to middle Holocene in age.

Deposits mapped as Qal_2 lying along Chriss and Pierce Creeks are incised 40 to 60 feet (12-18 m) by modern streams. Their thickness ranges from 0 to about 30 feet (0-9 m), and they are thought to be late Pleistocene to early Holocene in age. These deposits appear superficially like those mapped as Qaf_1 along Little Salt Creek in section 3 (CR), but Qaf_1 deposits rise much higher on the valley walls and form true alluvial fans.

Alluvial-Fan Deposits (Qaf_1, $Qacf_1$, Qacf , QTaf)

Alluvial fans are aprons of rocky debris – from gravel to mud – deposited by streams at a point where the stream gradient decreases significantly and reduces the stream's ability to transport sediment. The sediment is very like that of the alluvial deposits along streams in color, texture, and the lack of structure. In the small fans deposited on flood plains by tributary gulches during storms, the clasts are more angular than those in the stream deposits and on the larger fans because they have not been milled repeatedly in turbulent water. The small fans are also less well bedded than the deposits in the larger fans.

Qaf_1 marks two patches of dissected, coalesced alluvial fans in the valley of Little Salt Creek, in section 3 in the CR. Their lower parts grade to an old flood plain of Little Salt Creek, and their upper parts rise 80 or 90 feet (24-27 m) above the modern channel; they are 0 to 70 feet (0-21 m) thick. Being older than fans under construction, they are considered correlative with the older Holocene alluvium (Qal_1). No small fans correlative in age to modern alluvium are mapped in the quadrangle.

Much larger fans that extend into and fill Juab Valley are labeled as either $Qacf_1$, $Qacf_2$, or QTaf. The "c" indicates that the fans are coalesced and part of a larger apron of sediment shed off the Gunnison Plateau and Skinner Peaks; the subscripts 1 and 2 indicate different levels of the upper surface of the great mass of basin-fill deposits mapped as QTaf. These labels are chosen to accomplish both the best match with the names used for the same deposits on published maps of adjacent quadrangles and to draw appropriate distinctions within this quadrangle.

$Qacf_1$ is the coalesced alluvial-fan and valley-fill sediment in Juab Valley that lies close to the highland source. This is the younger fan material being spilled out periodically into Juab Valley in the northwest corner of the quadrangle. These deposits do not reach very far from the mountain front, and are of the order of 0 to 50 feet (0-15 m) thick. They are modern at the surface and probably older Holocene at depth.

$Qacf_2$ is sediment similar to that of $Qacf_1$, but older, as evidenced by the fact that deposits of $Qacf_1$ lie upon it and that it is being dissected by the modern streams that deliver the sediment of $Qacf_1$ and continue in box washes (in the adjacent quadrangle) to more distal parts of the valley-fill fans. Sediment mapped as $Qacf_2$ is up to several tens of feet thick. No data are available on the thickness of the older fans in adjacent southern Juab Valley. Given the proximity of the south end of Long Ridge and the north end of the Valley Mountains, however, their thickness probably is not greater than 1,000 feet (305 m) near the middle of Juab Valley. The thickness of these older, coalesced alluvial-fan deposits in the northwest corner of the Chriss Canyon quadrangle is unknown, but they may be several hundred feet or more thick. The thickness of $Qacf_2$ in Flat Canyon is also unknown, for it lies on the older fan deposit (QTaf), and may therefore be only 100 to 200 feet (30-60 m) thick. $Qacf_2$ represents a long span of ages. It is late Pleistocene at the youngest, and its base may be older than Pleistocene; we choose a Quaternary designation for simplicity.

The modern and older coalesced fans, $Qacf_1$ and $Qacf_2$, mapped in the NWR match in both concept and area the usage of Auby (1991) and Felger (1991). Our usage for the deposits in Flat Canyon (which has a very gentle V-shape and is not really flat) differs slightly from that of Mattox (1987), who called them Qaf_1, the younger of two ages of fan aprons. We believe that because there is little modern supply of new sediment to the floor of Flat Canyon, and because the floor is deeply gulched and dissected by the drainage net, that these deposits should be called $Qacf_2$. If the surface is followed down-canyon to Sevier Valley, one sees that it melds with a bajada surface in that valley that accords with the great sheet of older coalesced fan in Juab Valley, unit $Qacf_2$. Felger (1991) mapped the floor of Flat Canyon as modern alluvium (Qal), but she had only a small sample of the valley to observe. As her map is not yet published, we prefer to accommodate our concepts to those of both Mattox (1987) and Auby (1991).

QTaf is the thick mass of consolidated alluvial, debris flow, and colluvial sediment that by its thickness, elevation, area, and dissection suggests an age much greater than that of the other fan deposits mapped in the quadrangle. Most of the mass lies south of lower Chriss Creek, in the Skinner Peaks and Hells Kitchen Canyon Southwest quadrangles, but its eastern elements in this quadrangle lie in the S1/2 of section 13, SWR, and in small hills in upper Flat Canyon, in section 24. It was studied first by Niehaus (1956) and Vogel (1957), who called it "rubble beds" and mapped it as TQr, and later by Felger (1991), who called it "older alluvial fan" and mapped it as QTaf. Vogel and Felger mapped it very nearly the same way in the Skinner Peaks quadrangle, and agreed on the nature of the deposit and its history. Felger (1991) enlarged on Vogel's concept and concluded that the pebbly pediment alluvium (QTap of Felger) that lies unconformably on the Oligocene volcaniclastic Goldens Ranch Formation in the South Hills (across Juab Valley from Skinner Peaks and Chriss Creek) is a distal facies of the fan deposit.

The mass has no bedding except a few local lenses or beds – of small to medium thickness and lateral extent of 10 to 30 feet (3-9 m) – of sand, limestone (formed in ponds), sandstone, or conglomerate. It is colored yellowish gray or light brownish orange; Vogel (1957) used the term "tawny," a term then commonly applied to the uppermost beds of the Green River Formation in the Chriss Canyon quadrangle. It is true that the two are very similar in color, and also that much of the material in the fan seems to have been derived from the limestone member of the Green River Formation. Some clasts are identifiable as having come from pre-Green River formations on the plateau. Where it lies on the Goldens Ranch Formation, outside this quadrangle, it contains some volcanic clasts as well (Felger, 1991).

The QTaf deposit is unconformable on the Arapien Shale, the limestone member of the Green River Formation, and the Goldens Ranch Formation, all in the Skinner Peaks quadrangle (Vogel, 1957; Felger, 1991). The base is not exposed in the Chriss Canyon quadrangle. The thickness of the remnants of the former great alluvial fan is from 0 to a minimum of 300 feet (0-91 m), and it is thickest in the northeast corner of the Hells Kitchen Canyon Southwest quadrangle (Niehaus, 1956; Vogel, 1957). Seen in profile in the vicinity of the Skinner Peaks (just west of Flat Canyon), the surfaces of the remnants of the fan show a concave-up curve that decreases in slope westward (Felger, 1991, figure 32).

The great variation of the thickness of the deposit is ascribed to deposition on a surface of moderate relief that was faulted early in the episode of Basin and Range extension, and then eroded to soften the profile (Vogel, 1957). Vogel's idea seems still to be the best explanation, which makes the earliest possible age of QTaf early Miocene. Most of the deposit has been removed since its development, and younger alluvial materials lap onto the edges of its remnants in Flat Canyon, and in Sevier Valley outside this quadrangle. At one place in the southwest corner of the Skinner Peaks quadrangle, Lake Bonneville sediments overlie the pediment alluvium that lies on the Goldens Ranch Formation in the South Hills (Felger, 1991). As that pediment deposit is taken to be the downstream facies of this old alluvial-fan deposit, the age of both is greater than late Pleistocene. Although little remains of the fan, it was once an enormous deposit, and most of the limestone member of the Green River Formation was stripped from the West Gunnison moncline to build it. This suggests to us that it is probably pre-Pliocene (Miocene?) in age in its lower part.

Colluvial Deposits (Qc)

Colluvium is the name given to deposits of soil and broken rock lying on steep slopes. It is deposited principally by slopewash and soil creep and takes the color of the formation from which it is derived. Because the larger rock fragments are not milled as pebbles are in a stream, they are typically angular and even sharp. Thin sheets of colluvial material lie on most slopes in any area, but they are mapped here as colluvium only where the mass or layer is thick enough to obscure the bedrock beneath it. The thickness differs greatly between the smaller and larger patches, but is seldom greater than 70 feet (21 m). Elsewhere on the Gunnison Plateau there are sheets of colluvium of different ages, but only the modern deposits (Qc) of late Holocene age are found in the Chriss Canyon quadrangle.

Mixed Alluvial and Colluvial Deposits (Qac)

Deposits mapped as Qac are restricted to small swales on the divide between Little Salt Creek and Chriss Creek. The deposits consist of poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited principally by slopewash and minor alluvial processes. Mixed alluvial and colluvial deposits are gradational with both alluvial and colluvial deposits. The thickness of these deposits is uncertain, but probably is no greater than 50 feet (15 m). They are Holocene in age.

Mass-Wasting Deposits (Qms_1, Qms_2, Qms_2(c), Qms_2(gs), Qms_2(mp), and Qmtc)

Like colluvium, mass-wasting deposits are also formed in response to gravity, but differ from colluvium in their greater volume, the fact that they move as semi-coherent masses instead of particle by particle, and, in some cases, by the speed with which they form (landslides). The deposits are made up of rock particles of all sizes and the soils and vegetation (including big trees) that covered the material before it was displaced. As in the case of colluvium, mass-wasting deposits take the color of the formation from which they were derived, but are made darker by the organic matter incorporated into them. They usually have a crescentic scarp at the upper edge, where the mass broke away. The depression at the base of the scarp tends to hold water, and the Qms_1 and Qms_2 are thereby likely to be better vegetated than nearby bedrock slopes. The deposits are typically unstable, and may move many times over many years. The larger, patch-like landslides move slowly; the long, linear landslides (of which there are few in the quadrangle) form catastrophically in short periods of time. Small and linear landslides are 0 to about 50 feet (0-15 m) thick. The large ones may be as thick as 150 feet (46 m).

Qms_1 is used for Holocene deposits that may still be historically active, as during the 1983-85 wet period. Qms_2 is used for those deposits that are being dissected; that is, they have stabilized for the most part, and are themselves undergoing erosion; these are Pleistocene in age.

Qms_2(c) represents deposits derived from the colorful Colton Formation; they preserve the colors and some bedding of the formation because they have not moved very far nor are they fully disordered. Qms_2(gs) represents deposits derived from the shale member of the Green River Formation under conditions similar to those of Qms_2(c). Qms_2(mp) represents the deeply weathered and displaced monzonite prophyry in the Broad Canyon stock (NCR). Each of these deposits is considered to be Pleistocene to Holocene in age.

Qmtc is used for a toreva block, a large, displaced mass of coherent beds of the Colton Formation. This block moved down and outward on a concave-upward glide plane, which rotated the bedding backward. Although tilted, the bedding within the displaced block is not much disturbed. This toreva block is crossed by the road in the SW1/4SW1/4NE1/4 section 18, WCR. The mass of Colton beds is about 450 feet (137 m) thick stratigraphically. It slid from higher up on the monocline and rotated so much that beds in part of the mass are overturned. The block also lies close to a synthetic fault oblique to the monocline. Probably it was emplaced during the Pleistocene Epoch.

STRUCTURE

The body of the Gunnison Plateau is a great horst – 40 miles (64 km) long and about 15 miles (24 km) in maximum width – between Juab and Sanpete Valleys. Much of the plateau mass that rises above the valleys is a part of the upper plate of the Gunnison thrust that was first elevated by thrusting during the Sevier orogeny and later trimmed off on both the west and east sides by normal faults during Basin and Range extension (Standlee, 1982, figure 14; Lawton and

Weiss, 1999) (figure 3). The bounding fault on the west is the Wasatch fault and that on the east has been called the Gunnison fault by Weiss (1982b), the "valley fault" by Fong (1995), and the "range-front fault system" by Lawton and Weiss (1999). The plateau block is tilted toward the south, so that the beds and structures within it plunge southward into Sevier Valley. The principal structures within the plateau block are folds parallel to its length: antiformal belts near the east and west bounding faults are the oldest; paired synclines between those two belts are younger. Grabens subparallel to the folds are next most important, and a variety of cross faults also cut the Gunnison block. The fault systems bounding the plateau block are described first.

Range-Front Fault System

The normal faults on the east side of the plateau lie about 6 miles (10 km) east of the edge of the quadrangle, in the Wales quadrangle, and east (outside) of the folded beds in the horst. The fault system dropped Sanpete Valley along a zone already affected by west-directed back-thrusting during the late stages of the Sevier orogeny (Lawton and Weiss, 1999, figure 3), and coincidentally formed the Wasatch monocline, east of Sanpete Valley that flanks the west side of the Wasatch Plateau. The stratigraphic separation on the faults bounding the Gunnison Plateau horst is greatest at the north end of the plateau and decreases to the south, where the synclinal horst block plunges beneath Sevier Valley at the city of Gunnison. Banks (1991) estimated the separation on the range-front faults on the east side to be 8,000 to 9,000 feet (2,438-2,743 m) at the north end of the plateau. Gilliland (1963, plate 3) estimated 8,000 feet (2,438 m) of structural relief in western Sanpete Valley in T. 15 S. Lawton and Weiss (1999) found that the separation on the Flagstaff Limestone is at least 4,400 feet (1,340 m) at the latitude of the boundary between T. 15 S. and T. 16 S.

The Wasatch Fault

The zone of normal faults that bounds the Gunnison Plateau on the west is continuous with the same fault system that lies at the foot of the Wasatch Range in northern Utah. This zone of faults divides the plateau from Juab Valley and lies west of the folded flank of the plateau horst. The Levan segment of the Wasatch fault offsets level 2 alluvial fan ($Qacf_2$) deposits in the northwestern corner of the quadrangle. The Levan segment continues south-southwesterly in the Skinner Peaks quadrangle for about 3 miles (4.6 km). At that point, about 0.8 mile (1.3 km) north of Chriss Creek, the fault splits. One splay continues on the southwesterly trend, at least as far as Skinner Peaks (Jackson, 1991), and dies out, or is obscured by Quaternary deposits where Juab and Sevier Valleys join. The other splay turns 60 degrees to the southeast into the valley of Chriss Creek, and up the valley back into the Chriss Canyon quadrangle (Felger, 1991). Near the western edge of the quadrangle, although concealed beneath alluvium, the fault separates upper Green River strata on the north side of Chriss Creek from consolidated alluvial-fan deposits to the south of the creek. In sections 13 and 18 of the SWR this eastern branch joins (by turning about 80 degrees clockwise) one or more north-south faults that are thrown down-to-the-west. The more western of these passes down the east side of Flat Canyon into the Hells Kitchen Canyon Southeast quadrangle, where it is recognized as the Fayette segment of the Wasatch fault (McKee and Arabasz, 1982; Mattox, 1987; Jackson, 1991).

Both splays of the Wasatch fault dropped Juab Valley down with respect to the Gunnison Plateau, forming the monocline that flanks the plateau on the west; it was called the West Gunnison monocline by Felger (1991). Hardy and Zeller (1953) called attention to the similarity of this monocline and its rocks to the Wasatch monocline that borders the Wasatch Plateau on the west, in Sanpete Valley.

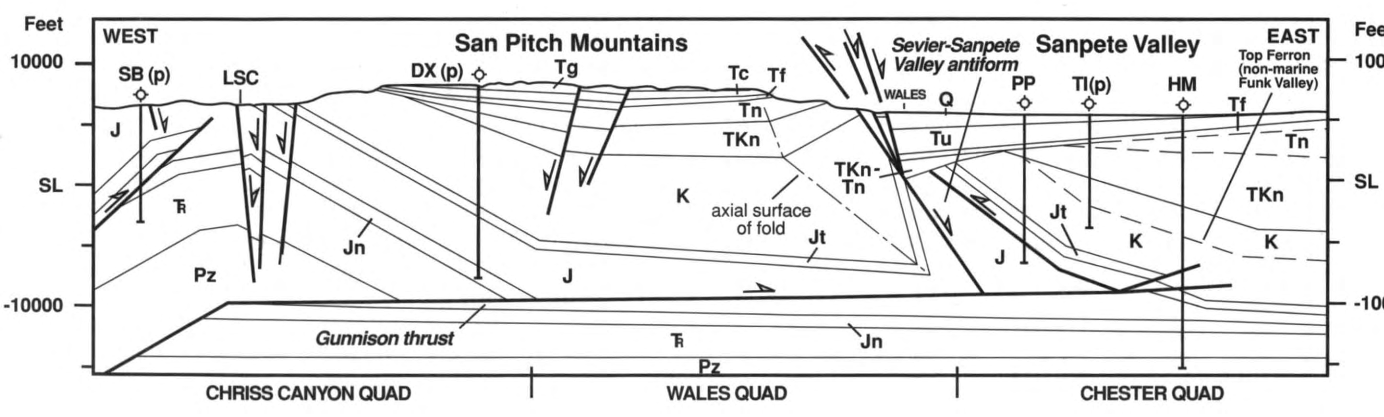

Figure 3. Structure section of San Pitch Mountains and Sanpete Valley at the latitude of the Chriss Canyon quadrangle (from Lawton and Weiss, 1999). ***Oil wells*** *(p, projected onto line of section): DX=Dixel Gunnison State #1, NE1/4NE1/4 section 15, T. 16 S., R. 1 E.; HM=Hanson Oil Moroni #1-AX, SE1/4NW1/4 section 14, T. 15 S., R. 3 E.; PP=Phillips Price N #1, SE1/4SE1/4 section 29, T. 15 S., R. 3 E.; SB=Amoco Sevier Bridge Unit #1, SW1/4SE1/4 section 11, T. 16 S., R. 1 W.; TI=Tennessee Gas Irons #1, SE1/4NE1/4 section 16, T. 15 S., R. 3 E.* ***Rock units:*** *Pz=undifferentiated Paleozoic strata; TR=undifferentiated Triassic strata; Jn=Navajo Sandstone; J=undifferentiated Middle Jurassic strata; Jt=Twist Gulch Formation; K=Cedar Mountain Formation and Indianola Group; TKn=North Horn Formation (basal conglomerate through Big Mountain units); Tn=North Horn Formation (Coal Canyon through upper redbed units); Tf=main body of Flagstaff Limestone; Tc=Colton Formation; Tg=Green River Formation; Tu=undifferentiated Colton and Green River Formations; Q=Quaternary deposits. LSC is Little Salt Creek in Chriss Canyon quadrangle. Unlabelled panels of fault-bounded rock on east flank of range contain undifferentiated Jurassic and Cretaceous strata.*

The stratigraphic separation on the Wasatch fault at the northwest corner of the Gunnison Plateau is about 8,530 feet (2,600 m) (Zoback, 1983). Mattox (1987) estimated that the separation is a minimum of 1,400 feet (427 m) at an unspecified latitude in the Hells Kitchen Canyon Southeast quadrangle. The separation in the Chriss Canyon quadrangle is intermediate between those values, but nearer the lower one – perhaps 3,000 feet (914 m). At the southwest corner of the plateau, west of the city of Gunnison, the juxtaposition of Eocene beds against Middle Jurassic beds at first suggests a separation – in the sense opposite to the rest of the Wasatch fault – of as much as 10,300 feet (3,140 m) (Mattox, 1992), but the authors believe this is the consequence of local diapirism of the Arapien Shale upward along the trace of the Wasatch fault.

Jackson (1991) studied the stratigraphy exposed in trenches dug across the fault in order to determine the number and timing of Holocene movements on the Wasatch fault in the Nephi and Levan segments. One of the trenches was dug across the Levan segment near Skinner Peaks, west of and about at the latitude of the southern edge of the Chriss Canyon quadrangle. This was on the western splay of the Wasatch fault, not the one that passes down Flat Canyon. He found evidence of two earthquakes that yielded a combined minimum of 9.2 feet (2.8 m) of vertical displacement of the ground surface. The older occurred sometime after 3,900 years B.P. and the younger took place between 1,000 and 1,500 years B.P. (Jackson, 1991).

Structures within the Gunnison Plateau Horst

The older structures within the Gunnison Plateau horst are folds. The oldest ones, the Levan culmination on the west and the zone of imbricate reverse faults on the east margins of the block, are antiformal, and helped to build the plateau. They resulted from fault-propagation folds in the upper plate of the Gunnison thrust, a structure of the Sevier orogeny (Ritzma, 1972; Standlee, 1982; Lawton and Weiss, 1999). Two younger folds, both synclines, lie between the bounding antiformal belts and form the mass of the plateau.

Levan Culmination

The oldest fold on the west is the Levan anticline of John (1972) and Auby (1991), but it is so severely distorted by early and subsequent deformation that it is better called the Levan culmination. The culmination is expressed at the surface mostly by the Arapien Shale, which lies like a great doubly plunging whaleback from about Fourmile Creek in the Levan quadrangle to Little Salt Creek in the Chriss Canyon quadrangle, a distance of 11.5 miles (18.5 km). At Little Salt Creek the culmination plunges beneath Cretaceous and Tertiary beds and continues, diminished in elevation, southward east of Flat Canyon. The moderately dipping east limb of the culmination contains a concordant section of Arapien through Indianola strata. This section is unconformably overlain by North Horn through Colton strata that onlap westward onto the Arapien. The northwest-dipping limb, however, is approximately concordant with northwest-dipping beds of the Green River Formation.

The fundamental aspect of the culmination is that it developed as a fault-propagation fold overturned to the east all along the trend of the west edge of the Gunnison Plateau (Ritzma, 1972). Continued shortening of that fold, perhaps aided by local diapirism of the evaporite deposits within the Arapien Shale, raised the Levan culmination in the two quadrangles and caused it to shed most of its Cretaceous and Tertiary cover. The crest of the Levan culmination is at Radio Tower Hill, an elevation of 8,360 feet (2,584 m), in the SE1/4 of section 20, NCR.

The Arapien beds were once covered by Cretaceous and Tertiary strata, but most of those have been eroded from the fold. Over most of the exposed length of the Arapien Shale in both the Levan and Chriss Canyon quadrangles only patches of younger beds dip steeply off to the west, toward the Wasatch fault. This was called the Gunnison monocline by Auby (1991) and the West Gunnison monocline by Felger (1991), a termed preferred in this report (plate 2, cross section B-B′). At Little Salt Creek, the antiformal Arapien Shale plunges beneath younger rocks under the West Gunnison monocline, and continues that way for some distance into the Hells Kitchen Canyon Southeast quadrangle (Mattox, 1987). A splay of the monocline lies at Skinner Peaks in the quadrangle of that name, west of Flat Canyon, and between the two splays of the Wasatch fault already described.

As described above, Cretaceous strata on the east limb of the culmination are roughly concordant with Jurassic strata and dip 35 to 40 degrees east. However, Tertiary strata are subhorizontal or dip only very slightly east. This shows that prior to the formation of the West Gunnison monocline, the Levan culmination was an east-dipping monocline – it lacked a west-dipping limb in the map area. We interpret the Levan culmination to be the result of two widely separated phases of deformation: (1) the southeast limb formed prior to deposition of the North Horn Formation (or during its initial deposition) as the east limb of a ramp anticline or fault-bend fold, and (2) the northwest limb formed during the formation of the West Gunnison monocline during Tertiary extension.

A number of short, local folds are mapped in the Arapien Shale, particularly low on the Levan culmination in the northwesternmost part of the quadrangle. Other folds are expressed locally by the twists and turns of gypsum and resistant beds of limestone and siltstone, and are shown on plate 1 by special symbols. In the absence of sedimentary structures that distinguish the tops of sedimentary beds, none of these folds can be said with certainty to be anticlines or synclines; some may be antiformal synclines and others synformal anticlines. A few faults are also mappable in the exposures of the Arapien Shale; these and the folds suggest how contorted the interior of the mass of Arapien beds may be. The igneous intrusions further distort the culmination where it is exposed, and perhaps more so at depth.

Zone of Imbricate Reverse Faults

The oldest fold on the east side of the plateau is a much-faulted antiform along the east flank and toe of the plateau facing Sanpete Valley, about 6 miles (10 km) east of the edge of the Chriss Canyon quadrangle. The breadth of the zone and the number of panels of faulted rock justified this rather complex term (zone of imbricate reverse faults) to Lawton and Weiss (1999). West-directed thrusting of the upper part of the upper plate of the Gunnison thrust – under what is now Sanpete Valley – forced Jurassic and Cretaceous rocks into a steep zone of shears and imbricated faults that overturned many of the beds to the west as they were elevated by the back-thrust. During development of this faulted fold on the east and the Levan culmination on the west, great volumes of sediment from the Sevier hinterland were swept eastward across central and eastern Utah to produce the deposits that now form the Book Cliffs. The coarsest material stayed in central Utah in some of the conglomerate formations, and the sands and fines were swept farther eastward (Schwans, 1988a, 1988b).

Synclines

The zone of imbricate reverse faults on the east side of the plateau seems to have been the dominant local Sevier structure, forming a highland that created a piggyback basin to the west (Lawton and Trexler, 1991) that caught great volumes of Cretaceous and Tertiary sediment in the area now occupied by the plateau block. That sediment is folded into two parallel, nested synclines today, partly by renewed uplift in the antiformal belts to west and east and partly by compaction of the numerous fine-grained formations within the plateau. These paired synclines are the two older folds of the horst block and make up the body of the plateau. They are not observable within the Chriss Canyon quadrangle, but are recognizable in cross sections across the plateau (Standlee, 1982, figure 14; Lawton and Weiss, 1999, figure 3).

The deeper syncline has the greater closure. Its axis lies close to the east edge of the plateau, and the fold involves principally the Jurassic and older Cretaceous rocks. The shallower syncline has much less closure. Its axis parallels that of the deeper structure just east of the middle of the plateau, and the western limb extends into the Chriss Canyon quadrangle. It involves mostly the Tertiary upper North Horn through Green River Formations. The whole of this architecture is shown in figure 3 of Lawton and Weiss (1999), and the details of the western part in the Chriss Canyon quadrangle are shown in cross sections A-A′ and B-B′ (plate 2) of this report.

Grabens

Two grabens that cut the southernmost parts of the plateau extend from the south into the Chriss Canyon quadrangle. The grabens were mapped and named the Divide graben (on the east) and Chriss/Mellor graben (on the west) by Mattox (1987). Hardy and Zeller (1953) mapped only the west wall of the Divide graben, but mapped the Chriss/Mellor graben fully, although they named neither of them. A third graben, the Flat Canyon graben, is the westernmost and lies across the common corners of the Chriss Canyon, Hells Kitchen Canyon Southeast, Hells Kitchen Canyon Southwest, and Skinner Peaks quadrangles.

Divide graben: South of the Chriss Canyon quadrangle the Divide graben occupies the highest part of the plateau, whose crest is formed by the resistant limestone beds of the limestone member of the Green River Formation. Were the graben not there, the soft shale beds of the thick shale member of the Green River would have been fully exposed to erosion, and the "crest" would have eroded away. The height of that south-central part of the plateau is made possible by being in a structural trench. The Divide graben bends northwest as it leaves the Hells Kitchen Canyon Southeast quadrangle and enters the Chriss Canyon quadrangle.

The western bounding fault of the Divide graben enters the Chriss Canyon quadrangle in the NW1/4 of section 34 in the SCR, and trends north-northwest to Chriss Creek. The eastern bounding fault enters this quadrangle near the center of section 35 in the SER, and trends northwesterly across Chriss Creek into section 15. The graben thus dies out about 3 miles (4.8 km) into the Chriss Canyon quadrangle. Several shorter faults lie parallel to the graben faults, and were probably developed by the same stresses. The eastern bounding fault shows a stratigraphic separation of about 300 feet (91 m) 1.5 miles (2.4 km) north of the south edge of the quadrangle. Two miles (3.2 km) farther north the separation is only about 100 feet (30 m). The western bounding fault has a much greater displacement – 600 to 700 feet (183-213 m) – south of Chriss Canyon.

Chriss/Mellor graben: The Chriss/Mellor graben was observed through most of its length by Hardy and Zeller (1953) and Mattox (1987), who noted that it dies out in the vicinity of Chriss Creek. Its full length of about 14.5 miles (23.3 km) extends from near Fayette, Utah, to north of Chriss Creek (Mattox, 1992). The graben is antithetic to the West Gunnison monocline that flanks the west side of the plateau. The western bounding fault of the Chriss/Mellor graben enters this quadrangle in the NE1/4 of section 31 in the SWR, and continues, with some complications, northeasterly to and across Chriss Creek. The eastern bounding fault enters this quadrangle in the NE1/4 of section 32 in the SCR, and continues northerly across Chriss Creek, but not so far as the western one. The graben, diminishing in width, thus reaches about 4 miles (6.4 km) into the Chriss Canyon quadrangle. The graben is complicated by a number of subsidiary subparallel faults and some cross faults within the block. Between Chriss and Little Salt Creeks the Divide and Chriss/Mellor graben approach each other obliquely and lose their distinctive qualities, except that the western bounding fault of the Chriss/Mellor graben is a coherent line of rupture all the way to Little Salt Creek Canyon.

The eastern bounding fault has a stratigraphic separation of about 520 feet (159 m) near the south edge of the quadrangle, and nearly 2,000 feet (610 m) in Chriss Canyon close to the great promontory ("the battleship") in section 21 of the SCR. The western bounding fault has a minimum stratigraphic separation of 300 feet (91 m) near the south edge of the quadrangle. Along the line of cross section B-B′, its separation is about 2,000 feet (610 m).

Flat Canyon graben: The Flat Canyon graben is a part of the Gunnison Plateau landform, but because its eastern bounding fault is the eastern splay of the Wasatch fault, it is not fully a part of the plateau horst block. Rather it separates a splinter of the horst block (Skinner Peaks) from the main plateau. It was not recognized as a graben by Hardy and Zeller (1953), who mapped a down-to-the-west fault in the flank of the monocline to the east of Flat Canyon, but not in the valley. Vogel (1957) mapped the western bounding fault in the northern part of Flat Canyon. Felger (1991) made what is to date the most thorough analysis of the Flat Canyon graben, and the course of the Wasatch fault described above and summarized below is from her conclusions.

Flat Canyon lies mostly in the Skinner Peaks and Hells Kitchen Canyon Southwest quadrangles, but its eastern quarter or third lies in the Chriss Canyon and Hells Kitchen Canyon Southeast quadrangles. The graben that makes it has for years been considered to be only a north-south, flat-bottomed valley with its northern end in section 24 SWR. Felger (1991) concluded that, although the "canyon" ends there, the graben structure turns about 30 degrees to the northwest and extends to Juab Valley between the Skinner Peaks and Chriss Creek, crossing to the north side of Chriss Creek one mile (1.6 km) upstream from Utah Highway 28. By this analysis, the segment of the fault coming southeasterly up Chriss Creek and extending south down the east side of Flat Canyon is the main trace of the Wasatch fault (the Fayette segment of Machette and others, 1992). There it borders the foot of the West Gunnison monocline and passes from the Chriss Canyon quadrangle into the Hells Kitchen Canyon Southeast quadrangle, still as the Wasatch fault (McKee and Arabasz, 1982; Mattox, 1987).

The Wasatch fault in this quadrangle thus includes parts of the Levan and Fayette segments (Jackson, 1991, figures 1 and 6). Felger (1991) and the present authors mapped and described the connection between these segments of the Wasatch fault. We interpret the Wasatch fault to be offset southeastward along an oblique fault up the valley of Chriss Creek to join the eastern bounding fault of the Flat Canyon graben. The length of this "dog-legged" Flat Canyon graben, as expressed by the length of the western bounding fault, which lies in the Skinner Peaks and Hells Kitchen Canyon Southwest quadrangles, is at least 8.5 miles (14 km). Farther south, in the Gunnison quadrangle, the Wasatch fault is poorly exposed and devolves into a zone of faults (Mattox, 1992). It seems that that zone must continue into, and die out under, the alluvium of Sevier Valley, south of the city of Gunnison.

Near its northern end the Flat Canyon graben is expressed by the dropping of volcanic beds of the Goldens Ranch Formation down against Green River sedimentary beds (Vogel, 1957; Felger, 1991). Felger estimated the stratigraphic separation on the eastern bounding fault to be 1,000 to 1,100 feet (305-335 m) and on the western bounding fault to be about 500 feet (152 m) (Felger, 1991, plate 2). Without good subsurface data the eastern value is exceedingly difficult to determine, for the Green River beds dip very steeply (75 to 80 degrees) in the West Gunnison monocline (sections 19 and 30, SWR) across from Skinner Peaks, and there are no matching strata in the valley against which to measure the separation.

Normal Faults

Few of the numerous other normal faults in the quadrangle are in clearly organized sets. Even so, some commonalities can be discerned. Several faults antithetic to the rise of the West Gunnison monocline cut the Green River and Colton beds north of Pierce Canyon and at the lower gorge of Chriss Creek, in sections 17 and 18 in the SWR and SCR. The northern 40 percent of the quadrangle contains a number of faults, both down to the west and down to the east, that are parallel to the regional strike of the Jurassic and older Cretaceous beds. We consider most of these faults to have resulted from slip on the bedding planes of the Arapien, Twist Gulch, Cedar Mountain, San Pitch, and Indianola units. As bedding-plane faults in steeply dipping beds, they do not everywhere juxtapose different stratigraphic units at the surface. This same set of faults extends from the northwest quadrant of the quadrangle southward along its western side nearly to Chriss Creek. Some of this series of faults may have resulted from diapirism of the Arapien Shale in the Levan culmination.

The concentration of normal faults cutting the middle reaches of both Little Salt and Chriss Creeks suggests that the creeks followed paths of weakness formed by the intersections of numerous faults. Despite the knowledge that it is easier to find normal faults in the walls of the canyons, it seems that the concentrations mapped are real, and that faults are less numerous in the hills between those creeks.

ECONOMIC GEOLOGY

Petroleum

Sporadic exploration for petroleum, both in and close to the Chriss Canyon quadrangle, began about 40 years ago. The Standard of California and Camay Drilling No. 1 Levan well was drilled in 1959-60 on lower Deep Creek, in the NE1/4SW1/4 of section 17, just a quarter mile (0.4 km) north of the north edge of the quadrangle (Ritzma, 1972). American Quasar 16-34 Chicken Creek was drilled 1.25 miles (2 km) farther upstream in 1980-81, in SW1/4SE1/4 of section 16, about the same distance north of the Chriss Canyon quadrangle. Both holes were dry, but the Levan No. 1 is important because it showed that a regionally significant reservoir rock – the Navajo Sandstone – is both overturned to the east and faulted at depth (Ritzma, 1972). The Dixel Resources No. 1 Gunnison State well was drilled in the NW1/4NE1/4 NE1/4 of section 15, ECR, in 1978, and was also dry. Chevron U.S.A. No. 1 Chriss Canyon well was drilled in 1979 in NE1/4SW1/4 of section 33, just 0.1 mile (0.16 km) south of the quadrangle. Each of these tests has yielded important stratigraphic data, but no economic oil or gas.

The latter wells attempted to locate reservoirs in the thrusted structures within the Navajo Sandstone. However, no Cretaceous source rocks – the principal sources of oil and gas to the north – appear to be present here. There is the possibility of a source rock of Permian age in the region that could provide economic quantities, mostly of gas. The target for these possible deposits would be at depths greater than 17,000 feet (5,182 m) in Triassic and upper Paleozoic reservoirs.

Oil Shale

An economic product chiefly of historical interest is the oil and grease that pioneers extracted from thin beds of pale bluish oil shale in the limestone member of the Green River Formation (Crawford, 1961). The paucity of the material available in outcrop – one bed a few feet thick (Winchester, 1916) – shows how great were the need, determination, and energy of the pioneers to extract the product, by retorting pieces of oil shale. The source rock and the site of their still is in the SW1/4SW1/4SW1/4 of section 7, WCR, on a dry gulch locally known as Shale Hollow. Apparently the retort was built and operated between 1854 and 1865, and was the first such operation in Utah; the product was used for harness dressing, lubricant, and lamp fuel (Crawford, 1961).

Parts of the apparatus and some piping may still be found at the site, which is marked on the map. The story of the development and operation of the shale retort, together with some photographs, is given by Crawford (1961). He accurately cites a photograph of the still, taken in 1916 by Winchester (1918), but the quote at the top of Crawford's page 5 is wrongly attributed; Winchester used that identical quote about early use of oil shale by the Mormons twice in U.S. Geological Survey bulletins. It appears on page 141 of Winchester (1916) and on pages 44 to 45 of Winchester (1918). Crawford's report of the dip of the beds (his figure 3) is stated ambiguously; the rocks dip gently to the west.

Gypsum

Severely contorted masses of gypsum and some bedded gypsum are present locally in the Arapien Shale. Some are stained red by associated red mudstone, but most are white and nearly free of mud. These are mapped individually by special symbols (see plate 2). The Energy and Minerals Program at the Utah Geological Survey has additional information on these deposits. The greatest concentration of gypsum, on Little Salt Creek, has been exploited intermittently for more than 40 years. As is true of other gypsum deposits in the Arapien Shale in the region, the gypsum removed has been used mostly for wallboard.

Gypsum has provided the largest dollar return from the geologic resources of the quadrangle. Nearly all of the gypsum removed to date has come from the group of quarries on the north side of Little Salt Creek, in SE1/4SW1/4 of section 31, NWR. Production occurred there most recently in the middle and late 1980s, but the quarries were inactive in the early and middle 1990s, when mapping of the Chriss Canyon quadrangle was completed. More recently, two smaller pits were re-opened in the walls of the dry creeks in section 30 in the NWR.

Water Resources

The most useful enduring resource of the Chriss Canyon quadrangle is the water, both ground and surface, captured and discharged to the cultivated valleys to the west. The quadrangle is mainly a catchment area; very little water is used within the quadrangle. Springs supply cattle and sheep, and stream water is trapped and diverted to the ranches in Flat Canyon. Most of the runoff from, and the infiltration into, the quadrangle flows west and southwest to the alluvial fill in Juab and Sevier Valleys. A recent study of the hydrology of Juab Valley (Thiros and others, 1996) covered the northern part of the valley thoroughly, but reached only as far south as Chriss Creek. In the "southern part of the valley," they found that the average annual recharge to the ground water of Juab Valley is about 12,000 acre-feet. This may be taken as a reasonable estimate of the contribution of the Chriss Canyon quadrangle to the subsurface storage in the valley. South of this quadrangle the catchment on the west side of the plateau is much reduced in area, and there are no perennial streams there. Thus, much less water is delivered from the plateau to Sevier Valley than to Juab Valley.

Water from wells in Salt Creek Valley, at the north end of the Gunnison Plateau and on the fan below it, is somewhat salty because of the gypsum and salt in the Arapien Shale over which Salt Creek flows (Bjorklund, 1967). The same is probably true of the water under the fan of Little Salt Creek, although only gypsum is known to be exposed in that drainage.

GEOLOGIC HAZARDS

Even though the Chriss Canyon quadrangle is mostly undeveloped, geologic hazards associated with earthquakes, mass movements, flooding, unstable soils, and radon are known in the quadrangle and the surrounding area. The discussion below identifies potential problem areas but should not be used in place of site-specific investigations.

Earthquakes and Seismic Hazards

The Chriss Canyon quadrangle lies within the Intermountain seismic belt, a north-trending zone of pronounced shallow seismicity that extends from northern Arizona to western Montana (Smith and Arabasz, 1991). Parts of two segments of the Wasatch fault zone, the Levan and Fayette segments, are in the quadrangle. The Levan segment has documented Holocene offset (Jackson, 1991; Machette and others, 1992), and we mapped a scarp in level 2 alluvial-fan deposits ($Qacf_2$) in the northwest corner of the quadrangle. Although no detailed paleoseismic studies have been made of the Fayette segment, scarps south of the Chriss Canyon quadrangle suggest the most recent movement on the Fayette segment occurred between 10,000 and 15,000 years ago (Machette and others, 1992). The epicenter of the 1901 Richfield earthquake, the second largest historical quake in Utah, is located only about 40 miles (64 km) south of the Chriss Canyon quadrangle. Seismic hazards in the quadrangle may thus be significant. Buildings should be constructed in accordance with the International Building Code (2000). Damage from earthquakes may include surface rupture, ground shaking, liquefaction, slope failure, and rock falls, which may cause damage to structures and roads.

The damage potential from surface rupture and deformation is greatest along and adjacent to both exposed and concealed high-angle normal faults shown on plate 1, particularly those associated with the Wasatch fault zone. We mapped a fault scarp in level 2 alluvial-fan deposits in the northwest corner of this quadrangle.

Ground-shaking potential along the Wasatch fault zone in the Chriss Canyon quadrangle has not been mapped in detail, but for any given earthquake, ground shaking tends to be more severe on low-lying unconsolidated deposits rather than on bedrock. National seismic-hazard maps developed by Frankel and others (1996) give probabilistic ground motions (severity of shaking) for the Chriss Canyon quadrangle area in terms of peak accelerations and 0.2-, 0.3-, and 1.0-second-period spectral accelerations having 10, 5, and 2 percent probabilities of exceedance in 50 years.

In general, Quaternary units that contain sandy sediments and have shallow ground water levels are those most prone to damage from liquefaction. Because only coarse and poorly sorted alluvial-fan deposits on the margins of Juab Valley and in Flat Canyon are in the Chriss Canyon quadrangle, ground-shaking hazards associated with saturated fine grained sediments may not be significant in the quadrangle. Because of their generally coarse grain size and the inferred depth to ground water, these alluvial fans probably have a very low liquefaction potential.

Earthquake-induced slope failures and rock falls are a potential hazard throughout the quadrangle. The potential hazard of such mass movements is discussed in more detail below. In the Chriss Canyon quadrangle, earthquakes could also trigger flooding caused by landslides that dam drainages, divert streams, or lower and tilt the ground surface.

Mass Movements

Mass movement is a natural hillslope process in which rock and soil move downslope under the direct influence of gravity. Hazardous forms of mass movement in the quadrangle include debris flows, landslides (slides, slumps, and flows), and rock falls. Although the quadrangle is currently only sparsely developed, mass movements are among the most serious potential geologic hazards in the quadrangle.

Poorly preserved, unmapped debris-flow deposits are likely present along the margins of Juab Valley and Flat Canyon. Streams in these two areas are deeply incised, which serves to channel and likely reduce the potential threat of mudflows or debris flows in the Chriss canyon quadrangle. Still, exceptional rainfall or snowmelt events could produce such flows, with the highest potential for damage in the upper parts of alluvial- fan deposits mapped as $Qacf_1$ and $Qacf_2$ along the mountain front. Small debris-flow deposits are also present in Holocene alluvium (Qal_1).

Landslides – including slides, slumps, and flows mapped as Qms_1 and Qms_2 – in the Chriss Canyon quadrangle are developed mostly in the weak formations and associated soils and in colluvial deposits that are easily mobilized when wet. Rock units particularly susceptible to such slope failures include the calcareous siltstone unit of the North Horn Formation, the Colton Formation, and the lower shale member of the Green River Formation.

Evidence of rock falls throughout the mountainous portions of the quadrangle includes accumulations of broken rock of cobble and boulder size at the bases of steep slopes. Rock falls are a natural part of the erosion process and happen where coherent fractured or jointed strata break loose and tumble downslope. They commonly are associated with heavy rainfall events or earthquakes, but many probably happen as isolated events after prolonged weathering. Slopes that are over-steepened by construction, including road-building, may present additional rock-fall and slope-failure hazards. The extent of the hazard can be assessed by the relative abundance of rock-fall debris at the base of a slope. The relative hazard differs locally, and depends upon the height of the slope, its steepness, the nature and stability of slope debris, and local topography.

Flooding

Each of the four major streams in the quadrangle debouches onto large alluvial fans in Juab or Sevier Valleys. Each stream is deeply incised, both in the canyons and across its fan, such that flooding is likely to happen only on the downstream portions of the fans. Even so, canyons in the quadrangle should be considered susceptible to flash-flooding during exceptional rainfall and rapid snowmelt events. Large volumes of snowmelt runoff in the spring seasons of 1983 and 1984 resulted in numerous floods and debris flows in the valleys and gulches and many mass movements along mountain fronts in most of northern and central Utah. In contrast to seasonal floods on the major streams, flash floods from storms are localized and short-lived (although every bit as dangerous). They reach a maximum flow quickly and diminish quickly. Flash floods commonly contain large loads of sediment and rock debris, and commonly begin or end as debris flows, which adds to their destructiveness.

Problem Soil and Rock

Soil surveys that include the Chriss Canyon quadrangle indicate a low to moderate shrink-swell potential in soils in the Flat Canyon area and a generally low shrink-swell potential elsewhere in the quadrangle (Swenson and others, 1981; Trickler and others, 1984). Expansive soil and rock contain clay minerals that swell conspicuously when wet and shrink as they dry. This swelling and shrinking can cause significant problems with foundations and road beds, and may damage underground utilities. Generally, Quaternary units derived from formations with a high clay content, including Colton and lower Green River strata, may contain expansive soils.

Collapsible soils may be present in geologically young, dry, low-density deposits such as are common in alluvial fans and colluvium of Holocene age. These soils have considerable strength and stiffness when dry, but can settle dramatically when wet and cause significant damage to roads and other structures. The collapse, or hydrocompaction, can happen when susceptible soils are wetted below the depth normally reached by rainfall, which destroys the bonds between clay grains. Irrigation water, lawn watering, or water from leach fields can cause hydrocompaction. Collapsible soils are known in the Nephi area (Biek, 1991) and may be present in the Juab Valley and Flat Canyon portions of the Chriss Canyon quadrangle. In addition, sediments derived from the gypsiferous Arapien strata may be especially susceptible to compaction that results from dissolution of gypsum.

Radon

Radon is an odorless, tasteless, colorless radioactive gas that exists at some concentrations in nearly all rocks and soil. Radon can become a health hazard when it accumulates in sufficient concentrations in enclosed spaces such as buildings. A variety of geologic and non-geologic factors combine to influence radon concentrations indoors; these include soils or rocks with naturally elevated levels of uranium, soil permeability, ground-water levels, atmospheric pressure, building materials and design, as well as other factors. Indoor-radon concentrations can differ dramatically within short distances due to both geologic and non-geologic factors.

The radon hazard has been depicted in only a general way for the Chriss Canyon quadrangle (Sprinkel and Solomon, 1990; Black, 1993). These generalized maps, which should not be used in place of site-specific studies, show that the Chriss Canyon quadrangle has a moderate to high radon hazard potential. It is important to note, however, that a quantitative relationship between geologic factors and indoor-radon levels does not exist, and that localized spots of higher or lower radon potential are likely to be present in any given area. Actual indoor-radon levels can vary widely over short distances, even between buildings on a single lot.

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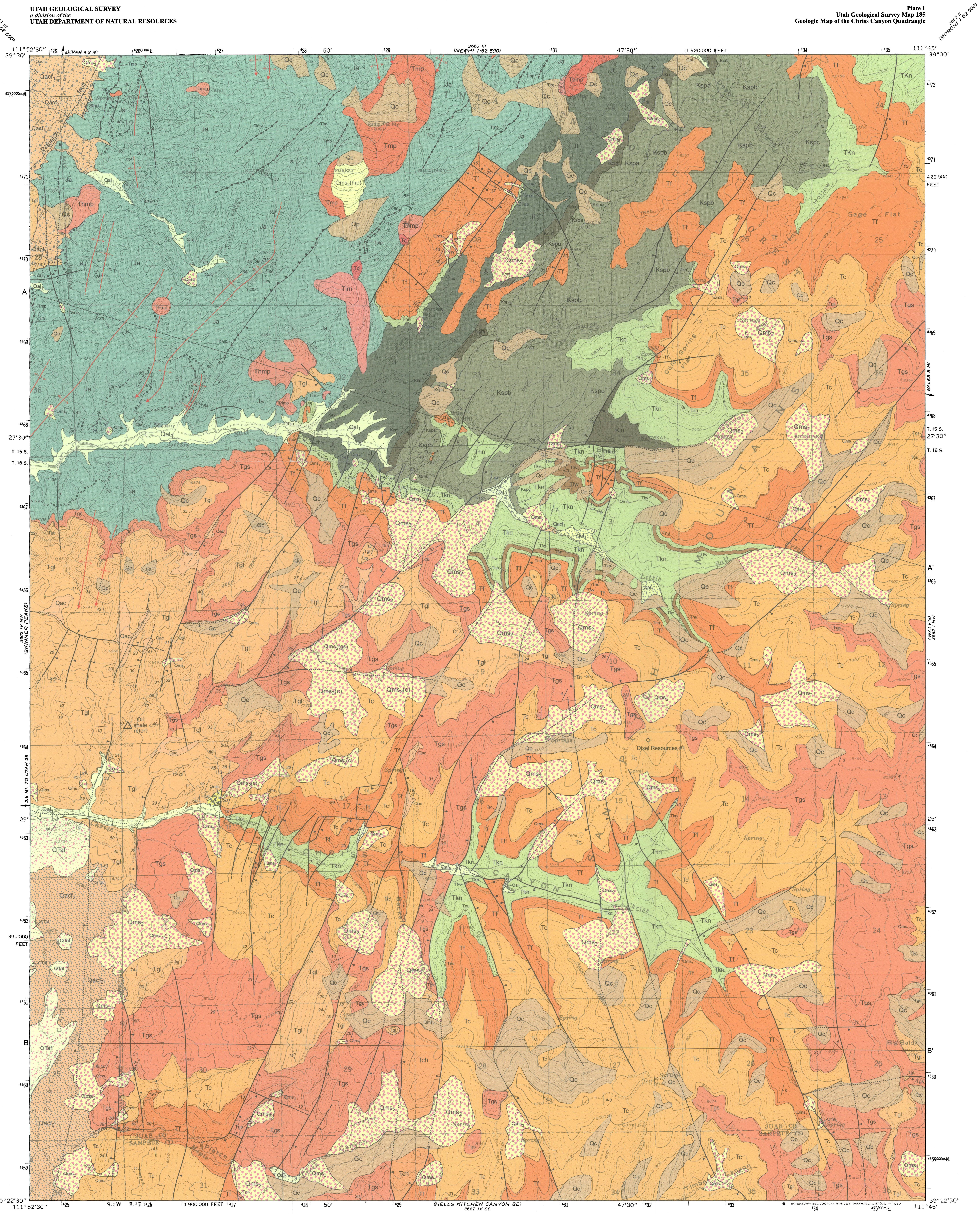


Base map from U.S. Geological Survey
Chriss Canyon 7.5' Quadrangle, 1965

13°
231 mils
2003 MAGNETIC DECLINATION
AT CENTER OF SHEET

SCALE 1 : 24,000
1 1/2 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTAH
QUADRANGLE LOCATION

Cartographers: Lori Douglas
Patricia Speranza

GEOLOGIC MAP OF THE CHRISS CANYON QUADRANGLE, JUAB AND SANPETE COUNTIES, UTAH

by

Malcolm P. Weiss,
James G. McDermott,
Douglas A. Sprinkel,
Raymond L. Banks,
and Robert F. Biek

2003

DESCRIPTION OF MAP UNITS

Qal1 Stream alluvium (Holocene) - *Light-yellowish-gray to yellowish-brown silt, sand, and rounded gravel closely associated with the major streams, but incised as much as 20 feet (6 m) or more by the streams; up to 20 to 30 feet (6-9 m) thick.*

Qal2 Stream alluvium (lower Holocene to upper Pleistocene) - *Like Qal_1 but more compacted and with thin soil on top. Forms dissected deposits in Chriss and Pierce Creeks with upper surfaces 40 to 60 feet (12-18 m) above the creek; 0 to about 30 feet (0-9 m) thick.*

Qaf1 Alluvial-fan deposits (Holocene) - *Deposits of yellowish-gray to yellowish-brown mud, sand, and poorly sorted angular gravel to boulder size, at the mouths of two small streams in Little Salt Creek Canyon; surfaces are deeply dissected, and 80 to 90 feet (24-27 m) above the modern stream bed at upper edges of fans; 0 to 70 feet (21 m) thick.*

Qacf1 Younger coalesced alluvial-fan deposits (Holocene) - *Poorly to moderately sorted, boulder- to clay-size sediment deposited principally by debris flows in large, coalescing alluvial fans of Juab Valley. Clast size generally increases toward apex of fans. They overlie older coalesced fan deposits ($Qacf_2$), are 0 to about 50 feet (0-15 m) thick, and do not extend far beyond the mountain front.*

Qacf2 Older coalesced alluvial-fan deposits (Pleistocene) - *Deposits like those of $Qacf_1$, but with better developed soils. The surface is dissected by the streams that transport the younger alluvial-fan deposits ($Qacf_1$). Thickness is uncertain but may be several hundred feet or more. In Flat Canyon it lies on the older deposit (QTaf) and may be only 100 to 200 feet (30-60 m) thick.*

QTaf Older alluvial-fan deposits (lower Pleistocene-Miocene?) - *Deeply dissected, structureless, yellowish-gray and brownish-orange consolidated alluvial, mudflow, and colluvial mud, sand, and gravel with mature soil on top. Present only in the west-central and southwest parts of the Chriss Canyon quadrangle, but it extends over large areas of the neighboring Skinner Peaks and Hells Kitchen Canyon Southwest quadrangles; 0 to at least 300 feet thick (0-91 m) in the latter quadrangle.*

Qc Colluvial deposits (upper Holocene) - *Unconsolidated mud, sand, and angular clasts to boulder size lying on steep, unstable slopes, and commonly containing organic matter from soils and vegetation. Weather to gray or yellowish brown; thicknesses range from 0 to 70 feet (0-21 m).*

Qac Mixed alluvial and colluvial deposits (Holocene) - *Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediments deposited principally by slopewash in swales and small drainages; gradational with both alluvial and colluvial deposits. Probably less than 50 feet (15 m) thick.*

Qms1 Mass-wasting deposits (Holocene) - *Deposits of large volumes of rock, soil, and vegetation that have moved downslope as semi-coherent masses, such as slumps or some landslides; probably moving throughout the Holocene and may still be active. Contained organic matter tends to impart yellowish-brown color. Smaller ones are from 0 to about 50 feet (0-15 m) in thickness, but the larger ones may reach 150 feet (46 m).*

Qms2 Mass-wasting deposits (Pleistocene) - *Deposits like those of Qms_1, but older because they are dissected by modern drainages. Small or linear deposits are 0 to 50 feet (0-15 m) thick; large ones are 0 to 150 feet (0-46 m).*

Qms2 gs, c, mp Mass-wasting deposits (Holocene and Pleistocene) - *Mostly rock from a single formation, with typical colors of that formation, darkened by organic matter. Deposits mapped with the subscripts "c" or "gs" are from the Colton Formation or the shale member of the Green River Formation, respectively. That labeled "mp" is from the monzonite porphyry in the Broad Canyon stock. Each deposit is from 0 to 50 feet thick (0-15 m).*

Qmtc Toreva block (Pleistocene) - *A large, rotated block of the Colton Formation lies in the SW1/4SW1/4NE1/4 of section 18, WCR. It exposes about 450 feet (137 m) of Colton beds. Where the road crosses it the beds are overturned.*

Tch Crazy Hollow Formation (Eocene) - *Brownish-orange mudstone and pebbly sandstone; well-rounded pebbles of black chert. Neither upper nor lower contacts are exposed in the quadrangle, nor nearby; estimated to be 400 feet (122 m) thick.*

Green River Formation

Tgl Limestone member (Eocene) - *In the east and northeast areas of the quadrangle it is light-gray-weathering, thin- and medium-bedded limestone with some dolomite. Its upper layers include some sparite, thin beds of clean quartz sandstone and biotitic tuff. Westward the member loses carbonate beds and gains mudstone, siltstone, sandstone, and pebbly beds. The pebbles and small cobbles are well-rounded black chert. Beds of white tuff that weather yellowish orange are locally 3 feet (1 m) thick. Not present in the northeastern part of the quadrangle, but 1,117 feet (340 m) thick on Deep Creek, just north of the quadrangle. It is 735 feet (224 m) thick in the monocline between Chriss and Pierce Creeks.*

Tgs Shale member (Eocene) - *Light-gray mudstone and shale with many thin beds of very light gray, white-weathering limestone and a few beds of weakly cemented quartz sandstone that weather dark brown. The limestone beds are micritic or glassy, and some are dolomitic. There are fewer carbonate beds in the western districts; from 0 to 800 feet (0-245 m) thick.*

Tc Colton Formation (Eocene) - *Reddish-brown, red, purple, violet, light-gray, greenish-gray, and very light gray mudstone and claystone, with many thin beds of glassy micritic limestone and sparite. The carbonate beds display the same range of colors, but most are some shade of gray. Poorly cemented siltstone and silty sandstone beds that weather yellowish brown are noticeably feldspathic, and either planar or channel-form beds are locally conspicuous, but form a minor part of the formation. The Colton is absent from the cliffs along the lower reaches of Little Salt Creek, probably by non-deposition; varies from 0 to 480 feet (0-146 m) thick.*

Tf Flagstaff Limestone (main body) (Eocene) - *Thin to thick beds of micritic pale-yellowish-gray limestone and dolomite, separated by thin to thick beds of limy mudstone weathering to slopes of angular chips between cliffs of the more durable beds. Gastropod fossils are locally numerous in both the carbonate ledges and the limy mudstone beds. This large, thick, pale-grey to white, cliff-forming unit of lacustrine limestone and dolomite is separated locally from similar rock (the Wales Tongue) by the upper redbed member of the North Horn Formation. The Flagstaff ranges from 0 to about 500 feet (0-152 m) thick, thinning westward; however, it is 781 feet (238 m) thick just south of the southwest edge of the quadrangle.*

Tfw Wales Tongue of Flagstaff Limestone (upper Paleocene) - *Light-gray, muddy dolomite and dolomitic limestone that weathers brownish orange, and dark-gray fossiliferous wackestone. Thin to medium-resistant beds form small blocky cliffs. Separated locally from the main body of the Flagstaff by the northwestward- and southeastward-thinning tongue of the upper redbed member (Tnu) of the North Horn Formation. Pinches out northwestward in the NER and NCR of the quadrangle and southeastward in the SCR and SER. The unit is generally about 20 feet (6 m) thick in the western districts, and up to 50 feet (15 m) thick in the ECR.*

North Horn Formation

Tnu Upper redbed unit (lower Eocene) - *A tongue of reddish-brown to reddish-yellow limy mudstone, siltstone and sandstone, with some claystone. Where present, it separates the main body of the Flagstaff from the Wales Tongue. Locally it contains numerous pea- and pebble-sized hard calcareous nodules, and sparse beds of micrite with gastropods, charophytes, and oncolites. In the NER of the quadrangle this unit is red enough to be mapped even where the Wales Tongue is absent, but in the SER its color does not distinguish it sufficiently from the calcareous siltstone unit (TKn). Where the Wales Tongue is absent the upper redbed and calcareous siltstone units are mapped as a combined unit also labeled (TKn). The unit ranges from 0 to 112 feet (0-34 m) in thickness.*

TKn Calcareous siltstone unit (Maastrichtian(?) to Paleocene) - *Beds of red and reddish-brown calcareous siltstone and mudstone are interleaved with gray, blocky ledges of well-cemented siltstone and light-yellowish-gray ledges of sandstone; the whole unit is readily weathered and slumped; gastropods are present locally. It thins northwestward onto the Levan culmination, where it is overstepped by the Flagstaff Limestone. Where the Wales Tongue pinches out, and the upper redbed unit is therefore not mappable, its beds are included with those of the calcareous siltstone and the combined unit is labeled TKn. Thickness ranges from 0 to 2,900 feet (0-885 m).*

Kiu Indianola Group, undifferentiated (Cenomanian to Campanian) - *Medium and thick beds of mostly cobble conglomerate; some are gray and others red with interstitial mud. These beds are the conspicuous and dominant features of the unit, but they are separated by many softer beds of sandstone, siltstone, and mudstone. Regionally the unit becomes less red upward, but the part exposed in the quadrangle is quite red. Neither the base nor the top of the unit is exposed; exposed thickness of 1,800 feet (549 m); probably varies from 0 to 4,000 feet (0-1,219 m) thick.*

Ksp San Pitch Formation, undivided - *shown in cross section only.*

Kspc Member C (Albian) - *Mostly reddish-brown or gray mudstone and sandstone, locally with large thicknesses of mostly quartzite cobble and boulder conglomerate. Conglomerates are very light gray or yellowish gray, with numerous limonite nodules. The unit is 1,450 feet (442 m) thick just beyond the northeast corner of the quadrangle, but thins generally southward through the plateau.*

Kspb Member B (Albian) - *Stacked tabular beds of gray cobble and boulder conglomerate interbedded with mudstone and pinkish-orange to light-gray sandstone. The fine- to medium-grained sandstones contain trough cross-beds, asymmetrical ripple marks, flute casts, tool and groove marks, burrows, root casts, a few gastropods, and rare leaf impressions. A nearly complete section on Little Salt Creek is 2,110 feet (643 m) thick, and it thickens northeast of Little Red Hill to about 3,500 feet (1,068 m).*

Kspa Member A (Albian) - *Medium and thick channel-form deposits of cobble and boulder conglomerates, about equally of quartzite and carbonate clasts. Red and reddish-brown mudstones separate the conglomerate beds, and their dull colors contrast sharply with the lighter and brighter colors of the Cedar Mountain Formation. At the base is a conspicuous, tabular, cliff-forming bed of conglomerate about 50 feet (15 m) thick. The member is 168 to 918 feet (51-280 m) thick in this quadrangle.*

Kcm Cedar Mountain Formation (Aptian to Albian) - *Bright red, reddish-orange, and variegated mudstone and siltstone, with thin beds and lenses of conglomerate, sandstone, and micritic limestone. The mudstones contain lumpy, angular nodules of micrite and chalcedony, and gastroliths are commonly associated with the limy nodules. The formation is readily eroded and covered at most places by mass-wasting deposits from the conglomeratic formations above it. Exposed thickness is about 270 feet (82 m), but it may thicken eastward to about 600 feet (183 m).*

Jt Twist Gulch Formation (Callovian) - *A slope-forming unit of well-sorted and thin-bedded fine-grained clastic rocks, mostly reddish-chocolate or brownish-red mudstone, siltstone, and sandstone, and light orange or pinkish-tan feldspathic sandstone; thin beds of gritstone are present at the base locally, but are a very minor fraction of the whole. The Twist Gulch is from 1,420 to 1,837 feet (433-560 m) thick in this quadrangle.*

Ja Arapien Shale (Callovian) - *Mostly thin-bedded calcareous mudstone and muddy micritic limestone, light yellowish or olive gray, weathering to very light gray or white. The few beds of fine-grained sandstone or sandy siltstone are also calcareous. Gypsum occurs in many beds and also forms beds or large pods locally tens of feet thick; pods are marked with "G" on the map and extensive beds are mapped. Many mudstone beds near the larger pods of gypsum are red or light gray streaked with red. The Arapien Shale is so folded and faulted that a reasonable thickness cannot be measured; the best estimates come from wells on the plateau top where it is 3,668 feet (1,118 m) thick and contains about 100 feet (30 m) of salt. Up to about 2,000 feet (610 m) of Arapien strata is exposed in the quadrangle.*

Igneous Rocks

Five kinds of igneous rock are in several types of intrusions, mostly into the Arapien Shale. Small stocks, plugs, dikes, and sills are present, and some of the rock types are restricted to certain types of intrusive bodies. All are early Miocene but have a recognizable succession. They are listed from youngest to oldest.

Tlm Leucomonzonite - *Pale-colored leucomonzonite that darkens very little on weathering to a pale yellowish brown; forms one stock and several small plugs and dikes. It is very fine grained, mostly oligoclase or andesine, and with few mafic minerals.*

Thmp Hornblende monzonite porphyry - *Light-gray hornblende monzonite porphyry with conspicuous (20 percent minimum) black phenocrysts of hornblende; present in stocks and plugs, and nearly as abundant as the monzonite porphyry (Tmp).*

Tbmp Biotite-augite monzonite porphyry - *The small stock of biotite-augite monzonite porphyry in N1/2 section 22, NCR, is phaneritic with white feldspar and greenish-gray grains of biotite and augite. It is stained by limonite on weathering.*

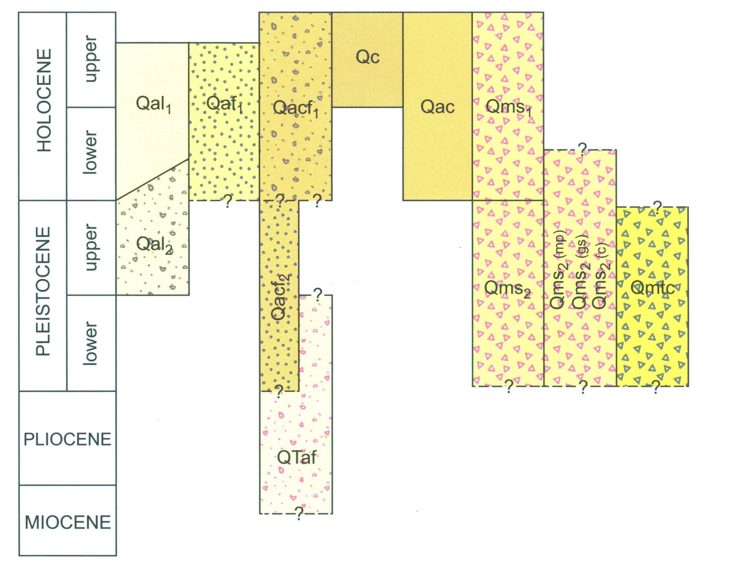
Tmp Monzonite porphyry - *Pinkish-gray to light-gray monzonite porphyry that weathers to yellow and brown forms the Broad Canyon stock in sections 20, 21, 28 and 29, NCR and NWR, but is partly obscured by mass-wasting deposits [Qms_2(mp)]. The same rock type forms plugs, dikes, and sills elsewhere. It has an aphanitic groundmass of K-feldspar and andesine and phenocrysts of feldspar, hornblende, and biotite.*

Td Porphyritic diabase - *Light-greenish-gray porphyritic diabase that darkens on weathering; large phenocrysts of biotite, feldspar, and hornblende are conspicuous; present in dikes and small plugs, but constitutes only a minor volume of the intrusives in the quadrangle.*

MAP SYMBOLS

- Contact
- Normal Fault - *bar and ball on downthrown side where known, dashed where approximate, dotted where concealed*
- Thrust fault - *teeth on upper plate; dotted where concealed*
- Mass-movement scarp
- Anticline - *showing direction of plunge*
- Syncline - *showing direction of plunge*
- Overturned anticline
- Dike or sill of intrusive igneous rock
- w — Wales Tongue of Flagstaff Limestone - *where too thin to map both lower and upper contacts*
- Oil well - *plugged and abandoned*
- Oil-shale retort
- 50 — Strike and dip of inclined bedding - *10-14 gives range of dips*
- 28 — Strike of vertical bedding
- Strike and dip of overturned bedding
- 35 — Approximate strike and dip of bedding
- Approximate strike and dip direction of bedding
- Spring
- Adit
- Quarry
- x — Prospect
- Arapien Shale symbols
  - G — large pods of gypsum
  - major beds of gypsum
  - form lines of resistant beds

CORRELATION OF SURFICIAL DEPOSITS



TIME-STRATIGRAPHIC UNIT			FORMATION			MAP SYMBOL	THICKNESS Feet (meters)	LITHOLOGY
Quaternary		Holocene Pleistocene	surficial deposits			see correlation of Neogene and Quaternary units for symbols	0-1,000 (0-305)	
Tertiary		Pliocene						unconformity
Tertiary		Miocene	Levan monzonite suite	leucomonzonite		Tlm	variable thickness	
				hornblende monzonite porphyry		Thmp		
				biotite-augite monzonite		Tbmp		
				monzonite porphyry		Tmp		
				porphyritic diabase		Td		unconformity
		Eocene	Crazy Hollow Formation			Tch	400 (122)	unconformity
			Green River Formation	limestone member		Tgl	735 (224)	
				shale member		Tgs	0-800 (0-245)	
			Colton Formation			Tc	0-480 (0-146)	
			Flagstaff Limestone			Tf	0-500 (0-152)	
			North Horn Formation	upper redbed unit		Tnu	0-112 (0-34)	
		Paleocene		Wales Tongue of the Flagstaff Limestone		Tfw	20-50 (6-15)	
				calcareous siltstone unit		TKn*	0-2,900+ (0-885+)	
Cretaceous	Upper	Maastrichtian						unconformity
		Campanian	Indianola Group	Indianola Group undivided		Kiu	0-4,000+ (0-1,219+)	
		Santonian-Conacian						
		Turonian						
		Cenomanian						unconformity
	Lower	Aptian-Albian		San Pitch Formation (**Ksp)	mbr. C	Kspc	< 1,450 (< 442)	
					mbr. B	Kspb	2,100-3,500 (643-1,068)	
					mbr. A	Kspa	168-918 (51-280)	
			Cedar Mountain Formation			Kcm	270-600 (82-183)	unconformity
Jurassic	Middle	Callovian	Twist Gulch Formation			Jt	1,420-1,837 (433-560)	local disconformity
		Bathonian (part)	Arapien Shale			Ja	***3,668 (1,118)	

* May include equivalent and older members of the North Horn Formation in the eastern part of the quadrangle.
** Shown on cross sections only.
*** Subsurface thickness. The Arapien Shale is estimated to be 2,000 feet (610 m) thick at surface in the quadrangle.