Interim Geologic Map of the Richfield Quadrangle, Sevier County, Utah

by

Grant C. Willis
Utah Geological Survey

1994

Open-File Report 309

Utah Geological Survey
a division of
Utah Department of Natural Resources
in cooperation with
U.S. Geological Survey

State Contract 94-1325
STATEMAP Agreement No. 1434-93-A-1175

ABSTRACT

The Richfield quadrangle is located in central Utah and includes parts of the Pavant Range, Sevier Valley, and Bull Claim Hill. Exposed strata are Tertiary in age and include the Flagstaff Formation (about 2000 feet [600 m] exposed) which is mapped in six informal members, The Green River Formation (70 to 90 feet [21-27 m] thick), the Crazy Hollow Formation (350 feet [105 m] thick), the Aurora Formation (550 feet [165 m] thick), and the Dipping Vat Formation (about 600 feet [180 m] thick). The Dipping Vat Formation is overlain by volcanic units derived from the Marysvale volcanic belt south of the quadrangle, including the Three Creeks Tuff Member of the Bullion Canyon volcanics (0 to at least 300 feet [0-90 m] thick), crystal-poor dacitic lava flows (about 300 feet [90 m] thick), the tuff of Albinus Canyon (up to 800 feet [240 m] thick) which is mapped in two informal members, the lava flows of Signal Peak (100 feet [30 m] thick), and the Osiris Tuff (less than 100 feet [30 m] thick). The Aurora Formation is formalized and a type section is designated.

Surficial deposits include alluvial fans, floodplain deposits, landslides, talus, alluvium, and colluvium. Sevier Valley is filled with thick alluvial-fan and floodplain deposits that may be as old as Miocene at the base. The Miocene Sevier River Formation is probably present beneath Sevier Valley.

Sevier Valley is bounded on both sides by potentially active normal faults. The Elsinore fault, on the west side margin, is a broad zone of exposed and buried faults. The Sevier fault is on the east side. Strata beneath the valley fill are assumed to be folded into a broad syncline and cut by high-angle faults. Exposed rocks in the Pavant Range dip eastward 5 to 10 degrees and rocks in Bull Claim Hill dip westward about 30 degrees. A swarm of faults in the Pavant Range, most with offsets of less than 200 feet (60 m), are a northern extension of the Little Valley fault zone. The front edge of the Pavant thrust may be beneath the quadrangle.

Geologic hazards include ground shaking and liquefaction from fault movement, flash floods, debris flows, expansive soils, radon gas, rock falls, landslides, and slumps. Several very large landslides masses are mapped in the Pavant Range, but only one with historic movement. Economic resources include gravel, road fill, calcite, cement rock, and decorative stone. Several prospects have been dug in limonitically altered rock and in a quartz dike along faults. Water resources are extensively utilized. No petroleum wells have been drilled in the quadrangle.

INTRODUCTION

The Richfield quadrangle is located in the High Plateaus province of central Utah (figure 1). The northwest half of the quadrangle is mountainous terrain on the east side of the Pavant Range and the southeast half is part of Sevier Valley. Bull Claim Hill extends into the southeast corner of the quadrangle. The mountainous part of the quadrangle consists of inclined table-like ridges cut by rugged canyons up to 1,200 feet (360 m) deep. The canyon walls are interlayered cliffs and steep slopes and are unscalable in most places. The highest peak in the quadrangle, at 8,252 feet (2,515 m) is near the northwest corner. The Sevier River meanders across a broad floodplain and forms the low point, near Venice, with an elevation of 5,230 feet (1,594 m).

[figure 1 near here]

Richfield, in the southwestern part of the quadrangle, is the largest city in central Utah with 5,593 inhabitants (1990 census). It is the major commerce, agriculture, transportation, and government hub in central Utah. The smaller community of Venice is in the east-central part of the quadrangle. Interstate 70, U.S. Highway 89, State Highway 119, and several city and county roads cross the southeastern half of the quadrangle. A graded National Forest road accesses the mountains in the southwestern part of the quadrangle, and rough dirt roads provide access to the mouths of the larger canyons. A few hiking trails, most of which are former logging tracks, follow the bottoms of the major canyons and a few ridges. The rest of the mountainous area is difficult to access.

The Sevier River floodplain supports a variety of phreatophytes and is used primarily for grazing. The lower parts of broad alluvial fans between the mountain front and the floodplain have fertile soils (hence the name "Richfield") and are used extensively for growing corn, alfalfa, grains, and a few other crops. The upper parts of alluvial fans are rocky and support sagebrush, greasewood, junipers, pinons, and sparse grasses, and are used primarily for grazing. Mountainous areas are typified by pinon, juniper, maple, oak brush, sagebrush, and grasses. Ponderosa Pine, Limber Pine, Bristlecone Pine, Douglas Fir, and White Fir grow in the higher elevations on north-facing slopes.

PREVIOUS WORK

Lautenschlager (1952) described and mapped the northern part of the quadrangle at a scale of about 1:50,000 and Schneider (1964) described and mapped the southwestern part at about 1:36,000 (figure 2). Young and Carpenter (1965) compiled a map of Sevier Valley at a scale of 1:125,000 as part of a water resources study, and Steven and others (1990) mapped the Richfield 1°x2° quadrangle at 1:250,000. Callaghan and Parker (1961) mapped the Monroe quadrangle, to the south, at 1:62,500. Steven (1979) mapped the Elsinore quadrangle, to the southwest, and Rowley and others (1981) mapped the Annabella quadrangle, to the south, at 1:24,000, focusing on volcanic units. Willis (1988) described and mapped the Aurora quadrangle, to the northeast,

at 1:24,000. Cunningham and others (1983) mapped the Marysvale volcanic field south of the quadrangle at 1:50,000.
[figure 2 near here]

Spieker (1946) provided the first detailed report on the geology of the Sanpete-Sevier Valley area and described most of the exposed formations. Spieker (1949) described the stratigraphy and structure of the area; Hardy (1952) mapped the Arapien Shale and Gilliland (1963) studied the Sanpete-Sevier Valley anticline; McGookey (1960) mapped and described Tertiary strata in the western part of the Sevier and Wasatch Plateaus; Steven and others (1979, 1984) and Rowley and others (1994) described, dated, and correlated rocks of the Marysvale volcanic field; Standlee (1982) used seismic and drill hole data to study the structure of the area; Villien and Kligfield (1986) discussed area thrust faults; Witkind (1982, 1983, 1992) and Witkind and Page (1984) studied salt tectonics and valley margin structures; and Arabasz and Julander (1986) and Anderson and Barnhard (1992) studied the neotectonics and seismic features of the area. Schneider (1967) measured sections and applied the name Cedar Breaks Formation to outcrops of Flagstaff Formation in the quadrangle. This usage has not been accepted by other workers and is not used here.

REGIONAL SETTING AND SUBSURFACE GEOLOGY

The Richfield quadrangle is near several geologic features that complicate local geology. It is near the leading edge of the Cretaceous to early Tertiary Sevier orogenic thrust belt (Armstrong, 1968; Standlee, 1982; Villien and Kligfield, 1986; Willis, 1986; Lawton, 1985; 1994). It is in the transition zone between highly extended, block-faulted terrain of the Basin and Range province and the mostly undeformed Colorado Plateau (Stokes, 1986). It is near the north edge of the Marysvale volcanic field (Cunningham and others, 1983; Steven and others, 1990) and also received material derived from the Tintic or Thomas-Drum volcanic fields to the northwest (Willis, 1986; 1988). The Sanpete-Sevier Valley anticline, a zone of Cretaceous to Quaternary structural folding and faulting, salt and mudstone diapirism, and salt dissolution and collapse, is just east of the quadrangle (Gilliland, 1963; Witkind, 1982; Willis, 1986).

Throughout the Eocene and early Oligocene, the central Sevier valley area was a subsiding basin bounded on the east by the rising San Rafael Swell and on the west by highlands in western Utah (figure 3). The southern termination of the basin is obscured by later volcanism in the Marysvale volcanic field south of Richfield. To the north and northeast the basin opened into the main part of the ancestral Uinta Basin and is therefore known as the Flagstaff arm of the Uinta Basin (Franczyk and others, 1992). Structures such as the Sanpete-Sevier valley anticline formed highlands within the basin (Gilliland, 1963; Weiss, 1969; 1980; Willis, 1986). About 3000 feet (900 m) of lacustrine, marginal lacustrine, and alluvial floodplain sediments accumulated in this basin in the Richfield quadrangle during the Eocene. The structural sag accumulated thick volcanic and volcaniclastic deposits in the Oligocene.

[figure 3 near here]

The Eocene Flagstaff Formation is the oldest unit exposed in the Richfield quadrangle. However, the Pavant Range is tilted 5 to 15 degrees to the southeast, such that older rocks and structures are exposed farther to the west. The Cretaceous to early Tertiary North Horn Formation underlies the Flagstaff Formation and is 2,500 to 3,500 feet (750-1,050 m) thick (Lautenschlager, 1952). The North Horn is a fluvial-lacustrine sequence that is contemporaneous with the waning stages of Sevier thrust deformation (Lawton and others, 1993). The North Horn overlies 0 to 900 feet (0-270 m) of Upper Cretaceous rocks that were assigned to the Price River Formation by Lautenschlager (1952) and Steven and others (1990) or to the Canyon Range conglomerate by Michaels and Hintze (1993). These rocks unconformably overlie over 9000 feet (2700 m) of Cambrian to Devonian carbonate and clastic rocks that are allochthonous on the Pavant thrust fault (George, 1985; Michaels and Hintze, 1993).

MAP UNITS

Tertiary

Flagstaff Formation

The Flagstaff Formation is exposed in the northern half of the quadrangle where it forms prominent, reddish-brown and pale-yellowish-gray, blocky cliffs. It consists of interbedded calcareous siltstone, sandstone, limestone, mudstone, and conglomerate. Grains in the sandstones and siltstones are dominantly carbonate with varying amounts of quartz sand and argillaceous material. Schneider (1967) estimated that the formation consists of 57 percent calcisiltite, 21 percent calcilutite, 13 percent argillaceous calcilutite, and 9 percent sandstone and conglomerate, but noted the presence of other lithologies within each of these basic types. (Calcisiltite is a clastic rock with silt-sized limestone or dolomite grains; calcilutite is similar but with clay-sized grains). The sandstones are quartz and lithic arenites. Bedding ranges from thin to massive and from planar to lenticular. Beds vary in resistance such that the formation forms steep canyons with cliffs up to 50 feet (15 m) high alternating with steep slopes. The base of the Flagstaff Formation is not exposed in the quadrangle, but is exposed about 0.5 miles (0.8 km) northwest of the quadrangle in upper Strawberry Canyon (Schneider, 1964, 1967). All but the lower 100 feet (30 m) of the formation is exposed.

I divided the Flagstaff Formation into six informal members based primarily on lithology. These members are mappable throughout the quadrangle but may not be mappable more than a few miles beyond the quadrangle boundaries due to facies changes. Three members are dominated by dark-reddish-brown calcareous sandstone, mudstone, and conglomerate and three are dominated by pale-yellowish-gray to pale-purplish-gray calcareous sandstone, sandy limestone, and calcareous mudstone. The contacts between the members are gradational and vary slightly because of facies changes and interfingering of lenticular beds.

The Flagstaff Formation is mostly early Eocene in age, but may extend into the early middle Eocene (Fouch and others, 1983; Franczyk and others, 1992; Lawton and Weiss, in press). No data is presently available to constrain the ages of the members of the Flagstaff Formation. The cumulative thickness of the Flagstaff in the quadrangle is about 2,000 feet (600 m).

To the northeast, the Flagstaff Formation thins dramatically over the Sanpete-Sevier valley anticline (McGookey, 1960; Stanley and Collinson, 1969; Witkind, 1982; Willis, 1986). Such thickness variations are not seen in the Richfield quadrangle because no exposures are close to the anticline and because of the limited areal extent of exposures.

The Flagstaff Formation is part of a carbonate-dominated lacustrine sequence deposited in the Flagstaff arm of Eocene Lake Uinta. The Flagstaff arm was a southwest extension of the main lake, which was centered in the ancestral Uinta Basin (figure 3) (Stanley and Collinson, 1969; Weiss, 1969; Franczyk and others, 1992). Strata in the quadrangle were deposited near the southern end of the arm in an alternating alluvial plain, shallow lake, and distributary delta setting. Overbank and subaerial carbonates are common while lacustrine deposits are minor. Coarse boulder and gravel conglomerates were deposited in river channels and indicate moderate- to high-energy environments near highlands to the east, west, or southwest. Most beds are intensely rooted and bioturbated. Bedded gypsum indicates closed-basin hypersaline conditions existed at times.

Lower red member (Tflr): The lower red member is exposed near the floor of South Cedar Ridge Canyon and near the north quadrangle boundary. It is interbedded, dark-reddish-brown, dusky brown, grayish-red, or purplish-red calcareous sandstone, sandstone, and conglomerate and dark-reddish-brown to reddish-purple calcareous siltstone, mudstone, and sandstone that forms alternating cliffs and slopes. The sandstone is mostly fine to very fine grained but ranges up to pebbly. Conglomerate occurs in channel lenses that are incised into underlying rock and that pinch out laterally (figure 4). Clasts are mostly quartzite with some chert, dolomite, and limestone derived from Precambrian and Paleozoic sources, and mudstone ripup clasts. Clasts are up to about 12 inches (30 cm) in diameter, but most are less than 4 inches (10 cm). Clastic rocks are slightly to highly calcareous and some may be classified as limestone. Bioturbation, including rooting and burrowing, is common to intense in both resistant and nonresistant beds and has destroyed most internal bedding features. The member forms steep ledgy cliffs interlayered with steep slopes. Overall, it is darker reddish-brown and has more cliff-forming units than the other members of the Flagstaff Formation. The upper contact is variable but is picked where the dominate lithology changes from dark-reddish-brown sandstone to pale-gray, purplish-gray, and orangish-gray calcareous sandstone and sandy limestone.

[figure 4 near here]

The exposed part of the member is 320 feet (96 m) thick in lower South Cedar Ridge Canyon. The base is not exposed in the quadrangle, but it is projected to be about 100 feet (30

m) below the lowest exposed beds.

Lower white member (Tflw): The lower white member is exposed in most of South Cedar Ridge Canyon (figure 5). It is a slope former with three to four 6- to 10-foot-thick (1.8-3 m) ledges and has a pale-purplish- to pale-yellowish-gray appearance.
[figure 5 near here]

The member consists of pale-purplish-gray, orangish-gray, or purplish-yellow, mottled, calcareous sandstone, sandy limestone, calcareous mudstone, and siltstone. Locally, it contains thin beds of conglomerate with clasts less than 4 inches (10 cm) in diameter. Coarser conglomerates similar to those in other members were not observed but may be present locally. Beds are commonly intensely bioturbated and sedimentary structures are rare. Slope-forming intervals weather to form a soft clayey cover. The upper contact is sharp but is in the middle of a slope and is generally covered by rubble. It is easily recognized as a color change from pale-purplish-gray to medium-reddish-brown. The member contrasts with the underlying and overlying members due to its lighter color, less resistant nature, and higher carbonate content. The lower white member is 236 feet (72 m) thick in lower South Cedar Ridge Canyon. The thickness appears uniform throughout the quadrangle.

Middle red member (Tfmr, Tfmrs): The middle red member is exposed over a large area in the northern part of the quadrangle where it forms steep ledgy cliffs cut by narrow canyons (figure 5). The middle red member is similar to the lower red member and is difficult to distinguish from it in small fault blocks. It is mostly medium- to thick-bedded, medium- to dark-reddish-brown, calcareous sandstone and conglomerate that forms ledges and thin-bedded sandstone and mudstone that forms slopes. Most sandstone beds are very fine to fine grained and well sorted, but grain size varies significantly. Some beds have pebbly to conglomeratic layers with clasts up to about 4 inches (10 cm) in diameter. Conglomerate also occurs in channel lenses. Clasts in the lenses are as much as 14 inches (36 cm) in diameter, though most are less than 6 inches (15 cm). They average about 50 percent quartzite, 35 percent carbonate, and 15 percent chert; most are recognizable as derived from Precambrian and Paleozoic sources. Clasts are subrounded to subangular and are poorly to moderately sorted. Sandstone beds range up to about 50 feet (15 m) thick but average around 10 feet (3 m). Conglomerate beds are less than 10 feet (3 m) thick. Most beds are moderately to intensely bioturbated. It is mapped as Tfmrs where it is slightly offset by slump movement.

The upper contact is poorly defined due to facies changes in the overlying middle white member. It is mapped at the change from mostly dark-reddish-brown, ledge- or cliff-forming sandstone, to mostly pale-to medium-grayish-red, slope-forming mudstone and sandstone, or pale-yellowish-gray, cliff-forming calcareous sandstone. The middle red member is 600 feet (180 m) thick in South Cedar Ridge Canyon.

Middle white member (Tfmw) and marker bed (m): The middle white member is exposed over a large area in the north and central parts of the quadrangle (figure 6). Overall, it is pale-yellowish- to pinkish-gray, calcareous sandstone and sandy limestone that contrasts sharply with the adjacent dark-reddish-brown members. In small fault blocks, parts can be confused with the Green River Formation. Conglomerate lenses similar to those in the middle red member are locally present in the middle white member. Most beds in the member are strongly bioturbated and are mottled with pale-purple and pale-yellowish-gray blotches. The sandstone is mostly fine to very fine grained, but some beds are coarse to pebbly. Grit is mostly angular and poorly sorted. Red chert is a minor but prominent component in some pebbly layers.

[figure 6 near here]

The member consists of two parts separated by a 10- to 20-foot-thick (3-6 m), medium-orangish-red, blocky, ledge-forming marker bed (labeled "m" on the map) (figure 6). In the South Cedar Ridge Canyon area, the lower part consists of thick beds of smooth, gypsiferous, slope-forming clayey mudstone with thin sandstone and limestone ledges. It is generally highly weathered, but in fresh exposures discordant "coconut" gypsum stringers are abundant. Some intervals contain minor amounts of clayey, bedded gypsum or gypsiferous shale. It forms a distinctive smooth slope that contrasts sharply with the ledgy intervals in the rest of the Flagstaff Formation. It changes facies to the southwest where it forms pale-yellowish-gray ledges similar to the upper part.

The upper part consists of resistant pale-yellowish-gray to light-olive-gray, calcareous sandstone and sandy limestone that forms high ledges and cliffs. It forms most of the prominent white cliffs along the mountain front in the northeastern part of the quadrangle. The upper contact is placed at a generally sharp change from pale-yellowish-gray calcareous sandstone to dark-reddish-brown sandstone or mudstone. The middle white member is 515 feet (155 m) thick in section 6, T. 23 S., R. 2 W. The lower part is 160 feet (48 m) thick at that site and is 210 feet (63 m) thick in South Cedar Ridge Canyon. Thickness variations are probably due to facies changes.

Upper red member (Tfur): The upper red member forms a thin but prominent bed in the west central part of the quadrangle (figure 7). It consists of dark-reddish-brown calcareous sandstone, siltstone, and mudstone. In some areas it contains a lenticular conglomerate bed as much as 15 feet (4.5 m) thick. Clasts in the conglomerate are poorly to moderately sorted and are up to 12 inches (30 cm) in diameter and are similar to those described in other members. The member contrasts sharply with underlying and overlying light-colored members and thus is an important marker bed in the highly faulted terrain near the range front. The upper contact is picked at the base of a prominent, very pale-gray limestone bed or at a change from dark-reddish-brown sandstone and mudstone to pale-gray or purplish-gray mudstone.

[figure 7 near here]

The upper red member thins from southwest to northeast across the quadrangle. It is 162 feet (49 m) thick near Cottonwood Creek and 96 feet (29 m) thick in section 6, T. 23 S., R. 2 W. It is estimated to be less than 50 feet (15 m) thick near the north quadrangle boundary. It is only an indistinctive, pale-reddish-brown band a few feet thick in a prominent ridge about 0.5 miles (0.8 km) north of the quadrangle.

Upper white member (Tfuw): The upper white member is exposed in the west-central part of the quadrangle where it forms a steep slope beneath the resistant Green River Formation (figure 8). It is composed of pale-gray, pale-pinkish-gray, or pale-purplish-gray, interbedded, sandy to clayey limestone and mudstone, calcareous siltstone, and sandstone. It is thinner bedded and has distinctively fewer ledges than other members of the Flagstaff Formation.

[figure 8 near here]

In most areas the upper contact is covered by rubble eroded from the upper part of the Green River Formation. It is marked by a change from pale-purplish-gray muddy limestone and mudstone to pale-yellowish-orange or pale-greenish-gray mudstone of the Green River Formation. A greenish-gray, altered volcanic ash bed, which is the primary detachment surface for many of the landslides and slumps in the quadrangle, also marks the contact.

In fault blocks the upper white member can be distinguished from the middle white member in that it is more purplish-gray, forms more slopes with fewer ledges, has whiter limestone and sandstone beds, and does not have thick, resistant, yellowish sandstone or limestone beds.

The upper white member is 185 feet (56 m) thick near Cottonwood Creek and 170 feet (51 m) thick north of Willow Creek Canyon. Significant thinning is not apparent in the quadrangle.

Colton Formation (not mapped)

The Colton Formation was not recognized in the Richfield quadrangle, but, because it is present between the Flagstaff and Green River Formations in quadrangles to the north and northeast (Willis, 1986; 1988; 1991), it is discussed here. There the Colton Formation consists of variegated, bentonitic shale, mudstone, limestone, and sandstone and forms a strike valley. It thins southward. Willis (1988) mapped a thin interval of questionable Colton in the southern part of the Aurora quadrangle, but in the Richfield quadrangle, no Colton Formation is recognizable. The upper part of the Flagstaff is more bentonitic than other parts of the formation, suggesting that it may correlate with the Colton interval.

Green River Formation (Tg, Tgs)

The Green River Formation forms prominent pale-greenish-yellow to grayish-yellow cliffs throughout the western part of the quadrangle. It is the most resistant unit in the quadrangle and caps several of the high ridges (figures 7 and 8). Most outcrops are affected by landsliding and slumping because the formation rests on a clay-rich layer that forms a major slide detachment surface. Outcrops involved in minor to moderate slumping are labeled Tgs. Extensively deformed masses are mapped as Qmsg or Qms (see discussion in "landslide and slump deposits").

The Green River Formation is composed of pale-yellowish-orange, pale-yellowish-gray, and pale-greenish-gray, silicified limestone and dolomite; calcareous, very fine-grained sandstone; and algal limestone (Sheliga, 1980). It has thin to thick blocky bedding and is generally highly jointed. Pale brown, white, and gray chert, common in irregular blebs in the upper part of the formation, is diagnostic. Large algal mounds are common in the upper part of the formation. A continuous bed of interlocking, round-topped, polygonal algal mounds 5 to 10 feet (1.5- 3 m) across and 2 to 5 feet (0.6-1.5 m) thick floor washes west of Richfield. Very resistant oolite beds are excellent markers in the Aurora quadrangle to the northeast (Willis, 1988) but none were found in the Richfield quadrangle. The Green River Formation can be confused with the middle white member of the Flagstaff Formation in small blocks in the Elsinore fault zone but the greenish-yellow hue, chert, and algal structures are helpful in identification. The upper contact with the Crazy Hollow Formation is a gradational zone 5 to 10 feet (1.5-3 m) thick. The contact is placed where dark-brownish-orange sandstone becomes dominant.

The Green River Formation is middle Eocene in age in the Sevier Valley area, though it has a broader age range in the main part of the Uinta Basin (figure 3) (Fouch and others, 1983; Bryant and others, 1989a; Franczyk and others, 1992). Bryant and others (1989a) obtained latest Eocene ages from Green River Formation samples from the Uinta Basin in northeastern Utah, but I believe the Green River Formation in the Richfield area is older. Locally, the Green River Formation was deposited in a shallow, carbonate-rich lake in the Flagstaff arm of Eocene Lake Uinta. Volcanic material from distant sources probably provided silica that formed the chert in the formation. The Green River Formation is 70 to 90 feet (21-27 m) thick in the quadrangle and thins to the southwest.

Crazy Hollow Formation (Tch, Tchs)

The Crazy Hollow Formation forms dark-brownish-orange hills directly west of Richfield (figure 8). Outcrops that are involved in minor to moderate slumping are labeled Tchs. Very thin to thin, planar-bedded, dark-brownish-orange to brownish-red, fine-grained sandstone, siltstone, and mudstone make up 70 to 80 percent of the formation and pale-grayish-orange, thick-bedded to massive, lenticular, channel sandstone beds make up 20 to 30 percent. One to three percent conglomerate is also present.

The channel sandstone beds are mostly medium grained, but range from fine grained to pebbly, and in some areas have a distinctive "salt and pepper" appearance caused by light- and dark-colored chert grains (Spieker, 1949; Norton, 1986). Channel sands are approximately 50 percent quartz, 45 percent lithic fragments (mostly chert with some carbonate and siltstone fragments), and 5 percent feldspar, and are classified as litharenites (Norton, 1986). The sandstone is friable to poorly cemented but typically has a case-hardened rind that causes the beds to weather into a myriad of unusual shapes. The channel sandstone beds are typically 10 to 30 feet (3-9 m) thick but are locally stacked, forming a thicker cliff. Typically, there are 3 to 5 channel sandstone beds in the formation in any one section. North of the Forest Service road in section 26, T. 23 S., R. 3 W., the formation has an unusually thick interval without any channel sandstone beds.

Black chert pebbles in conglomerate lenses and fingers are diagnostic of the formation. An unusually coarse conglomerate with clasts up to about 12 inches (30 cm) in diameter is exposed in excavations northwest of the concrete water tank in NW 1/4, section 26, T. 23 S., R. 3 W. Clasts are subrounded to subangular quartzite, limestone, dolomite, chert, sandstone, and mudstone.

The contact of the Crazy Hollow with the overlying Aurora Formation is gradational over a 10-foot (3 m) interval. The contact is picked at the change from dominantly dark-brownish-orange sandstone to pale-gray or pale-reddish-gray bentonitic mudstone. The Aurora Formation has a few thick, pale-grayish-orange channel sandstone beds near the base that are similar to sandstone beds in the Crazy Hollow. One such sandstone bed is in a small fault sliver in the SE 1/4, section 27, T. 23 S., R. 3 W., west of Richfield.

The Crazy Hollow Formation is easily recognized by its stratigraphic position and distinct lithology. In small fault blocks it may be confused with the reddish-brown members of the Flagstaff Formation, but can be identified by the black chert pebbles, the "salt and pepper" sandstone, and the interbedded light-colored channel sandstones and dark-colored planar sandstones and siltstones. The Crazy Hollow also has an orangish cast while the Flagstaff is more reddish or brownish.

The Crazy Hollow Formation was not dated and no diagnostic fossils were found in the formation. However, it is between, and interfingers with, the middle Eocene Green River Formation and the late Eocene Aurora Formation and is considered late middle Eocene to late Eocene in age. The Crazy Hollow Formation is mostly fluvial and overbank deposits. Some were locally derived while some may have been transported from the Uncompahgre uplift near the present Utah-Colorado border (Norton, 1986). It is 350 feet (105 m) thick west of Richfield. Schneider (1964) cited a thickness of 260 feet (79 m), which may have been measured farther to the southwest. The formation thins regionally to the southwest, though thinning is not evident in the Richfield quadrangle due to the limited areal extent of outcrops.

Aurora Formation (Tau) (new name)

The Aurora Formation forms pale-gray to pale-orangish-gray slopes with sparse vegetation in the southwestern part of the quadrangle (figure 9). The formation of Aurora was informally named by Willis (1986, 1988) to replace the Bald Knoll Formation. Gilliland (1949, 1951) defined the Bald Knoll Formation and designated a type section near Bald Knoll, west of

Redmond, Utah. This name has subsequently been used on many maps in the area for pale-gray, fine-grained, mostly lacustrine sediment overlying the Crazy Hollow Formation and underlying volcaniclastic and volcanic deposits (for example: McGookey, 1960; Williams and Hackman, 1971; Steven and others, 1990). Unfortunately, because Gilliland did not recognize an obscure fault, the Bald Knoll type section was placed in beds now known to be part of the Sevier River Formation (Willis, 1987, 1988, 1991). The Sevier River Formation was named by Callaghan (1938) and since that name is older it must have precedence. Therefore, following the rules of the North American Commission on Stratigraphic Nomenclature (1983), it is necessary to drop the name Bald Knoll Formation and rename the strata. The strata overlying the Crazy Hollow Formation, and in most areas underlying the Dipping Vat Formation, are herein named the Aurora Formation and the name Bald Knoll Formation is herein abandoned. The type section of the new Aurora Formation is located about 1 mile (1.6 km) west of Aurora in the south half of section 31, T. 21 S., R. 1 W., (appendix).

[figure 9 near here]

The Aurora Formation consists of shale, bentonitic clay, mudstone, fine- to very fine-grained sandstone, and limestone. Much of the unit was derived from distant volcanic sources. Limestone, shale, and mudstone are most common in the lower part and amount of volcanic material increases upward. Discordant gypsum stringers and bentonitic clay are abundant in some layers (figure 10). Minor amounts of pumice were recognized, but a thick pumice-bearing clay bed mined west of Aurora (Willis, 1988) is not present in the Richfield quadrangle. Limestone beds are thin, medium to dark olive gray, and fetid and make up about 5 percent of the formation (Schneider, 1964). The formation weathers readily to form soft spongy slopes.

[figure 10 near here]

Lautenschlager (1952) mapped the upper part of the Aurora Formation in the Richfield quadrangle as the Gray Gulch Formation based on increased pyroclastic content. Schneider (1964) found this distinction to be arbitrary and unworkable as a map unit. I agree with Schneider and do not distinguish the Gray Gulch Formation. The upper contact of the Aurora Formation is poorly exposed but is placed at a transition from shale and mudstone to coarse, poorly to moderately sorted, volcaniclastic conglomerate and sandstone of the Dipping Vat Formation.

Willis (1988) obtained radiometric ages on biotite of 38.4±1.5, 39.6±1.5, and 40.5±1.7 Ma (late Eocene) from the upper part of the Aurora Formation in the Aurora quadrangle. The lower part of the formation was not dated. These ages are older than volcanism in the Marysvale volcanic field and thus, the volcanic material was not derived from that area. Willis (1987) showed that the likely source for the volcanic material was late Eocene volcanism in the Tintic area rather than the younger Marysvale volcanic field (figure 3). Bryant and others (1989a) dated volcanic material in lacustrine sediments from the uppermost part of the Green River Formation near Duchesne at 37.6±1.9, 43.9±5.4, 42.8±2.2, and 42.3±2.0 Ma, contemporaneous with the ages from the Aurora Formation. Therefore, the Aurora Formation was deposited in the final stages of the Flagstaff arm of Eocene Lake Uinta and is contemporaneous with youngest Green River Formation strata in the center of the Uinta Basin (figure 3). The Aurora Formation is 550 feet (165 m) thick in the southwest corner of the quadrangle. Schneider measured a thickness of 475 feet (145 m) about 1 mile (1.6 km) southwest of my measurement.

Dipping Vat Formation (Tdv)

The Dipping Vat Formation forms a steep ledgy slope in scattered outcrops in the southern corner of the quadrangle and near the low volcanic hills to the north. It consists of poorly cemented, volcaniclastic sandstone, conglomerate, and reworked volcanic tuff. It is pale-gray to pale-bluish-gray and is planar- to lenticular-bedded, with planar and trough cross-bedding. Clasts in conglomerate beds vary from mostly volcanic to mostly sedimentary, and include welded tuff, quartzite, limestone, and dolomite, are poorly sorted, and range up to about 14 inches (36 cm) in diameter. Schneider (1964) included the Dipping Vat interval in the Dry Hollow Formation.

Willis (1986) obtained radiometric ages of about 35 million years on material from the Dipping Vat Formation collected near the type section about 8 miles east of the Richfield quadrangle (McGookey, 1960) . However, since the material was water-lain and was reworked, the formation may be as young as 27 million years old. About 600 feet (180 m) of Dipping Vat strata are exposed in a slump block in the southwestern corner of the quadrangle. The Dipping Vat Formation was deposited in a basin marginal to early eruptions in the Marysvale volcanic field. Lacustrine deposits may be present in the formation to the northeast (McGookey, 1960; Willis, 1986), but none were recognized in the Richfield quadrangle.

Three Creeks Tuff Member of Bullion Canyon Volcanics (Tbt)

The Three Creeks Tuff Member is poorly exposed on the east side of Bull Claim Hill and in the hills in the southwest corner of the quadrangle. This unit was previously mapped as Needles Range Formation (Rowley and others, 1981) but was later identified as the Three Creeks Tuff Member (Steven and others, 1990; Rowley and others, 1994). It is better exposed just south of the quadrangle.

The Three Creeks Tuff Member consists of resistant, pink, purplish-red, and pale-gray, moderately welded, lithic- and phenocryst-rich, ash-flow tuff with some interbedded volcaniclastic sandstone (Rowley and others, 1981). The tuff contains plagioclase, hornblende, biotite, quartz, and minor Fe-Ti oxide and sanidine phenocrysts. White to pink pumice lenticules up to 4 inches (10 cm) long and 2 inches (5 cm) wide are common. To the south it consists of multiple cooling units interbedded with volcanic mudflow breccia, volcanic conglomerate, volcanic sandstone, and lava flows (Rowley and others, 1981), but these facies are not exposed in the quadrangle. Exposed thickness is about 100 feet (30 m) but the unit is much thicker to the south.

It is about 27 million years old (Steven and others, 1979; Rowley and others, 1994).

Crystal-Poor Dacitic Lava Flows (Tcp)

The crystal-poor dacitic lava flows unit is exposed on the upper east slope on the east side of Bull Claim Hill about 200 feet (60 m) below the ridge crest (figure 11). The unit forms a smooth slope that contrasts with jagged ledges and cliffs of the overlying tuff of Albinus Canyon. The contact is sharp with little or no erosional relief. The unit is mostly covered by abundant detritus that has cascaded down from the more-resistant overlying tuff.

[figure 11 near here]

The flows consist of moderately resistant, pale-gray, pale- to moderately greenish-gray, and pale-reddish-gray, vesicular or amygdaloidal, aphanitic, dacitic lava flows and volcanic mudflow breccia (Rowley and others, 1981). They contain small sparse phenocrysts of plagioclase, pyroxene, and Fe-Ti oxides. The unit has not been dated but is sandwiched between units that are 25 and 27 million years old. It is at least 300 feet (90 m) thick but the base is not exposed.

Tuff of Albinus Canyon (Ta)

The tuff of Albinus Canyon forms most of the ridge crest of Bull Claim Hill, is exposed on a ridge in the southwest corner of the quadrangle, and is exposed in low, down-faulted hills north of Richfield (figures 9 and 11). It consists of two to four cooling units, each with a basal vitrophyre 1 to 3 feet (0.3-0.9 m) thick. The lowest vitrophyre is the thickest. In Bull Claim Hill, the tuff of Albinus Canyon is divided into a densely welded tuff facies (Taw) and a moderately welded lithic tuff and tuff breccia facies (Tab). The two facies interfinger, but the welded tuff is more common in the lower part of the formation. The contact between the two facies is generalized, but is welded, interfingering, and in places "swirled" together by post-depositional flowage. The tuff of Albinus Canyon is as much as 800 feet (240 m) thick in the quadrangle. It is about 25 million years old (Rowley and others, 1994).

Welded tuff unit (Taw): The welded tuff unit consists of dense vesicular tuff. It is mostly dark brown to reddish brown on weathered surfaces and is pale to medium gray, purplish gray, brownish gray, purplish-gray, or reddish gray on fresh surfaces. It contains small sparse-but-prominent phenocrysts of plagioclase, pyroxene, and Fe-Ti oxides (Rowley and others, 1981). Secondary flowage structures are common. Vesicles are drawn out into long "pencil-like" shapes. Some are filled with secondary calcite or quartz but most are empty. Pale-gray to white chalcedony commonly fills veins and fractures. Foliation mostly parallels the formational contacts but locally is discordant.

Lithic tuff and tuff breccia (Tab): The lithic tuff and tuff breccia unit is dark-brown, reddish-brown, greenish-gray, and gray lithic tuff, lithic breccia, autoclastic breccia, and stony tuff. Lithic fragments vary from less than one percent to about 20 percent of the total volume. Most blocks are volcanic but locally a few are sedimentary. Some clasts are slightly rounded but most are angular.

Lava Flows of Signal Peak (Tsp)

The lava flows of Signal Peak are exposed on the lower west slope of Bull Claim Hill where they form low rounded hills with a few ledgy outcrops. The unit is composed of resistant, dark-gray to black, crystal-rich, vesicular or amygdaloidal, andesitic lava flows. It contains abundant large (up to 0.6 in [1.5 cm]) phenocryts of plagioclase, subordinate pyroxene and olivine, and minor Fe-Ti oxides in an aphanitic matrix (Rowley and others, 1981). The contact with the tuff of Albinus Canyon is poorly exposed. In one area a few feet of volcaniclastic sandstone are exposed at the contact and are mapped with the upper unit. Outside of the quadrangle the unit is thicker and has more lithologic variability. Rowley and others (1994) reported a whole-rock K-Ar date of 21.6±1.0 Ma on basaltic andesite that they indicate may represent the flows of Signal Peak, but they question this date because elsewhere the flows are overlain by the 23 million-year-old Osiris Tuff. The flows are about 100 feet (30 m) thick in the quadrangle.

Osiris Tuff (To)

The Osiris Tuff is exposed in volcanic hills southwest of Richfield (figure 9). All outcrops are involved in landsliding or faulting and consist mostly of mounds of resistant, weathered boulders. The Osiris Tuff consists of orangish-brown, reddish-brown, and light-gray, densely welded, crystal-rich rhyodacitic ash-flow tuff containing phenocrysts of plagioclase and subordinate sanidine, and minor biotite, pyroxene, and Fe-Ti oxides (Rowley and others, 1981). It contains drawn out pumice lenticules and flow foliation is common. The Osiris is characterized by rough grus weathering, conspicuous coppery weathering biotites, and large plagioclase phenocrysts. It is about 23 million years old and was erupted from the Monroe Peak caldera about 15 miles (24 km) to the south (Fleck and others, 1975; Steven and others, 1984; Rowley and others, 1994). No place was found to measure the Osiris Tuff in the quadrangle, but it is as much as 300 feet (90 m) thick in the area (Willis, 1988).

Quartz dike (q)

A quartz dike is emplaced along a fault on the east side of Bull Claim Hill. It is composed of dense, pale-reddish-brown, reddish-gray, and gray, cryptocrystalline quartz and quartz breccia. Scattered voids are partially filled with quartz and calcite crystals. The dike forms a resistant ledge and is on trend with additional quartz bodies in the Annabella quadrangle to the south (Rowley and others, 1981). The age is unknown, but the dikes are assumed to be contemporaneous with Miocene volcanic activity.

Quaternary-Tertiary

Older Alluvial Deposit (QTa)

A small outcrop of alluvial material about 200 feet (60 m) across and 30 feet (9 m) thick is preserved on the upper surface of a large slumped mass of Green River Formation in the southeast corner of section 14, T. 23 S., R. 3 W., north of Cottonwood Creek. The outcrop forms a small mound that sits on the lip of a bench about 180 feet (55 m) above a nearby wash bottom and near the mountain front on the up-thrown side of the Elsinore fault zone. It appears to be deformed by the slump movement. The deposit consists of moderately to moderately well-sorted, bedded gravel, sand, and silt and has an orangish-brown hue. It is unconsolidated to slightly consolidated and forms a slope. The gravel contains mostly quartzite and Paleozoic carbonate clasts, but contains a small percentage of volcanic clasts. Clasts are mostly less than 4 inches (10 cm) in diameter. The deposit is about 30 feet (9 m) thick. Its age is assumed to be late Tertiary or early Quaternary. There are two explanations for the deposit. It may have been deposited by an early stream that crossed the area. The wash now adjacent to the deposit is not a candidate because there is no volcanic material within its source area. However, a late Tertiary or early Quaternary predecessor to Cottonwood Creek, now incised about 300 feet (90 m) lower than the deposit, drains volcanic terrain and may have deposited the material. The stream would have been graded to Sevier Valley, indicating significant uplift on the Elsinore fault since deposition. This theory is supported by the presence of orangish-brown, silty mud in open fractures in the slump about 300 feet (90 m) west of the deposit, suggesting infiltration beneath the stream.

Alternatively, the deposit may be a remnant of the Sevier River Formation, a middle Miocene to early Pliocene clastic basin-fill deposit. Exposures north and south of the quadrangle imply that the Sevier River Formation once covered most of the quadrangle (Callaghan and Parker, 1961; Willis, 1988, 1991). However, the Sevier River Formation was deposited on volcanic units and this deposit sits on the Green River Formation.

Quaternary

Quaternary surficial deposits are common throughout the quadrangle. They are mapped based on a combination of lithology and depositional environment. Some contacts are generalized and are arbitrarily placed to delineate areas dominated by a particular deposit. The capitalized first letter or letters of map symbols indicates the age of the deposits (Q-Quaternary or QT-Quaternary and/or Tertiary), the second letter indicates the dominant depositional environment (for example: a-alluvial, m- mass movement), and the third and fourth letters indicate either a second depositional environment or an important characteristic of the deposit. Number subscripts indicate age with the oldest deposits labeled with the higher number (example: Qaf_1). Deposits in which age is only broadly defined as younger or older are labeled with a "y" or an "o".

Older Colluvial Deposits (Qco)

Older colluvial deposits are mapped on ridges and slopes on Bull Claim Hill. They consist of locally derived, moderate- to poorly sorted, angular to subangular boulder- to clay-sized material. The deposits form erosional remnants on several slopes on the west side of the hill and are isolated by downcutting of adjacent drainages. Exposures are too poor to determine if the deposits have been tilted or deformed. Deposits are up to 100 feet (30 m) thick. Their age is unknown, but they are dissected by adjacent drainages. Younger colluvial deposits are not mapped separately but are mapped as mixed alluvial and colluvial deposits (Qac, Qca).

Mass Movement Deposits

Landslide and slump deposits (Qms, Qmsg, Qmsch, Qmsau, Qmsdv, Qmsbt, Qmsa, Qmso, Qmsv): Landslides and slumps are common on the slopes of the Pavant Range in the western part of the quadrangle (figure 12). Several factors make those rocks vulnerable to slumping and sliding: (1) strata in the mountains dip toward the valley at 5 to 10 degrees; (2) the rock is composed of interlayered, highly fractured, permeable and impermeable layers; (3) water percolates down through the fractured and permeable rock and collects on impermeable layers; (4) the impermeable layers commonly contain clay that loses strength when moistened; and (5) uplift and tilting of the range has developed high topographic relief and removed downslope support for the unstable masses.

[figure 12 near here]

Landslide and slump deposits consist of jumbled blocks up to several hundred feet across that are transported downslope in large masses. Amount of movement and deformation varies from slight to extensive. Rock that has undergone extensive slumping and landsliding such that it is jumbled, brecciated, and has few or no large intact blocks is mapped as Qms. Where one formation or rock type is primarily involved, a letter suffix is added (for example: Qmsg-Green River Formation, Qmso-Osiris Tuff, v-volcanic). Rock that has experienced moderate slumping, but that is still mostly internally coherent, is mapped as a bedrock unit over a low-angle fault and is given an "s" suffix (for example: Tgs, Tchs) (figure 13).

[figure 13 near here]

The age of landslide and slump deposits is poorly constrained. The deposits are highly dissected 200 feet (60 m) or more, but because they are developed on slopes, it is difficult to determine how much of this downcutting post-dates sliding. Pedogenic carbonate is stage 1 to stage 1+ (Birkeland and others, 1991), indicating late Quaternary movement. It is likely that they are related to the last glacial wet cycle, which occurred about 15,000 to 25,000 years ago. The slides and slumps did not reactivate during the 1983-1985 wet cycle.

Young landslide deposits (Qmsy): A landslide with historic movement is on a steep slope just south of South Cedar Ridge Canyon. In contrast to the older landslides that involve bedrock, it involves colluvial and talus materials and the detachment parallels the steep slope rather than bedding planes. It is sliding on the muddy, gypsiferous lower part of the middle white member of the Flagstaff Formation.

Talus Deposits (Qmt): Talus deposits are common in the canyons of the Pavant Range (figure 13). Only larger deposits are mapped separately. They consist of locally derived, poorly sorted, angular boulders with minor fine-grained interstitial material deposited in cones on and at the base of steep slopes. Most material is dislodged by freeze-thaw cycles.

Alluvial Deposits

Alluvial-fan deposits (Qaf$_1$, Qaf$_2$, Qaf$_3$, Qaff): Alluvial fans extend from the front of the Pavant Range to middle of Sevier Valley and are also found east of Bull Claim Hill. They consist of moderately to poorly sorted boulder- to clay-size material derived from the washes and canyons that drain the mountains and minor to moderate amounts of eolian material. Near the head, the fans are mostly debris flow deposits that contain boulders up to about 18 feet (5.4 m) in diameter, though 3- to 6-foot (.9-1.8 m) boulders are most common (figure 14). The materials decrease in size and contain more moderately sorted alluvial material farther from the mountains. The distal portion of the fans are dominated by fine-grained materials, have a higher percentage of eolian deposits, have a well-developed soil profile, and are mapped separately (Qaff). The contact is placed near the point where fans decrease in slope and the fan shape becomes poorly defined.

[figure 14 near here]

Three ages of fans are distinguished by the degree of dissection by large adjacent washes. Youngest fans (Qaf$_1$) are dissected less than 10 feet (3 m). Level 2 fans (Qaf$_2$) are dissected 10 to 30 feet (3-9 m), and level 3 fans (Qaf$_3$) are dissected more than 30 feet (9 m) and as much as 80 feet (24 m). Though dissected by larger washes, level 2 fans are crossed by many small active washes that are not yet incised. Level 3 fans are only found close to the mountain front as small erosional remnants.

Floodplain and marsh deposits (Qafp): Floodplain and marsh deposits are mapped in the 1- to 2-mile-wide (1.6 -3.2 m) Sevier River floodplain in the southeastern part of the quadrangle. They consist of clay to lower medium-grained sand, most of which was derived from the Marysvale volcanic field. No coarse-grained sand or gravel deposits were found even though drill hole data does indicate that there are gravels 25 to 50 feet (7.5-15 m) below the surface (Young, 1960). The unit consists mostly of overbank sediments deposited in marshes and abandoned meander loops, and of channel deposits. Wind has slightly reworked some of the material. Springs are common on the floodplain but no spring deposits were identified. Salt and alkali crust are common in the marshes. The floodplain deposits grade into alluvial-fan deposits over a wide zone. The contact is poorly defined, especially in the southern part of the quadrangle.

Mixed-Environment Deposits

Alluvial and colluvial deposits (Qac, Qacy, Qaco): The mixed alluvial and colluvial unit is exposed in the bottoms of canyons and washes throughout the Pavant Range. It is poorly to moderately sorted, angular to subrounded, boulder- to clay-sized material deposited by streams, wash from adjacent slopes, and rock falls. Locally, talus is the dominant part of the unit. The deposits are generally less than 20 feet (6 m) thick. They are dissected by streams in larger canyons and include deposits on canyon floors and that form a slightly older bench or terrace about 10 feet (3 m) above the floor. Deposits are discontinuous in the upper part of major canyons and in many places streams flow directly on bedrock. In most places exposures are too small to divide by age, but in an area south of Cottonwood Creek near the west quadrangle boundary, deposits are more extensive and are divided into younger (Qacy) and older units (Qaco).

Colluvial and alluvial deposits (Qca): These deposits are similar to Qac deposits except they have a lower percentage of alluvial material and are found on slopes instead of in the bottoms of canyons. Near Bull Claim Hill a mix of talus, colluvium, and alluvial-fan material is lumped into this unit.

Artificial Fill and Disturbed Areas (Qf, Qfd)

Artificial fill is material emplaced by human activity. Only fill in dikes and dams was mapped (Qf). Unmapped fill includes material emplaced for the construction of Interstate 70, as railroad base, and for smaller construction projects. Mapped disturbed areas (Qfd) include fill, waste piles, and scattered, recontoured outcrops in large road-fill pits excavated for highway construction.

STRUCTURAL GEOLOGY

Subsurface Structures

Pavant Thrust

The Pavant thrust fault is exposed along the west side of the Pavant Range where Cambrian or Ordovician strata are thrust over the Jurassic Navajo Sandstone (Maxey, 1946; George, 1985). The thrust fault was tilted 10 to 15 degrees to the southeast during the Tertiary and it now plunges beneath the range. Data from exposures and drill holes indicate that the leading edge of the Pavant thrust is located near the eastern part of the Pavant Range, probably beneath the Richfield quadrangle. East of the Richfield quadrangle, the Jurassic Arapien Shale, which is structurally below the Pavant thrust, is exposed in a complex anticline (Hardy, 1952; Gilliland, 1963; Willis, 1986; 1988). Drill holes northeast of the quadrangle also penetrated directly into the Jurassic and did not penetrate the Paleozoic section that typically overlies the Pavant thrust (Standlee, 1982). The Paxton #1 well, in SW1/4 NW1/4 section 28, T. 24 S., R. 4 W, 8 miles (13 km) southwest of the southwest quadrangle corner, penetrated the Pavant thrust 14,300 feet (4,359 m) below ground surface (figure 1) (D.A. Sprinkel, personal communication, 1994). Mississippian rocks overlie the thrust in the well, indicating that the thrust cuts up section from exposures to the west.

Gunnison Thrust

Folding of the Pavant thrust, duplication of strata in the Jurassic Arapien Shale, drill hole information, and seismic data indicate that at least one lower thrust underlies, and extends east of the Pavant thrust (Standlee, 1982; Willis, 1986). Villien and Kligfield (1986) named this fault the Gunnison thrust. It probably does not duplicate formations, but does duplicate strata within the Arapien Shale deep beneath the quadrangle.

Pavant Range

The Pavant Range is a horst that is bounded by late Tertiary to Quaternary high-angle normal faults and by down-faulted, alluvial-filled basins (Lautenschlager, 1952; Steven and others, 1990). It is tilted 5 to 10 degrees southeast (figure 5). It is bounded on the east by the Elsinore fault zone and on the northeast by a series of northwest-trending faults (Willis, 1988). The Little Valley fault zone cuts the block about 1 mile (1.6 km) west of the Elsinore fault.

Elsinore Fault Zone

The Elsinore fault or fault zone forms the structural east boundary of the Pavant Range

(Callaghan and Parker, 1961; Steven and others, 1990). Southwest of the quadrangle the Elsinore fault merges with structures in the Marysvale volcanic pile (Cunningham and others, 1983; Anderson and Barnhard, 1992). Northeast of the quadrangle the Elsinore fault decreases in magnitude and merges with a northwest-trending fault set (Willis, 1988; Anderson and Barnhard, 1992). In the Richfield quadrangle it is a zone up to 1 mile (1.6 km) wide of several faults that bound small fractured, brecciated, and rotated blocks (cross section A-A'). Exposed faults are near-vertical and most are down-to-the-southeast, but a few are down-to-the-northwest. Offset on individual faults is up to about 1,500 feet (450 m); cumulative offset is unknown, but probably exceeds 5,000 feet (1,500 m). The fault zone is widest in the northern part of the quadrangle and narrows to the southwest. The faults form a series of structural benches that mostly are stepped down toward the valley. The largest fault in the zone is postulated to be just east of remnants of volcanic units, approximately in the position of Interstate 70.

The range front between Willow Creek Canyon and South Cedar Ridge Canyon is intensely faulted and locally extensively brecciated (figure 15) (many faults could not be shown at this map scale). Fractures are open and down-dropped keystone blocks are common (figure 16). Part of this deformation may be attributed to gravity-induced slumping related to topographic relief along the range front (see discussion under "Gravity Sliding and Slumping").

[figure 15 near here]
[figure 16 near here]

The nature of the Elsinore fault zone is controversial. Callaghan and Parker (1961) mapped a fault and described faulting and folding in the area south of Richfield. Witkind and Page (1984) described monoclinal folds along mountain fronts throughout Sanpete and Sevier Valleys, including in the Richfield area. Willis (1988) mapped a fault bounding the range northeast of the Richfield quadrangle. Steven and others (1990) mapped a buried fault along the Pavant Range through the Richfield quadrangle. Anderson and Barnhard (1992) described both faulting and monoclinal folding along the range front and discussed variations in structural style along different segments. Hecker (1993) showed a buried Quaternary monocline instead of a fault through the quadrangle and noted that structural data from the area between Joseph and Richfield are "incompatible with the existence ... of a major range-front fault." She suggested that a southeast-facing monocline overlying a major buried fault is the principal range-front structure. The major structure may be a monocline south of Richfield, but I believe it is a fault or fault zone north of Richfield. Minor monoclinal folding is indicated by steeper dips in fault blocks near the mountain-front, but in this area, the range-front is straight, sharp and faceted, commensurate with a fault-bounded block. Though the major fault is probably buried beneath late Quaternary sediment, several smaller faults with offsets up to 1,500 feet (450 m) are exposed in the zone. The various tilt directions of fault-bounded blocks in the fault zone are also incompatible with a monoclinal explanation.

Slumping and landsliding have also added to the confusion. Near the concrete water tank west of Richfield, a large slump block of Green River and Crazy Hollow Formation steepen near the mountain front, creating a monoclinal form. However, north of the tank, an east limb of the fold is tilted west, forming a V-shaped syncline rather than a monocline (figure 17).

[figure 17 near here]

Little Valley Fault Zone

The eastern flank of the Pavant Range is cut by a group of northeast-trending faults 1 to 3 miles (1.6-4.8 km) west of the Elsinore fault zone. Most of these faults are down-to-the-west and have less than 100 feet (30 m) of offset; cumulatively, they have about 500 feet (150 m) of down-to-the-west offset. These faults are a northern extension of the Little Valley fault zone, which forms a graben west of the southern part of the quadrangle (Lautenschlager, 1952; Schneider, 1964). Near Little Valley, about 3 miles (4.8 km) west of Richfield, faults in the zone have offsets up to 1,000 feet (300 m). To the northeast, in the Richfield quadrangle, the faults splay into a horsetail pattern of many faults with smaller offsets. The fault zone is terminated just north of the quadrangle boundary where it intersects with northwest-trending faults that mark the structural edge of the Pavant Range. Intramontane faults such as these may be related to movement on buried low-angle detachment faults (Standlee, 1982) or to faulting in the hinge area of uplifted folds (Anderson and Christenson, 1989; Hecker, 1993).

Sevier Valley

Sevier Valley is a graben bounded on the west by the Elsinore fault zone and on the east by the Sevier fault, near the east side of the Richfield quadrangle. The structure beneath the valley is poorly known. Bedding on both sides dips toward the valley. In Bull Claim Hill strata dip about 30 degrees and 5 to 10 degrees in the Pavant Range, with steeper attitudes near the range front. I believe the strata beneath the valley form a syncline and are probably cut by many high-angle normal faults (cross section A-A'; also see Willis, 1988). Young (1960) reported a well 2 miles (3.2 km) southeast of Richfield (NW 1/4, SW 1/4, SE 1/4, section 31, T. 23 S., R. 2 W.) that penetrated the top of the Sevier River Formation at 728 feet (222 m) below ground surface.

Sevier Fault

Steven and others (1990) showed the Sevier fault on the west side of Bull Claim Hill; however, at least one strand of the fault is known to be 1 mile (0.6 km) east of Bull Claim Hill (see discussion of Annabella segment of the Sevier fault in Anderson and Barnhard [1992]). Total offset near the Richfield quadrangle is unknown, but probably exceeds 6,000 feet (1,800 m). Southeast of Bull Claim Hill, the Sevier fault has large scarps that offset middle to late Quaternary sediments (Anderson and Barnhard, 1992; Hecker, 1993).

The fault extends southward to near the Arizona border; to the north it is shown to end near Venice (Steven and others, 1990), but it may extend northward to align with the Redmond Hills (Willis, 1991). Its northern known extend coincides with the southern end of the Sanpete-Sevier Valley anticline, suggesting that the fault may merge with that structure (Hardy, 1952; Gilliland, 1963; Willis, 1986; 1988).

Bull Claim Hill

Bull Claim Hill is a north-trending structural block tilted about 30 degrees west (figure 11). Two faults with opposite sense of offset are exposed near the south quadrangle boundary on the east side of the hill, and a concealed, down-to-the-west fault is hypothesized on the west side of the hill. One of the faults on the east side of the hill places crystal-poor dacitic lava flows against the tuff of Albinus Canyon and the other juxtaposes the tuff of Albinus Canyon against the Three Creeks Tuff Member. A quartz breccia dike is emplaced along the latter fault, suggesting that it may be an older fault and associated with igneous activity.

The hill may be part of an intermediate structural level between strands of the Sevier fault, it may have been pushed up by local diapirism, or it may have been pushed up and tilted by complex withdrawal of rock from beneath the Sevier Plateau (Anderson and Barnhard, 1992). The Arapien Shale is exposed about 1 mile (1.6 km) northeast of the hill in the core of the Sanpete-Sevier Valley anticline (Williams and Hackman, 1971) and diapirism has occurred along the structure in that area (Witkind, 1982; Willis, 1986; 1988). The problem with this interpretation is that the contact between the Arapien Shale and adjacent deformed rock is low angle in the Venice area as opposed to a typical diapiric contact (Anderson and Barnhard, 1992).

Gravity Sliding and Slumping

Extensive landsliding and slumping make mapping and interpretation of structural features difficult in the Richfield quadrangle. (See the discussion of causes in "Landslide and slump Deposits".) Many of the bedrock outcrops in the western and northern parts of the quadrangle participated in bedding-plane sliding and discordant slumping, masking tectonic features.

Bedding-Plane Sliding

Bedding-plane slip is most common in the southwestern part of the quadrangle and involves movement on low-angle surfaces toward the valley. Movement is concentrated on three main detachment surfaces. One is near the base of the upper white member of the Flagstaff, one is near the base of the Green River Formation, and one is near the top of the Aurora Formation. Other bedding surfaces have detached locally. Activity shifted to stratigraphically higher surfaces southward since the strata are younger in that direction. Extensively deformed masses are mapped as landslide and slump deposits (Qms). Moderately offset, partially intact masses are mapped using their bedrock name, but a detachment fault is mapped around the base of these blocks where it can be identified. Large open fractures indicating a few feet of slumping are mapped in a few "in-place" and slumped blocks, including on the ridge north of Willow Creek Canyon, north of the Forest Service road near the west edge of the quadrangle, and in the ridge of Green River Formation north of Cottonwood Creek (figure 18). Lack of significant colluvial fill suggests that the fractures are young, possibly historic, but they are visible on 1958 aerial photographs. One possibility is that they opened during earthquakes in 1901 or 1921.

[figure 18 near here]

The large landslide mass south of Willow Creek Canyon mapped as Qms has experienced extensive movement. Blocks are highly fractured and disjointed and little recognizable bedding is preserved. The primary slide surface is near the base of the upper white member. The ridges south of that landslide mapped as Tgs and Tchs have experienced moderate movement. The primary detachment is near the base of the Green River Formation. Amount of offset varies from a few feet near the head scarp to perhaps a few hundred feet near the toe. Offset also decreases from north to south across the zone. The blocks are fractured, are cut by many small faults, and are rotated backward (figure 13). The upper end of the slump blocks consist of steep head scarps, discordant folds, and forward and backward-rotated blocks. Schneider (1964) mapped many small folds on these blocks but I did not because they are surficial features. Bedding attitudes in the slump blocks steepen where the toe plunged over the mountain front. Near the concrete water tank in section 26, T. 23 S., R. 3 W., the bedding is folded into a V-shaped syncline (figure 17). The detachment surface is exposed beneath the northern part of this slump complex, particularly in Cottonwood Creek Canyon (figure 13). Bedding dips to the southwest and the detachment plunges beneath the surface along the mountain front. Southwest of Richfield it is estimated to be about 300 feet (90 m) beneath the ground surface. The shallow alluvial fill is not a sufficient buttress to impede slump movement.

Discordant Slumping

Along the steep range front, particularly north of Willow Creek Canyon, the rocks are cut by many high-angle faults. Forward rotation of blocks and brecciation are common. Fractures are open and in many places keystone blocks are faulted down a few feet to tens of feet (figure 16). I attribute this deformation to a combination of tectonic and slump deformation. Once blocks are elevated by faulting, the rocks are deformed by gravity induced slumping and deformation. Gravity deformation alters the tectonic structure and creates misleading data when attempting to understand the local structural regime. Anderson and Barnhard (1992) noted such problems in their study of the neotectonics of the central Sevier Valley area.

Timing of Structural Events

All sedimentary strata exposed in the quadrangle are essentially parallel and do not show evidence of local structural deformation during the early to middle Tertiary when they were deposited. Volcanic rocks are also parallel though exposures are limited. Possibly the oldest structural feature in the quadrangle is the quartz-intruded fault on the east side of Bull Claim Hill, which may be contemporaneous with volcanic activity. In summary, all exposed faulting, folding, and tilting are middle Miocene or younger, and are contemporaneous with basin and range deformation. Tilted pediments and gravels of assumed Quaternary age north of Aurora suggest continued tilting of the range (Willis, 1988).

Basin and range faulting began during the early-middle Miocene, about 17 million years ago (Bryant and others, 1989b); however, faulting along the Pavant Range may not have begun until late Miocene or Pliocene time. Timing of uplift of the Pavant Range is constrained by the Sevier River Formation, which was deposited across the area from about 15 million years ago to about 5 million years ago, apparently prior to major uplift of the range (Willis, 1988; Steven and others, 1990). The Sevier River Formation overlapped rocks now exposed on the range, indicating that the range did not significantly rise until after its deposition.

The Elsinore fault, which bounds the range, dates back to the inception of Pavant Range uplift, and has been active intermittently since then. The timing of latest movement is difficult to determine. No Quaternary fault scarps have been recognized in the quadrangle, though a few sites with questionable Quaternary deformation have been identified. The primary reason is that alluvial-fan deposition along the range front is very active and rapidly obliterates fault scarps. Most alluvial deposits are Late Quaternary in age and post-date latest fault movement. The tops of even the oldest alluvial-fan deposits (Qaf_3) only have a stage 1 to 1+ pedogenic carbonate horizon, suggesting late Quaternary deposition (Birkeland and others, 1991). Thus, the most recent movement may be as young as the middle Quaternary. There are several locations along the Elsinore fault zone with features that may have been caused by Quaternary movement. Poorly exposed outcrops of older alluvial-fan deposits just south of the mouth of South Cedar Ridge Canyon in SE 1/4, NE 1/4, section 28, t. 22 S., R. 2 W., are butted against bedrock in what may be a fault contact. Steven and others (1992) mapped the entire hill at this location as a faulted block of Sevier River Formation but I believe the deposits are alluvial-fan materials and are probably Quaternary in age. The lower part of the landslide and slumped bedrock north of Richfield and south of Willow Creek has a semi-linear break in slope that coincides with the mountain front. This break may be an erosion-modified fault scarp or it may have formed as a detached mass "plunged" over the mountain front as it moved down slope. Along the mountain front, older alluvial-fan deposits (Qaf_3) are dissected more than 50 feet (15 m) by adjacent downcutting washes, suggesting that they rest on uplifted blocks west of the main fault. North of Cottonwood Creek, an isolated outcrop of older alluvium (QTa) sits on slumped rock and is about 180 feet (54 m) above the nearby wash bottom. It may have been stranded at this position by fault movement.

The age of the Little Valley fault zone is best constrained by exposures southwest of the quadrangle where rock of Miocene age is preserved in downdropped blocks (Steven and others, 1990), but the fault zone may be significantly younger. It seems likely that it developed during uplift of the range.

The Sevier fault cuts Quaternary fans of Holocene to latest Pleistocene age southeast of the quadrangle (Hecker, 1993). The youngest deformed rock on or adjacent Bull Claim Hill is early Miocene in age. However, it is likely that the fault deformation is younger. The Sanpete-Sevier Valley anticline has a long history dating back to the Cretaceous, but it has also deformed Quaternary sediments north of the quadrangle (Witkind, 1982; Willis, 1986; 1988; 1991; Weiss, 1990). Older colluvial deposits may be tilted, but good evidence is lacking. Thus, the age of Bull Claim Hill tilting can only be constrained to post early Miocene.

Landslides and slumps in the Pavant Range are related to present topography and are believed to be Quaternary in age. Topography on the surface of the slides is slightly to moderately subdued and most slides have been dissected by washes. However, carbonate development is only stage 1 to stage 2, suggesting young upper surfaces. There is no evidence of historic landslide activity except for one slide just south of the mouth of South Cedar Ridge Canyon. The large landslides may be related to the last glacial wet cycle 15,000 to 25,000 years ago.

ECONOMIC GEOLOGY

Quartz

A prospect and small workings have been developed on an outcrop of jasperoid quartz breccia on the east side of Bull Claim Hill (table 1). The quartz parallels a fault and is exposed in a series of pods that continues to the south. It and the host rock are brecciated and are partially recemented with quartz. Typical breccia fragments are .25 to .5 inches (0.6-1.3 cm) in diameter. The quartz is cryptocrystalline with some fine crystals on open surfaces and is mostly tan, yellowish tan, and purple, with lesser white, gray, and brown quartz. The quartz may have been explored for valuable metals or for decorative stone. Workings consist of a few small pits and cuts in the outcrop and small rubble piles.

[table 1 near here]

Calcite

Calcite was mined from a small claim immediately southwest of the quartz prospect on the east slope of Bull Claim Hill. The calcite is in veins up to 15 inches (38 cm) thick and apparently is in brecciated bedrock near a fault. The calcite ranges from finely crystalline to sparry crystals up to about 0.25 inches (0.6 cm) in diameter. Workings consist of a cut about 130 feet (39 m) long parallel to the vein trend and an abandoned loading facility. The amount of removed material is unknown, but was probably only a few truck loads.

Limestone

Early settlers quarried limestone northwest of Richfield to calcine into cement (figure 19). The limestone was from the Green River Formation, which is highly fractured and brecciated by slumping and faulting, such that it is broken into easily workable blocks. Much of the worked material was mined thick talus cones. Several charcoal kilns used to calcine the limestone are still present in and near Cottonwood Canyon. I found no record of the amount of limestone that was produced.

[figure 19 near here]

Metals

Several prospects have been opened along the Elsinore fault zone at the foot of the Pavant Range. The prospects are in weathered, brecciated bedrock with moderate to extensive limonitic alteration. There is no evidence to suggest that any profitable mining took place. Table 1 reports results of analyses of selected samples from several of the prospects.

Sand, Gravel, and Road Fill

Many pits have been opened for sand, gravel, and road fill. Several large pits were excavated in the 1980's for road base for Interstate 70. Smaller pits are used by local residents. Most of the quarried material is from alluvial-fan deposits derived from the Flagstaff and Green River Formations. It is moderately to poorly sorted and ranges from clay- to boulder-sized fragments. Some may be suitable as asphalt or cement aggregate after washing and screening (table 2). Volcanic colluvium and fractured bedrock has also been produced from a few small fill pits in the southeastern and southwestern parts of the quadrangle.

[table 2 near here]

Sand and gravel in the Sevier River floodplain is excavated in areas north and south of the quadrangle for use as concrete and asphalt aggregate, and as road fill. Such materials underlie parts of the floodplain in the quadrangle, but are buried under 20 to 50 feet (6-15 m) of silt and clay (Young, 1960).

Oil and Gas

The Richfield quadrangle is in the foreland part of the Sevier overthrust belt and the area has been explored for petroleum (Stark and Gordon, 1982). No wells have been drilled in the quadrangle but several have been drilled within 10 miles (16 km) (figure 1) (files of Utah Department of Natural Resources, Division of Oil, Gas and Mining). No production has been achieved from any of them. Moulton (1975) and Britt and Howard (1982) summarized the petroleum potential and possible source and reservoir rocks in the area. Complex structural and stratigraphic relationships, over-mature source rocks, and poor reservoirs have frustrated exploration to date.

Clay and Zeolites

The Aurora Formation contains large quantities of clays. Crawford and Cowles (1932) and Van Sant (1964) analyzed and described clay from a mine in the same formation in the Aurora quadrangle (figure 2) as Fuller's earth. The bed that is mined near Aurora is not exposed in the Richfield quadrangle but other clay intervals may have a similar composition. The Aurora Formation and the Dipping Vat Formation may have zeolitized materials but no sampling or analyses have been done.

WATER RESOURCES

Water is vital in the Richfield area due to the arid setting, population, and importance of agriculture. Major water sources are the Sevier River, springs and wells in the floodplain and alluvial fans, and springs and streams in canyons of the Pavant Range. Richardson (1907), Young (1960), Young and Carpenter (1961), Carpenter and Young (1963), and Young and Carpenter (1965) have studied and described water resources. Additional studies and data are on file with the Utah Division of Water Resources, Division of Water Rights, and Division of Drinking Water and Sanitation.

The Sevier River meanders across the southern part of the quadrangle and has formed a broad floodplain (figure 12). For water studies, the river system is divided into five basins (Young and Carpenter, 1965). The Richfield quadrangle is within the Sevier-Sigurd basin, which extends from about 20 miles (32 km) south to about 10 miles (16 km) northeast of Richfield. Average annual river flow from 1917 to 1959 at Rockyford Dam, at the northern edge of the basin, was 73,100 acre-feet ($9.01x10^7$ m^3). The flow is considerably less than 40 miles (64 km) upstream at Piute Reservoir, where average flow was 165,800 acre-feet ($2.04x10^8$ m^3), because of high irrigation use.

Within the floodplain in the quadrangle, the water table is at or within a few feet of the ground surface. Springs and flowing wells are common. Most wells are less than 100 feet (30 m) deep and tap several gravel and sand aquifers (Young, 1960; Carpenter and Young, 1963). The surface and shallow subsurface water systems are interconnected and water tends to emerge and sink repeatedly along the river corridor. Springs are particularly abundant around the edges of Bull Claim Hill, which diverts and concentrates flow. The fractured bedrock in the hill may also be a conduit for water sourced in highlands to the east. The three largest canyons that cross the western part of the quadrangle, Cottonwood, Willow, and South Cedar Ridge, all have small perennial streams. Cottonwood Creek has an annual discharge of about 2,200 acre-feet (2.71×10^6 m^3) and Willow Creek discharges about 1,500 acre-feet (1.85×10^6 m^3) (Young and Carpenter, 1965). Annual discharge of South Cedar Ridge Canyon was not reported; based on casual observation (fall 1993-spring 1994) I estimate its average annual flow at about 3,000 acre-feet (3.70×10^6 m^3). The streams normally submerge into alluvial fans soon after crossing the Elsinore fault zone. All the streams have water collection systems developed near canyon mouths to transport the water across the alluvial fans for agricultural use. Strawberry and Nash Canyons, tributaries of South Cedar Ridge Canyon, also have small perennial streams. Other canyons are dry except during spring runoff and storms.

The numerous gravel and sand intervals in the thick valley fill and in the alluvial fans along the range front constitute the major shallow aquifers. There are no significant alluvial aquifers in the mountain areas. Sandstone and limestone in formations in the Pavant Range have intergranular and fracture porosity. Water has also been noted in deep oil and gas exploration wells in the area, but the quality is generally poor.

Young and Carpenter (1965) summarized water quality as related to various uses (table 3). They noted that in general water quality from the major aquifers is good, but that there are local areas with high salinity, harmful quantities of minerals, and dissolved solids. Quality is typically best for springs and deep water wells, slightly less in shallow wells, and lowest in surface flow. The quality of the Sevier River decreases downstream due to recycling of irrigation runoff. Water sourced near the Arapien Shale typically has very high concentrations of dissolved solids.

[table 3 near here]

GEOLOGIC HAZARDS

Earthquakes

Active tectonic stresses in the Richfield area are complex, making it difficult to evaluate earthquake potential. Faults in the area south of the quadrangle are characterized by strike-slip movement, while faults in the quadrangle and areas to the north, east, and west are characterized by dip-slip displacement (Anderson and Barnhard, 1992). The region appears to overlie low-angle decollement structures that may be aseismic (Arabasz and Julander, 1986; Anderson and Barnhard, 1992). Quaternary deformation is common in the region, but some is related to salt diapirism and dissolution, landsliding, or other surficial processes (Witkind, 1982; 1983; Anderson and Barnhard, 1992; Willis, 1986, 1988, 1991; Weiss, 1990).

The Richfield quadrangle is within one of the most seismically active parts of the Intermountain Seismic belt (Anderson and Barnhard, 1992). The Elsinore fault crosses the middle of the quadrangle and the Sevier fault is located near the east side. The Sevier fault has experienced late Pleistocene to Holocene movement and has large scarps that cut surficial deposits (Hecker, 1993). No Quaternary scarps have been identified on the Elsinore fault in the quadrangle because most Quaternary sediments are so young that they probably post-date latest Quaternary offset. Both faults are capable of generating large earthquakes (possibly in the 6.0 to 7.5 magnitude range on the Richter scale) (Hecker, 1993).

Two of the five largest historic earthquakes in Utah were centered in or near the quadrangle. On November 13, 1901 an earthquake with an estimated Richter magnitude of 6.5 or larger was centered near Richfield and on September 29 and October 1, 1921 two shocks of estimated Richter magnitude 6 were centered near Elsinore, just south of the quadrangle (Hopper, 1988; Hecker, 1993). There have been several other earthquakes with magnitudes above 4.0 in the area (Arabasz and others, 1979; Hecker, 1993).

Earthquake hazards include shaking, ground movement, liquefaction, rockfalls, and landslides. These risks should be considered when constructing and retrofitting buildings and roads. There are many older, unreinforced masonry buildings in Richfield that are particularly vulnerable to earthquake damage. Rockfalls in the canyons and near the mountain front are likely in the event of moderate to large earthquakes. Most of the valley area has unconsolidated, water-saturated sediments that have a high potential for liquefaction (Hecker and others, 1988).

The quadrangle is in Uniform Building Code zone 2B but is near the boundary with zone 3, the highest zone in Utah (International Conference of Building Officials, 1991). Nationally, zones range from 1 to 6; an increase in zone requires adhering to a more stringent criteria for earthquake-resistant building design and construction.

Landslides and Slumping

There are several large landslide and slump masses within the quadrangle (figures 12 and 13). Richfield and Interstate 70 are situated near the toe of these features and thus are at some risk. Apparently, the slides moved during wet climatic periods and are dormant at the present time. They could be re-activated by unusual precipitation, seismic activity, or a combination thereof. Except for ground cracking that was probably due to hydrocompaction, none of the slides were reactivated in the 1983-1985 wet period when many landslides throughout the state experienced renewed movement (Kaliser and Slossen, 1988; Kaliser, 1989; Harty, 1993). The only mapped active landslide is in a remote area near the mouth of South Cedar Ridge Canyon that poses little threat to cultural features. As construction in Richfield continues to expand onto the toes of the old landslides measures should be taken to safeguard foundations from differential settling.

Radon

The Richfield quadrangle has areas with known high radon gas concentrations (Solomon, in press). Radon gas is produced by the natural decay of radioactive elements such as uranium and is a known cause of cancer. It has a tendency to concentrate in basements and other closed structures with low air circulation. In the Richfield area the uranium occurs in trace amounts in volcanic rock and in alluvium derived from volcanic bedrock sources. Organic shale is also a known source, but is less common in the Richfield area. Solomon (in press) noted high concentrations in the southwestern part of the quadrangle and near Bull Claim Hill. The alluvial fans and sedimentary bedrock areas in the central to northern parts of the quadrangle have moderate concentrations and the ground-water-saturated, floodplain areas have low concentrations. Inexpensive tests can be conducted to determine radon concentrations in homes. Risks can be reduced by sealing basement floors, increasing ventilation, and other procedures.

Floods and Debris Flows

Flooding is common in the Sevier River floodplain but it generally only affects marsh lands. Unusually high runoff has damaged roads, bridges, and flooded a few homes in the area. Canyons that cross the western part of the quadrangle have large drainage basins and occasionally produce large debris flows and mudflows. Richfield is near the mouth of several such canyons, but most of the city is currently protected by catchment basins that can contain all but very large flows. Continued growth in the area may expand into vulnerable areas. Interstate 70 crosses several large alluvial fans composed of debris flow and mudflow deposits and could be impacted. Recent debris-flow deposits contain boulders up to 18 feet (5.5 m) in diameter that have been transported more than 1 mile (1.6 km) from the mountain front, indicating the potential for large flows (figure 14). Several large debris flows were deposited on the alluvial fans during the 1983-85 wet years.

Expansive and Collapsible Soils

Expansive soils contain clays that swell when moistened and shrink as they dry. Collapsible soils are porous with loose interlocking grains and tend to settle when moistened. Roads and structures built on such materials tend to have structural damage. Such soils have caused problems in the Richfield area. The area in and near the western half of the city is of most concern and on-site evaluation should be done before construction begins. Collapse tests of soils from that area exhibited 2 to 18 percent settlement (Rollins and others, 1992).

Rock Falls

The canyons in the Pavant Range are steep and the interbedded resistant and nonresistant units naturally produce large loose boulders that rest on steep slopes. Large rock falls are common in the canyons. A fall that occurred in early 1993 in lower Willow Creek Canyon involved several boulders in excess of 10 feet (3 m) in average diameter. Currently, risk of property damage is low since there is no significant development in most canyons. Spring freeze-thaw cycles and during earthquakes are high-risk times for rock falls.

ACKNOWLEDGMENTS

This study has benefitted from discussions and visits to the field by R.E. Anderson, P.D. Rowley, I.J. Witkind, D.A. Sprinkel, and H.H. Doelling. The Richfield office of Fishlake National Forest provided colored aerial photographs and the Richfield office of the U.S. Soil Conservation Service provided copies of soil maps of Sevier Valley. H.H. Doelling served as project manager and reviewed preliminary copies of the manuscript and map. Kent Brown aided in transfer of field data from aerial photographs to the digital computer files and in printing and editing copies of the map.

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APPENDIX

Type section of Aurora Formation

Start in NE 1/4, SW 1/4, section 31, T. 21 S., R. 1 W.; end in SW 1/4, SE 1/4, section 31. Aurora 7 1/2' quadrangle, Sevier County, Utah. Measured May and June, 1986.

UNIT	FEET	CUM. FT.	DESCRIPTION
41	--	--	Tuff, strongly welded, dark-brownish-gray.

Base of Tuff of Albinus Canyon
Top of Dipping Vat Formation

UNIT	FEET	CUM. FT.	DESCRIPTION
40	12	1132	Sandstone, coarse granular, sandy to clayey matrix, well- to moderately indurated, minor clay or mudstone, pebbly in some places, prominent pumice and biotite grains, has a more fluvial appearance than earlier units; upper contact may be slight angular unconformity.

Base of Dipping Vat Formation
Top of Aurora Formation, total thickness 1120 feet.

UNIT	FEET	CUM. FT.	DESCRIPTION
39	35	1120	Similar to unit 37, but with more interbedded sandstone and slightly better indurated.
38	5	1085	Mudstone and sandstone similar to unit 37 but is moderately indurated and is more calcareous.
37	55	1080	Mudstone, sandstone, volcanic, pale-gray, very fine-grained to clay, well-sorted, well-bedded, minor cross-bedding, moderately indurated to friable, thin-bedded to laminated, ledgy slope former, reworked, abundant fine pumice, lithic fragments, and biotite, pumice fragments to 0.08 inches, low density (porous).
36	45	1025	Similar to unit 34; mostly bentonitc mudstone, poorly exposed, sandy, biotite grains are prominent.
35	4	980	Calcareous sandstone, light-olive-gray, fine- to very fine-grained, subangular to subrounded grains, moderately well-sorted, moderately indurated, medium-bedded, ledge

			former, blocky weathering, covered upper contact, grains are lithic fragments, biotite, mudstone and limestone.
34	23	976	Sandstone and mudstone, bentonitic, brownish-gray to light- gray, coarse- to fine-grained, moderately poor sorting, poorly indurated to friable, ledgy slope-former, grains are lithic fragments, biotite and pumice.
33	105	953	Mudstone (70%), sandstone (30%), and minor limestone, pale-gray, medium- to fine-grained to clay, subrounded, moderately well to moderately poor sorting, poorly exposed, poorly indurated to friable, grains are quartz, feldspar, and clay, thin- to thick-bedded, float indicates probable pumice fragments and volcanic clasts in covered parts of unit, gradational upper contact.
32	100	848	Covered interval; (moved along strike about 300 feet. May be less than 100 feet of missing section due to a fold or fault).
31	53	748.0	Sandstone, light-gray to yellowish-gray, coarse- to very fine-grained, angular to subangular, moderately well-sorted, thin- to thick-bedded, ledgy cliff-former, weathers to form rounded blocks, abundant 6-inch to 2-foot crossbeds, has mud rip-up and pebbles in some horizons, eroded upper surface.
30	55.3	695.0	Interbedded sandstone, mudstone, and minor limestone, light-gray to yellowish-gray, biotite is common in sandstone beds, limestone beds are up to 6 inches thick, coarse- to very fine-grained, angular to subangular, individual beds are moderately well sorted, poorly indurated, ledgy slope former, thin- to medium-bedded, weathers crumbly to chippy (limestone), gradational upper contact.
29	34.8	639.7	Interbedded sandstone similar to unit 27, mudstone similar to unit 28, and pebbly sandstone; the pebbly sandstone is light gray to light brownish-gray, very fine-grained to pebbles 0.5 inches in diameter (pebbles are mostly reworked from welded ash-flow tuffs), angular, moderately poor sorting, moderately poor induratiion, abundant lithic fragments, medium- to thick-bedded, forms a slope with crumbly weathering, upper contact at base of steep slope.
28	26.9	604.9	Sandy mudstone, moderate-olive-brown, slope-former, friable, poorly exposed, minor interbedded chippy limestone.
27	12.2	578.0	Sandstone, light-gray, very fine-grained to pebbly, poorly

			sorted, angular to subangular, moderately indurated, mostly quartz with 15% lithic fragments and 1-2% biotite, thin-bedded, ledgy slope-former, blocky to crumbly weathering, pumice fragments to 2 inches in length, abundant volcanic-derived grains.
26	39.6	565.8	Interbedded, reworked tuff (60-70%), limestone and claystone; tuff is gray to pinkish-gray, well- to moderately-well-indurated, medium- to thin-bedded, ledgy slope-former, has pumice in some beds to 1/2 inches in diameter; limestone is sandy with abundant volcanic grains, micritic, pinkish-gray, medium-bedded, forms ledges, blocky, sharp upper contact; claystone is crumbly, poorly exposed.
25	21.4	526.2	Water-lain ash-flow tuff, abundant pumice with fragments up to 6 inches near base, size of pumice fragments decreases upward to less than 1 inch in upper part, has two to three depositional sequences, pinkish-gray, light-gray or very light-gray, thin- to thick-bedded, as much as 2% biotite, up to 5% lithic fragments which are as much as 0.5 inches in diameter, has distinctive yellowish-brown Fe-rich alteration band that cuts slightly oblique to bedding, contains compressed lapilli up to 3 inches in length, much of unit is devitrified to clean white clay which has been mined, yielded K-Ar date on biotite of 38.4±1.5 Ma.
24	20	504.8	Covered interval (bottom of mined out pit).
23	2.2	484.8	Ash-flow tuff, little or no reworking, very light-gray to pinkish-gray, has abundant coarse- to very coarse quartz and biotite, mostly altered to clay, abundant pumice fragments, yielded K-Ar date on biotite of 39.6±1.5 Ma.
22	3	482.6	Sandy limestone, light-gray, fine-grained, thin-bedded, slope former, splitty or chippy weathering, sharp upper contact, unit is slope on side of mined out clay pit.
21	31	479.6	Covered, probably underlain by mudstone similar to unit 18.
20	29	448.6	Mudstone, similar to unit 18, has a thin chippy limestone lense.
19	3.5	419.6	Sandstone with thin interbedded limestone similar to limestone of unit 17, dark-yellowish-orange, biotite-bearing, very fine- to medium-grained, moderately well-sorted, calcareous, moderately poor induration, medium-bedded, ledge former, blocky weathering, limestone is lenticular and discontinuous, has rooting or burrowing.

18	67.4	416.1	Mudstone and minor limestone, yellowish-gray to olive-gray, limestone is pale orangish gray, laminated to thinly laminated, forms float on surface, slope former, popcorn weathering.
17	7.1	348.7	Limestone, grayish-orange to dark-yellowish-orange, micritic with sparite stringers, thin-bedded, lenticular and discontinuous laterally, ledge former, white chippy limestone at top, blocky, bioturbated.
16	65.9	341.6	Mudstone, olive-gray, brownish-gray, greenish-gray, and grayish-red, poorly exposed slope former, forms punky soil, sharp upper contact.
15	8	275.7	Limestone, pale-yellowish-gray to orangish-gray, thin-bedded, lenticular, ledge former, chippy weathering, few poorly preserved gastropods.
14	19.7	267.7	Mudstone (70%), carbonaceous shale (30%) and minor interbedded limestone similar to unit 15, yellowish-brown, yellowish-gray, grayish-black, brownish-gray, medium-bedded to laminated, friable, crumbly, poorly-exposed slope-former.
13	17.3	248.0	Interbedded calcareous mudstone and muddy limestone, grayish-orange to yellowish-orange, ledgy slope former, weathers to small crumbly blocks, limestone beds are 3-6 inches thick and are vuggy.
12	66	230.7	Interbedded mudstone and sandstone, grayish-orange to grayish-pink, thick-bedded, poorly exposed hummocky slope former, crumbly to popcorn weathering, sandstone is very fine to medium grained and yellowish gray.
11	4.2	164.7	Carbonaceous shale and mudstone, black to brownish-black, friable, abundant charcoal, coaly, laminated to thinly laminated, crumbly slope-former, abundant selenite gypsum crystals to 3 inches long, macerated plant fragments on bedding surfaces, interbedded with orangish-gray sandstone, (sample from unit was barren of pollen).
10	85	160.5	Interbedded mudstone and claystone, olive-gray and yellowish-gray, medium- to thin-bedded, slope former, popcorn weathering, gypsum crystals; includes interbedded muddy, fine- to very fine-grained, noncemented sandstone; contains biotite, interbedded carbonaceous mudstone in 1-5 foot beds.
9	1	75.5	Sandstone, yellowish-gray, medium- to very fine-grained, moderately well-sorted, calcite cement, biotite grains,

			laminated to thinly laminated, ledge former, platey to chippy weathering, sharp upper contact.
8	7.1	74.5	Similar to unit 6.
7	1.2	67.4	Sandstone, yellowish-gray, very fine-grained, calcite cement, moderately indurated, biotite grains, thinly laminated, slope former, chippy weathering-especially near base, slightly more resistant than adjacent units.
6	54.5	66.2	Interbedded mudstone (90%) and sandstone (10%), locally sandy, moderate-olive-brown, light-olive-gray, light-gray, poorly exposed slope former, selenite gypsum crystals to 3 inches long, sandstone is medium to fine grained similar to unit 5, unit pinches out laterally.
5	2.2	11.7	Sandstone, yellowish-gray, medium- to very fine-grained, subangular to subrounded, moderately well-sorted, friable, noncemented, mostly quartz with 1% biotite and 5-10% lithic fragments, poorly exposed slope former, crumbly weathering, gradational upper contact, lithic fragments are probably volcanic-derived.
4	9.5	9.5	Interbedded mudstone and claystone, variegated grayish-red, pale-reddish-purple, moderate-reddish-orange, yellowish-gray, and grayish-orange, silt to clay, friable, poorly exposed slope former, crumbly to shaley weathering, forms clayey soil, gradational upper contact.

Base of Aurora Formation
Top of Crazy Hollow Formation

3	18.9		Sandstone, pale-yellowish-orange to dark-yellowish-orange, lower part is medium to fine grained, upper part is fine to very fine grained, angular to subangular, moderately well-sorted, quartz with 2-4% weathered feldspar, varies from well to poorly indurated, has minor biotite and dark lithic fragments (5%), medium-bedded to laminated, ledgy-cliff former, rounded irregular knobs to blocky weathering, lenticular channel deposit, mostly planar bedding, some small-scale cross-bedding, sharp upper contact.
2	9.2		Covered interval.
1	40+		Pebbly sandstone, grayish-orange to dark-yellowish-gray, pebbles up to 0.3 inches, mostly coarse-grained sandstone, angular to subangular, moderate- to poorly sorted, poor- to well-indurated, dark chert in pebbly layers, medium- to thin-bedded, ledge former, blocky weathering, strongly jointed, covered upper contact.

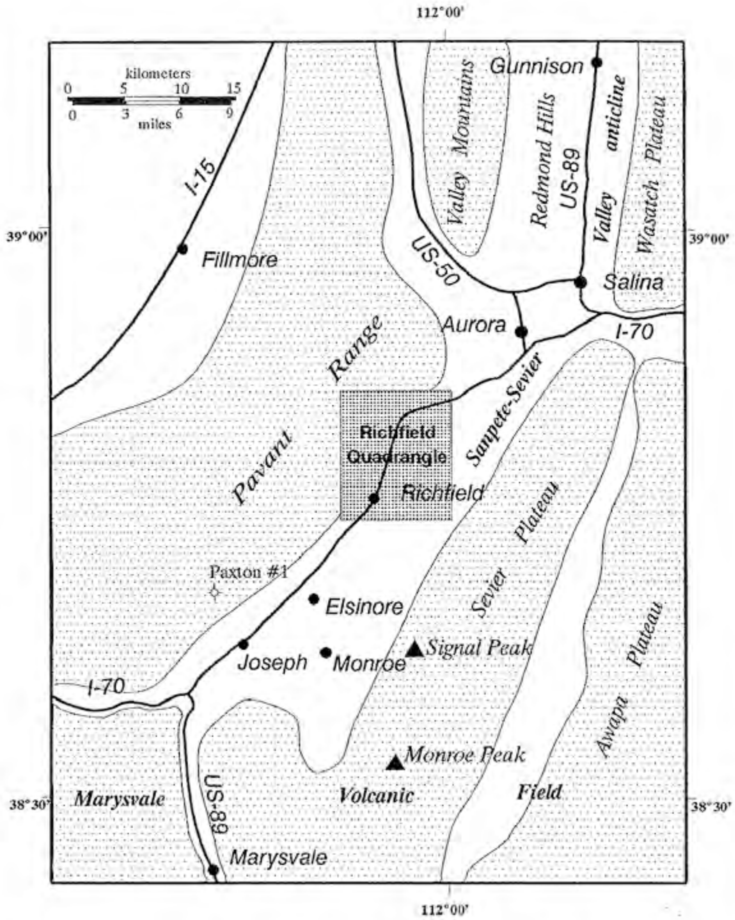

Figure 1. Index map showing major geographic and physiographic features in the Richfield quadrangle area. Paxton #1 well, southwest of the quadrangle, is also shown.

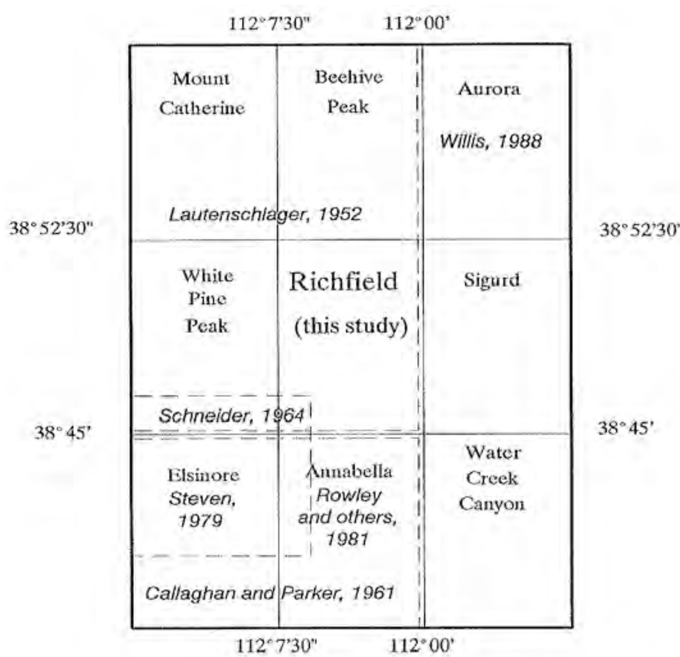

Figure 2. Index map showing geologic mapping in the Richfield area and names of 7 1/2' quadrangles surrounding the Richfield quadrangle.

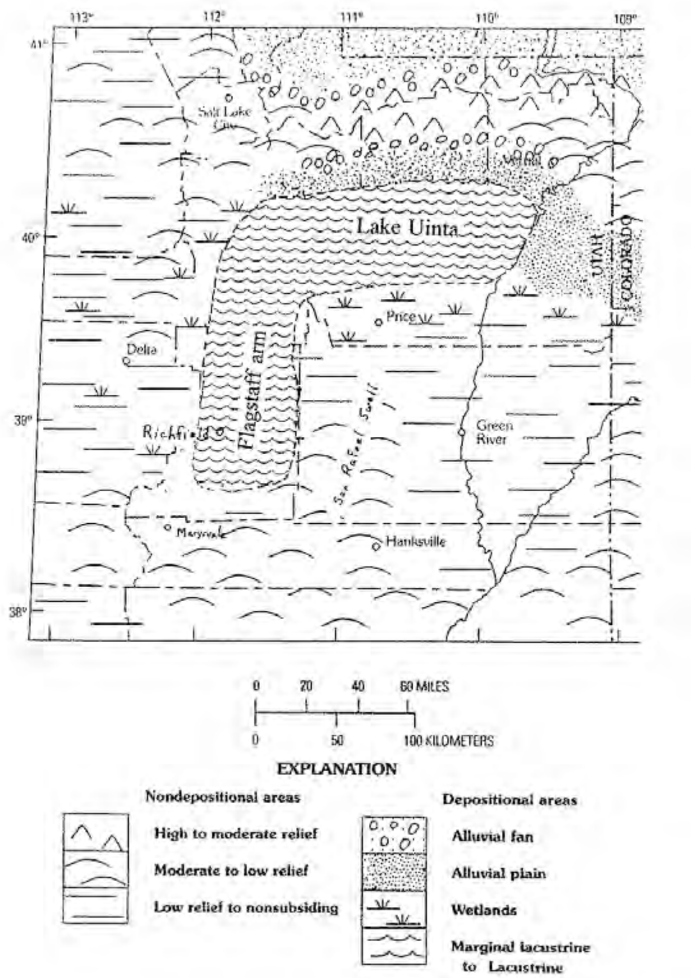

Figure 3. Paleogeographic reconstruction showing the depositional setting during the Eocene. The Richfield quadrangle is near the southern end of the Flagstaff arm of Lake Uinta, which extended into a basin in central Utah west of the San Rafael Swell and east of highlands in western Utah. The Flagstaff, Green River, Crazy Hollow, and Aurora Formations were deposited in lacustrine, marginal lacustrine, and alluvial plains in the arm. The arm remained a depositional area into the Oligocene and received volcanic and volcaniclastic rock derived from the Tintic volcanic field to the northwest and the Marysvale volcanic field to the south. (Modified from Franczyk and others, 1992).

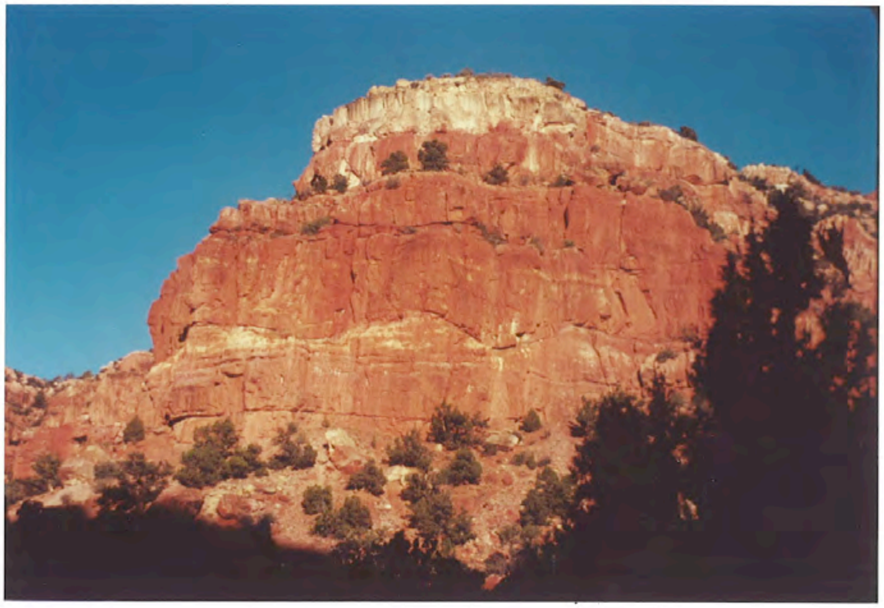

Figure 4. Incised channel deposits in sandstones of the lower red member of the Flagstaff Formation in South Cedar Ridge Canyon.

Figure 5. Looking northwestward toward the mouth of South Cedar Ridge Canyon. The middle red member of the Flagstaff Formation forms the dark-colored hill in the middle of the photograph. The lower white member forms the light-colored ledges near the right side of the photograph and the middle white member caps the ridge near the left side. The lower half of the middle white member is a smooth-slope-forming gypsiferous mudstone in this area. The upper part of the middle white and the basal part of the upper red members form the faulted hills in the middle distance. The main strand of the Elsinore fault probably passes in front of the faulted hills.

Figure 6. Looking westward up Willow Creek Canyon. The middle red member of the Flagstaff Formation is exposed in the lower half of the slope and the middle white member is exposed in the upper half. The narrow dark band in the upper slope is the marker bed in the middle of the middle white member. Note that in this area, the lower half part of the middle white member is white ledge-forming calcareous sandstone.

Figure 7. Looking north along the front of the Pavant Range between Willow Creek Canyon and South Cedar Ridge Canyon. The upper red member of the Flagstaff Formation forms the dark-colored band. It is downdropped on a series of faults in the right half of the photograph.

Figure 8. The upper red member of the Flagstaff Formation forms the dark-colored ledgy slope near the bottom of Cottonwood Creek canyon. The upper white member is mostly pinkish-gray in this area and forms the middle slope. The contact is at the base of the white ledge. The Green River Formation forms the thick blocky cliff. The lower few feet of the Crazy Hollow Formation forms the planar dark-colored ledges near the top of the photograph. A thin residual cover of landslide deposits covers the upper red member in the lower right corner of the photograph.

Figure 9. The Aurora Formation forms sparsely vegetated hills in the southwestern part of the quadrangle. Banding is due to slightly different colors cause by lithologic changes. The upper surface of the formation is a common detachment surface on which the overlying Dipping Vat Formation and volcanic units are sliding toward the valley.

Figure 10. Discordant selenite veinlets cutting a rare exposure of the Aurora Formation near the southwestern corner of the quadrangle.

Figure 11. East slope of Bull Claim Hill. The lower slope is crystal-poor dacitic lava flows that are mostly covered by talus and colluvium. The resistant upper half of the ridge is tuff of Albinus Canyon. The volcanic units dip about 30 degrees westward.

Figure 12. Looking northwest from Bull Claim Hill toward the large landslide complex near the center of the photograph. Most of the slide material is Green River Formation. Table Mountain, capped by relatively undeformed Green Formation, is in the center of the photograph. The snow-covered crest of the Pavant Range is in the background. Note that Tertiary strata in this part of the range dip southeastward at 5 to 10 degrees.

Figure 13. The Green River Formation is broken and rotated into a series of toreva blocks that are riding on a detachment near the base of the blocky cliff in Cottonwood Creek Canyon. Note the undeformed strata in the upper part of the upper white member of the Flagstaff Formation just below the cliffs.

Figure 14. Large boulders deposited by debris flows in a small wash south of South Cedar Ridge Canyon. Boulders up to 18 feet (5.5 m) in diameter are common in most washes on the broad alluvial fans in front of the Pavant Range. Some deposits are as young as 1983.

Figure 15. Elsinore fault zone north of Willow Creek canyon. The dark band near the top is upper red member of the Flagstaff Formation. The dark ledge beds exposed near the middle of the photograph, and repeated near the base of the slope by faulting, is the marker bed in the middle white member. The lower part of the middle white member forms a smooth slope near the right side of the photograph.

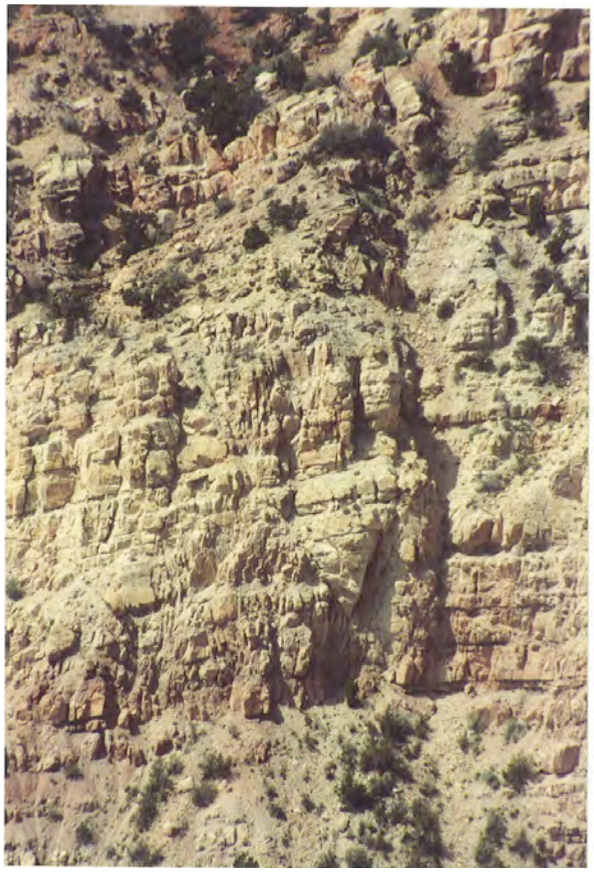

Figure 16. Wedge-shaped keystone block downdropped about 20 feet (6 m) in the middle white member of the Flagstaff Formation in unnamed canyon about 1 mile (1.6 km) north of the mouth of Willow Creek Canyon. Similar jointing and brecciation is common in the Elsinore fault zone throughout the quadrangle.

Figure 17. Looking north toward a V-shaped fold in Crazy Hollow strata west of Richfield. The rock was folded during slumping as the block moved down-slope toward the valley. Just south of the photographer the west limb of the fold has a rounded form that could be confused as part of a range-front monocline.

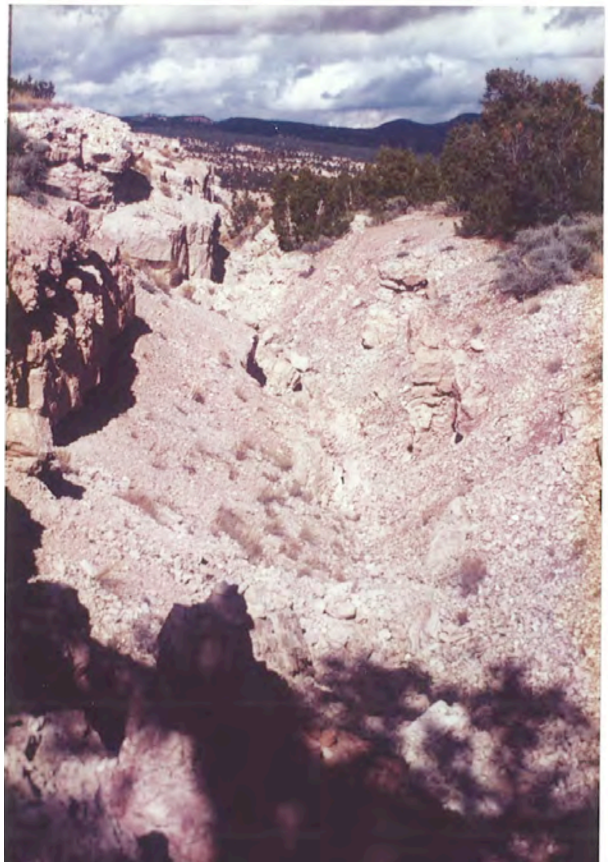

Figure 18. Large open fracture in a slump block of Green River Formation in the NE 1/4, section 16, T. 23 S., R. 3 W. The fracture may have historic movement.

Figure 19. Limestone quarry behind a kiln that was used to produce cement north of Richfield.

SAMPLE #		RIQT0501	RIQT0503	RITG0506	RITG0507	RICH0509	RICH0510	RICH0607
Percentages	Na	0.03	0.05	0.12	0.07	0.08	0.11	0.23
	Mg	0.02	0.02	0.41	0.62	0.43	1.35	2.65
	Al	0.15	0.20	0.46	0.60	2.05	1.40	1.75
	K	0.05	0.03	0.16	0.10	0.61	0.84	0.50
	Ca	0.05	0.06	0.51	0.34	0.88	11.16	3.00
	Ti	0.15	0.07	0.02	0.03	0.06	0.04	0.10
	Fe	0.30	0.80	10.00	> 10.00	6.10	1.10	> 10.00
Parts per Million	Li	22	17	37	23	55	32	29
	Be	0.7	< 0.5	1.3	1.7	1.4	0.5	2.1
	Sc	4.3	2.0	2.2	3.6	1.5	9.2	5.8
	V	23	31	237	483	63	39	92
	Cr	163	318	207	28	138	67	55
	Mn	47	76	95	1485	65	424	196
	Co	5.8	6.9	9.3	81.9	13.1	10.5	14.7
	Ni	19.1	23.4	34.8	114.6	35.1	42.9	71.9
	Cu	29.7	25.6	63.4	26.1	37.4	22.5	30.5
	Zn	13.9	11.5	65.2	585.6	45.4	29.9	33.3
	Ga	9	7	14	5	12	9	10
	Ge	< 1	1	3	3	2	< 1	4
	As	28	61	> 5000	3140	4760	106	> 5000
	Rb	8	6	20	14	35	58	48
	Sr	64	82	335	75	202	355	176
	Y	16	13	13	59	13	15	16
	Zr	91	77	40	30	40	33	61
	Nb	7	4	3	14	8	16	39
	Mo	11.4	278.7	20.1	16.7	44	11.7	15.3
	Ag	< 0.5	0.8	< 0.5	< 0.5	0.3	< 0.5	0.5
	Cd	< 0.5	4.1	1.0	0.5	1.1	0.5	0.8
	In	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	Sn	3	5	2	2	1	1	3
	Sb	11.5	10.9	37.7	4.4	452.6	10.5	29.4
	Te	< 0.5	2.2	< 0.5	0.5	0.5	< 0.5	< 0.5
	Cs	1	1	3	3	5	3	8
	Ba	992	774	1005	157	743	520	270
	La	5	6	6	25	19	12	35
	Ta	< 1	< 1	< 1	1	< 1	2	7
	W	5	5	2	2	3	3	3
	Tl	0.5	1.0	25.6	11.7	98.7	2.2	26.7
	Pb	31	24	36	11	24	28	32
	Bi	1.9	5.7	0.5	0.5	1.0	< 0.5	0.8
	Th	2	1	4	11	11	9	13
	U	8	13	5	3	8	3	6
Parts per Billion	Au	10	13	8	20	25	30	15

Table 1. Assays of selected samples from prospect pits in the Richfield quadrangle. Grab samples were selected for high values.

RITQ0501	38°45'8.9"N.	112°0'38.3"W.	brecciated quartz dike
RITQ0503	38°45'8.9"N.	112°0'38.3"W.	quartz dike
RITG0506	38°49'25.2"N.	112°3'23.0"W.	brecciated limonitic alteration in Green River Formation in fault zone
RITG0507	38°49'25.2"N.	112°3'23.0"W.	limonitic alteration in Green River Formation in fault zone
RICH0509	38°51'42.7"N.	112°1'10.9"W.	limonitic alteration in Crazy Hollow Formation in fault zone
RICH0510	38°51'35.7"N.	112°1'16.5"W.	limonitic alteration in Crazy Hollow Formation in fault zone
RITF0607	38°49'3.1"N.	112°3'55.1"W.	limonitic alteration in Flagstaff Formation in fault zone

PITS AND POTENTIAL SITES - TEST DATA SHEET

LOCATION						OWNERSHIP		MATERIAL					TEST DATA - REPRESENTATIVE SAMPLE																			
																SIEVE ANALYSIS																
																BEFORE CRUSHING		PERCENT PASSING AFTER CRUSHING TO 1" MAX. SIZE										IMMERSION COMPRESSION AVE. P.S.I. LIME			SODIUM SULPHATE LOSS	
PIT OR SITE NUMBER	TOWNSHIP	RANGE	40 ACRE TRACT	QUARTER SECTION	SECTION	P = PRIVATE C = COMMERCIAL CO = COUNTY F = FEDERAL S = STATE	OWNER	USE OF MATERIAL	TYPE OF DEPOSIT	PRESENT ESTIMATED QUANTITY (CU. YDS.)	THICKNESS OF MATERIAL	DEPTH OF OVERBURDEN	DATE SAMPLED *	TYPE OF SAMPLE	DEPTH OF SAMPLE	> 3"	> 1"	1"	1/2"	NO. 4	NO. 10 *	NO. 40 *	NO. 200	LIQUID LIMIT	PLASTICITY INDEX	SWELL	A.A.S.H.O. CLASSIFICATION	WO/	W/	ABRASION 500 REV.	+4	-4
21019	23S	3W	NW	SW	24	P	Viola Ivey Richfield City	B.G., S.G.	Alluvial Fan	330,000	15	2	1955			3.6	42.4	100		33.0	24.5	15.7	5.5	15.3	NP	.010	A-1-a			35.1		
21020	23S	3W	SW	NE	23	CO	Sevier County	B.G., S.G.	Stream Channel	220,000	12	0-1	1955			2.3	44.2	100		39.3	29.2	18.0	5.1	15.9	NP	.010	A-1-a			35.0		
21021	23S	2W	SW	SW	8	P	Howard Hansen	B.G., S.G.	Alluvial Fan	640,000	10	0-1	1961	Cut Bank		1.7	33.2	100	67.6	40.7	31.8	24.0	9.6	14.2	NP	.010	A-1-a			40.0		
21022	22S	2W		S½	34	P	Nina Snow	Borrow	Stream Channel	47,000+	6	0-1	* 1963	Test Hole		0	30.3	100	70.7	43.2	* 35.3	* 21.1	7.4	15	NP	.002	A-1-a	119	474	36	42.9	11.9

Table 2. Analyses of samples from gravel and road-fill pits in the quadrangle (from Utah Department of Transportation, 1966).

Table 3. Analyses of water from selected wells in the Richfield quadrangle (from Young and Carpenter, 1965).

TABLE 3.

Location	Date of Collection	Well or Spring	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Na+K: Sodium (Na)	Na+K: Potassium (K)	Lithium (Li)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids[3]	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos per centimeter at 25°C)	pH
				Parts per million																		
SW NW NE 9, 23S. 2W.	8-6-59	W	58	29	----	----	37	38	27		----	262	36	39	---	.5	336	248	33	.8	563	7.9
SW SW SE 10, 23S. 2W.	4-18-60	W	53	22	----	----	89	67	88		----	529	154	62	---	11	753	500	66	1.7	1,170	7.7
SE NE SW 15, 23S. 2W.	4-25-58	W	52	15	----	----	220	145	211		----	492	523	465	---	1.9	1,820	1,140	742	2.7	2,830	7.5
NE SW SW 15, 23S. 2W.	4-25-58	W	53	25	----	----	178	192	359		----	448	699	650	---	5.0	2,330	1,240	868	4.4	3,580	7.4
NW SE SW 15, 23S. 2W.	4-25-58	W	53	27	----	----	164	119	256		----	431	482	420	---	8.3	1,690	898	545	3.7	2,660	7.4
NW NW SE 15, 23S. 2W.	4-25-58	W	52	30	----	----	109	30	17		----	160	200	63	---	5.9	534	396	265	.4	818	7.9
SW NW SE 15, 23S. 2W.	4-25-58	W	53	33	----	----	165	97	176		----	471	361	298	---	17	1,380	812	426	2.7	2,170	7.5
NW SW SE 15, 23S. 2W.	7-15-57	W	52	35	.03	.00	69	34	2.1	4.1	.3	318	51	29	.2	4.3	404	312	52	.5	650	7.7
SE NW NE 20, 23S. 2W.	4-25-58	W	52	19	----	----	293	381	564		----	540	1,350	1,180	---	10	4,060	2,300	1,850	5.1	5,820	7.3
SW SW NW 27, 23S. 2W.	9-21-56	W	55	---	----	----	----	-----	30	----	----	172	44	34	---	-----	------	180	39	.9	490	8.0
SE SW SW 27, 23S. 2W.	8-21-56	S	56	---	-----	----	----	-----	30	----	----	192	76	42	---	-----	------	224	67	.9	560	7.8
	7-15-57	S	56	36	.00	.00	52	20	25	4.1	.7	184	68	39	.2	2.9	338	212	60	.8	552	7.9
SE SE NW 28, 23S. 2W.	8-21-56	W	51	37	.01	.04	726	184	45	7.5	1.6	578	2,020	76	.0	20	3,400	2,570	2,090	.4	3,560	7.0
SE NW SE 28, 23S. 2W.	9-21-56	S	57	---	----	----	----	-----	36	----	----	250	324	46	---	-----	------	532	327	.7	1,060	7.4
SE SE SE 28, 23S. 2W.	9-21-56	S	55	---	----	----	----	-----	32	----	----	190	76	36	---	-----	------	212	56	1.0	544	7.7
NW SW SE 31, 23S. 2W.	5-5-60	W	54	32	----	----	65	13	10		----	156	53	36	---	4.9	291	216	88	.3	459	7.4
NE NW NE 34, 23S. 2W.	9-21-56	W	53	---	----	----	----	-----	56	----	----	398	42	70	---	-----	------	356	30	1.3	871	7.3
SE NW SW 36, 23S. 2W.	7-15-57	S	59	41	.00	.00	26	6.4	10	1.9	.3	114	3.2	13	.1	.7	159	91	0	.5	232	8.0
NW NE NW 25, 23S. 3W.	7-6-60	W	61	12	----	----	52	35	27		----	313	37	29	---	.4	341	271	14	.7	576	7.7
NE SW NE 26, 23S. 3W.	7-30-57	S	68	14	.04	.01	45	38	12	4.0	.5	298	27	20	.2	.8	310	269	25	.3	548	7.9
SE NW NE 36, 23S. 3W.	7-9-59	W	53	6.6	----	----	60	47	29		----	349	54	46	---	.0	415	343	57	.7	752	8.0

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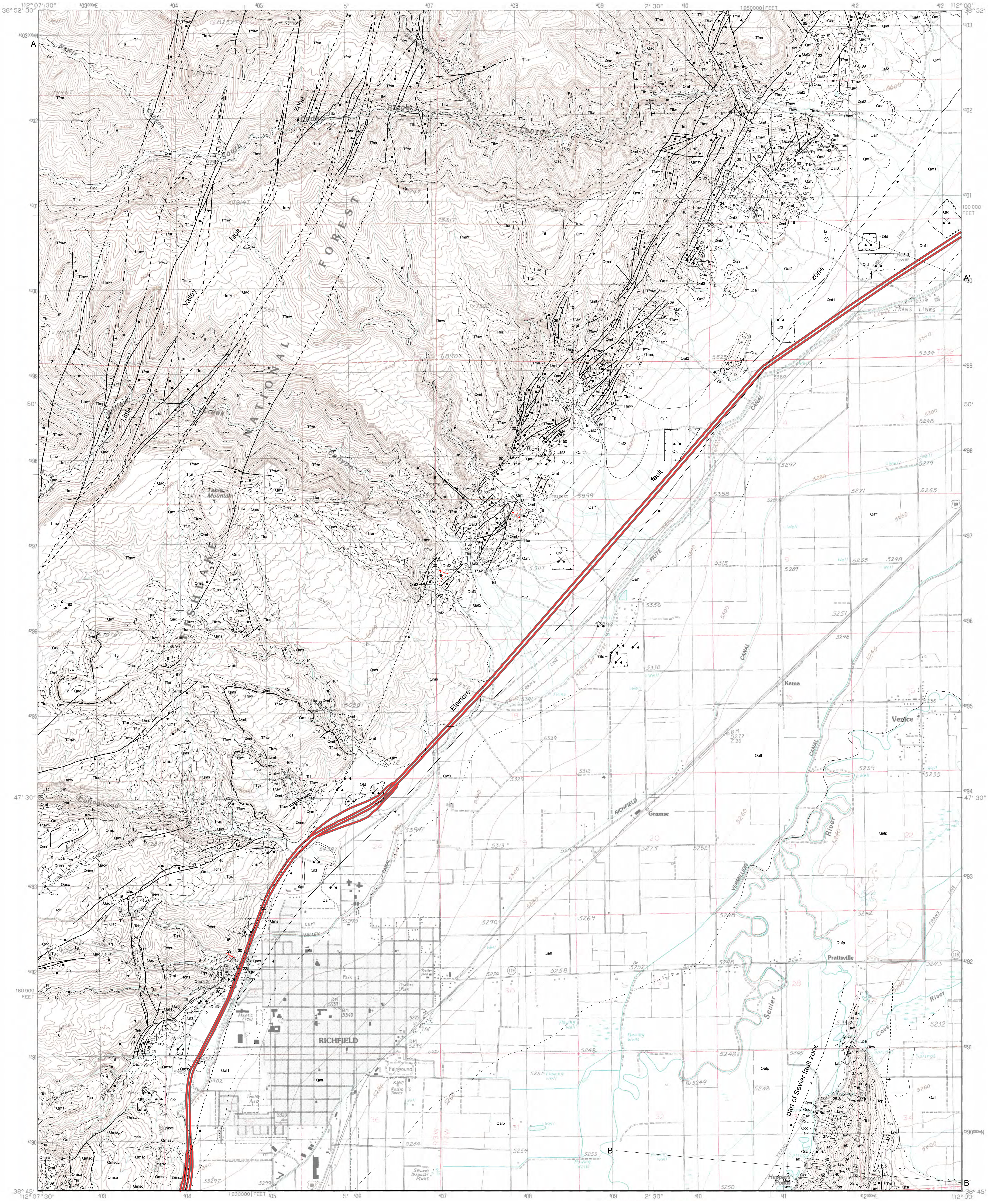


State Contract 94-1325
STATEMAP Agreement No. 1434-93-A-1175

Base from USGS Richfield 7.5' Quadrangle (1986)
Field work in 1993 - 1994

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
SUPPLEMENTAL COUNTOUR INTERVAL 20 FEET

1	2	3
4		5
6	7	8

1. Mount Catherine
2. Beehive Peak
3. Aurora
4. White Pine Peak
5. Sigurd
6. Elsinore
7. Annabella
8. Water Creek Canyon

ADJOINING 7.5' QUADRANGLE NAMES

INTERIM GEOLOGIC MAP OF THE RICHFIELD QUADRANGLE, SEVIER COUNTY, UTAH

by

Grant C. Willis

1994

Description of Map Units

Quaternary

Artificial (human-made) deposits:

Qf — **Artificial fill:** fill emplaced in construction of dikes and dams.

Qfd — **Artificial fill and disturbed areas**: gravel and road fill pits; includes recontoured areas, waste piles, and exposures modified during excavation.

Alluvial Deposits: Valley-fill deposits in Sevier Valley are as old as Miocene. Map age designations are based on upper exposed interval.

Qafp — **Mixed alluvial floodplain and marsh deposits**: moderately well- to well-sorted, medium- to fine-grained sand, silt, and clay deposited in the Sevier River floodplain; includes channel, overbank, and marsh deposits in abandoned meanders; locally has a salt and alkali evaporitic crust.

Qaff — **Fine-grained alluvial-fan deposits**: moderately to well-sorted, mostly clay- to fine-grained sand-sized alluvial and eolian materials deposited on the distal portions of alluvial fans near the middle of Sevier Valley; contains some lenses of gravel- to small boulder-sized materials; upper surface is aggrading; extensively cultivated.

Qaf_{1-3} — **Level 1-3 alluvial-fan deposits:** moderately to very poorly sorted boulders to fine-grained materials deposited in fan-shaped lobes at the mouths of canyons and in front of steep mountains; consist mostly of mudflow and debris-flow deposits with boulders up to 18 feet (5.5 m) in diameter; coalesced into broad slopes; distal, mostly fine-grained parts, are mapped separately (Qaff); mapped in three levels differentiated by age of upper surface and by amount of incision by cross-cutting washes; level 1 deposits are youngest and are dissected less than 10 feet (3 m) by washes and have broad areas of active deposition; level 2 deposits are dissected 10 to 30 feet (3-9 m) and have only small areas with active deposition; level 3 deposits are dissected more than 30 feet (6 m) by washes and are limited to small erosional remnants near mountain fronts.

Mass-movement deposits: Many outcrops in the quadrangle are affected by slumping and landsliding. Where deformation and movement are extensive, outcrops are mapped as landslide and slump deposits (Qms).

Qmsy — **Active landslide deposits**: extremely poorly sorted, angular, boulder to fine-grained material; includes uprooted vegetation and signs of historic movement; only one active landslide was recognized--near South Cedar Ridge Canyon.

Qms, Qms- — **Landslide and slump deposits**: extremely poorly sorted, angular blocks up to several tens of feet across; forms hummocky slopes with lobate fronts; head scarps are common; large, mostly intact blocks are mapped by their formation names with an "s" suffix to indicate slump; age unknown but are dissected up to 200 feet (60 m) by washes and do not show signs of historic movement; may be middle Pleistocene; up to 200 feet (60 m) thick; primary involved formations are indicated in some areas: (g-Green River Formation, ch-Crazy Hollow Formation, au-Aurora Formation, dv-Dipping Vat Formation, bt-Three Creeks Tuff Member of Bullion Canyon volcanics, a-tuff of Albinus Canyon, o-Osiris Tuff; v-undifferentiated volcanics). (Bedrock outcrops with moderate slump deformation are mapped by their bedrock symbol with an "s" suffix).

Qmt — **Talus deposits**: very poorly sorted, angular blocks deposited on and at the base of steep slopes; commonly form cone-shaped lobes; includes both active and inactive deposits.

Mixed-environment deposits:

Qac, Qacy, Qaco — **Mixed alluvial, colluvial, and talus deposits:** moderate- to poorly sorted materials in canyons and washes; consists of alluvial materials carried by small ephemeral and perennial streams and colluvial and talus deposits derived from canyon walls; base of deposits is not exposed in some areas; 10 to 30 feet (3-9 m) thick; differentiated into older (Qaco) and younger (Qacy) deposits near quadrangle boundary west of Richfield.

Qca — **Mixed colluvial, alluvial, and talus deposits**: similar to Qac deposits except have a lower percentage of alluvial material and found on slopes instead of in narrow drainages; near Bull Claim Hill includes some alluvial-fan deposits.

Qco — **Older colluvial deposits**: mixed angular blocks to fine-grained materials on low to moderate slopes; includes some alluvial-fan and talus deposits; mapped only in Bull Claim Hills where deposits are dissected by washes and cap ridges and hills; (younger colluvial deposits included in Qac and Qca).

Quaternary - Tertiary

QTa — **Older alluvial deposits**: moderately to well-sorted coarse gravel to silt with clasts ranging up to 6 inches (15 cm) in diameter; clasts are quartzite, limestone, dolomite, and volcanic tuffs; form small mound on slump block west of Richfield; age is poorly constrained.

QTu — **Undivided Quaternary and Tertiary surficial and valley-fill deposits**: shown on cross section only; age is Miocene to modern, contemporaneous with basin and range development.

Tertiary -- Pliocene-Miocene

Tsr — **Sevier River Formation:** shown on cross section only; predates most basin and range development.

Tertiary -- Miocene

q — **Quartz dike**: pale-reddish-brown, reddish-gray, and gray quartz dike; found only along a fault; brecciated; very resistant; about 50 feet (15 m) thick; age unknown.

To — **Osiris Tuff**: resistant orangish-brown, reddish-brown, and pale-gray, densely welded, crystal-rich, rhyodacitic ash-flow tuff containing phenocrysts of plagioclase and subordinate sanidine, and minor biotite, pyroxene, and Fe-Ti oxides (Rowley and others, 1981); contains drawn-out pumice lenticules; flow foliation is common; characterized by coppery weathering biotite and large plagioclase phenocrysts; weathers into large rounded boulders and fine grus; thickness varies due to slump deformation in the quadrangle, but in the area it is as much as 300 feet (90 m) thick (Willis, 1988); about 23 million years old (Fleck and others, 1975).

Tertiary -- Miocene-Oligocene

Tv — **Undivided volcanic rocks**: shown on cross sections only.

Tertiary -- Oligocene

Tsp — **Lava Flows of Signal Peak:** medium- to dark-gray to black, vesicular or amygdaloidal, andesitic lava flows (Rowley and others, 1981); contain abundant large (up to 0.6 inch [1.5 cm]) phenocrysts of plagioclase, subordinate pyroxene and olivine, and minor Fe-Ti oxides in an aphanitic matrix; forms rounded hills with only a few ledgy outcrops; includes a few feet of volcaniclastic sandstone exposed at lower contact; thickness is 100+ feet (30+ m); 23-25 million years old.

Ta — **Tuff of Albinus Canyon**: two to four cooling units of complexly interfingering, densely welded tuff and moderately welded to stony lithic tuff and tuff breccia; a vitrophyre 1 to 3 feet (.3-0.9) thick is common at the base of each cooling unit; differentiated into subunits in Bull Claim Hill; up to 800 feet (240 m) thick; about 25 million years old.

Tab — **Lithic tuff and tuff-breccia**: dark-brown, reddish-brown, greenish-gray, or gray tuff with lithic fragments that vary from 1 to 20 percent of total volume; autoclastic and lithic breccia in some areas; some clasts are slightly rounded but most are angular.

Taw — **Welded tuff**: dense, dark-brown to reddish-brown weathering, vesicular tuff; pale to medium gray, purplish gray, brownish gray, purplish gray, or reddish gray on fresh surfaces; contains sparse, small but prominent phenocrysts of plagioclase, pyroxene, and Fe-Ti oxides (Rowley and others, 1981); secondary flowage structures are common; vesicles are drawn out into long "pencil-like" shapes; some are filled with secondary calcite or quartz; strongly foliated.

Tcp — **Crystal-poor dacitic lava flows**: moderately resistant, pale-gray, pale- to moderate-greenish-gray, and reddish-gray, vesicular or amygdaloidal, aphanitic, dacitic lava flows and volcanic mudflow breccia (Rowley and others, 1981); contains small sparse phenocrysts of plagioclase, pyroxene, and Fe-Ti oxides; forms a steep smooth slope that contrasts with sharp jagged ledges and cliffs of the overlying Albinus Tuff; base not exposed; thickness is 300+ feet (90+); between 25 and 27 million years old.

Tbt — **Three Creeks Tuff Member of Bullion Canyon Volcanics:** resistant pink, purplish-red, or pale-gray, moderately welded, lithic- and phenocryst-rich ash-flow tuff with some interbedded volcaniclastic sandstone (Rowley and others, 1981; Steven and others, 1990); contains plagioclase, hornblende, biotite, quartz, and minor Fe-Ti oxide and sanidine phenocrysts; white to pink pumice lenticules up to 4 inches (10 cm) long and 2 inches (5 cm) wide are common; to the south it consists of multiple cooling units interbedded with volcanic mudflow breccia, volcanic conglomerate, volcanic sandstone, and lava flows (Rowley and others, 1981) but small, poor exposures in the quadrangle prevent recognition of these units; forms discontinuous lenses; 0 to 300+ feet (0-90+ m) thick, but is much thicker to the south (Rowley and others, 1981); about 27 million years old (Steven and others, 1979; 1990).

Tdv — **Dipping Vat Formation**: pale-gray to white, interbedded volcanic sandstone, conglomerate, and minor volcanic ash; subrounded to subangular volcanic tuff, quartzite, dolomite, and limestone clasts; upper contact generally obscured by rubble; forms ledgy slope; about 600 feet (180 m) thick; about 35 million years old (Willis, 1988).

unconformity?

Tertiary -- Eocene

Tau — **Aurora Formation**: pale-greenish-gray, orangish-gray, purplish-gray, or yellowish-gray mudstone and claystone, with thin beds of limestone and sandstone; mudstone is bentonitic; secondary gypsum veinlets are common; forms steep "badlands" slopes; about 550 feet (165 m) thick; about 39 to 40 million years old (Willis, 1988).

Tch, Tchs — **Crazy Hollow Formation:** dark-reddish-brown, thin- to medium-bedded sandstone, siltstone, and mudstone, interbedded with prominent thick to massive orangish-yellow, locally pebbly channel sandstone beds; locally conglomeratic; black chert pebbles are diagnostic; forms ledgy cliffs to ledgy slopes; 350 feet (105 m) thick; middle to late Eocene in age; slumped and moderately deformed blocks mapped as Tchs.

Tg, Tgs — **Green River Formation:** pale-yellowish-orange to grayish-yellow, sandy limestone, siliceous limestone, and dolomite; prominent stromatolites in some intervals; dark-brown, tan, or white nodular chert is common in upper part and is diagnostic of the formation; forms a prominent cliff and ledgy cliff; has a thin altered volcanic ash layer near base that is a common detachment surface for landslides and slumps; 70 to 90 feet (21-27 m) thick; middle Eocene in age; slumped and moderately deformed blocks are mapped as Tgs (slump blocks commonly include a small amount of the upper member of the Flagstaff Formation).

Flagstaff Formation: total thickness is about 2,000 feet (600 m); early to early-middle Eocene in age.

Tfuw — **Upper white member**: pale-gray, pale-purplish-gray, or pale-yellowish-gray calcareous mudstone, sandy limestone, and limestone; less resistant than other Flagstaff members and forms a broad slope with a few ledges; commonly covered by rubble from overlying formations; 170 to 185 feet (51-56 m) thick.

Tfur — **Upper red member**: interbedded brick-red, sandy mudstone, sandstone, and conglomerate; forms a ledgy slope with local cliffs; forms a narrow, prominent band throughout the quadrangle; less than 50 feet to 160 feet (15-48 m) thick; thins from southwest to northeast.

Tfmw, m — **Middle white member and marker bed**: interbedded pale-gray, pale-yellowish-gray or pale-reddish-gray calcareous sandstone, sandy limestone, and limestone with minor sandy mudstone slope zones; lower part is mostly mudstone with a few feet of bedded gypsum and abundant discordant gypsum veinlets; lower part grades laterally into sandy limestone and calcareous sandstone toward southwest; a prominent medium-reddish-orange, blocky sandstone marker bed (mapped as "m") is at top of lower part; about 515 feet (155 m) thick (160 to 210 feet [48-64 m] thick below marker bed and 350 feet [105 m] thick above marker bed).

Tfmr, Tfmrs — **Middle red member**: interbedded, brick-red sandstone, siltstone, and mudstone with minor conglomerate beds; conglomerate contains rounded to subrounded quartzite and carbonate clasts up to 14 inches (36 cm) in diameter; forms cliffs and ledges typically 10 to 50 feet (3-15 m) high separated by steep slopes; about 600 feet (180 m) thick.

Tflw — **Lower white member**: interbedded, pale-gray to pale-reddish-gray, calcareous sandstone, sandy limestone, and pale-purplish-gray silty to sandy mudstone; intensely bioturbated; forms three to four distinct ledges 5 to 15 feet (1.5-4.5 m) high separated by moderate slopes; about 240 feet (73 m) thick.

Tflr — **Lower red member**: interbedded brick-red-sandstone, siltstone, and mudstone with minor conglomerate beds; forms alternating cliffs 5 to 20 feet (1.5-6 m) high and steep slopes; 320+ feet (98+ m) thick but base not exposed in quadrangle.

Tertiary - Cretaceous

TKnh — **North Horn Formation:** shown on cross section only; probably 2,500 to 3,500 feet (750-1,050 m) thick beneath quadrangle.

TKs — **Undivided Cretaceous to middle Tertiary sedimentary rocks**: shown on cross section only; may include strata from Upper Cretaceous Cedar Mountain Formation to Oligocene Dipping Vat Formation.

Cretaceous

Ku — **Undivided Cretaceous rocks**: shown on cross section only; may include 0 to 500 feet (0-150 m) of Price River Formation as mapped by Michaels and Hintze (1993) in western part of quadrangle and an unknown amount of Indianola Group rocks in eastern part.

Jurassic

Ja — **Arapien Shale**: shown on cross section only; may include small amount of Twist Gulch Formation.

Paleozoic

C-D — **Undivided Cambrian to Devonian rocks:** shown on cross section only; includes rocks transported on Pavant thrust fault during Cretaceous Sevier orogeny (Michaels and Hintze, 1993).

Interim Geologic Map of the Richfield Quadrangle, Sevier County, Utah

by

Grant C. Willis

Utah Geological Survey

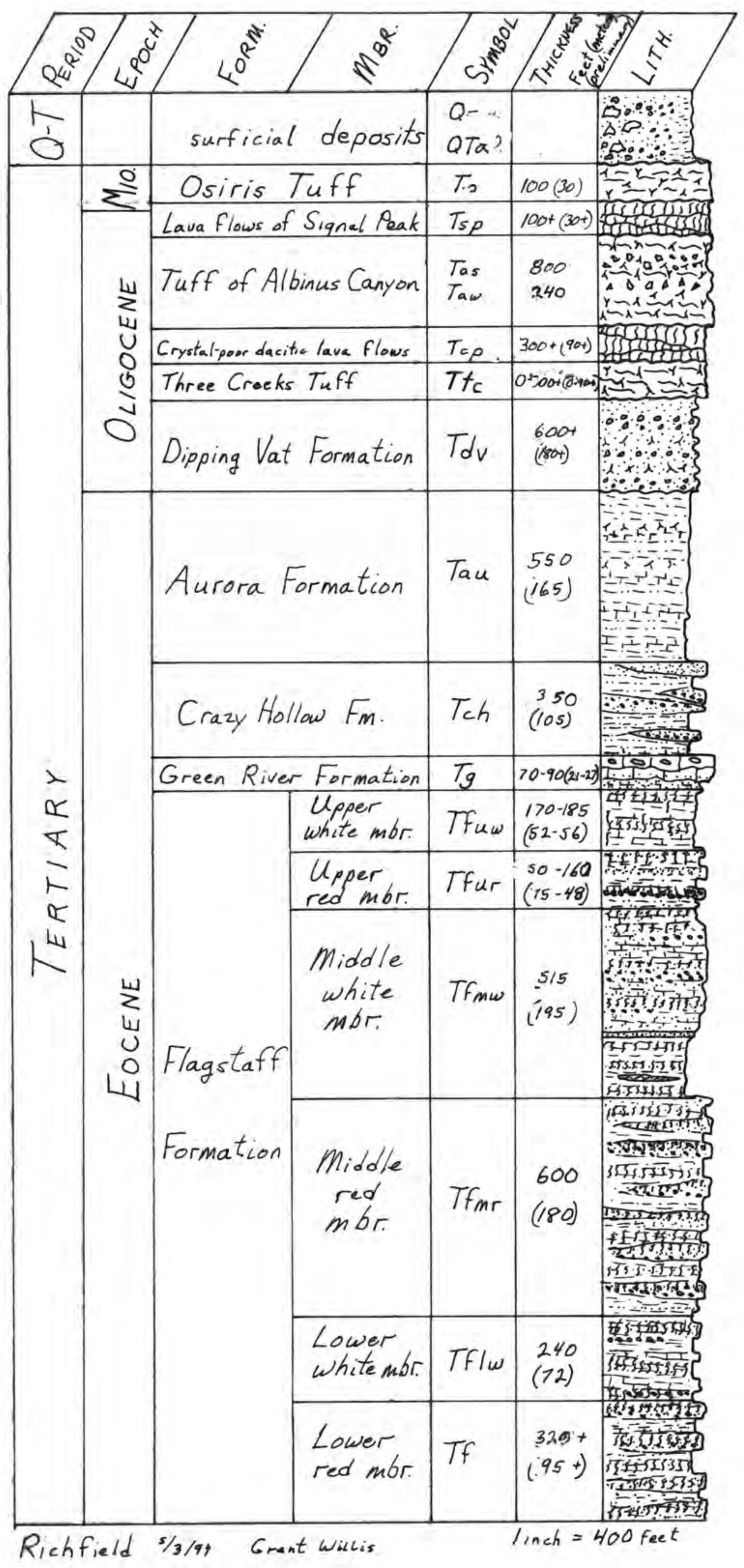
Open-File Report 309

Utah Geological Survey
in cooperation with
U.S. Geological Survey

Plate 2

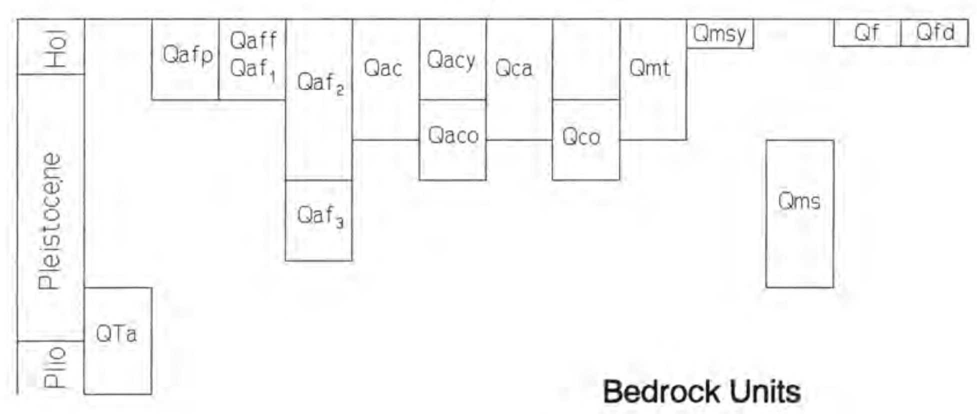
Explanation of Map Symbols

- Contact--dashed where approximately located
- High-angle fault--dashed where approximately located, dotted where concealed, bar and ball on down-thrown side
- Fault or fracture bounding shallow detached block
- Axial trace of anticline
- Strike and dip of bedding--inclined, overturned (8, 80)
- Strike and dip of foliation--inclined (35)
- Strike and dip of joints--inclined, vertical or near-vertical (75)
- Adit
- Prospect pit--l-limestone, s-ornamental stone, m-metals, c-calcite, q-quartz (possibly for metals exploration); not labeled-unknown (X_s)
- Gravel or road-fill pit--hachured line shows approximate edge of pit



Correlation of Map Units

Surficial Deposits



Bedrock Units