GEOLOGIC MAP OF THE SALINA QUADRANGLE, SEVIER COUNTY, UTAH

By Grant C. Willis
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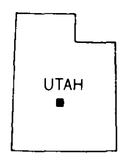

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ABSTRACT

The Salina quadrangle contains about 23,000 feet (7000 m) of Middle Jurassic to Recent rocks, 16,000 feet (4800 m) of which are exposed to form four sequences. The oldest sequence consists of Middle Jurassic Arapien Shale and Twist Gulch Formation; the next has Late Cretaceous rocks, most of which were deposited in a foreland basin in front of the Sevier Orogenic belt. The two sequences are unconformably overlain by sub-horizontal fluvial and lacustrine units of the third sequence which comprises one of the most complete early Tertiary sections in Utah. The fourth group consists of Oligocene through Miocene reworked volcanic sediments and ash-flow tuffs. A wide variety of surficial deposits, including those of alluvial, colluvial, mass movement, and lacustrine origin, also occurs.

Structure in the quadrangle is dominated by the north-trending Sanpete-Sevier Valley anticline (SSVA). The SSVA formed during the Late Cretaceous, probably as a direct result of thrust deformation during the Sevier Orogeny. Most of the thrust deformation occurred in the relatively incompetent Arapien Shale core of the SSVA, intensely folding, faulting, and thickening the unit. At that time, overlying units, the Twist Gulch and Cedar Mountain Formations and Indianola Group, were folded into a large, comparatively simple anticline. During the Cenozoic, the Arapien core part of the SSVA underwent relatively minor secondary movement, probably due to evaporite diapirism, deforming Tertiary units. The other units folded in the original formation of the SSVA were not involved in the subsequent movement. Recently, salt dissolution and subsequent collapse of overlying rocks has occurred, further complicating the structure in the quadrangle.

A wide variety of economic deposits including lead, zinc, salt, gypsum, limestone, calcite, clay, and gravel occur within the quadrangle. Gypsum and gravel are the only ones that are currently being exploited. Exploratory drilling in the area for hydrocarbons has resulted in oil and gas shows but no production. Coal and geothermal resources also have potential.

The quadrangle lies in the Intermountain seismic belt and could experience earthquake damage. No recent fault scarps are known in the quadrangle, but historic quakes have occurred in surrounding areas. Landslides, flooding, ground collapse due to salt dissolution, and swelling clays present other significant geologic hazards.

INTRODUCTION

The Salina 7 1/2' quadrangle is located about 20 miles (32 km) northeast of Richfield on the east side of Sevier Valley in central Utah. U. S. Interstate 70 crosses the central part of the quadrangle, intersecting with U. S. Highway 89 and State Route 26 near Salina. Salina Canyon, a major drainage system for the southern part of the Wasatch Plateau and northern part of the Fish Lake Plateau, bisects the quadrangle.

Cedar Mountain, near the east-central margin of the quadrangle, is the highest point at 7260 feet (2213 m). Sevier Valley is lowest with an altitude of 5100 feet (1554 m). Annual precipitation ranges from 8-10 inches (20-25 cm) in the valley to 16-20 inches (40-50 cm) in the mountains (Covington and Williams, 1972). Natural vegetation is primarily grass and sage brush in the lowlands and juniper, pinon pine, and oak brush in the higher areas.

Although discussed briefly in earlier studies, the Salina area was first described in detail by Spieker (1946; 1949) who named and defined many of the stratigraphic units and discussed the structure of the area. Smaller areas were studied in more detail by Ohio State University students under Spieker's direction including studies by Gilliland (1951), Hardy (1952), Lautenschlager (1952), and McGookey (1960). More recently, many other important studies have been completed including Witkind (1982; 1983), Standlee (1982), Lawton (1982; 1985), and Witkind and Page (1984).

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Hardy (1952) included part of the quadrangle in a small-scale map focusing on Jurassic units. McGookey (1960) included the southern half of the quadrangle in a geologic map of the northern Fish Lake Plateau. Williams and Hackman (1971) published a geologic map of the Salina 1° by 2° quadrangle (1:250,000) that uses more current terminology but is not detailed. Erb (1971) mapped the volcanic area north of Salina Canyon, while Witkind (1981) mapped the adjacent Redmond quadrangle.

STRATIGRAPHY

Consolidated rocks in the Salina quadrangle are divisible into four main sequences: (1) Jurassic rocks at least 6000 feet (1800 m) thick that occur in the southwestern and north-central parts of the quadrangle, (2) about 3000 feet (900 m) of exposed Cretaceous rocks (an additional 7000 feet (2100 m) underlie the quadrangle), (3) up to 5000 feet (1500 m) of early Tertiary fluvial-lacustrine strata, and (4) Oligocene and Miocene volcaniclastic and volcanic rocks which are up to 2000 feet (600 m) thick and which cap the earlier rocks. In Salina Canyon the Jurassic and Cretaceous beds have a nearly vertical altitude and are truncated by a major unconformity of local extent. The early Tertiary sequence of nearly horizontal rocks overlies the unconformity and contrasts strikingly with the steeply dipping beds (figure 1). Surficial deposits of several varieties are scattered across the area.

JURASSIC

Jurassic rocks crop out along a north-northeast-trending complex anticline and include the Arapien Shale and Twist Gulch Formation, which were originally defined as the Twelvemile Canyon and Twist Gulch Members, respectively, of the Arapien Shale (Spieker, 1946, p. 124-125). Hardy (1952) suggested upgrading the members to formational status but did not do so. Subsequent nomenclature has confusingly alternated between member and formational status (for example: Hardy, 1952; Witkind and Sprinkel, 1982; Standlee, 1982). Finally Witkind and Hardy (1984) officially changed the names to those used on this map.

Figure 1. Angular unconformity in lower Salina Canyon. Vertical beds are Jurassic Twist Gulch Formation. Horizontal beds are Eocene Flagstaff Formation.

Arapien Shale

The Arapien Shale was subdivided by Hardy (1952) into five mappable members, units A to E. Units A, C, D, and E of the Arapien Shale are generally mapped in accordance with Hardy's work. Unit B is not present in the quadrangle, probably due to a stratigraphic facies change. Structural complexities prevent precise measurement of the thickness of the Arapien Shale but it is estimated to be 4000-6000 feet (1200-1800 m) thick, and it is Callovian in age (Imlay, 1982).

The lowest member, unit A, is exposed only in the core of a complex anticline in the southwest corner of the quadrangle where it forms a small, resistant, rounded hill. Unit A is composed primarily of medium gray, thin-bedded, argillaceous limestone. It weathers to angular, brownish-yellow chips. Only the uppermost part of the unit is exposed in the quadrangle. The rocks are so folded that it is difficult to determine the exact exposed thickness, however it probably does not exceed 100 feet (30 m).

Unit C occurs in low, intricately dissected hills surrounding exposures of unit A. It is composed of bluish-gray calcareous shale with gray, thin-bedded calcareous sandstone, massive gray to white lenticular gypsum beds and resistant layers of fossil-bearing arenaceous limestone. It forms steep, intricately dissected "badlands" topography which supports sparse vegetation, and is about 1000 feet (300 m) thick.

Gypsum outcrops up to 100 feet (30 m) thick occur in the lower part of unit C and were mapped separately. The gypsum is massive pale gray to white mottled and forms resistant protruding ledges. These gypsum outcrops may have been part of a single bed that has been repeated at the surface by folding and faulting. The gypsum is the most resistant part of unit C and forms sinuous to linear grayish-white ledges.

The contact between units C and D is gradational over 1000 feet (300 m) from uniform bluish-gray mudstone and minor sandstone of unit C to blotched red and gray mudstone with more sandstone of unit D.

Unit D consists primarily of interbedded, bluish-gray and reddish-gray gypsiferous shale, mudstone, sandstone and occasional shaly, thin-bedded gypsum. It is mostly thin-bedded to laminated. Intense folding, highly contorted beds, and facies changes give the unit a blotched or streaked appearance. It forms steep, intricately dissected "badlands" topography which supports sparse vegetation. It is 2000-4000 feet (600-1200 m) thick.

Unit E, the uppermost member of the Arapien Shale, consists primarily of dark reddish-brown, salt-bearing siltstone and shale. The salt is generally dissolved 5-10 feet (1.5-3 m) below ground surface, leaving a residual silt and clay cover which forms distinctive dark red, steep, rounded hills with intricate drainage patterns and no vegetation.

Large patches of white "salt bloom" form on the surface of salt-cored hills. The salt, which is only exposed in fresh cuts along washes or in old mine workings, is massive with occasional secondary crystals and has a high clay and silt content which gives it a mottled red color.

Unit E occurs along the flanks of the complex anticline. Outcrops occur along the edge of the volcanics south of Salina, east of Salina, in Salina Canyon near Twist Canyon, and east of Stone Quarry Ridge. Small salt mines and salt prospect pits occur at most of the outcrops. Unit E is also exposed in parts of the Redmond Hills in quadrangles to the north and northwest and probably underlies the small gravel outcrop mapped in the northwest corner of the quadrangle as well.

The Arapien Shale was deposited in a long, narrow seaway which opened to the north and which became hypersaline near the end of Arapien deposition. Fossils are rare except in a few beds and include only a few tolerant forms. Hardy (1952) lists fauna found in the Arapien. Current directions in the Arapien are unimodal to the north (Picard and Uygur, 1982).

Twist Gulch Formation

The Twist Gulch Formation conformably overlies the Arapien Shale. No complete section is exposed in central Utah but the minimum estimated thickness is 1800 feet (550 m). The basal contact is sharp in the few places where it is exposed and is placed at the base of the lowest sandstone. The Twist Gulch forms nearly vertical fins protruding beneath the major unconformity in Salina Canyon and in the low, linear hills south of Salina (figure 1). The type section of the Twist Gulch Formation is in Salina Canyon (Spieker, 1949, p. 36) where parts of the Twist Gulch are recognizable as the Entrada, Curtis, and possibly the Summerville Formations of the San Rafael Swell area (Imlay, 1980). The outcrops in Salina Canyon have been mapped using the "equivalent" terms informally to indicate this relationship. The Salina Canyon beds are generally coarser than corresponding beds in the San Rafael Swell area and contain a few grit and fine conglomerate beds of fluvial origin.

The Entrada portion of the Twist Gulch Formation is interbedded reddish-brown siltstone, mudstone, sandstone, and minor conglomerate. It is generally thin-bedded but varies from occasional thick beds to laminated bedding.

The Curtis portion is medium brownish-gray conglomerate, yellowish-white sandstone, and reddish to yellowish-gray mudstone and shale. It has a basal conglomerate with pebbles up to 3 inches (8 cm) in diameter overlain by mudstone with marine fossils and glauconitic sandstone. The sandstone is massively bedded and forms a cliff. It is exposed only in Salina Canyon.

The identity of Summerville equivalent beds in the Salina Canyon section is questionable. The outcrop tentatively mapped as such consists of interbedded reddish-brown siltstone and mudstone. It is poorly exposed and forms a slope.

I have mapped the outcrops of Twist Gulch Formation south of Salina as equivalent to the Entrada Sandstone. Unfortunately, highway construction has covered most of the outcrop. The Twist Gulch Formation was deposited primarily in a tidal flat environment. The mudstone and glauconitic sandstone beds are shallow marine and shoreline deposits.

CRETACEOUS

Cretaceous rocks in the quadrangle include the Cedar Mountain Formation which is 850 feet (260 m) thick and is Albian-Cenomanian in age and the Upper Cretaceous Indianola Group which has about 2200 feet (660 m) of exposed strata. No rocks from most of the Early Cretaceous are preserved in the Sanpete-Sevier Valley area; the Cedar Mountain Formation is deposited directly on middle Jurassic rocks. The Cedar Mountain and Indianola were deposited in a foreland basin in front of the Sevier Orogenic belt (Armstrong, 1968). After these Cretaceous units were deposited, they were folded and subsequently overlain by early Tertiary rocks.

Cedar Mountain Formation

The Cedar Mountain Formation consists of interbedded, reddish-brown, purple, and gray conglomerate, sandstone, siltstone, and shale with variegated purple, gray and white bentonitic mudstone. It forms a small rounded hill with resistant ledges within.

Beds mapped as Cedar Mountain Formation unconformably overlie the Twist Gulch Formation in Salina Canyon. The Cedar Mountain beds were previously called Morrison(?) Formation, which is a Jurassic unit, by Spieker (1946) and subsequent workers (Hardy, 1952; Williams and Hackman, 1971). Until recently, definitive studies to properly correlate or date these rocks have yielded inconclusive results (Bayley, 1970; Frazier, 1970; G. C. Willis, unpublished data). However, recent fission track dating of zircon yielded ages of 90.3 ± 4.8 ma, 90.6 ± 4.8 ma, and 96.2 ± 5.0 ma (table 2) and of apatite yielded ages of 103 ± 8 ma and 105 ± 10 ma (Willis and Kowallis, in prep.), indicating the rocks are Cedar Mountain Formation.

The Cedar Mountain Formation is exposed as steeply dipping beds on both sides of the creek beneath the unconformity in Salina Canyon. The base is marked by the lowest occurrence of nonresistant conglomerate beds which appear as pebble float on a low hill side. Thick conglomerate beds with clasts up to 3 inches (8 cm) in diameter are interbedded with slope-forming bentonitic mudstone in the lower part of the formation. The upper part is interbedded conglomerate, sandstone and bentonitic mudstone. The Cedar Mountain Formation is fluvial-lacustrine and was derived from Sevier Orogenic highlands to the west.

Indianola Group

The Indianola Group consists of four formations, in ascending order, Sanpete, Allen Valley Shale, Funk Valley, and Sixmile Canyon. The upper parts of the Funk Valley and the Sixmile Canyon Formations are not exposed in the quadrangle. The others are exposed in small outcrops beneath the major unconformity along both sides of Salina Creek where they form alternating resistant and nonresistant ribs. Deposition was in a foreland basin along the east edge of the Sevier orogenic belt and along the west edge of the Mancos Sea. The group grades westward into coarser grained facies and eastward into finer grained rocks.

The Indianola Group overlies the Cedar Mountain Formation in Salina Canyon. They were generally considered to be separated by a hiatus of at least 4 million years (Fouch et al., 1982), however, this mapping and recent fission track dating (Willis and Kowallis, in prep.) suggest that the contact may represent a continuous depositional sequence. No good marker exists to fix the lower contact; it is placed arbitrarily at the base of a thick conglomerate bed composed primarily of light-colored clasts up to 9 inches (23 cm) in diameter.

The Sanpete Formation consists of gray, reddish-gray, and yellowish-gray interbedded conglomerate, sandstone, mudstone, and shale. It fines upward overall with several smaller scale fining upward sequences within. Conglomerate with light-colored quartzite clasts up to 9 inches (23 cm) in diameter occurs near the base of the formation. Pebble conglomerate lag deposits also occur near the base of repeated massive sandstone beds. Near the top the formation is predominantly mudstone and thin-bedded sandstone with minor carbonaceous shale and coal.

The Sanpete Formation contains alluvial fan facies in the lower part which grade upward to lagoonal, and finally to the nearshore marine facies of the Allen Valley Shale at the top (Lawton, 1982). The Sanpete is probably Turonian and Cenomanian (Lawton, 1982).

The Allen Valley Shale is gray, greenish-gray, and brownish-gray bentonitic mudstone and shale, and minor, thin-bedded sandstone. Some beds are moderately organic. It is nonresistant and poorly exposed. The Allen Valley Shale is equivalent to the Tununk Member of the Mancos Shale and represents the maximum transgression of the Late Cretaceous sea toward the west. It is probably Turonian (Lawton, 1982).

The Funk Valley Formation is pale yellowish-gray to orangish-gray interbedded sandstone, siltstone, mudstone, and shale. The unit coarsens upward overall with smaller repeated coarsening upward sequences within. It erodes to repeated ledges and slopes. Only the lower part of the formation is exposed in the quadrangle and the thickness shown on plate 2 was extrapolated from Lawton (1982). The exposed portion of the Funk Valley Formation represents a regressive phase of the Mancos sea with the lower part shallow, open marine which grades upward to meandering fluvial deposits. The Funk Valley is probably Turonian and Coniacian in age (Lawton, 1982).

The Sixmile Canyon Formation is not exposed in the Salina quadrangle, but it is shown on the cross section and the thickness extrapolated from Lawton (1982). The Sixmile Canyon Formation is probably Santonian to Campanian in age (Lawton, 1982). It and the upper part of the Funk Valley probably represent another transgression and final regression of the Mancos Sea across the area (Lawton, 1982).

TERTIARY

More than 5000 feet (1500 m) of Paleocene through Miocene rocks, which include one of the most complete early Tertiary sections in Utah, crop out in the quadrangle. Paleocene and early Eocene formations are mostly fluvial and lacustrine sediments, and are part of formations that cover much of Utah. In the late Eocene, deposition became more localized and included volcanic sediments and tuffs derived from eruptions in central Utah. Oligocene and Miocene deposits are primarily volcaniclastic sediments and welded ash-flow tuffs. The latter were deposited in a paleo-valley eroded into the relatively non-resistant Arapien Shale following a period of structural deformation. No Tertiary deposits younger than 23 million years are recognized in the quadrangle except for possible surficial deposits.

North Horn Formation

The North Horn Formation, a reddish-brown mudstone with lesser amounts of reddish-purple, pale to moderate green, or pale brownish-gray sandstone, calcareous mudstone, and sandy limestone, has heavily rooted zones and is often mottled. It generally forms slopes with occasional interspersed resistant sandstone ledges. In most areas it is latest Cretaceous and early Tertiary, but, in the Salina quadrangle exposures are probably late Paleocene or Eocene (Fouch et al., 1982).

This was the first unit deposited on a major angular unconformity in the Salina area. It thins rapidly westward in Salina Canyon, pinching out over steeply dipping Allen Valley Shale (see cross section). Several hundred feet of it occur in the Valley Mountains west of Sevier Valley.

A fluvial-lacustrine deposit, much of its coarser clastic material was probably derived from the paleo-topographic high over which it pinches out. It often forms landslides, several of which occur in Salina Canyon.

Flagstaff Formation

The Flagstaff Formation is composed of reddish-brown to pale gray calcareous sandstone, sandy limestone, micritic limestone and lenticular and planar conglomerate beds. The micritic limestone is pale gray and relatively free of interclastic material. The formation, of late Paleocene to early Eocene (Fouch et al., 1982) age, is often stained by the overlying Colton Formation.

The Flagstaff forms a narrow cliff that thins westward through Salina Canyon. It oversteps the North Horn Formation, finally pinching out over a paleo-topographic high (see cross section). Like the North Horn, the Flagstaff Formation again appears on the west side of the paleo-topographic high south and northeast of Salina, indicating that the area of nondeposition was only a few miles wide during Flagstaff time.

Several facies of the Flagstaff occur in the quadrangle. In Salina Canyon it is primarily fine-to coarse-grained sandstone with local lenticular channel deposits of coarse conglomerate that contain clasts up to 9 inches (23 cm) in diameter. The conglomerate grades eastward into sandstone; most traces are gone east of Gooseberry Creek. The similarity of clasts and clast sizes and restricted distribution suggest that the conglomerate was derived locally from the Sanpete and Cedar Mountain beds exposed on the paleo-topographic high which the Flagstaff overlapped. Isolated "dropstones", probably also derived from exposed beds in the paleo-high, occur in all facies of the Flagstaff Formation throughout the area. South of Salina the Flagstaff forms a linear ridge of massive conglomerate. East of Stone Quarry Ridge it occurs in scattered outcrops of interbedded conglomerate, micritic limestone, sandstone and mudstone.

Although the Flagstaff Formation of the Salina area and west of Sevier Valley is primarily sandstone and conglomerate, it is mostly limestone in the Wasatch Plateau to the northeast. The local paleo-high and highlands to the west were the source areas for the coarser facies.

Colton Formation

The late Paleocene to early Eocene Colton Formation is composed of brownish-red, purplish-red, and gray mudstone, and minor shale, limestone, and feldspathic sandstone. It is usually evenly colored but occasionally mottled. Bedding is thin to very thin-bedded with the sandstone beds forming ledges one to three feet (0.3-1 m) thick.

In Salina Canyon, the Colton Formation forms a gentle to steep slope above a cliff formed by the more resistant Flagstaff Formation. It is also exposed in a few outcrops northeast of Salina. Like the North Horn and Flagstaff Formations, the Colton was influenced by the paleo-topographic high that existed in the Salina area during the early Tertiary. It is thinner over the high but was the first unit to cover it. The Colton is a shallow lacustrine deposit interspersed with occasional small fluvial channel deposits. Elsewhere it has a more fluvial character than in the Salina area. Laramide upwarp structures in southeast Utah probably provided the source areas (Zawiskie et al., 1982). The Colton Formation is gradational with the overlying Green River Formation with the contact marked by a change from dark red to pale green shale and siltstone. It is highly susceptible to landsliding.

Green River Formation

The Green River Formation is herein divided into two informal map units. The lower unit is greenish-gray to pale green thin-bedded to laminated shale, light brown calcareous sandstone, and pale gray to pale yellowish-gray chalky limestone. It forms slopes with low ledges held up by sandstone and limestone.

The upper unit is pale yellow, pale yellowish-gray or white, massive, cherty limestone interbedded with gray, greenish-gray or light brown shale. The limestone is often highly silicified and thin-bedded, forming brittle plates. The upper part of the upper unit contains massive, jagged cliff-forming beds 5-20 feet (1.5-6 m) thick composed primarily of coalesced algal mounds. The lower and upper units of the Green River Formation interfinger, the upper being the most resistant early Tertiary unit in the quadrangle and capping many of the mountains.

Of early to late Eocene age, the Green River Formation may thin over an early Tertiary paleo-topographic high centered in the area of lower Salina Canyon that also affected the underlying Colton, Flagstaff, and North Horn Formations. The upper contact is disconformable in most areas and the Green River thins southward due to erosion prior to deposition of the Crazy Hollow Formation (McGookey, 1960), however, it locally interfingers with the Crazy Hollow Formation in Twist Canyon. The lower part of the Green River Formation has numerous landslides.

Crazy Hollow Formation

The Crazy Hollow Formation, which forms dark, mottled, orange, red, and yellow hills with interspersed discontinuous ledges, makes a sharp contrast with the pale yellow and green of the underlying Green River Formation. It is primarily brownish-red and orangish-red and, to a lesser extent, medium gray and light yellowish-gray sandstone, mudstone, and siltstone. The sandstone has an immature "salt and pepper" texture. The unit generally has a basal conglomerate with dark gray to black chert pebbles 1/2-2 inches (1-5 cm) in diameter which are usually diagnostic of the formation. It locally interfingers with the upper member of the Green River Formation. The Crazy Hollow Formation is late Eocene.

The Green River and Crazy Hollow Formations interfinger in the Twist Canyon area where conglomeratic sandstone with dark chert pebbles interfingers with pale yellow siliceous limestone. This interfingering is interpreted as having occurred in an area of early Crazy Hollow fluvial discharge into the Green River lake prior to the basin being filled with Crazy Hollow sediments, probably derived from the west (K. Norton, personal commun., 1984). The formation of Aurora gradationally overlies the Crazy Hollow Formation and the contact occurs where beds become dominantly pale greenish-gray mudstone.

The type section of the Crazy Hollow Formation is in the Salina quadrangle near Crazy Hollow which is the small gulch southwest of the confluence of Soldier Creek and Salina Creek. About 1000 feet (300 m) of the unit are exposed there (McGookey, 1960) but the section is probably partly repeated by faulting. No unfaulted section could be found in the quadrangle but the true thickness is estimated to be 600-800 feet (180-240 m).

Formation of Aurora

Beds herein mapped as the formation of Aurora were originally the Bald Knoll Formation (McGookey, 1960; Erb, 1971), so named by Gilliland (1949) with the type section in Bald Knoll Wash, located about five miles (8 km) northwest of the Salina quadrangle in the Redmond

Canyon quadrangle. Through recent mapping in the Redmond Canyon and Aurora quadrangles, it is determined that the strata included in the Bald Knoll type section is not equivalent to rocks mapped as Bald Knoll Formation elsewhere in central Sevier Valley. To prevent further confusion, the term "formation of Aurora" replaces "Bald Knoll Formation" for the involved strata. This problem will be addressed further in Willis (in prep.).

The formation of Aurora is composed of interbedded mudstone, bentonitic shale, limestone, and sandstone. It is white, pale gray, or pale orangish-gray with occasional pale reddish-orange beds. It is thin to massive bedded and forms ledgy slopes. Bioturbation is common in the units with finer grain. The unit becomes increasingly volcanic upwards. Beds near the top are composed almost entirely of reworked volcanic deposits, some primarily of angular pumice fragments.

In the southern part of the quadrangle, the lower part of the formation contains a pale reddish-white rhyolitic ash-flow tuff with pumice fragments up to 6 inches (15 cm) in diameter and conspicuous biotite grains in a poorly-welded matrix. The rhyolite tuff is up to 20 feet (6 m) thick and is traceable for about 2 miles (3 km) southward into the Rex Reservoir quadrangle. A K-Ar date on biotite from the rhyolite tuff yielded an age of 40.5 ± 1.7 ma (table 2). K-Ar dates from the pumiceous units near the top of the formation taken in the adjacent Aurora quadrangle yielded ages of 39.6 ± 1.5 ma and 38.4 ± 1.5 ma (table 2). Table 3 gives a modal analysis of the rhyolite tuff.

The formation of Aurora varies from 0 to 1000 feet (0-300 m) in thickness, a variation probably due primarily to subsequent structural deformation and erosion. It is primarily lacustrine with some fluvial channel deposits.

Unnamed Sandstone, Mudstone, and Conglomerate Beds

Up to 600 feet (180 m) of unnamed beds composed primarily of volcanic-derived sediments overlies the formation of Aurora in the Salina area. These beds are composed of white to pale gray water-lain tuffaceous sandstone, mudstone, conglomerate, marlstone and minor air-fall tuff. The sandstone is primarily volcanic material, including glass shards (up to 80%), quartz, feldspar, biotite, magnetite, altered clay and pumice. The conglomerate beds range up to 6 feet (2 m) thick and contain rounded clasts up to 6 inches (15 cm) in diameter. Some of the conglomerate beds contain primarily volcanic clasts while others contain sedimentary-derived clasts. Bioturbation is common in the finer grained units. Though no radiometric dates have been obtained, the abundance, size, and diversity of volcanic clasts suggest that the unnamed beds were derived from the Marysvale volcanic field to the south and are 25-30 million years old.

Part of the beds may be older, perhaps equivalent to the Dipping Vat Formation which forms a prominent ledge in the Rex Reservoir quadrangle, to the south. The Dipping Vat Formation was dated at 34.2 ± 1.4 ma (table 2) and may be the oldest deposit in the Salina area to be derived from the Marysvale volcanic area. The Dipping Vat thins rapidly northward, to become discontinuous near the southern boundary of the Salina quadrangle. I believe the beds in the Salina quadrangle should remain unnamed until definite correlation can be established.

Underlain by the formation of Aurora in some areas and the Arapien Shale in others, these beds are generally overlain by the formation of Black Cap Mountain. Angular relationships in the Twist Gulch area suggest that the unnamed beds are more closely related to the formation of Black Cap Mountain than to the underlying formation of Aurora.

Three Creeks Tuff Member of Bullion Canyon Volcanics

A small outcrop in the southwest part of the map is herein mapped as the Three Creeks Tuff Member of the Bullion Canyon volcanics (Steven et al., 1979). The Three Creeks Tuff Member is composed of pale gray to pinkish-gray latitic tuff. It contains plagioclase, amphibole, biotite, and minor other minerals. It erupted from the Three Creeks caldera in the southern Pavant Range about 40 miles (60 km) to the southwest and is about 27 my old (Steven et al., 1979). Table 3 gives a representative modal analysis.

The Three Creeks Tuff Member occurs as a single outcrop about 100 feet (30 m) in diameter and 5 to 20 feet (1.5-6 m) thick in section 18, T. 22 S., R. 1 E. It directly overlies the salt-bearing unit E of the Arapien Shale. As is typical of rock overlying unit E, it has been intensely brecciated, probably in multiple episodes of deformation. Its relationship to the unnamed sandstone, mudstone, and conglomerate beds and to other volcanic units in the area is uncertain but it appears to directly underlie the tuff of Albinus Canyon.

Intrusion of Carter Peak

A steep conical hill of Arapien Shale located in the southwest corner of the quadrangle is cored by an isolated intrusion herein called the "intrusion of Carter Peak." The intrusion of Carter Peak is composed of greenish-gray to black and gray, fine-grained, holocrystalline diorite. It contains plagioclase, clinopyroxene, pyroxene, biotite, hornblende, and accessory sphene and apatite. It is well weathered and has a sharp contact with the intruded Arapien Shale. The chilled zone is primarily aphanitic near the contact but rapidly becomes phaneritic inward. Dated at 26.6 ± 1.1 ma (table 2), the intrusion's relationship to other igneous units in the area is unknown. Table 3 gives representative modal analyses of selected samples; large variations in the analyses are due to samples being from the aphanitic chilled zone, the phaneritic interior, or intermediate sections.

The exposed part of the intrusion is about 200 feet (60 m) thick, was formerly mapped as "undifferentiated latite and basaltic andesite flows" (Williams and Hackman, 1971), and has vertical contacts with the Arapien on both its north and south sides. The Arapien has a baked zone up to 30 feet (9 m) wide next to the contacts while the intrusion has an aphanitic margin but becomes phaneritic 5 to 20 feet (1.5-6 m) from the contact. A secondary dike on the east side of Carter Peak extends into the Arapien, confirming that the igneous body is an intrusion.

Formation of Black Cap Mountain

Bluish-gray volcaniclastic sandstone with minor interbedded conglomerate, air-fall tuff, and breccia overlies the Arapien Shale or unnamed sandstone, mudstone, and conglomerate beds in part of the quadrangle. It is herein given the informal name "formation of Black Cap Mountain." It is nonbedded, horizontally bedded, or crossbedded. Clasts are primarily volcanilithic and are poorly cemented. The formation appears bluish-gray due to a weathered coating on individual grains. Clasts, angular to rounded and fine to coarse grained, are generally well sorted but occasional poorly sorted channel deposits with rare Paleozoic-derived cobbles also occur. Occasional angular blocks up to 3 feet (0.9 m) in diameter derived from the tuff of Albinus Canyon/Antimony Tuff Member occur in the unit. It also has zones with abundant angular welded tuff and pumice fragments. Black Cap Mountain beds were deposited in a valley eroded into the nonresistant Arapien Shale. The formation of Black Cap Mountain was previously mapped as part of the "Bullion Canyon volcanics, clastics" (McGookey, 1960), and is described in more detail in Erb (1971).

Tuff of Albinus Canyon and Antimony Tuff Member of Mount Dutton Formation

In the Salina quadrangle, two adjacent densely welded tuff units, the tuff of Albinus Canyon (Steven, 1979) and the Antimony Tuff Member of the Mount Dutton Formation (Anderson and Rowley, 1975), occur which interfinger with the formation of Black Cap Mountain. The units are undifferentiated on the map because of the small size of outcrops and the difficulty in distinguishing them in the field. They both are dark reddish brown, dark brownish-gray, or dark gray crystal-poor ash-flow tuff of quartz latite composition. Both are brittle, densely welded, and commonly contain drawn-out vesicles and pumice lenticules. They contain phenocrysts of plagioclase, sanidine, and pyroxene, but P. D. Rowley (U. S. Geological Survey, personal commun., 1984) stated that the Antimony Tuff Member has a higher sanidine content. They are composed of 85-90% matrix, 4-9% plagioclase, 0-4% sanidine, and 1-2% pyroxene (table 3). Unpublished radiometric dates by H.H. Mehnert of the US Geological Survey indicate that they are about 25 my old.

The tuffs were deposited in small valleys eroded into the formation of Black Cap Mountain and crop out as discontinuous, lenticular, protruding ledges. They are overlain by additional deposits of the formation of Black Cap Mountain. In the Salina Canyon area, the Antimony Tuff Member rests on the tuff of Albinus Canyon with only minor or no intervening beds, but in the Monroe area to the south they are separated by thick local lava flows (Rowley et al., 1981).

Osiris Tuff

The Osiris Tuff (Anderson and Rowley, 1975), which caps Black Mountain and Black Cap Mountain, is the major volcanic unit in the quadrangle. It is composed of densely welded porphyritic, latitic tuff, usually light gray, but also reddish brown, reddish-purple, or brownish-gray. It typically contains 70-80% matrix, 10-20% plagioclase, 1-3% biotite, 2-5% sanidine, 0.5-2% pyroxene and minor Fe-Ti oxides. The biotite, which weathers copper-brown, and the plagioclase are particularly conspicuous in hand samples. The Osiris typically erodes into large rounded blocks which form steep hills and ledges and weathers to granular fragments. It has a black basal vitrophere up to 5 feet (1.5 m) thick overlain by a grayish-red zone 0-30 feet (0-9 m) thick. The remainder of the unit, which exceeds 300 feet (90 m) in some areas, is pale gray or pale brownish-gray, and brecciation, probably of multiple causes, is common.

The Osiris is the youngest and most extensive volcanic unit in the Salina area. Along with underlying volcanic and volcaniclastic units, it was deposited in a paleo-valley eroded into the nonresistant Arapien Shale and older volcanic and volcaniclastic units (figure 2). Isolated outcrops in the Redmond Hills to the north indicate deposition in the area of the modern Sevier Valley as well. The Osiris erupted from the Monroe Peak Caldera located 30 miles (50 km) to the south (Steven et al., 1984) about 23 million years ago (table 2) (Fleck et al., 1975).

QUATERNARY

Gravel deposits of Redmond Hills: The Redmond Hills, in the northwest corner of the quadrangle, are capped by moderately well sorted fluvial deposits of cobbles, pebbles, and sand interbedded with finer grained deposits. The coarser deposits are mostly crossbedded and graded bedding and imbrication of clasts are also common. Cementation is poor or nonexistant. Most of the gravel deposits are well sorted but occasional lenses of poorly sorted materials with subangular clasts also occur.

Although they presently cap low hills, I believe that they are fluvial channel and flood plain deposits of the Sevier River. Many of the clasts are similar to bedrock located several miles up river to the south and other clasts may have been derived from nearby mountains. Following deposition of the gravels, the hills were probably elevated to their present position by salt diapirism. These deposits are considered Pleistocene but may be late Tertiary in age.

Landslide deposits: Numerous landslides occur in the quadrangle, primarily along the steep walls of Salina Canyon. They are generally poorly sorted, unconsolidated bedrock and erosional material and form hummocky irregular topography. The landslides in Salina Canyon generally form in the lower Green River Formation which has a high clay content and which is held at a steep angle by resis-

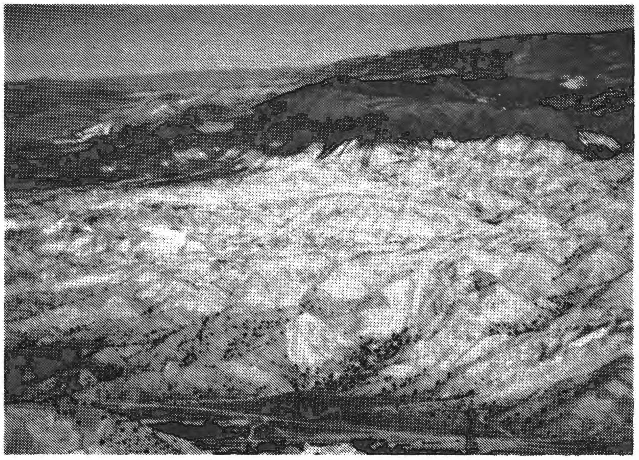

Figure 2. View northward from Carter Peak approximately along trend of the Sanpete-Sevier Valley anticline (SSVA). The dark capping beds are Oligocene and Miocene volcaniclastic and ash flow tuff units deposited in a paleovalley eroded into the light-colored Arapien Shale. Steep west-facing hogbacks of the Green River Formation are exposed in the upper left. The Wasatch Monocline plunges westward in the upper right.

tant, overlying beds. The Colton and North Horn Formations are also contributors, while the Flagstaff Formation acts as a resistant buttress over which the slides drape. Many of the slides have not moved in recent history, but several exhibit fresh fractures and zones of creep.

The largest landslide occurs in section 3, T. 22 S., R. 1 E. It dammed Salina Creek about 6460 years ago, forming a lake at least 150 feet (50 m) deep and 2 miles (3.2 km) long, and may have moved episodically, repeatedly damming the creek.

Lacustrine deposits in Salina Canyon: In Salina Canyon medium gray, laminated to thin-bedded mudstone and claystone outcrops cap small hills and are exposed near stream level. They are remnants of sediments deposited in a lake formed by a landslide dam (see above). The deposits contain abundant plant fragments, especially near the base, representative of current flora. A C^{14} date from plant fragments at the base of the deposit indicates that the landslide occurred 6460 ± 80 years ago (table 2).

Ranging up to 12 feet (3.7 m) thick, the deposits contain numerous low angle compressional faults and tight folds overlain by penecontemporaneous horizontal deposits. The deformation occurred as the highly mobile sediments settled over sloping terrain on the lake bottom, resulting in slumping.

Colluvium: Colluvium occurs throughout the quadrangle, primarily on steep slopes, and consists primarily of fallen blocks, talus, and surface cover derived from adjacent and topographically higher bedrock. Colluvium comprised primarily of volcanic-derived material was mapped separately. Colluvial deposits are often gradational with alluvial deposits, landslides, and volcanic colluvium.

Volcanic colluvium: Deposits mapped as volcanic colluvium are similar to the colluvial deposits except that they are primarily volcanic-derived material and occur on slopes adjacent to the volcanic units. They are often gradational with alluvial deposits, colluvium, and bedrock units.

Older alluvial terrace deposits: Dissected alluvium-covered benches and terrace remnants stranded above active drainages occur in several areas, primarily near Salina and Lost Creeks where several episodes of downcutting are evident. Gravel, sand, silt, clay, and boulders occur from 30 feet (9 m) to 200 feet (60 m) above the present drainage. Most of the higher deposits contain volcanic boulders that were necessarily transported a considerable distance. These terrace deposits may be equivalent in part to deposits south of Salina mapped as older alluvial deposits.

Older alluvial deposits: These deposits consisting of sand, silt, mud, gravel, and boulders, occur primarily in the area south of Salina. Most were locally derived and include deposits that have been dissected or isolated by downcutting of drainage systems. They include stream alluvium, alluvial fan deposits, and deposits on old pediment surfaces and are often gradational with colluvial, landslide, and other alluvial deposits.

Older alluvial deposits too small to map also occur. Volcanic boulders are strewn across the bench formed by the Flagstaff Formation in sections 11 and 12, T. 22 S., R. 1 E. Small alluvial deposits are included in landslide deposits in section 3, T. 22 S., R. 1 E. A small amount of stranded gravel occurs in the saddle between the two summits of Carter Peak in the southwest corner of the quadrangle 950 feet (290 m) above the present level of Lost Creek.

Younger alluvial deposits: They include locally derived sand, silt, mud, gravel, and boulders, which vary from poor to well sorted. Alluvium in smaller streams and canyons, and some slope wash and young stream terrace deposits, are often gradational with colluvial, landslide, and other alluvial deposits.

Alluvial fan and alluvial slope deposits: Boulders, cobbles, sand, silt, and clay covering gently sloping valley and valley margin areas have been mapped as alluvial fan and alluvial slope deposits. The two types are undifferentiated on the map, however the fans have typical "delta-shaped" fan morphology while the slope deposits are more sheetlike. Both are poorly to moderately sorted and include well developed fans in Sevier Valley and lesser developed fans and slope deposits in Salina Canyon. They are often gradational with other alluvial and colluvial deposits.

Flood plain and channel deposits: Deposits of Sevier River, Salina Creek, and Lost Creek have all been mapped as one unit and consist of boulders, gravel, sand, silt, mud, and clay. Some of the deposits may be derived from distant sources. They are poorly sorted in Salina and Lost Creeks, and moderately-well sorted in the Sevier River flood plain.

STRUCTURE

Rocks of the Salina area have undergone several episodes of faulting and folding, resulting in puzzling geologic relationships. The quadrangle is near the leading east edge of the Sevier Orogenic belt, sits astride the center of the Arapien Shale depositional basin (Stokes, 1982), and has been influenced by diapirism of Arapien evaporitic units. It is also in the transition zone between the Basin and Range and Colorado Plateau geologic provinces and bears features of both.

Structure within the Salina quadrangle is dominated by a complex north-northeast-trending "anticline-like" feature which Gilliland (1963) called the "Sanpete-Sevier Valley anticline" (SSVA). Tertiary rocks unconformably overlie part of the SSVA and have in turn been deformed by secondary movement on the structure. A west-facing fold, the Wasatch monocline, occurs just east of the SSVA. West of the SSVA, early Tertiary beds are tilted into steep hogbacks which dip westward beneath the Sevier Valley. It is speculated that rocks beneath the valley form a faulted syncline. On the west side of Sevier Valley are the small anomalous, north-trending Redmond Hills.

SANPETE-SEVIER VALLEY ANTICLINE

The Sanpete-Sevier Valley anticline (SSVA) is at least 50 miles (80 km) long and has structural relief of as much as 20,000 feet (6000 m). The Salina quadrangle is about 15 mi (25 km) from the southern end where volcanic deposits obscure the structure. The SSVA has undergone two types of movement, an original major period of deformation during the Late Cretaceous which folded Jurassic and Cretaceous rocks into a complex anticline several miles across, and subsequent smaller magnitude movements which primarily involved the Arapien core of the SSVA.

Much of the history of the SSVA is revealed by outcrops in Salina Canyon where part of the east limb of the structure is exposed, revealing steeply dipping Jurassic and Cretaceous beds unconformably overlain by near-horizontal early Tertiary rocks. The latter are in turn locally folded into a tight syncline a few hundred yards across. Nearby the Jurassic and early Tertiary rocks are unconformably overlain by Oligocene and Miocene volcanic and volcaniclastic deposits. Where the volcanic deposits overlie the Arapien Shale, they have been faulted, folded and brecciated in still later periods of deformation.

I believe the SSVA was formed by thrust deformation during the Sevier Orogeny which folded competent rock into an anticlinal structure and intensely crumpled and thickened the less competent Arapien Shale. Underlying rocks were only slightly or not at all deformed. Later, diapirism produced many smaller secondary structures. Major evidences supporting thrusting are discussed in Standlee (1982) and Lawton (1985).

Original Episode of Deformation

Complex Internal Folding and Faulting: Middle Jurassic Arapien Shale occurs in the core of the SSVA. Bedding attitudes in the Arapien rocks are complex; intense folds and faults occur on both small and large scales. Typically, however, beds are steep, vertical, or steeply overturned, and generally strike parallel to the trend of the SSVA. Axial planes of most folds lean toward the east (Hardy, 1952).

In the southwest part of the quadrangle, bedding attitudes are deflected by a series of large, complex folds. Fold axes and gypsum outcrop patterns, shown on the map, reveal the complexity of these folds (stratigraphic and structural relations suggest all the mapped gypsum outcrops in this area were originally part of the same bed which has been duplicated at the surface by folding and faulting). In addition, numerous smaller folds occur which were not differentiated on the map. The complex internal structure and large complex folds were probably formed by thrusting compression during the original formation of the SSVA. The folds were probably complicated by the subsequent diapiric movement.

Paleo-topographic High: Following the original episode of deformation, the SSVA was eroded off to about the level seen in Salina Canyon. However, part of the SSVA still had some topographic relief which persisted well into the Tertiary. The North Horn and Flagstaff Formations were not deposited over the crest of the SSVA but rather pinch out against the flank of the structure. They can be seen to feather out westward in lower Salina Canyon where the Flagstaff oversteps the North Horn. Both formations are again present on the west side of the SSVA. The Colton Formation thins over the SSVA but probably covered it. The younger Green River and Crazy Hollow Formations were affected only slightly or not at all by the paleo-topography. It is possible this long-lasting topographic relief was enhanced by minor diapiric uplift.

Second Episode of Deformation

The second, and all subsequent episodes of deformation on the SSVA, involved only the incompetent beds of the Arapien core. The flanking Jurassic and Cretaceous rocks folded in the original thrust deformation were not involved. This is evidenced by two features: 1-the flanking beds, which are exposed in Salina Canyon are overlain by undeformed early Tertiary rocks, and 2-as mentioned, the Jurassic and Cretaceous rocks on the flank of the SSVA were bevelled off prior to deposition of the Green River Formation. The Arapien must have been eroded down to near this level as well. This bevelled surface, which dips gently westward, is exposed beneath the unconformity in Salina Canyon at an elevation of about 5600 feet (1700 m), however the Arapien presently occurs near the center of the SSVA at elevations up to 6400 feet (1950 m), requiring subsequent deformation. I attribute the subsequent episodes to two causes, evaporite diapirism, and salt dissolution and resulting collapse of overlying rocks.

Post "formation of Aurora" Unconformity: The second episode occurred after deposition of the formation of Aurora and prior to deposition of beds mapped as "unnamed sandstone, mudstone, and conglomerate" (Tsu). The unnamed beds, which contain conglomeratic fluvial deposits with volcanic clasts, are deposited directly on Arapien Shale in several areas, especially in the northern part of the quadrangle. This required an episode of uplift and erosion after deposition of the formation of Aurora with enough erosion to strip off the Aurora, Crazy Hollow, Green River and Colton Formations; a total thickness of several thousand feet. The uplift was localized since in some areas, such as southeast of Salina and south of Salina Canyon, the unnamed beds are deposited on the formation of Aurora. In those areas the unnamed beds and the Aurora are subparallel. In Twist Canyon an angular relationship exists between the Aurora and unnamed rocks, however, involved beds are not immediately adjacent. This episode of deformation may have been the same that formed a syncline in Twist Canyon and that formed hogbacks north of Salina (described below).

Syncline in Twist Canyon: A tight fold occurs in Twist Canyon along the east side of the SSVA. There the formation of Aurora and older Tertiary rocks have been folded into an asymmetrical syncline in which the beds on the east dip moderately westward while those on the west limb are nearly vertical. In addition, beds of the west limb have been brecciated and thinned such that the Green River Formation is only a few feet thick in some places. The west limb is juxtaposed against unit E, the salt-bearing member of the Arapien Shale. The contact cuts diagonally across bedding such that the Green River and Crazy Hollow are both adjacent to the Arapien. The contact has striations indicative of high-angle normal faulting at several localities. As the syncline is traced northward it becomes shallower and eventually disappears under surficial deposits near the northeast corner of the quadrangle. The asymmetrical form, thinned, brecciated beds, position adjacent to salt-bearing rock, relationship to undeformed rock, and other evidences suggest that the syncline was formed by diapirism between 25 and 40 million years ago.

Hogbacks near Salina: North of Salina, adjacent to the Arapien Shale on the west flank of the SSVA, the Flagstaff through Crazy Hollow Formations are tilted steeply toward the west, forming hogbacks. These beds dip from 45° to 90° and are partially overlain by near-horizontal volcanic beds, bracketing an age of tilting of 25-40 million years. Similar tilted Green River and associated beds occur to the south in the Aurora and Sigurd quadrangles, making a discontinuous trend at least 25 miles (40 km) long (in some places volcanic units are tilted as well, probably due to a later event). The only major gap in this distance is south of Salina in the area of the complex internal folding of the SSVA described previously. The position along the flank of the SSVA, relationship to the Arapien Shale, and the timing suggest that the hogbacks were tilted by diapirism. Alternatively, Billings (1933) described the hogbacks as strip thrusts.

The general relationship of the previously described unnamed beds and Arapien Shale, the syncline, and the hogbacks suggest they are all related to the same episode or episodes of diapiric movement. This diapiric deformation was relatively minor compared to the earlier thrust-related deformation, and it created smaller structures.

Later Episodes of Deformation

Strike and dip measurements suggest an angular relationship between the formation of Black Cap mountain and the overlying Osiris Tuff. Limited exposures prevent confirmation of this relationship but it does suggest a pulse of diapirism about 24 million years ago.

Volcanic outcrops overlying the Arapien are typically near horizontal, though several areas occur where beds are steeply tilted. In Twist Canyon, the east side of the volcanic beds dip eastward about 40°. This folding may be due to continued diapiric uplift. North of Salina Canyon the volcanics are cut by several faults, blocks of which are steeply tilted at various angles. This deformation may be a result of either diapirism or salt dissolution and subsequent collapse.

Along many of the volcanic-Arapien Shale contacts the volcanic rocks are brecciated, thinned, or have missing units. In addition, the volcanic units are usually tilted at a steep angle away from the Arapien. Unit E of the Arapien Shale is often exposed along the contact, particularly in sections 7, 18, and 19 south of Salina Canyon. Digging in some localities along the contact has revealed slickensides and well foliated clays. Striations usually have a moderate to high-angle normal component. This contact is still considered primarily depositional though there probably was significant movement in some places. This would suggest that the Arapien continued to rise or diapir after deposition of the volcanic units. As it did so it tilted and brecciated adjacent rocks. Tilted and deformed surficial deposits also suggest either recent diapiric movement or salt dissolution and collapse as well. Diapirism has occurred recently in the Redmond Hills as well. The relatively undeformed nature in several areas of the volcanic units that overlie the Arapien Shale suggests that later diapirism or upward movement has been relatively minor compared to the pre-volcanic episodes.

It thus appears that diapirism was minor (but still significant) from Late Cretaceous to the present. The major diapiric pulse occurred between 25 and 40 million years ago. That pulse may have been structurally induced since it coincides with the time of formation of the Wasatch monocline (described below).

Salt Dissolution and Collapse

Some of the deformation in the Salina area is most easily explained by salt dissolution and subsequent collapse of overlying rock. While most of the volcanic units in the Salina area are nearly horizontal and relatively undeformed except as described previously, some outcrops have been intensely faulted, tilted, brecciated and dropped down compared to the main rock body. Deformation is most intense where the volcanics overlie the salt-bearing part of the Arapien.

Two major collapse areas occur in the quadrangle. A complex graben in sections 21, 28, 29, and 32, T. 21 S., R. 1 E.

trends northeastward along projected salt beds. Recent collapse features with internal drainage occur in the alluvium along this trend (SE 1/4, section 29) and indicate that salt dissolution has occurred below. The second area is directly east of Salina in a zone about 2 miles (3 km) long. There, complexly deformed volcanic rocks have been intensely faulted and brecciated, and have locally been dropped down as much as 500 feet (150 m). Salt is exposed in several places along this trend. That most of the brecciated volcanic rocks appear to be downdropped relative to equivalent less-deformed rocks, and that exposed salt often occurs nearby, suggest that much of the deformation occurred by salt dissolution and collapse. In one exposure in the SE 1/4, section 19, a cavity overlying massive salt is filled with brecciated salt and silt blocks. Other areas of collapse may also occur.

History of the Sanpete-Sevier Valley Anticline.

Method of formation of structural features in the Sevier and Sanpete Valley area has been controversial since first studied by geologists. Spieker (1946, 1949) explained the complex structures of the area by a series of 14 "crustal movements." Stokes (1952, 1982) said many of the features were caused by salt diapirism. Gilliland (1963) attributed the SSVA to a combination of compression and salt and shale flowage. More recently Witkind (1982) and Witkind and Page (1984) have extended the diapirism concept, using a model of repeated episodes of diapirism to explain complex unconformities, sedimentary thinning, the Wasatch monocline and other features in the area. Standlee (1982) renewed the controversy by suggesting that diapirism was minimal and that most features were related to Sevier thrusting and later backthrusting. Willis (1984) claimed major features in the area were formed by thrusting and later modified by diapirism and salt dissolution. Lawton (1985) sited additional evidence supporting thrusting in the area, proposing a model similar to Standlee's but using the "triangle zone" concept of Jones (1982).

I believe the Sanpete-Sevier Valley anticline was formed by thrusting during the Sevier Orogeny as proposed by Standlee and Lawton and that diapirism was a relatively minor, but significant, secondary event. The thrust detachment surfaces and most of the deformation caused by the thrusting occurred in the Arapien Shale which is very incompetent compared to underlying and overlying units. This deformation probably doubled or even tripled the apparent thickness of the Arapien in the Salina area and created numerous complex internal folds and faults. Thrusting also thickened relatively minor amounts of evaporites in the Arapien into bodies thick enough to diapir at a later time. More competent Jurassic and Cretaceous rocks overlying the Arapien were folded into a large, relatively simple anticline.

After formation of the SSVA by thrusting, it was eroded down to a topographic surface of moderate relief. This was followed by deposition of thick early Tertiary fluvial and lacustrine sediments which first lapped up against and later covered the SSVA. The loading of these sediments, possibly combined with regional structural forces, may have rendered the previously thickened evaporite bodies unstable, causing diapirism during the late Eocene or Oligocene. Alternatively the thick Arapien mudstone itself may have flowed diapirically. The resulting diapirism created the hogbacks near Salina, the syncline in Twist Canyon, the unconformity between the formation of Aurora and unnamed beds, and other structures, and also masked some of the original effects of thrusting. The diapirism also exposed the relatively nonresistant Arapien which was then eroded into a valley. The valley, and adjacent Sevier Valley which must have also been topographically low at that time, became conduits for Oligocene and Miocene volcanic and volcaniclastic deposits derived from the Marysvale volcanic field to the south (figure 2). There may have been some movement on the SSVA during this period of deposition although evidence is not conclusive.

Since the Miocene, the Arapien has undergone additional minor diapiric movement affecting immediately adjacent and overlying rocks. Episodes of salt dissolution and subsequent collapse of overlying rocks has further complicated features in the area.

REDMOND HILLS

Diapirism has also occurred outside of the SSVA. A linear chain of small hills which deflects the Sevier River begins near the center of Sevier Valley in the extreme northwest corner of the Salina quadrangle and continues northward for several miles. Projected southward, this trend intersects the gap in the hogbacks and the area of intense folding south of Salina described previously. Most of the hills are capped by unconsolidated gravel similar to modern Sevier River deposits that generally dip away from the center of the hills. Salt is being, or has been, mined in several areas in the hills. I believe the hills to be active diapiric structures. The nonresistant caps and the location of the hills in the active floodplain suggest that the hills would not stand as topographic highs unless they are actively being elevated. The linear trend of the hills suggests that their location may be controlled by a preexisting fault or zone of weakness.

WASATCH MONOCLINE

The Wasatch monocline, which trends north-northeastward along the east side of Sevier and Sanpete Valleys for about 70 miles, crosses the Salina quadrangle on the east side of the SSVA. It faces west and has maximum structural relief a few miles north of the quadrangle of 8,500 feet (2600 m) (Spieker, 1949). The southernmost exposure occurs just south of Salina Canyon where the monocline projects beneath volcanic deposits. The monocline involves beds as young as the formation of Aurora but does not fold volcanic deposits, bracketing a time of formation between 25 and 40 million years. A fault that is down on the west parallels the monocline approximately along the zone of maximum curvature, preventing precise determination of structural offset in the quadrangle.

Witkind and Page (1984) attributed formation of the monocline primarily to salt flowage away from the east side of the valleys, lowering the overlying rocks. In cross sections, Standlee (1982) and Lawton (1985) show the monocline deforming lower Paleozoic and Precambrian basement rocks. I believe the monocline is related to a basement structural feature rather than to evaporite flowage though I am uncertain as to its origin. It may be a drape fold caused by renewed movement on the ancient Ephraim fault (Moulton, 1975; Standlee, 1982), or related to backthrusting and early extensional faulting (L. A. Standlee, personal commun., 1985). The fact that it coincides in time with diapirism in the SSVA suggests that diapirism may have been triggered by the same structural event that formed the monocline.

GENTLE FOLD AND HIGH-ANGLE FAULTS

A broad, gentle fold with an east-trending axis crosses the central part of the quadrangle and projects eastward into the Wasatch Plateau. The axis generally coincides with Salina Canyon and may have influenced location of the canyon. There are few controls on timing of the fold though it seems to postdate all bedrock deposits in the area. I am uncertain as to the cause of the fold.

Several high-angle extensional faults cut the eastern part of the quadrangle at a slightly oblique angle to the SSVA. Offset on the faults varies up to 100 feet (30 m) and is primarily down to the east although a few have opposite displacement. Age is uncertain although they appear to cut across the east-trending fold. The fault trends conform to the strike of the steep beds underlying the unconformity in Salina Canyon and may be controlled by bedding plane slippage. I believe the faults are related to Basin and Range extensional faulting which may have affected the Wasatch Plateau. However, they may also be due to backthrusting, evaporite flowage, or be older and related to formation of the Wasatch monocline.

SEVIER VALLEY

Structure of rocks underlying the Sevier Valley is highly speculative due to sparse subsurface control. However, I believe Tertiary rocks exposed in hogbacks along the east side of the valley (and possibly Cretaceous rocks as well) are present beneath Sevier Valley and form a shallow syncline. They are probably intensely faulted, creating poor seismic reflectors. Circumstantial evidence to support the presence of the Tertiary and earlier rocks and the synclinal fold beneath the valley includes:

- the hogbacks north of Salina have beds dipping about 60° on the east side and about 45° on the west, suggesting that they may flatten out into a syncline under the valley.
- early Tertiary rocks equivalent to those forming the hogbacks are located on the west side of Sevier Valley. They have a shallow eastward dip and project beneath the valley at a shallow angle.
- blocks of possible Green River Formation and Miocene tuffs are exposed in the Redmond Hills. I believe the blocks were recently drug up by diapirism (indicating that early Tertiary rocks may still be present elsewhere beneath the valley). The lower elevation of the volcanic rocks compared to exposures a few miles to the southeast suggests that the valley may have been dropped down by faulting or folding.
- the Gunnison Plateau, which has a synclinal form, lies on trend with Sevier Valley to the north.
- a drill hole near Sigurd (Champlin No. 13-31 USA; NW, SW, section 31, T. 22 S., R. 1 W.) on the west side of the SSVA penetrated a complete early Tertiary section before passing into the Twist Gulch Formation and the Arapien Shale, however this may be too far south to be indicative.
- the hogbacks north and south of Salina seem to be too linear and unbroken to be strip thrusts (Billings, 1933) or detached blocks.

I believe the Sevier Valley may have been formed by Basin and Range extensional faulting. To the south near Richfield, young high-angle normal faults occur along both sides of the valley, creating straight mountain fronts characteristic of Basin and Range faulting. Similar faults are also present to the north in Sanpete and Sevier Valleys. In an alternative opinion, Witkind (1981) shows the surficial valley fill to be entirely underlain by diapiric Arapien Shale.

OTHER STRUCTURES

A small syncline just south of Salina involves Arapien through formation of Aurora rocks. The Crazy Hollow and Twist Gulch Formations are unusually thin in the fold. I believe the fold is related to minor diapirism that occurred during the late Eocene or Oligocene.

A road cut through the Cedar Mountain Formation in Salina Canyon exposes beds with an anomalous westward dip possibly due to slumping. A few hundred feet to the north the beds have the usual near-vertical to slightly eastward dip.

The oldest beds beneath the unconformity in Salina Canyon are nearly vertical, but the dip changes rapidly to about 35° east in the middle of the Sanpete Formation. Curvature of beds before and after suggest that the change is due to folding rather than faulting.

Two detached blocks composed of the Colton and Green River Formations occur in the Salina quadrangle, one just north of Salina and the other near the northern border. Both have anomalous attitudes compared to nearby hogbacks and are broken and brecciated. I believe these blocks are slump blocks which slid westward off the topographic high formed by diapirism in the Arapien Shale.

A major high-angle fault which juxtaposes the Green River and Crazy Hollow Formations intersects the previously described asymmetric syncline in Twist Canyon (SE 1/4, section 32, T. 21 S., R. 1 E.). Movement on the fault is down to the west but both sides of the fault appear to have downward drag (figure 3) (Spieker, 1949). The fault cuts through the axis of the syncline at an oblique angle, cutting out much of the zone of curvature. Typical fault drag has occurred, but not enough to change the original synclinal dip of the beds. Thus drag appears down on both sides.

The low hills directly south of Salina and the Redmond Hills are capped with unconsolidated gravel. Gravel pits in both areas have revealed steeply tilted gravels. The tilting in the Redmond Hills is explained by diapirism; the mechanism near Salina may be diapirism or salt dissolution.

Currently much of the Salina Quadrangle is undergoing active downcutting and erosion related to uplift of the Colorado Plateau. It is probably this uplift that is allowing groundwater to dissolve salt, creating some of the youngest structural features present in the area.

ECONOMIC GEOLOGY

Several mineral resources occur in the Salina quadrangle; gypsum, salt, lead, zinc, limestone, calcite, and gravel have been produced. Others show potential for future production. Gypsum is the most important commodity and is presently being mined. The Salina quadrangle lies in an area "favorable for discovery and development of local sources of low-temperature (less than 90° C, 195° F) water" (Utah Geological and Mineral Survey, 1983). One spring with 22° C (72° F) and flow of 1-2 liters per minute was reported in NW 1/4, secion 17, T. 21 S., R. 1 E (Goode, 1978), but could not be located in the present investigation.

Gypsum

All minable gypsum deposits are located in the southwest part of the quadrangle near Lost Creek and in adjacent quadrangles. United States Gypsum Company and Georgia-Pacific Corporation presently control the reserves in the quadrangle and both are actively mining.

Figure 3. Fault near Salina Creek with paradoxical "downward drag" on both sides. The Crazy Hollow Formation (right) is down against the Green River Formation (left). The fault cuts out much of the axis of curvature of an asymmetrical syncline.

Important deposits (mapped as Jacg) occur in unit C of the Arapien Shale. The deposits are mostly steeply dipping to vertical planar to lenticular bedded deposits with the thickest parts generally concentrated in the apex of folds. The deposits, which are part of a single bed repeated at the surface by faulting and folding, are usually 20 to 100 feet (6-30 m) thick but are completely cut out in places. Bounding rock is shaly limestone, gypsiferous shale, siltstone, or sandstone. The gypsum is most resistant to erosion and forms linear ridges.

Typical composition of the gypsum deposit is: gypsum-93.65%, SiO_2-3.64%, other inert rock material-1.62%, and $CaCO_3$-1.60%. Minor constituents are: KCl-13.9 ppm (parts per million), NaCl-10.9 ppm, Na_2SO_4-8.7 ppm, $MgSO_4$-65.1 ppm, and $MgCl_2$ 0.2 ppm (R. J. Beckman, U. S. Gypsum Co., written comm., 1984). The gypsum is recovered entirely by open pit mining primarily for sheetrock wall board. Less pure, uncalcined gypsum is used as a soil conditioner. As of 1983, approximately 550,000 tons (490,000 mt) of raw gypsum had been removed from the quadrangle (J.B. Carter, written comm., 1983), practically all from the area north of Lost Creek. The area south of Lost Creek has not been extensively developed. Approximately 2 million tons (1,800,000 mt) of reserves remain within the quadrangle.

Salt

Salt was the first mineral resource produced in Sevier Valley. Deposits in the area are associated with the dark reddish-brown clay of unit E of the Arapien Shale. The salt dissolves quickly at the surface leaving a residual clay cover on steep, dark red, vegetation-free hills; hills that appear to be clay may be salt cored. Major outcrops in the quadrangle are east of the town of Salina, in the first draw west of Twist Gulch in Salina Canyon, in small washes along the west side of the volcanics from Salina south to Lost Creek, and in the gap in Stone Quarry Ridge north of Salina. Salt is exposed immediately north of the quadrangle in the Redmond Hills, and probably underlies the quadrangle in that area as well. Small amounts of salt is mined for local use. None is presently being commercially produced from the quadrangle but some salt is being mined in the Redmond Quadrangle to the north.

Salt deposits usually occur as large structureless masses, often with secondary crystals in excess of 6 inches (15 cm). Residual bedding is sometimes present. Unevenly dispersed dark, red clay gives the salt a mottled appearance. Typical analysis of salt from the Redmond Hills area is: salt 95.6%, silica 2.16%, sulfate 1.1%, calcium 0.51%, iron and aluminum oxide 0.04%, magnesium 0.04%, and iodine 0.03% (Pratt et al., 1966). Smaller deposits typically have higher quantities of clay.

It is difficult to estimate the size of salt bodies or reserves due to the highly contorted and discontinuous nature and unknown depth. The Redmond Hills deposit is estimated to be about 1000 feet (300 m) across and at least 1000 feet (300 m) thick (Pratt et al., 1966). The Chevron USA No. 1

Salina Unit well penetrated in excess of 1000 feet (300 m) of salt in section 33. T. 22 S., R. 1 W., less than one half mile (0.8 km) southwest of the quadrangle, however, wells drilled in sections 31 and 32 nearby encountered much less salt (Standlee, 1982, p. 366). Other wells throughout central Utah also penetrated highly variable thicknesses.

Gravel and Road Metal

The Salina quadrangle contains significant deposits of gravel suitable for highway construction, concrete production, riprap, and other uses. Deposits are of four types. Colluvial and alluvial fan deposits occur at the mouths of washes and along mountain fronts. These are poorly sorted and contain material from angular boulders to clay utilized primarily for road base and riprap. Volcanic talus concentrated at the base of the volcanic units has been used for road fill and riprap in Salina Canyon. This material is primarily angular stones up to large boulder size with minor fine material intermixed. Stream deposited gravel and sand occurs along Salina Creek, Lost Creek, and in many parts of Sevier Valley, particularly the Redmond Hills. The deposits are moderate to well sorted cobbles, pebbles, and sand with little or no silt or clay-size material and are suitable for concrete production without washing. These deposits have been used extensively for highway and building construction. Gravel from conglomerate beds in the Crazy Hollow Formation in the southern part of the quadrangle has been used for road gravel to a limited extent.

Lead and Zinc

Minor lead and zinc deposits occur in the central and north-central parts of the quadrangle. One commercial deposit in Salina Canyon comprises the Salina Creek Mining District (Butler, 1920). The district has two mines, only one of which has produced any ore. The Lead Hill Mine (Butler, 1920) is in SW 1/4, sect. 33, T. 21 S., R. 1 E. and consists of 4 adits and one prospect pit. Workings trend NW and follow bedding planes at a 10° dip up to 800 feet (244m).

Perry and McCarthy (1976) made the most detailed study of the mine to date. Mineralization is along slightly dipping channel sandstone beds of the Flagstaff Formation which unconformably overlie near vertical beds of the Jurassic Twist Gulch Formation. Emplacement has occurred by secondary replacement of intergranular calcite cement with galena, cerrusite, sphalerite, pyrite, chalcocite, malachite, azurite, and celestite, probably by ascending hydrothermal solutions (Butler, 1920). The mineralized zone ranges from two inches to six feet (5cm-1.8m) thick and averages 2.5-3.5% lead, 0.5-1.0% zinc, and 0.1 ounces per ton of silver. Gold and copper are minimal. Over 100 tons (90 mt) of low-grade ore have been removed from the Lead Hill Mine (Perry and McCarthy, 1976). The mine has been abandoned for several years.

Some prospecting has been done in similar rock on the south side of Salina Creek and in breccia zones near the volcanic units but no known ore has been removed. Another silver-lead-zinc mine, the Redmond Silver Mine occurs 5 miles (8 km) to the north just outside the quadrangle (Heyl, 1963; 1978). How the two areas are related, if at all, is uncertain. The Claim Stake Mine, NW 1/4, NW 1/4, section 15, T. 21 S., R. 1 E. is the only other known prospect. There mineralized sand and rock has been washed and concentrated by gravity separation. Assays of the deposit show only marginal amounts of valuable metals.

Limestone, Building Stone, Calcite, Clay

Pure pale gray limestone occurs in the Flagstaff Formation in the northern part of the quadrangle. It has been quarried for use for the local sugar industry (Gilliland, 1951) and is presently being quarried and crushed just north of the quadrangle for use as rock dust in nearby coal mines.

Dense algal and oolitic limestone of the upper Green River Formation has been quarried for building stone in various parts of the Sanpete and Sevier Valleys because of its intrinsically pleasing golden yellow color and well indurated nature. A few small quarries have been started in the Salina quadrangle but only minor amounts have been removed.

Limestone and well-cemented conglomerate of the Flagstaff Formation and sandstone of the North Horn and Crazy Hollow Formations are the only other potential building stones of the quadrangle. However, they are generally not ornamental in nature and vary considerably in induration, bedding, and composition.

Calcite has been mined from two localities in the quadrangle in section 9, T. 21 S., R. 1 E. in the north part of the quadrangle and in section 32, T. 21 S., R. 1 E. Both deposits occur as secondary crystallization along fault zones. All known production has been for local use as crushed calcite for poultry.

Clay has been mined from volcanic clays in the upper part of the formation of Aurora in the adjacent Aurora quadrangle. Equivalent strata exist in the Salina quadrangle which have a potential for minable deposits.

Coal and Hydrocarbons

The Salina Canyon Coal Field occurs several miles to the east in upper Salina Canyon where coal has been produced from the Blackhawk Formation (Doelling, 1972). The Blackhawk Formation is equivalent in part to the Sixmile Canyon Formation which is not exposed but which underlies the quadrangle beneath thick overburden and which may contain the same coal horizon. A thin zone of low-grade coal is exposed in Salina Canyon in the Sanpete Formation. Part of the Sanpete may be equivalent to the Dakota Sandstone (Lawton, 1982) which contains minable coal elsewhere. The coal is expected to thicken eastward in the subsurface, but no exploration has been done.

Sevier County has been the scene of moderate hydrocarbon exploration in the past and the outlook for the discovery of commercial accumulations is considered good (Stark and Gordon, 1982). Six wells have been drilled within one mile of the quadrangle boundary with minor shows of oil and gas reported.

Britt and Howard (1982) summarize potential source beds and reservoir rocks in the area. Source beds that underlie or are close to the quadrangle, (with a regional average of total organic content) are the Mississippian Great Blue and Deseret Limestones (0.61%), Mississippian Chainman and Manning Canyon Shale (0.98%), Permian Park City Formation (1.26%), Jurassic Twin Creek Limestone and Arapien Shale (0.27%), and the Cretaceous Mancos Shale and Mesa Verde Formation (1.52%). Samples collected in the quadrangle from selected horizons in the Green River Formation also showed high organic content. Possible reservoir rocks occur in several formations.

WATER RESOURCES

As in most desert areas, water is the most valuable resource in the Sevier Valley area. Agriculture has been developed in the valley since about 1850 and surface-water rights are fully appropriated. The Sevier River crosses the western part of the quadrangle and has an average annual flow of 73,100 acre-feet. This is much less than upstream near Marysvale (165,800 acre-feet) because most is used for irrigation. The water table is within 10 feet of the surface in most of the valley and artesian conditions are common (Young and Carpenter, 1965).

Salina Creek and Lost Creek are the major perennial streams that cross the quadrangle; average annual flow is about 14,000 acre-feet and 4,400 acre-feet respectively (Young and Carpenter, 1965). Soldier Creek also usually has a minor trickle year round, and a few small springs are present in Salina Canyon and near the southern quadrangle boundary. The high country is dry most of the year but some water for livestock has been developed through piping from springs.

GEOLOGIC HAZARDS

Earthquake Hazards

The Salina quadrangle is not located on any of the major active fault zones of Utah (Anderson and Miller, 1979) and no Quaternary scarps have been recognized in the quadrangle. Several small faults that are potentially active do cross the quadrangle and several significant large faults, including the Wasatch and Elsinore Faults, occur within 50 miles (80 km). Several large earthquakes (over 4.0 on the Richter scale) with epicenters within 50 miles (80 km) of the quadrangle have occurred since 1850 when records were first kept (Arabasz et al., 1979; Richins et al., 1981). Several were 20-30 miles (32-48 km) to the south along the Elsinore Fault, one of the most seismicly active areas in the state. Shock waves from a quake in the area have the potential to do significant damage in the Salina area.

The Salina Quadrangle is located in high risk zone U-3 (on a scale of 1 to 4 with 4 being the highest; 3 is similar to 4 except with a lower population density) (Seismic Safety Advisory Council of Utah, 1979) and in Uniform Building Code zone 3. Damage risk from ground rupture is low but there is some risk of damaged or destroyed structures by ground shaking. There is some risk of liquefaction in the Sevier River flood plain and near the town of Salina. Salina and the surrounding agricultural community have numerous older habitations constructed of unreinforced masonry that present the greatest hazard to injury or property damage in the event of a significant earthquake.

Flooding

Flooding is a perennial problem along the major drainages. Salina Creek is the most troublesome since the stream runs parallel to the major interstate freeway and its frontage road and through the town of Salina. Gradient changes are causing it to actively erode laterally in some areas. It has cut out the frontage road in several places and threatened the interstate during the spring runoffs of 1983 and 1984 and probably will do so again in spite of efforts to riprap the channel.

The Salina Creek gradient flattens considerably after Salina Canyon causing the channel near the canyon mouth to fill with gravel and sand in the spring. The stream has been channeled but quickly fills in, causing flooding in Salina.

The Sevier River occupies a straight, dredged channel across a broad floodplain in the Sevier Valley. Meandering of the silt-laden river during spring runoff has caused damage to the channel. The flood-plain is mostly undeveloped marshland and pasture and monetary damage has been limited.

Landslides

Landslides have been a problem in Salina Canyon in the past and the potential is high for repeated occurrences. The canyon is significant because of the interstate freeway and the location of the town near the mouth. Large landslides derived from the North Horn, Colton, and lower Green River Formations occur on both sides of the steep canyon slopes. Most are semi-dormant but several show historic movement. Recent years of unusually heavy precipitation have reactivated several slides.

A particularly large recurring slide near Rattlesnake Point dammed Salina Creek 6460 ± 60 years ago. It formed a lake over 150 feet (50 m) deep and 2 miles (3.2 km) long. Salina Creek has since downcut to the original base level, leaving the slide without any frontal support. This is similar to the situation prior to the Thistle landslide which blocked the highway and created a lake in Spanish Fork Canyon 80 miles (130 km) to the north in 1983 (Witkind and Page, 1983). The freeway in Salina Canyon is built over the slide and has recent fractures, suggesting active creep on the landslide. Potential problems in the event of recurrent movement include breakup of the freeway, flooding the freeway, and the creation of an unstable dam which would threaten downstream communities in the event of a catastrophic break.

Debris Flows, Expanding Clay, Salt

Heavy runoff from spring melting or heavy rain has the potential to generate mud or debris flows in many of the canyons, as has occurred in the past. Many areas are sparsely vegetated with thick unconsolidated cover and are especially vulnerable. The major threat is to primary and secondary roads. Habitations are generally not threatened except near Salina.

Many of the formations in the Salina area, particularly the Arapien Shale, contain expanding clays which present a potential problem for buildings, roads, and other structures. Recent freeway construction required an extra thick filled base to compensate for this potential problem. Several older buildings have been damaged by expanding clays.

Salt deposits with thin overburden occur, and collapse by salt dissolution has occurred, both historically and prehistorically. Two small active collapse features are shown on the map. Areas in and near Salina are underlain by salt and could also settle or collapse. The potential for catastrophic collapse is probably low but settling enough to fracture foundations is possible. Past mining has left salt exposed and potential contamination of culinary and agricultural water through precipitation runoff from the salt is a possibility.

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TABLE 1. SOURCES OF AGES

1—^{14}C age 6460 ± 80 years (sample SARC-0111, Table 2) (sample locality shown on map)

2—Fleck et al., 1975, p.56-57 (samples ES-1 and EM-1, Table 2) (adjusted according to Dalrymple, 1979) (sample locality shown on map)

3—based on unpublished K-Ar dates by H. H. Mehnert of the U.S. Geological Survey

4—K-Ar age on biotite 26.6 ±1.1 ma (sample SACP-0510, Table 2) (sample locality shown on map)

5—Steven et al., 1981

6—K-Ar age on biotite 34.2 ±1.4 ma (sample RRDV-0101, Table 2)

7—K-Ar age on biotite 38.4 ±1.5 ma (sample AUBK-0112, Table 2)

8—K-Ar age on biotite 39.6 ±1.5 ma (sample AUBK-1010, Table 2)

9—K-Ar age on biotite 40.5 ±1.7 ma (sample SABK-1110, Table 2) (sample locality shown on map)

10—age bracketed by 9 and by Nelson et al., 1980

11—Fouch et al., 1982

12—Fission track age on zircon 90.6 ±4.8 ma (sample SACM-0110, Table 2) (sample locality shown on map) (Willis and Kowallis, in prep.)

13—Fission track age on zircon 90.3 ± 4.8 ma (sample SACM-0107, Table 2) (sample locality shown on map) (Willis and Kowallis, in prep.)

14—Fission track age on zircon 96.2 ± 5.0 ma (sample SACM-0101, Table 2) (sample locality shown on map) (Willis and Kowallis, in prep.)

15—Imlay, 1980

16—Sprinkel, 1982

TABLE 2. RADIOMETRIC DATES FROM SALINA QUADRANGLE AND VICINITY

SAMPLE #	GEOL. UNIT	LAT(N)	LONG(W)	QUAD	MATERIAL	METHOD	AGE Million years or years
SARC-0111	Lake sediment	38°55′21″	111°46′06″	Salina	Plant frag	C^{14}	6460 ± 80 yrs
ES-1	Osiris Tuff	38°57′30″	111°48′12″	Salina	Biotite	K-Ar	22.9 ± 0.4
EM-1	Osiris Tuff	38°57′30″	111°48′12″	Salina	Biotite	K-Ar	22.4 ± 0.4
SACP-0510	Int. Carter Pk	38°52′34″	111°52′29″	Salina	Biotite	K-Ar	26.6 ± 1.1
RRDV-0101	Dipping Vat Fm	38°47′29″	111°50′22″	Rex Res	Biotite	K-Ar	34.2 ± 1.4
AUBK-0112	fm of Aurora	38°56′10″	111°57′04″	Aurora	Biotite	K-Ar	38.4 ± 1.5
AUBK-1010	fm of Aurora	38°56′07″	111°57′05″	Aurora	Biotite	K-Ar	39.6 ± 1.5
SABK-1110	fm of Aurora	38°53′10″	111°49′03″	Salina	Biotite	K-Ar	40.5 ± 1.7
SACM-0110	Cedar Mtn Fm	38°55′59″	111°48′07″	Salina	Zircon	Fiss. trk.	90.6 ± 4.8
SACM-0107	Cedar Mtn Fm	38°55′59″	111°48′08″	Salina	Zircon	Fiss. trk.	90.3 ± 4.8
SACM-0101	Cedar Mtn Fm	38°55′59″	111°48′09″	Salina	Zircon	Fiss. trk.	96.2 ± 5.0

Data on unpublished ages (as reported by lab):

SARC-0111	Sample Number: Beta 9510 (BA)
SACP-0510	$^{40*}Ar$(ppm) = 0.01323; 0.01323—%K = 7.186; 7.044—$^{40*}Ar/^{40}Ar$ = 0.511; 0.398—(KE)
RRDV-0101	$^{40*}Ar$(ppm) = 0.01501; 0.01523—%K = 6.313; 6.310—$^{40*}Ar/^{40}Ar$ = 0.502; 0.526—(KE)
AUBK-0112	$^{40*}Ar$(ppm) = 0.01961; 0.01906—%K = 7.245; 7.134—$^{40*}Ar/^{40}Ar$ = 0.723; 0.811—(KE)
AUBK-1010	$^{40*}Ar$(ppm) = 0.02001; 0.02015—%K = 7.250; 7.215—$^{40*}Ar/^{40}Ar$ = 0.581; 0.672—(KE)
SABK-1110	wt.%K_2O = 7.37; 7.58—40*Ar($x10^{-10}$ moles/gm) = 4.411—%40*Ar = 41.0—(UU)

Laboratory: KE = Krueger Enterprises, Inc., Cambridge, MA; UU = University of Utah; Beta Analytic Inc., Coral Gables, FLA

$40^{*}Ar$ = radiogenic Argon 40

TABLE 3. MODAL ANALYSES OF VOLCANIC UNITS

	MTX	PLAG	SAN	BIOT	AMPH	PYX	FE-TI	SPH	APA	QTZ	LITH	OTHER
a)	59.6	23.6	—	1.7	13.0	—	1.9	—	0.1	tr	0.1	—
b)	54.5	28.3	—	3.8	12.0	—	1.1	—	0.1	0.1	0.1	—
c)	—	60.7	—	9.8	6.8	9.8	4.0	0.5	0.2	—	—	8.2[1]
d)	—	72.4	—	5.8	10.0	7.8	2.8	0.7	0.5	—	—	—
e)	9.9	36.1	—	—	0.4	16.8	1.2	0.4	0.2	—	—	35.0[2]
f)	54.1	19.7	—	—	—	10.2	3.5	—	—	—	—	12.5[3]
g)	83.8	2.3	tr	0.1	tr	—	0.8	—	—	0.9	1.1[4]	10.8[5]
h)	90.1	4.4	—	—	—	0.7	1.9	—	0.1	0.1	2.7	—
i)	84.6	2.0	0.3?	—	—	—	0.9	—	tr	—	—	12.2[6]
j)	88.8	6.6	2.6	—	—	0.3	1.4	—	0.3	—	—	—
k)	91.2	4.4	2.8	—	—	0.5	1.1	—	tr	—	—	—
l)	80.6	14.3	2.3	1.5	—	0.8	0.5	—	—	—	—	—
m)	71.3	17.6	4.8	2.2	0.2	1.7	2.2	—	—	—	—	—
n)	78.9	11.1	3.4	1.7	—	1.8	0.8	—	tr	tr	2.3	—

a) SABT-0201—700 counts—Three Creeks Tuff Member of Bullion Canyon Volcanics
b) SABT-0204—845 counts—Three Creeks Tuff Member of Bullion Canyon Volcanics
c) SACP-2501—600 counts—intrusion of Carter Peak
d) SACP-2502—600 counts—intrusion of Carter Peak
e) SACP-2503—500 counts—intrusion of Carter Peak
f) SACP-2504—600 counts—intrusion of Carter Peak
g) SABK-1110—640 counts—rhyolite tuff in formation of Aurora
h) SAAT-0801—708 counts—Albinus Tuff
i) SAAT-1172—650 counts—Albinus Tuff
j) SAAT-0806—760 counts—Antimony Tuff Member of Mount Dutton Formation
k) SAAT-0810—765 counts—Antimony Tuff Member of Mount Dutton Formation
l) SATO-0702—600 counts—Osiris Tuff
m) SATO-1013—600 counts—Osiris Tuff
n) SATO-0104—650 counts—Osiris Tuff

[1] Kaolinite-8.2%
[2] Kaolinite-31.2%, carbonate-2.6%, uralite-1.2%
[3] Voids-12.3%, olivine-0.2%
[4] Pumice present, but included in matrix count in thin section
[5] Carbonate-10.8%, zircon-tr
[6] Vesicles-12.2%

UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
Salt Lake City, Utah 84108-1280

THE UTAH GEOLOGICAL AND MINERAL SURVEY is one of eight divisions in the Utah Department of Natural Resources. The UGMS inventories the geologic resources of Utah (including metallic, nonmetallic, energy, and ground-water sources); identifies the state's geologic and topographic hazards (including seismic, landslide, mudflow, lake level fluctuations, rockfalls, adverse soil conditions, high groundwater); maps geology and studies the rock formations and their structural habitat; provides and disseminates educational materials concerning the geology of Utah; and provides information to decisionmakers at local, state, and federal levels.

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STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
UTAH GEOLOGICAL AND MINERAL SURVEY

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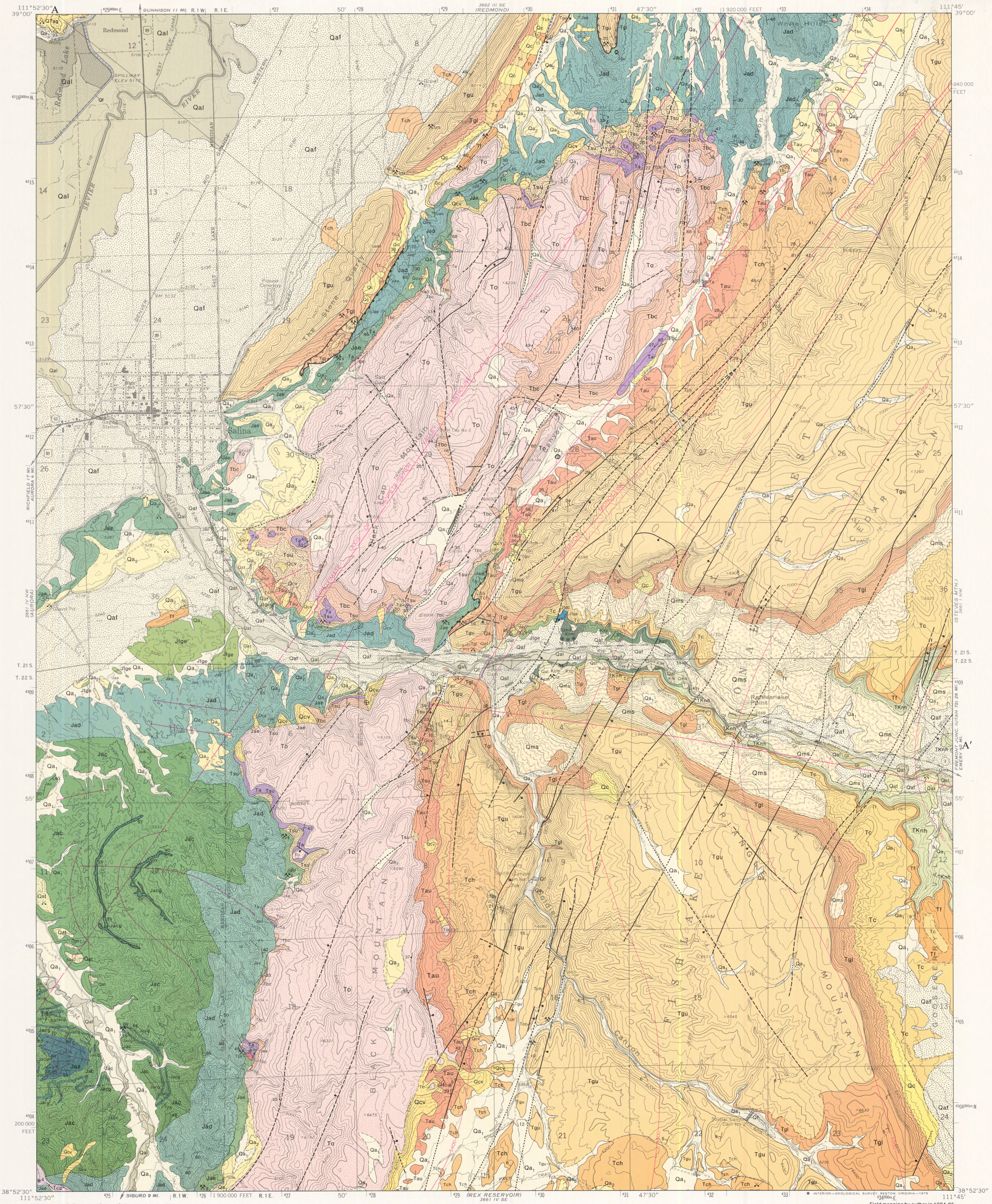
Plate 1
Utah Geological and Mineral Survey Map 83
Geologic Map of the Salina Quadrangle



Base from U.S. Geological Survey, Salina quadrangle 1966

Field mapping by author in 1984-85
Kent D. Brown, Cartographer

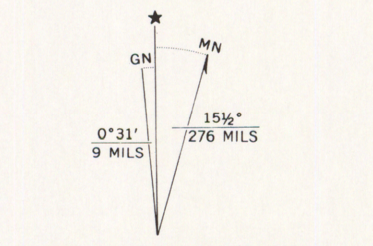
SCALE 1:24 000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

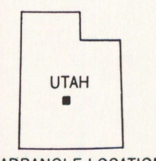


UTM GRID AND 1966 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

GEOLOGIC MAP OF THE SALINA QUADRANGLE, SEVIER COUNTY, UTAH

by
Grant C. Willis
Utah Geological and Mineral Survey

1986



QUADRANGLE LOCATION

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
UTAH GEOLOGICAL AND MINERAL SURVEY

Plate 2
Utah Geological and Mineral Survey Map 83
Geologic Map of the Salina Quadrangle

DESCRIPTION OF MAP UNITS

QUATERNARY

Qf Artificial fill—*Man-made dikes and dams.*

Qal Flood plain and channel deposits of Sevier River, Salina Creek, and Lost Creek—*Boulders, gravel, sand, silt, mud, and clay.*

Qaf Alluvial fan and alluvial slope deposits—*Moderately to poorly sorted boulders, cobbles, sand, silt, and clay.*

Qa1 Younger alluvial deposits—*Sand, silt, mud, gravel, and boulders. Primarily intermittent stream deposits in active depositional areas.*

Qa2 Older alluvial deposits—*Sand, silt, mud, gravel, and boulder deposits dissected or isolated by downcutting drainage systems.*

Qc Colluvium—*Slope cover composed of fallen blocks, talus, and surficial debris.*

Qcv Volcanic colluvium—*Slope cover composed primarily of volcanic-derived fallen blocks, talus, and surficial debris.*

Ql Lacustrine sediments deposited in a lake formed by a large landslide which dammed Salina Creek—*Well-bedded, medium-gray, organic rich clay with abundant plant fragments.*

Qat Older alluvial terrace deposits along Salina Creek and Lost Creek—*Gravel, sand, silt, clay, and boulders.*

Qms Landslide deposits—*Poorly sorted, unconsolidated bedrock and surficial material transported and deposited by mass movement.*

QTag Gravel deposits of Redmond Hills—*Moderately well sorted cobbles, pebbles, and sand with minor amounts of mud and clay.*

TERTIARY

Tu Undifferentiated middle and upper Tertiary deposits—*Shown only on the cross section.*

To Osiris Tuff—*Light gray, but also reddish-brown, reddish-purple, or brownish-gray, densely welded, porphyritic, latitic tuff with conspicuous plagioclase and biotite, and minor sanidine and Fe-Ti oxides.*

UNCONFORMITY

Tbc Formation of Black Cap Mountain— *Bluish-gray volcaniclastic sandstone with minor conglomerate, air-fall tuff, and breccia.*

Ta Tuff of Albinus Canyon and Antimony Tuff Member of Mount Dutton Formation, undifferentiated—*Dark reddish-brown, dark brownish-gray, or dark gray, densely welded, crystal-poor, ash-flow tuff of quartz latite composition with plagioclase, sanidine, pyroxene, and drawn-out vesicles and pumice lenticules.*

Tcp Intrusion of Carter Peak—*Greenish-gray to black and gray, fine-grained, holocrystalline diorite with plagioclase, clinopyroxene, pyroxene, biotite, hornblende, and accessory sphene and apatite.*

Tbt Three Creeks Tuff Member of Bullion Canyon Volcanics—*Pale gray latitic tuff with plagioclase, amphibole, biotite, and minor other minerals.*

Tsu Unnamed sandstone, mudstone, and conglomerate beds—*White to pale gray water-lain tuffaceous sandstone, mudstone, marlstone, and conglomerate. Conglomerate contains volcanic and sedimentary clasts.*

UNCONFORMITY

Tau Formation of Aurora (formerly Bald Knoll Formation)—*Pale gray interbedded mudstone, bentonitic shale, limestone, and sandstone with occasional pale reddish-orange beds. Has one ash-flow tuff bed in the lower part and pale gray volcaniclastic sandstone in the upper.*

Tch Crazy Hollow Formation—*Dark orangish-red and light yellowish-gray "salt and pepper" sandstone, mudstone, siltstone, shale, and black chert-pebble-bearing conglomerate.*

Green River Formation

Tgu Upper Member of the Green River Formation—*Pale yellow, massive, silicified limestone with chert nodules and interbedded greenish-gray or light brown shale.*

Tgl Lower Member of the Green River Formation—*Greenish-gray thin-bedded to laminated shale, light brown calcareous sandstone, and light yellowish-gray chalky limestone.*

Tc Colton Formation—*Reddish-brown mudstone, and minor feldspathic sandstone, shale, and limestone.*

Tf Flagstaff Formation—*Reddish-brown to pale gray calcareous sandstone, sandy limestone, and lenticular conglomerate beds in the eastern part of the quadrangle, and interbedded conglomerate, micritic limestone, and mudstone in the central and northern part.*

TKnh North Horn Formation—*Reddish-brown mudstone with lesser amounts of reddish-purple, pale green, or brownish-gray sandstone, calcareous mudstone, and sandy limestone.*

UNCONFORMITY

CRETACEOUS

Indianola Group

Ksm Sixmile Canyon Formation—*Not exposed in outcrop. Shown only on the cross section.*

Kfv Funk Valley Formation—*Pale yellowish-gray to orangish-gray interbedded sandstone, siltstone, mudstone, and shale.*

Kav Allen Valley Shale—*Greenish-gray and brownish-gray mudstone and shale, and minor thin-bedded sandstone.*

Ksp Sanpete Formation—*Gray and reddish-gray interbedded conglomerate, sandstone, mudstone, and shale.*

Kcm Cedar Mountain Formation—*Interbedded reddish-brown, purple, and gray conglomerate, sandstone, siltstone, and shale.*

UNCONFORMITY

JURASSIC

Twist Gulch Formation

Jtg Twist Gulch Formation (undifferentiated)—*Shown only on the cross section.*

Jtgs Beds of the Twist Gulch Formation that are probably equivalent to the Summerville Formation of the San Rafael Swell area—*Reddish-brown siltstone and mudstone.*

Jtgc Beds of the Twist Gulch Formation that are equivalent to the Entrada Sandstone of the San Rafael Swell area—*Interbedded reddish-brown siltstone, mudstone, sandstone, and minor conglomerate.*

Jtge Beds of the Twist Gulch Formation that are equivalent to the Entrada Sandstone of the San Rafael Swell area-*Interbedded reddish-brown siltstone, mudstone, sandstone, and minor conglomerate.*

Arapien Shale

Ja Arapien Shale, undifferentiated—*Shown only on the cross section.*

Jae Unit E—*Dark reddish-brown, salt-bearing, silty shale.*

Jad Unit D—*Interbedded, bluish-gray and reddish-gray gypsiferous shale, mudstone, and sandstone.*

Jac Unit C—*Bluish-gray calcareous shale with gray thin-bedded calcareous sandstone, massive gray to white lenticular gypsum beds, and arenaceous limestone.*

Jacg Lenticular beds of massive pale gray to white mottled gypsum within Jac.

Jaa Unit A—*Brownish-gray, thin-bedded, argillaceous limestone.*

FORMATION		SYMBOL	THICKNESS feet (meters)	LITHOLOGY
Surficial deposits		Q	0-300 (0-90)	
Osiris Tuff		To	0-350 (0-100)	
Formation of Black Cap Mtn.		Tbc	0-600 (0-180)	
T. of Albinus Cyn., Antimony T. Mbr. Mt. Dutton Fm. undiv.		Ta	0-250 (0-75)	
Three Creeks T. Mbr., Bullion Cyn. Volc.		Tbt	0-30 (0-9)	
Unnamed sandstone, mudstone, congl.		Tsu	0-600 (0-180)	
Formation of Aurora		Tau	0-1100 (0-340)	
Crazy Hollow Formation		Tch	500-1000 (150-300)	
Green River Formation	Upper Member	Tgu	730 (220)	
	Lower Member	Tgl	430 (130)	
Colton Formation		Tc	100-530 (31-160)	
Flagstaff Formation		Tf	0-200 (0-60)	
North Horn Formation		TKnh	0-1200 (0-370)	
Indianola Group	Sixmile Canyon Formation	Ksm	4500 (1400)	
	Funk Valley Formation	Kfv	2400 (730)	
	Allen Valley Shale	Kav	900 (270)	
	Sanpete Formation	Ksp	1200 (370)	
Cedar Mountain Formation		Kcm	850 (260)	
Twist Gulch Formation	Summerville Fm. eq.	Jtgs	10 (3)	
	Curtis Fm. eq.	Jtgc	170 (52)	
	Entrada Sandstone Equivalent	Jtge	1700 (520)	
Arapien Shale	Unit E	Jae	200-400 (60-120)	
	Unit D	Jad	3000-4000 (900-1200)	
	Unit C	Jac	1000-2000 (300-600)	
	gypsum bed	Jacg		
	Unit A	Jaa	100 (30)	

CONTACT
Dashed where approximate; dotted where covered

CONTACT
Generalized in zone of intertonguing units

FAULT
Dashed where location inferred, dotted where covered; queried where probable; bar and ball on downthrown side

FAULT
May be due to salt diapirism in the Arapien Shale; teeth on diapiric material

FAULT
Low angle; bounding detached blocks

Area of rupture and collapse in surficial deposits; probably caused by salt dissolution

STRUCTURE CONTOURS
Contour interval 400 ft.; Datum-Top of Colton Formation

TRACE OF AXIAL SURFACE OF FOLD
Arrows show direction of plunge; dotted where covered

Anticline Syncline Monoclinal fold

STRIKE AND DIP OF BEDDING

18 Inclined Horizontal

Vertical
Ball indicates stratigraphic top

STRIKE AND DIP OF VOLCANIC FOLIATION

Gypsum mine - open pit

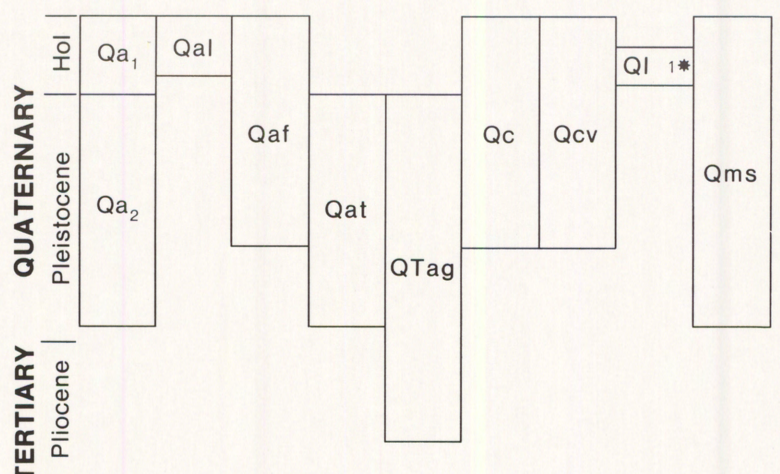
Prospect, small mine or pit;
s-salt, c-calcite, gy-gypsum, lm-limestone, lz-lead, zinc, gold, silver

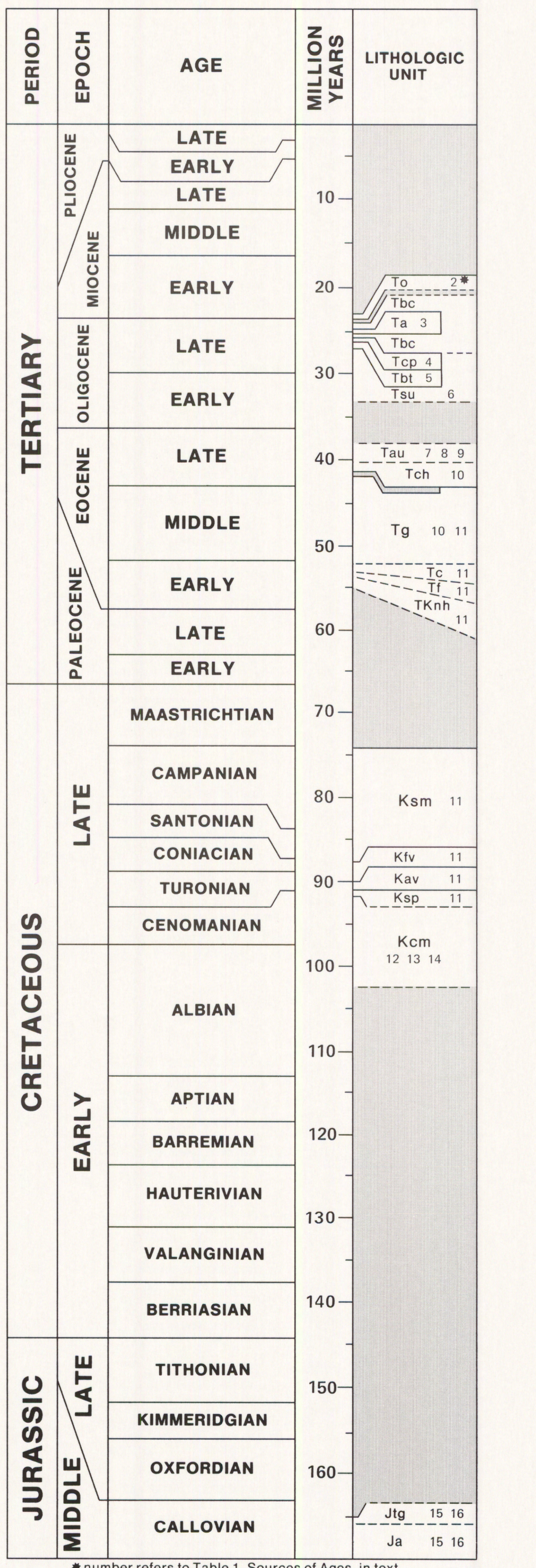
Gravel or road-fill pit

Adit

Location of radiometric age;
number refers to Table 1, Sources of Ages, in text

CORRELATION OF MAP UNITS





● number refers to Table 1, Sources of Ages, in text