GEOLOGIC MAP OF THE NEW HARMONY QUADRANGLE, WASHINGTON COUNTY, UTAH

by
S. Kerry Grant
University of Missouri - Rolla

MISCELLANEOUS PUBLICATION 95-2 1995
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

ISBN 1-55791-329-3

UTAH GEOLOGICAL SURVEY

The **UTAH GEOLOGICAL SURVEY** is organized into three geologic programs with Administration, Editorial, and Computer Resources providing necessary support to the programs. The **ECONOMIC GEOLOGY PROGRAM** undertakes studies to identify coal, geothermal, uranium, hydrocarbon, and industrial and metallic resources; to initiate detailed studies of the above resources including mining district and field studies; to develop computerized resource data bases, to answer state, federal, and industry requests for information; and to encourage the prudent development of Utah's geologic resources. The **APPLIED GEOLOGY PROGRAM** responds to requests from local and state governmental entities for engineering geologic investigations; and identifies, documents, and interprets Utah's geologic hazards. The **GEOLOGIC MAPPING PROGRAM** maps the bedrock and surficial geology of the state at a regional scale by county and at a more detailed scale by quadrangle. The Geologic Extension Service answers inquiries from the public and provides information about Utah's geology in a non-technical format. The Paleontology and Paleoecology Section maintains and publishes records of Utah's fossil resources, provides paleontological recovery services to state and local governments, and conducts studies of environmental change to aid resource management.

The UGS Library is open to the public and contains many reference works on Utah geology and many unpublished documents on aspects of Utah geology by UGS staff and others. The UGS has several computer data bases with information on mineral and energy resources, geologic hazards, stratigraphic sections, and bibliographic references. Most files may be viewed by using the UGS Library. The UGS also manages a sample library which contains core, cuttings, and soil samples from mineral and petroleum drill holes and engineering geology investigations. Samples may be viewed at the Sample Library or requested as a loan for outside study.

The UGS publishes the results of its investigations in the form of maps, reports, and compilations of data that are accessible to the public. For information on UGS publications, contact the Sales Office, 2363 South Foothill Drive, Salt Lake City, Utah 84109-1497, (801) 467-0401.

GEOLOGIC MAP OF THE NEW HARMONY QUADRANGLE, WASHINGTON COUNTY, UTAH

by
S. Kerry Grant
University of Missouri-Rolla

ABSTRACT

The New Harmony quadrangle lies between Cedar City and St. George, in southwest Utah. It is dominated by the eastern part of the Pine Valley Mountains, a complex mass of extrusive and intrusive latite-monzonite porphyry. Immediately east of the quadrangle is the north-trending Hurricane fault zone, which has influenced structural features in the map area. The oldest rocks are Jurassic in age. These rocks, together with Cretaceous rocks, are found in the deeply eroded southern part of the quadrangle. They have been deformed by the fold-and-thrust actions of the Late Cretaceous Sevier orogeny. A post-orogenic period of erosion beveled the area before deposition of the Claron Formation in early Tertiary time. Mid-Tertiary ash-flow tuffs may have covered the entire quadrangle before being deformed and removed by uplift and sliding due to the emplacement of the Pine Valley monzonite-latite rocks. Faulting related to horizontal extension occurred in several directions and in a systematic clockwise pattern during the late Cenozoic. During this time two episodes of basalt extrusion and three alluvial-fan depositional events are recognized. Younger alluvial and other surface processes completed the depositional activities in the Quaternary.

INTRODUCTION

The New Harmony quadrangle includes the town of New Harmony and the northeastern part of the Pine Valley Mountains. The eastern boundary is immediately west of Interstate Highway I-15, from Pintura to the New Harmony exit, and the quadrangle extends west to the summit of the Pine Valley Mountains. Altitudes range from 4,300 to 9,543 feet (1,310-2,909 m).

Previous geologic work in the quadrangle area includes reconnaissance mapping (Cook, 1957, 1960), compositional and structural analyses of igneous rocks in adjacent areas (Mackin, 1947, 1960), detailed descriptions of the ash-flow tuffs of the Quichapa Group (Williams, 1967), mapping of Sevier orogeny folding along the Hurricane Cliffs (Kurie, 1966), mapping of the Kanarraville quadrangle (Averitt, 1967), and analysis of the relationship between basalts and the Hurricane fault (Best and Brimhall, 1970; Hamblin, 1970; Hamblin and others, 1981).

STRATIGRAPHY

Sedimentary rocks in the southern part of the quadrangle range in age from Jurassic to mid-Tertiary. Along the west side of the quadrangle, the Miocene Pine Valley monzonite and latite form the cliffs along the southern mountain front. Late Cenozoic surficial deposits are thickest in the eastern and northern parts of the quadrangle.

Jurassic

Navajo Sandstone (Jn)

The Navajo Sandstone is the oldest formation exposed in the New Harmony quadrangle (figure 1). It occurs in the narrow canyons of Leap Creek and Maple Hollow Creek, where it is reddish colored and conspicuously cross-bedded. About 500 feet (150 m) of sandstone is present, but the formation is about

2,000 feet (600 m) thick nearby (Cook, 1960; Peterson and Pipiringos, 1979). Outside of the quadrangle, the formation is typically red in the lower part and white in the upper part. The lack of white Navajo outcrops in the quadrangle may indicate that the uppermost Navajo was removed by local thrusting. The overlying rocks have been folded and possibly thrusted.

The Navajo is a quartz-rich sandstone characterized by fine to medium grain size, and large-scale eolian cross-bedding in sets as much as 50 feet (15 m) thick. It forms massive cliffs. It is the spectacular rock unit exposed along the Hurricane Cliffs and in Zion National Park, on the upthrown block of the Hurricane fault immediately east of the quadrangle.

The Navajo is considered to be mainly of eolian origin (Stokes, 1986), deposited by wind currents that were moving from the north or northwest, in a desert setting.

Carmel Formation (Jc)

The Carmel Formation consists of a lower, thick, platy, gray, argillaceous, micrite limestone and an upper, thin, red siltstone and sandstone. The Carmel Formation is folded in Maple Hollow, apparently above a detachment zone that overlies the Navajo Sandstone. Immediately south of the quadrangle, a lower red siltstone is present below the micrite limestone and above the Navajo Sandstone. This red unit may extend into the quadrangle but exposures are poor. Carmel redbeds are known in this stratigraphic position from work conducted a few miles south of the quadrangle (Peterson and Pipiringos, 1979). However, the lower red siltstone may correlate with the Sinawava Member of the Temple Cap Sandstone. If the lower red siltstone beds are part of the Temple Cap Sandstone they are not separately mappable in this quadrangle because of structural complexities in the rocks above the Navajo Sandstone and sporadic outcrops. The lower red siltstone, if present, is here included as part of the Carmel Formation.

An erosional surface, termed the J-1 unconformity, separates the Lower Jurassic Navajo Sandstone from the Middle Jurassic Sinawava Member of the Temple Cap Sandstone (Peterson and Pipiringos, 1979). A second erosional surface, termed the J-2 unconformity, separates the Temple Cap Sandstone from the Carmel Formation. These unconformities may not be recognizable in the quadrangle because of tectonic disturbance.

The combined thickness of the micrite limestone and lower red siltstone units is about 650 feet (190 m). The upper red siltstone unit is about 150 feet (45 m) thick, making the formation about 800 feet (240 m) thick. The micrite limestone weathers to a talus slope of platy chips that resemble shale. It forms steep slopes and low hills that shed debris onto underlying units. The limestone formed in shallow marine conditions.

Upper Cretaceous

Iron Springs Formation (Kis)

Unconformably overlying the Carmel Formation is a sequence of alternating thin, buff to white, fine- to medium-grained sandstones and colorful shales that is as much as 3,800 feet thick (1,160 m) (Cook, 1957). The variegated shales are purple, gray, red, and yellow, but are often poorly exposed on vegetated slopes. The sandstones form repeating ledges, 10 to 40 feet (3-12 m) thick, visible on aerial photos at 50-foot (15 m) intervals. Some sandstone beds are contorted by soft-sediment deformation. A 20-foot-thick (6 m), pebble to cobble, quartzose conglomerate containing black, brown, and pale quartzite clasts lies at the base. This unit is the possible equivalent of the Dakota Formation. Coal beds, not seen [but possible, based on information about the unit from outside the quadrangle], may be present (Cook, 1957; Averitt, 1962; Lawrence, 1965). The best exposures of the Iron Springs Formation are on and northwest of Coal Hill. The Iron Springs Formation is possibly of fluvial, alluvial-plain, and paludal origin. It may include facies related to thrust pulses of the Sevier orogeny (Fillmore, 1991).

Tertiary

Claron Formation (Tc, Paleocene to Oligocene (?))

The Claron Formation unconformably overlies older rocks that were folded and thrusted during the Sevier orogeny in Late Cretaceous time. The Claron is a variegated sequence of fluvial and lacustrine sandstone, limestone, shale, and conglomerate. The base of the formation is a 30-foot-thick (10 m) conglomerate composed of brown, pink, tan, and black quartzite pebbles, cobbles, and boulders. Overlying the basal conglomerate is a section of pink to gray limestone having algal components with pisolitic texture. Above this is a series of alternating red and white to gray ledge- and slope-forming limestones and sandstones with some conglomerate and lesser shale. At the top of the Claron is a white, ledge-forming limestone, less than 100 feet (30 m) thick. The formation is 400 to 500 feet (120-150 m) thick, but may thicken eastward where concealed beneath igneous rocks. The formation is best exposed south of Leap Creek near the southeast corner of the quadrangle.

The Claron Formation underlies monzonite of the Pine Valley Mountains in the south half of the quadrangle, and the Leach Canyon Formation in the northwest corner in Comanche Canyon.

Quichapa Group (Oligocene (?) to Miocene)

The Quichapa Group includes the Leach Canyon Formation, Condor Canyon Formation, and Harmony Hills Tuff (Cook, 1957; Williams, 1967). The rock units in the group are a sequence of mid-Tertiary ash-flow tuffs (Rowley and others, 1979). The Table Butte Tuff Member of the Leach Canyon Formation and the Swett Tuff Member of the Condor Canyon Formation are missing from the volcanic section in the New Harmony quadrangle.

Leach Canyon Formation (Tl, Oligocene (?) to Miocene)

The oldest of the mid-Tertiary volcanic units exposed in the quadrangle is a resistant, purplish to pinkish-gray, densely welded, vitric-crystal ash-flow tuff. Phenocrysts comprise 15 to 25 percent of the rock and consist of quartz, sanidine, and

SYSTEM	SERIES	UNIT	SYMBOL	THICKNESS feet, (meters)
QUATERNARY	Holocene	Surficial deposits		0-200 (60)
QUATERNARY	Pleistocene	Younger basalt flows	Qb	300+ (90)
QUATERNARY	Pleistocene	Basaltic breccia	Qbb	300+ (90)
TERTIARY	Pliocene to Miocene(?)	Older basalt flows	Tb	200 (60)
TERTIARY	Pliocene to Miocene(?)	Oldest alluvial-fan deposits	Taf	400+ (120)
TERTIARY	Miocene	Monzonite of the Pine Valley Mountains	Tip	1000 (300)
TERTIARY	Miocene	Pine Valley Latite	Tvp	1700 (520)
TERTIARY	Miocene	Rencher Formation	Tr	500+ (150)
TERTIARY	Miocene	Quichapa Group: Harmony Hills Tuff	Th	240 (70)
TERTIARY	Miocene	Quichapa Group: Bauers Tuff Mbr. of Condor Cyn. Fm.	Tccb	200 (60)
TERTIARY	Miocene or Oligocene	Quichapa Group: Leach Canyon Formation	Tl	250 (75)
TERTIARY	Oligocene(?) to Paleocene	Claron Formation	Tc	400-500 (120-150)
CRETACEOUS	Upper	Iron Springs Formation	Kis	3800 (1160)
JURASSIC	Middle	Carmel Formation	Jc	800 (240)
JURASSIC	Lower	Navajo Sandstone	Jn	500+ (150)

LITHOLOGY

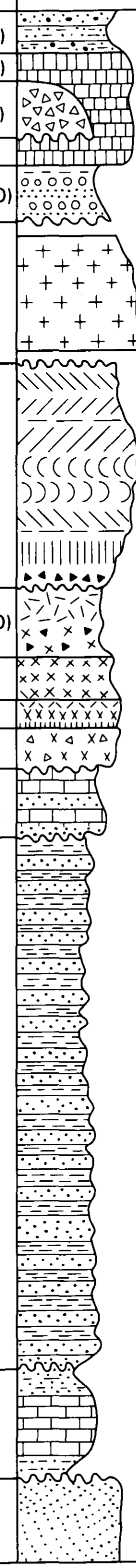


Figure 1. *Stratigraphy of the New Harmony quadrangle. Wavy lines in column represent unconformities. Tip is shown above Tvp because it is slightly younger and intruded beneath Tvp. Age relations among Quaternary units younger than the younger basalt flows are overlapping. Thicknesses do not apply to tectonically modified areas.*

plagioclase, with lesser biotite and traces of hornblende, pyroxene, sphene, and allanite (figure 2). Red lithic fragments constitute 5 percent of the rock and are surrounded by bleached halos in the altered matrix. Compositional and welding characteristics match the Narrows Tuff Member of the Leach Canyon Formation (Williams, 1967). The unit is about 250 feet (75 m) thick. The age is about 24.6 million years (Armstrong, 1970; new decay constants applied, Dalrymple, 1979).

The tuff is folded into a syncline at Comanche Spring in the northwest corner of the quadrangle. At this location it is unconformably overlain by the Pine Valley Latite. The tuff overlies the white limestone of the Claron Formation in Comanche Canyon, where both units are folded and faulted. North of the quadrangle the two units are in conformable contact.

Bauers Tuff Member of the Condor Canyon Formation (Tccb, Miocene)

The Bauers Tuff Member is a resistant, pale-red to pale-lavender, densely welded ash-flow tuff that forms slopes in the quadrangle. The rock has 10 to 15 percent phenocrysts of sanidine and plagioclase, with lesser biotite and traces of hornblende and pyroxene (figure 2). The unit has a thin, black vitrophyre, with strong normal magnetic polarity, at the base (Nairn and others, 1975). The middle portion of the tuff has 6-inch-long (15-cm), white pumice lenses. The uppermost layer is massive and sanidine rich. The Bauers Tuff is 200 feet (60 m) thick. A previous age estimate of 22.3 million years (Armstrong, 1970; Fleck and others, 1975; new decay constants applied, Dalrymple, 1979) has been questioned by Rowley and others (1990), who suggested an age of about 23 million years. This conclusion is supported by an age estimate of 22.8 million years on a pluton emplaced during the time of deposition of the Bauers Tuff, in the Antelope Peak quadrangle (Grant and Proctor, 1988). Recent studies suggest that the source caldera of the Bauers Tuff is near Caliente, Nevada (Rowley and others, 1990). The Bauers Tuff is also folded at Comanche Spring and unconformably overlain by the Pine Valley Latite.

Harmony Hills Tuff (Th, Miocene)

The Harmony Hills Tuff is a tan, moderately welded ash-flow tuff that forms moderately resistant outcrops. It has 40 to 45 percent phenocrysts of plagioclase and biotite, with lesser quartz, hornblende, and clinopyroxene (figure 2). Rare lithic fragments of felsic plutonic porphyry occur at the base. Pumice voids appear on weathered outcrops. In the region, the tuff is uniform and massive. The Harmony Hills Tuff is one of the most wide-

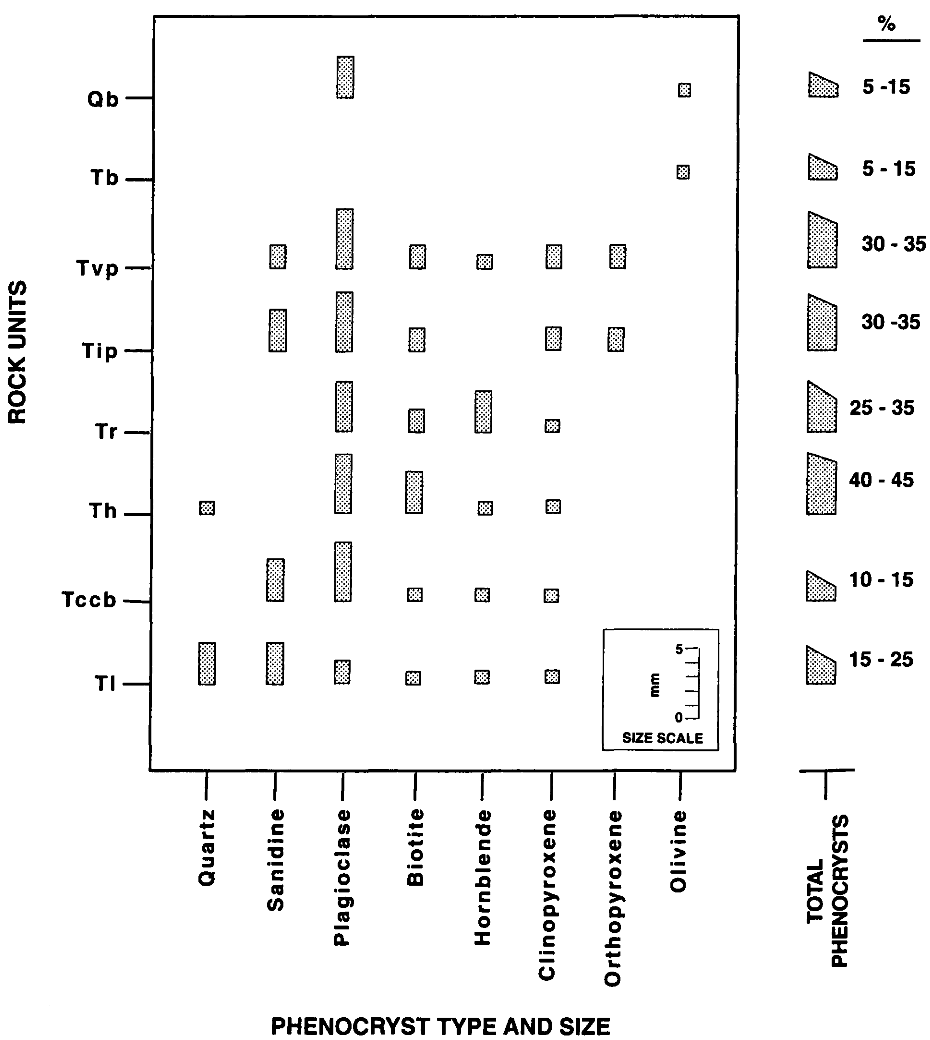


Figure 2. Phenocrysts of the igneous rocks. Crystal size highlights the importance of each mineral in each rock unit. Rock unit map symbols are shown on left side of figure. The total phenocryst content in each rock unit is shown on right side of figure.

spread ash-flow tuffs of the southwestern Utah and eastern Nevada volcanic field. It is 240 feet (70 m) thick and was dated at 21.6 million years (Armstrong, 1970; new decay constants applied, Dalrymple, 1979). Recent age estimates for the overlying Rencher Formation, however, suggest that the Harmony Hills Tuff is about 22 million years old (Rowley and others, 1989). The Harmony Hills Tuff is folded and overlain unconformably by the Pine Valley Latite at Comanche Spring.

Rencher Formation (Tr, Miocene)

The Rencher Formation is a complex assemblage of crystal-lithic ash-flow tuff, ash-fall tuff, breccia, and volcaniclastic sandstone. The ash-flow tuff is poorly resistant, gray to tan, and slightly welded. It contains 25 to 35 percent phenocrysts of plagioclase, hornblende, and lesser biotite and clinopyroxene (figure 2). Lithic fragments of quartzite and a variety of volcanic rocks constitute about 15 percent of the rock. The tuff matrix is rich in white pumice, a distinctive characteristic useful in identifying this unit in the field. The erosional remnant of the Rencher Formation in the syncline at Comanche Spring is about 500 feet (150 m) thick. Recent age estimates for the Rencher are 21.8 and 21.5 million years (Rowley and others, 1989).

Pine Valley Latite (Tvp, Miocene)

The upper half of the igneous mass that forms the Pine Valley Mountains is a layered, apparently extrusive lava formally named the Pine Valley Latite (Cook, 1957). Current mapping suggests that the latite is more extensive than originally believed. It is not restricted to the northern part of the mountains, but extends throughout the entire mountain range. The latite and the equivalent intrusive monzonite have similar, but distinctive, textures and mineral contents.

The latite is a gray to purple porphyry, with 30 to 35 percent phenocrysts of euhedral to subhedral plagioclase (andesine), subhedral biotite, and subhedral clinopyroxene, lesser anhedral sanidine and subhedral orthopyroxene, and scarce hornblende (figure 2). Sanidine is embayed and smaller than in the intrusive monzonite. Crystal size ranges from microcrystalline to as large as 0.2 inches (5 mm) in diameter. Opaque oxide is an accessory in this and all other igneous units. The groundmass is glassy, contributing to the crumbly weathering characteristics.

Flow layering characterizes the latite. Layers are as thin as a few inches and as thick as several feet. The individual flow layers are defined by joints that parallel the layers. The thin layers also contain normal joints, formed by primary flow, that are roughly perpendicular to the layer boundaries and confined to single layers. Where the layers are horizontal, the normal joints are vertical. These normal joint sets are parallel, from layer to layer, and are formed by extension during flow outward from the source vent. Jointed layers alternate with unjointed layers (figures 3 and 4). The jointed layers behaved in a brittle manner because of a lower volatile content, which caused them to extend laterally by fracturing. The unjointed layers were volatile-rich and extended in a ductile manner without fracturing. These normal extension fractures strike radially from the source vent

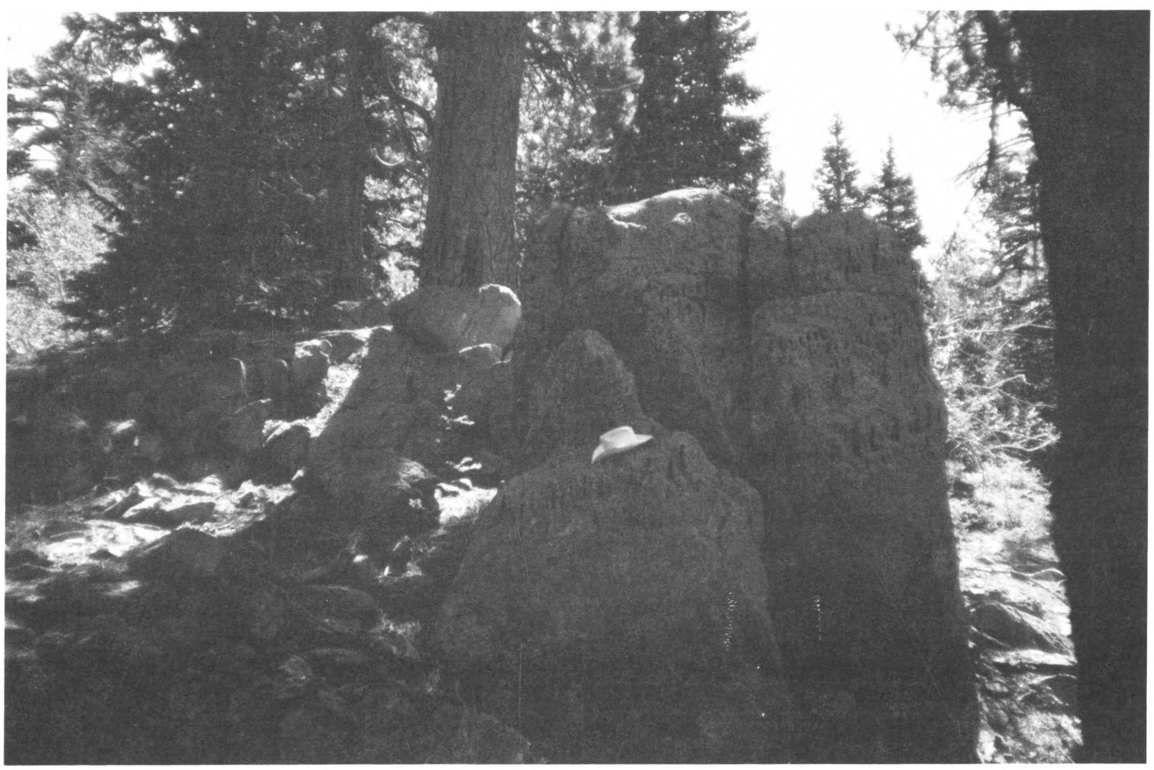


Figure 3. *Photograph of normal extension joints in the Pine Valley Latite. Joints dip steeply and have formed in about ten layers. View is along strike of joints. Alternate layers lack joints. Western hat for scale.*

Figure 4. Closeup view of normal extension joints (see figure 3). Joints extend indefinitely in the direction of view, (the joint face is hundreds of times longer than the height). Height of the joints is uniform in each layer, from a few inches (lower two layers) to more than a foot (upper layer, mainly above lens cap).

because the extension stress direction is concentric, parallel to the perimeter of the outward-growing flow mass.

The Pine Valley Latite may be divided into a basal flow breccia overlain by three lava units: lowermost, middle, and uppermost, each more than 100 feet (30 m) thick. The basal flow breccia is exposed along the northern and eastern margins of the latite outcrops and in deep canyons cut into the interior of the Pine Valley Mountains. The flow breccia contains angular clasts of black and red glass, as much as 3 feet (1 m) in diameter, in a poorly indurated, light-toned matrix. The flow breccia is about 100 feet (30 m) thick immediately south of Comanche Spring. The flow breccia formed subaerially from the crumbling surface of an advancing flow or flow dome that was later overridden by the moving lava.

Above the basal flow breccia, the lowermost lava unit is about 200 feet (60 m) thick and consists of steeply inclined layers of alternating stony and glassy textured latite, having an inbricate geometry. The individual layers are about 50 feet (15 m) thick. The stony texture results from a slight devitrification of volcanic glass. Normal extension joints are abundant in this lava unit. Some layers in the lowermost lava unit as well as the other two units are contorted into flow folds. Folding is of outcrop scale and larger.

The middle lava unit is about 800 feet (240 m) thick and is best exposed on the steep walls of Straight Canyon and the tributaries of Main Canyon. It also occurs on the south-facing cliffs of the Pine Valley Mountains, above about 8,000 feet (2,400 m) above sea level. On the mountain west of New Harmony, this lava unit outcrop is between 6,000 to 7,000 feet (1,800-2,100 m) above sea level. This lava unit is characterized by bold outcrops and thick, contorted layers. The layers commonly form large, tight folds that are usually recumbent. Normal extension joints are not abundant in this lava unit.

The uppermost lava unit is exposed at the highest altitudes of the Pine Valley Mountains; the thickest uneroded part is about 600 feet (180 m) thick. Layers in this lava unit are gently dipping and have abundant normal extension joints. Outcrop scale flow folds that are upright and open are common to this lava unit. The uppermost lava unit may define the upper crust of the latite that was carried along with the movements of the middle lava unit.

The three lava units appear in figure 5 as bands of differing vegetation. The upper third of the mountain front is the uppermost lava unit covered with dark ponderosa pines and aspen. The middle third is the middle lava unit, with sparse growth of scrub oak. It has visible rock outcrops and is lighter toned than the lowermost lava unit below. The lower third is the lowermost lava unit, covered with juniper and pinon pines. The age of the Pine Valley Latite is about 21 million years (Anderson and Mehnert, 1979). The latite is nearly coeval with the monzonite of the Pine Valley Mountains.

Monzonite of the Pine Valley Mountains (Tip, Miocene)

The monzonite intrusive phase of the Pine Valley igneous mass lies at the base of the high south-facing cliffs near Mount Baldy and in the broad valleys of the eastern foothills. The altitude at the top of the sill-like intrusion ranges from 9,000 feet (2,700 m) in the west to 5,000 feet (1,500 m) in the east part of the quadrangle. The monzonite rests on the Claron Formation, which is the floor of the tabular intrusive body. The uppermost white limestone of the Claron may have been removed during emplacement of the pluton. The northernmost exposure is at Rocky Knoll, but monzonite float is present at Archie Bell Hollow, one mile (1.6 km) west of New Harmony. This float is near the base of the latite, suggesting that the monzonite occurs immediately below the latite. However, the monzonite is absent at Comanche Spring, one mile (1.6 km) north of Archie Bell Hollow, where it should be exposed. The oldest rock exposed there is the upper Claron Formation. The monzonite may be in the subsurface, beneath these rocks.

The monzonite is a dark-brown to nearly white porphyry, with 30 to 35 percent phenocrysts of euhedral to subhedral plagioclase (andesine), subhedral biotite, subhedral clinopyroxene, and lesser anhedral sanidine and subhedral orthopyroxene (figure 2). Sanidine phenocrysts are large and not embayed. The margins of the sanadine phenocrysts have extended to enclose grains of the groundmass, suggesting sub-solidus crystal growth. This texture occurs in the upper part of the

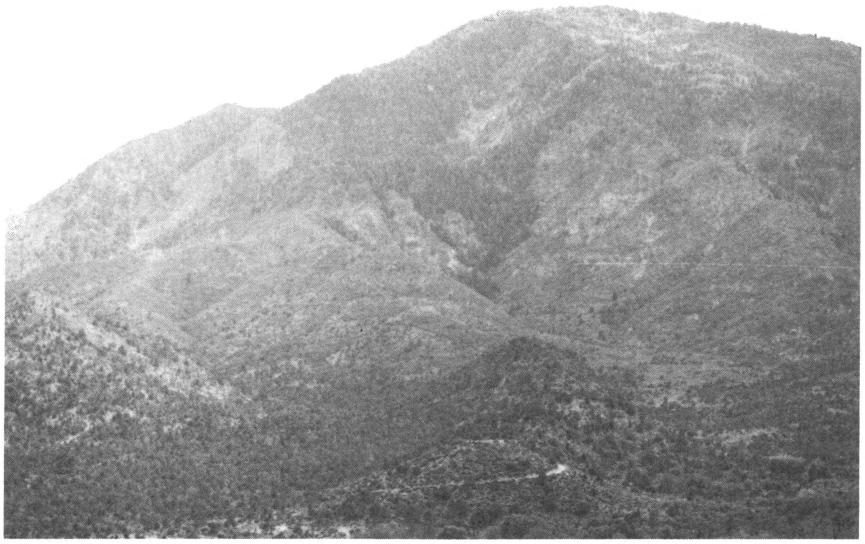


Figure 5. *Pine Valley Latite near New Harmony, Utah. Three stratigraphic zones are marked by vegetation (see text). Rocky Knoll slightly below and right of center. View is southwest.*

intrusive. The groundmass is holocrystalline with an average grain size of 0.002 inches (0.05 mm). A small amount of glass is present in some exposures at the base of the monzonite. Quartz and feldspar occur in the groundmass. In the upper part of the intrusive, quartz in the groundmass occurs as polycrystalline aggregates, particularly against plagioclase phenocrysts. Biotite is oxidized, and orthopyroxene is partly altered to a fibrous amphibole(?).

The monzonite is color zoned, from a dark brown in the basal few hundred feet, through a buff middle (several hundred feet thick), to a nearly white top (about 200 feet thick). Total thickness of the monzonite sill or laccolith is about 1,000 feet (300 m). The changes in color may reflect increased alteration due to a gradual increase in water content toward the top of the magma chamber (Williams and McBirney, 1979; Fisher and Schmincke, 1984). The greater water content in the white zone led to deuteric alteration of the mafic minerals, recrystallization of the groundmass and margins of the feldspar phenocrysts, and production of small miarolitic cavities.

Mattison (1972) analyzed the major element contents of the monzonite and Pine Valley Latite. The results, in average weight percent oxides, are:

SiO_2	64.10%
TiO_2	0.79%
Al_2O_3	15.72%
Fe_2O_3	4.04%
FeO	1.01%
MnO	0.07%
MgO	2.20%
CaO	4.41%
NaO	3.40%
K_2O	4.09%
Total	99.83%

The samples were collected in a vertical traverse near Pine Valley, Utah. The only vertical chemical gradient recognized was that the FeO/Fe_2O_3 ratio reached maxima near the middle of the monzonite and near the middle of the overlying latite. The major element content of the monzonite/latite is consistent with the worldwide average latite (Fisher and Schmincke, 1984).

Flow layering and normal extension joints are present in the monzonite, but are not common nor well developed. A monzonite dike intruded the latite on Rocky Knoll (figure 6). Similarly, thin sills of monzonite, a few feet thick, intruded between flow layers of latite immediately north of the intrusive contact near the center of section 14, T. 39 S. R. 13 W. The age of the monzonite is about 21 million years (Anderson and Mehnert, 1979).

Oldest alluvial-fan deposits (Taf, Miocene(?) to Pliocene)

Alluvial-fan deposits (Taf) of late Tertiary age occur on the lower part of Bald Hill, on a broad ridge known as the "hogback" east of Ash Creek and Death Valley Wash, and on the foothills of Harmony Mountain in the northeast corner of the quadrangle. These dissected remnants of alluvial fans and associated deposits consist of poorly to moderately consolidated sandstone and conglomerate, with minor mudstone. Outcrops form extensive cliffs and ledges. Clast types include rocks from the Claron Formation (brown, tan, and black quartzite and pinkish-gray algal limestone), Pine Valley Latite, Iron Springs Formation (buff sandstone), and the Stoddard Mountain monzonite porphyry pluton (exposed north-northwest of the quadrangle). Clasts are commonly cobbles and pebbles, but boulders of latite are as large as 10 feet (3 m) in diameter.

Along Comanche Creek, the base of the alluvial-fan deposits (Taf) rests on eroded Pine Valley Latite and older volcanic rocks. The eroded upper surface of these deposits is covered by a few feet of lag gravel. Pedogenic carbonate soil was not found, but incomplete thin carbonate rinds are present on quartzite and latite clasts at the top of the unit. These deposits dip gently, 5 to 15 degrees east-northeast within the quadrangle. North of the quadrangle, the deposits dip south to southeast. On Harmony Mountain, north of the quadrangle, these deposits are present up to 6,200 feet (1,900 m) above sea level. These observations suggest that the oldest alluvial-fan deposits once filled the New Harmony valley. Remaining thickness of the oldest alluvial-fan deposits is at least 400 feet (120 m).

Figure 6. Dike of monzonite (right) cutting latite (left), on west side of Rocky Knoll. Latite has joints parallel to flow layers, inclined moderately to left (west). View is to the north. Rock hammer and pen for scale.

Cook (1960) mapped this unit as the "Muddy Creek" Formation, which it resembles. The unit also resembles the Sevier River Formation of central Utah (Anderson and Rowley, 1975). These deposits are assigned a Tertiary age because they are moderately consolidated, deeply eroded, and because they lie beneath a basalt flow deemed to be of late Tertiary age.

Older basalt flows (Tb, Miocene (?) or Pliocene)

Older basalt flows (Tb) cap Bald Hill, are about 200 feet (60 m) thick, and overlie the oldest alluvial-fan deposits (Taf). Fresh surfaces exhibit dark-gray olivine-bearing basalt, with a medium-gray, 0.8-inch (2 cm) thick weathered rind. The basalt contains subhedral phenocrysts of olivine in an intergranular groundmass of plagioclase and clinopyroxene (figure 2). The older basalt flows have not been radiometrically dated. However, this basalt has normal magnetic polarity. The last extensive period of normal magnetic polarity older than the dated younger basalt flows (Qb, as follows) ended 2.48 million years ago (Morrison, 1991). Post-basalt erosion has removed several hundred feet of the underlying Tertiary alluvial-fan deposit. This amount of erosion, compared to the much smaller amount removed since the eruption of the 1- to 1.5-million-year-old younger basalt flows (Qb), suggests a much greater age for the older basalt flows (Tb).

Quaternary

Basalts

Basaltic breccia (Qbb, Pleistocene): Remnants of partially buried volcanic cinder cones, composed of poorly consolidated blocks of reddish-brown, scoriaceous basalt are present in the southeast corner of the quadrangle. The basaltic breccia (Qbb) may mark the vents from which the cinder cones and surrounding younger basalt flows (Qb) erupted. The cinder cones are at least 300 feet (90 m) high.

Younger basalt flows (Qb, Pleistocene) : A minor basalt field of dark-gray to black alkali olivine basalt flows (Best and Brimhall, 1970; Hamblin, 1970) is exposed from Ash Creek to the southeast corner of the quadrangle. The basalt contains phenocrysts of subhedral olivine and euhedral plagioclase in an intersertal groundmass of plagioclase, glass, olivine, and clinopyroxene (figure 2). This field is displaced by the Hurricane fault zone, just east of the quadrangle, allowing the flows to be seen in section on the upthrown block east of I-15. Several of these flows display vertical columnar jointing. Thickness of the combined flows is at least 300 feet (90 m). The net slip on the fault zone is about 1,500 feet (450 m) since the basalts were erupted. Using an average slip rate of 1,280 feet (390 m) per million years on this fault zone (Hamblin and others, 1981), the age of the younger basalt flows is about 1.0 to 1.5 million years. These and other basalt flows measured along I-15 from Washington to Cedar City have reversed magnetic polarity. The basalt flows near Cedar City have been dated at 1.1 million years (Anderson and Mehnert, 1979). The younger basalts belong to the Matuyama chronozone that extended from 2.48 to 0.77 million years ago (Morrison, 1991).

Alluvial deposits

Older alluvial-fan deposits (Qaf_2, Pleistocene): Older alluvial-fan deposits (Qaf_2) consist of poorly consolidated gravel, sand, and silt. These deposits are abandoned and are undergoing dissection and erosion. These deposits (Qaf_2) overlie the oldest alluvial-fan deposits (Taf) at the foot of Bald Hill and on the "hogback." They are also present in the upper reaches of Death Valley and Sawyers Canyon. Erosional remnants of much larger patches are found on the drainage divides between Leap Creek, Coal Hollow, and Mill Creek. The degree of dissection differs between exposures because of the greater rate of erosion in the southwest part of the quadrangle. The older fan deposits (Qaf_2) are dissected by modern channel and alluvial-fan deposits. Coeval valley-fill deposits located upstream from the fans were mapped with the older fan deposits (Qaf_2). The older fan deposits fit into the "old" category of Christenson and Purcell (1985).

North of New Harmony, the older fan deposits are more than 100 feet (30 m) thick (Cordova and others, 1972) and contain a variety of clasts from the bedrock units: white limestone and quartzite from the Claron Formation, Miocene tuffs, monzonite porphyry from the Stoddard Mountain pluton, and basalt. Clasts range upward to 3 feet (1 m) in diameter. In the Leap Creek-Mill Creek area, huge boulders, as large as 30 feet (10 m) in diameter, are common. The largest clasts in Leap and Mill Creeks are Pine Valley Latite, which may have been deposited by debris flows.

Modern alluvial-fan deposits (Qaf_1, Pleistocene to Holocene): These deposits consist of unconsolidated silt, sand, and minor clay and gravel deposited on active, or recently abandoned, coalescing alluvial fans. The deposits (Qaf_1) are approximately coeval with modern channel deposits (Qal). At the base of Lawson Hill, in the southwest quarter of section 21, T. 38 S., R. 13 W., the unit contains a continuous linear arrangement of large boulders of latite, as much as 12 feet (4 m) in diameter, of possible debris-flow origin. The fan deposits near Little Mountain and in Death Valley exhibit latite clasts as large as 7 feet (2 m) in diameter in a sand matrix. Modern alluvial-fan deposits fit the description of the "intermediate" fans of Christenson and Purcell (1985). Thickness of the modern fan deposits may exceed 100 feet (30 m).

Alluvium (Qa, Pleistocene to Holocene): Unconsolidated sand and silt deposits filling small, isolated basins with narrow outlets have been mapped as alluvium (Qa). The deposits are commonly located at the higher elevations in the Pine Valley Mountains, at the heads of minor tributaries. Each deposit is incipiently dissected by a rejuvenated stream channel. These deposits have a maximum thickness of about 30 feet (10 m).

Modern alluvium (Qal, Pleistocene to Holocene): Modern alluvium (Qal) consists of unconsolidated sand, silt, and gravel that occupy stream channels and their floodplains. These deposits are mainly located along Ash Creek and its tributaries. At higher elevations, these deposits are commonly too narrow to map at 1:24,000 scale. Along Mill Creek and its tributaries the deposits contain boulders as large as 30 feet (10 m) in diameter. The boulders rolled or slid downhill from the deeply dissected older alluvial-fan deposits, remnants of which occur on the divides between modern stream valleys. Modern alluvium deposits are about 30 feet (10 m) thick.

Mass-movement deposits

Landslide deposits (Qms, Pleistocene to Holocene): Large landslide deposits (Qms) are located in Comanche Canyon and along Leap Creek. Angular blocks of Pine Valley Latite as large as 30 feet (10 m) in diameter occur in the Comanche Canyon landslide. The Leap Creek landslide contains a significant amount of monzonite blocks. Both slides may have occurred by failure of the underlying Claron Formation mudstones. Both slides are near north-trending faults. The slides are partially dissected but appear to retain their original shape. They are at least 200 feet (60 m) thick. The landslides are probably late Pleistocene to Holocene in age.

Colluvium (Qmc, Pleistocene to Holocene): Colluvium (Qmc) consists of unconsolidated silt, sand, and gravel deposited on slopes below steep bedrock exposures. In Sawyer Canyon most colluvium occurs as dissected patches as much as 20 feet (6 m) thick. Colluvium may grade into the older (Qaf_2) and modern (Qaf_1) alluvial-fan deposits.

Talus (Qmt, Holocene): Northwest of Siler Flat and northwest of Willard Road Canyon are two small unvegetated patches of rock-fall talus. The deposits consist of coarse, angular debris with no finer grained matrix. The talus is located downslope from a bedrock source. In both places the source is the lowermost lava unit of the Pine Valley Latite. Maximum thickness is about 10 feet (3 m).

STRUCTURE

Rocks of the New Harmony quadrangle have been subjected to three tectonic events since the Jurassic. The first of these was the Sevier orogeny that produced fold and thrust structures from compressional forces oriented approximately east-west in the Late Cretaceous. The second event was the emplacement of the Pine Valley monzonite-latite system that uplifted some rocks and may have produced compressional features in the Miocene tuffs. The third event was extensional normal faulting that culminated in the late Cenozoic, producing faults that strike north-south to northeast. Normal faults with different strikes were produced earlier in the Tertiary.

Late Cretaceous Compressional Features

Immediately east of the quadrangle lies the axis of the Kanarra anticline, a major fold generated during the Sevier orogeny (Kurie, 1966). Its hinge line roughly follows the line marked by I-15 and the cliffs east of the highway. This fold can be traced from Cedar City to St. George, where it includes the Virgin anticline and the Harrisburg, Washington, and Bloomington domes (Noweir, 1990). It is a few miles wide and has an amplitude of a mile or more. It is upright to overturned and is cut by numerous small faults produced during folding.

In the quadrangle, the Kanarra anticline produced a westward dip of the Mesozoic strata, which persists in places despite later eastward tilting. The two tilting episodes are resolved by the Claron Formation, which was affected by the later tilting episode but not by the earlier (cross section A-A′). The Carmel Formation at Maple Hollow exhibits minor faults and folds generated during the Sevier orogeny. A fault south of Coal Hollow that thickens the Carmel by repetition could be a small thrust, but it is treated as part of the Tertiary deformation because exposures do not permit a definitive analysis. Similar structures formed by the Sevier orogeny are present on the western limb of the Kanarra anticline at Leeds (south of the quadrangle) and on the eastern limb elsewhere (Proctor, 1953; Proctor and Brimhall, 1986; Noweir, 1990). The small-scale structures in the Carmel Formation seem detached from the underlying Navajo Sandstone in a manner similar to that seen in Coal Creek east of Cedar City (Threet, 1963). A detachment zone separates the Carmel from the Navajo at Coal Creek and, probably, at Maple Hollow.

Some faults of pre-Claron age were rejuvenated during the Cenozoic. These include northeast-trending faults at Leap Creek and Maple Hollow that cut both Mesozoic and Tertiary rocks, with a greater displacement on the older rocks. Some faults shown in east-west cross section A-A′ are of this composite-action type. Elsewhere on the Kanarra anticline, it has been shown that post-Claron structures were superimposed on pre-Claron structures (Threet, 1963).

Structures Related To Mid-Tertiary Igneous Intrusion

Mackin (1947, 1960) and Blank and Mackin (1967) described structural features within and adjacent to laccolithic intrusions in the Iron Springs mining district. Above and adjacent to the plutons, unroofing by gravity sliding deformed the same welded ash-flow tuffs (Quichapa Group) that are found disturbed in Comanche Canyon. The east-northeast-trending syncline in Comanche Canyon illustrates this deformation. The fold is explained by a combined action of uplift of the welded tuffs by emplacement of the Pine Valley sill or laccolith, and then sliding of the welded tuffs from the uplift, aided by eruption of latite at the crest of the uplift. The trend of the synclinal fold axis is perpendicular to the north-northwest flow direction in the nearby latite and parallel to flow fold axes in the latite. The age of folding in the tuffs must be very close to the age of the latite eruption because the youngest folded rock (Rencher Formation) is not much older than the latite, the basal contact of which is not folded. Therefore, the Comanche Canyon syncline is tied to the Pine Valley igneous event by age, location, and orientation. Regional extension at the time of folding was not correctly oriented to have caused this folding (see below). Folding of tuffs that predate or match the age of local intrusives has been found in several nearby quadrangles (Cook, 1957, 1960; Averitt, 1967; Grant and Proctor, 1988; Shubat and Siders, 1988). Some structures in host rock adjacent to the vent of the Mount St. Helens flow dome formed by stresses similar to those proposed for the Pine Valley Latite (Chadwick and Swanson, 1989). Imbricate thrusts and folds parallel to the perimeter of the Pine Valley intrusion confirm radial compression. Extension fractures formed radially.

Attitudes of joints and layering were studied to determine the flow patterns in the Pine Valley Latite. Directions and antidirections of dip of the flow layering were compared to the trends of the normal extension joints and to the layer dip girdles on tangent vector diagrams. This was done for each of 38 sample sites, which were later placed in larger groups of similar deduced flow trends. Only 33 of the sites had normal extension joints.

Layer dip directions, fold girdles, and trends of normal extension joints were tested by the Spearman Rank Correlation Coefficient. The three variables, taken two at a time, were significantly correlated. In general, normal extension joints trend perpendicular to flow fold axes (taken from tangent vector diagrams), and these joints trend in the direction of dip of the flow layering. Correlations are strongest where flow layers are steeply dipping. This is to be expected because post-flow tilting events have a minimum effect on the dip direction of steep layers. Trends of fold axes and normal extension joints are only slightly affected by modest tilting, because they are linear features.

The line of flow is identified by the layer dips, flow folds, and the normal extension joints, but the sense of flow is not. Flow may have been up dip or down dip, toward or away from the vergence of the flow folds, and in either direction along the long dimension of the extension joints. Vents must be located to help identify the sense of flow. One possible vent is on Lawson Hill, one mile southwest of New Harmony. When flow lines are projected across the quadrangle, many intersect on Lawson Hill. Other intersections occur in the Death Valley-Sawyers Canyon area and between Mount Baldy and Anderson Valley. The vent on Lawson Hill is a circular structure. Steep layers strike parallel to the perimeter of this structure and dip consistently toward the center. This circular feature is more than 3, 500 feet (1,100 m) in diameter. This vent area includes all of the sites in the quadrangle that lack normal extension joints. Lava at a vent, being hotter and in only the initial stage of outward movement, would not be fractured by flow as would lava located distant from a vent.

The Pine Valley Latite, generally accompanied by monzonite, forms at least three lobes defined by topographic form and regular flow patterns. A northwest lobe follows the mountain summit west of New Harmony. Flow patterns at low elevations trend northwest to north with respect to Lawson Hill in this lobe. A southeast lobe occupies exposures from New Harmony toward Pintura. Flow directions in this lobe are southeast to east from Lawson Hill, and northeast-southwest to north-south from an unknown vent. A southwest lobe extends from Mt. Baldy toward Pine Valley town. Samples are incomplete in this lobe, but some southwest and northwest-southeast directions were found. The sites with northwest-southeast directions may actually be within the northwest lobe. A fourth lobe is conceivable between New Harmony and Kanarraville. This lobe is on the upthrown side of a fault zone that follows Ash Creek. It has been eroded and destroyed, or covered by the late Tertiary and Quaternary deposits. The former presence of this lobe is suggested by: (1) Pine Valley Latite clasts in the Tertiary alluvial-fan deposit (Taf) in the northeast corner of the map, (2) small masses of latite in the Hurricane fault zone between the latitude of New Harmony and Kanarraville (Kurie, 1966), and (3) large boulder debris of Pine Valley Latite (or monzonite) on Kanarra Mountain and along the Kanarra Mountain road (Anderson and Mehnert, 1979).

The relationships among the Pine Valley Latite, the monzonite of the Pine Valley Mountains, the mid-Tertiary welded tuffs, and the Claron Formation are intriguing. The igneous units rest on the Claron Formation. The latite rests on the mid-Tertiary welded tuffs (north) and on the monzonite (south). The latite has not been found on the Claron Formation in the quadrangle. However, south of Pintura, near Anderson Junction, the igneous rock resting on the Claron has the appearance of latite. Because no glass or flow breccia is evident, this rock could be chilled monzonite. The monzonite has not been found beneath the mid-Tertiary welded tuffs. The monzonite intrudes only the latite. This observation led Cook (1957) to propose a fault caused by intrusion along what he interpreted as the northern map contact of the monzonite with the latite. This explanation does not solve the new mapping relationships between the monzonite and latite south of the line of Cook's intrusive fault. If the mid-Tertiary welded tuffs were found between the latite and the monzonite, the emplacement mechanism might be clearer. They are not. The mid-Tertiary welded tuffs are not absent because of assimilation by the monzonite, which began crystallizing (phenocrysts) at depth and ceased crystallization (groundmass) soon after emplacement. It is possible that the monzonite intruded between the Claron and the mid-Tertiary welded tuffs, followed by venting of the latite through the roof of the monzonite. If the vents were numerous, the mid-Tertiary welded tuffs could have been squeezed laterally and removed by coalescing of the vents erupting latite.

Late Cenozoic Extensional Faulting

Deformation caused by horizontal crustal extension in the last 22 million years has produced most of the faults that cut Claron and younger rocks. Three systems are present : (1) older faults trending east-northeast, (2) intermediate-age faults trending north-northwest, and (3) younger faults trending north to north-northeast. The younger faults belong to the Hurricane fault system that developed in the last 6 million years. The older faults are parallel to faults in southwestern Utah known to be older than the Hurricane fault system. Faults with an east-northeast trend in the central portion of the Pioche-Marysvale mineral belt initiated movement in the early Miocene (Grant and Best, 1979; Rowley and others, 1979; Best, Grant, and others, 1987; Best, Mehnert, and others, 1987; Clayton, 1988). This early period of faulting occurred about the time the Pine Valley Latite and associated monzonite were emplaced. The latite and monzonite are cut by a east-northeast-trending fault, possibly related to intrusion (Cook, 1957).

Recent satellite image analysis (Nancy Morton-Linek, personal communication, 1992) has revealed a northwesterly trending fault system within the quadrangle. A strong lineament follows North Ash Creek from I-15 to New Harmony, runs through Bald Hill, and exits the quadrangle near its northwest corner. Several northwest-striking faults, downthrown to the southwest, parallel this feature. The faults of the northwest-trending system, along the lineament, are buried by late Tertiary and Quaternary deposits, making the age of the northwest-trending system intermediate between the other fault systems. The buried northwest-trending faults are older than the Miocene (?) to Pliocene oldest alluvial-fan deposits (Taf).

North- to north-northeast-trending faults that cut Quaternary basalt are directly related in age, trend, and sense of throw to the Hurricane fault that lies immediately east of the quadrangle. The faults in these basalts formed in the last 1.5 million years.

The three extension fault systems in the quadrangle exhibit a regional pattern of clockwise stress rotation throughout the late Tertiary. The older faults were produced by northwest-southeast extension from about 22 million years to before 12 to 13 million years ago (Best, Mehnert, and others, 1987). The faults of the older system are terminated by faults of the intermediate-age system (Grant and Best, 1979; Best, Grant, and others, 1987). The intermediate-age faults were caused by northeast-southwest extension. The youngest fault system is formed by east-west to southeast-northwest extension. During the clockwise rotation of the late Tertiary extensional stress field, strike-slip motion might be expected on these basin-and-range normal faults. Studies (Strecker and others, 1990; Ring and others, 1992) on fault systems in the East African Rift, which are similar to the intermediate-age and younger faults in the New Harmony area, indicate that reorientation of the stresses produced a temporary stage of strike-slip motion on the earlier normal faults. With one exception, slickensides were not observed in place in the New Harmony quadrangle. The one set of slickensides found was within the Harmony Hills Tuff in Comanche Canyon. Striae plunged 10 degrees southeast on a fault with a N. 40° W. strike and an 84° SW. dip. This suggests a strike-slip component to movement on the fault, which appears to be part of a set of dip-slip faults. Evidence, in the form of striae, of any early dip-slip action would be erased by later strike-slip movement.

Tilting of the rocks of the northern and eastern parts of the quadrangle probably occurred as a block rotation or reverse drag effect related to offset on the late Tertiary fault systems (Hamblin, 1965; Stewart, 1980). The Hurricane fault, having the greatest throw, caused much of the tilting, but the northwest faults, with downthrow to the southwest, also contributed. Rocks on Bald Hill have been tilted to the east approximately 10 degrees. The latite west and southwest of Bald Hill is inclined northeasterly. A combination of tilting and faulting produced a stream gradient that maintains the floor of Straight Canyon to a single stratigraphic level near the top of the basal latite flow breccia. At the latitude of Sawyer Canyon, and east of Mount Baldy, the latite-monzonite contact is repeatedly faulted down to the east and tilted within fault blocks.

ECONOMIC GEOLOGY

Extraction of geologic materials from within the quadrangle has been insignificant. Small quantities of stream sand and gravel have been used for local construction. Basaltic cinders have been quarried from basaltic breccia in section 19, T. 39 S., R. 12 W. Near the quadrangle, coal, petroleum, silver, uranium, and copper have been produced. The New Harmony coal field was a minor producer from the Iron Springs Formation (Richardson, 1909). Within the quadrangle, the Iron Springs Formation is exposed in the Leap and Mill Creek area. Exposures are limited, and trenching would be needed to determine if coal is present.

Petroleum was produced from Triassic strata near Virgin, Utah about 15 miles (24 km) southeast of the quadrangle. Production has amounted to more than 195,000 barrels (Bahr, 1963). The reservoir rock is the Rock Canyon Member of the Moenkopi Formation. The Anderson Junction field located about 9 miles (14 km) south of the quadrangle has produced oil from the Pennsylvanian Callville Limestone (Peterson, 1974) from traps associated with the Kanarra anticline. Drilling has tested a probable minor anticline on the west flank of the Kanarra anticline west of Pintura (Cary, 1963). Shows of oil were found in the well, but it was concluded that faulting had allowed any hydrocarbons present to escape. The west limb of the Kanarra anticline does extend into the subsurface of the New Harmony quadrangle and may represent a target for future drilling.

Silver, uranium, and copper occur in the Silver Reef mining district located about 20 miles (32 km) south of the quadrangle (Proctor, 1953; Proctor and Brimhall, 1986). The ore host is the Springdale Sandstone Member of the Jurassic Moenave Formation. Seven million ounces (3,175,200 kg) of silver were produced from the district. The deposits occur along minor anticlines and faults on the western flank of the Virgin (Kanarra) anticline. These minor structures may extend northward into the quadrangle. A small uranium deposit was developed on the Hurricane Cliffs, east of New Harmony (Lovejoy, 1973). It was found in the Permian Kaibab Limestone, near a plug-like mass of monzonite (or latite) of the Pine Valley Mountains.

The Iron Springs mining district is located about 6 miles (10 km) north-northwest of the quadrangle. The iron deposits of the Iron Springs district are formed in and around plutons of the same general age as the Pine Valley laccolith (or sill). The intrusive setting of the Iron Springs plutons is different from that of the Pine Valley pluton. They were emplaced at greater depth, which seems to have been critical for extensive leaching of iron from the minerals in the plutons. Iron deposits have not been found associated with the Pine Valley intrusion.

WATER RESOURCES

Water from permanent springs and perennial streams is used for agricultural purposes in the New Harmony area. Many springs occur along the Ash Creek lineament. A number of wells extract ground water from Pliocene through Quaternary aquifers for culinary and agricultural uses. The Navajo Sandstone is a potential aquifer at depth (Cordova, 1978) that should underlie the Tertiary and Quaternary rocks, except in the eastern part of the quadrangle, where it may have been removed by erosion in late Cretaceous to early Tertiary time. Annual rainfall ranges from 20 to 25 inches (50-64 cm) in the mountains to 12 to 16 inches (30-40 cm) near Pintura (Cordova and others, 1972).

GEOLOGIC HAZARDS

Earthquakes, flash floods, and rockfalls are the most obvious geologic hazards in the quadrangle. The quadrangle is located near the intermittently active Hurricane fault zone. Small earthquakes are not unknown, and an earthquake of Modified Mercalli magnitude VIII (Richter M_L 6.3) occurred in 1902 in the Pine Valley area (Williams and Tapper, 1953; Stover and others, 1986). Buildings were damaged and rockfalls were abundant. Recently, the area was shaken by a Richter magnitude 5.9 earthquake on September 2, 1992, centered 6 miles (10 km) east of St. George (Earthquake Engineering Research Institute, 1992; Black, 1993). This earthquake caused rock falls, liquefaction, and landslides. The quadrangle lies in Seismic Zone 2 of the Uniform Building Code (International Conference of Building Officals, 1988). The return period for a 7 to 7.5 magnitude earthquake in this area is predicted to be 213-556 years (Wollard, 1958; Greensfelder and others, 1980; Doser and Smith, 1982).

Flash floods associated with thunderstorms are a common summer event, and very large floods have occurred this century. One, in 1904, overflowed the banks of the wash that runs through New Harmony, flooding the town and driving the populace to high ground (Wooley, 1946). Homes were pushed from foundations, and farms and orchards were damaged. The area affected was one-half mile (0.8 km) wide and several miles (5 km) long. In unusual high-precipitation periods mud and debris flows could occur.

Rockfalls are another geologic hazard in the area. Hikers should be cautious of falling or rolling rocks. Loose boulders may be delicately balanced and easily dislodged. Individuals building on the steep slopes of the Pine Valley foothills would be wise to consider the possibility of rockfalls and rock slides during earthquakes.

Soil and rock causing engineering geologic problems have not been specifically identified in the populated area of the quadrangle. However, problem soil and rock are expected where the oldest alluvial-fan deposits (Taf), Claron, Iron Springs, or Carmel Formations crop out or on soils derived from these formations.

Radon gas has been found in undesirable concentrations in one sampling at New Harmony (Solomon, 1992). Radon is produced by radioactive decay of uranium that is commonly in the welded tuffs and other igneous rocks. It can concentrate in basements and other poorly ventilated areas. It can also migrate when dissolved in ground water.

Figure 7. *View northeast from the New Harmony-Anderson Valley trail. Hurricane Cliffs in the distance. Harmony Mountain in the middle distance.*

RECREATION

Hiking and horseback riding are important outdoor activities for residents and visitors. Those that traverse the Pine Valley Mountains may be interested in features of the terrain controlled by the geology. The small sedimentary basins that form open meadows are marked by patches of alluvium (Qa). Pack trails in the high elevations are on the upper lava unit of the Pine Valley Latite (figure 7). These have a gentle, pleasant gradient compared to the steep gradient of trails on the middle lava unit. These steep trails are marked by repeated switchbacks, such as on Long Ridge, southwest of Rocky Knoll. Sheep Pens, on the headwaters of Straight Canyon, west of the quadrangle, is a group of meadows formed in the flow breccia of the Pine Valley Latite. Many outcrops of black and red glass are found there.

ACKNOWLEDGMENTS

Lana Grant devoted countless hours of field and office assistance over the nearly 20 years that this project occupied. The Grant family annual backpack trips into the Pine Valley Mountains made data collection possible. The generous hospitality of the people of New Harmony is a rare commodity in the modern world. Appreciation is expressed for the helpful comments of those who critically reviewed the original manuscript. These include Lehi Hintze, Paul Dean Proctor, Michael Ross, Michael Shubat, and Mike Lowe.

REFERENCES CITED

Anderson, J.J. , and Rowley, P.D., 1975, Cenozoic stratigraphy of southwestern High Plateaus of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, 1975, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 1-51.

Anderson, R.E., and Mehnert, H.H., 1979, Reinterpretation of the history of the Hurricane fault in Utah, *in* Newman G.W., and Goode, H.D., editors, 1979 Basin and Range Symposium: Rocky Mountain Association of Geologists, p. 145-165.

Armstrong, R.L., 1970, Geochronology of Tertiary igneous rocks, eastern Basin and Range Province, western Utah, eastern Nevada, and vicinity, U.S.A.: Geochimica et Cosmochimica Acta, v. 34, p. 203-232.

Averitt, Paul, 1962, Geology and coal resources of the Cedar Mountain quadrangle, Iron County, Utah: U.S. Geological Survey Professional Paper 389, 72 p.

Averitt, Paul, 1967, Geologic map of the Kanarraville quadrangle, Iron County, Utah: U.S. Geological Survey Quadrangle Map GQ-694, scale 1:24,000.

Bahr, C.W., 1963, Virgin oil field, Washington County, Utah, *in* Heylmun, E.B., editor, Guidebook to the geology of southwestern Utah: Intermountain Association of Petroleum Geologists, Twelfth Annual Field Conference, p. 169-171.

Best, M.G., and Brimhall, W.H., 1970, Late Cenozoic basalt types in the western Grand Canyon region, *in* Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Guidebook to the Geology of Utah, no. 23, Utah Geological Society, p. 57-74.

Best, M.G., Grant, S.K., Hintze, L.F., Cleary, J.G., Hutsinpiller, A., and Saunders, D.M., 1987, Geologic map of the Indian Peak (southern Needle) Range, Beaver and Iron Counties, Utah: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-1795, scale 1:50,000.

Best, M.G., Mehnert, H.H., Keith, J.D., and Naeser, C.W., 1987, Miocene magmatism and tectonism in and near the southern Wah Wah Mountains, southwestern Utah: U.S. Geological Survey Professional Paper 1433-B, p. 31-47.

Black B.D., 1993, Effects of the Ml 5.9, September 2, 1992, St. George earthquake: Utah Geological Association Newsletter, v. 24, No. 1, 8 p.

Blank, H.R., Jr., and Mackin, J.H., 1967, Geologic interpretation of an aeromagnetic survey of the Iron Springs district, Utah: U.S. Geological Survey Professional Paper 516-B, 14 p.

Cary, R.S., 1963, Pintura anticline, Washington County, Utah, *in* Heylmun, E.B., editor, Guidebook to the geology of southwestern Utah: Intermountain Association of Petroleum Geologists, Twelfth Annual Field Conference, p. 172-180.

Chadwick, W.W., Jr., and Swanson, D.A., 1989, Thrust faults and related structures in the crater floor of Mount St. Helens volcano, Washington: Geological Society of America Bulletin, v. 101, no. 12, p. 1507-1519.

Christenson, G.E., and Purcell, Charles, 1985, Correlation and age of Quaternary alluvial-fan sequences, Basin and Range Province, southwestern United States, *in* Weide, D.L., editor, Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 115-122.

Clayton, R.W., 1988, Fault kinematics and paleostress determined from slickenlines in an area of unusual fault patterns, southwestern Utah: Brigham Young University Geology Studies, v. 35, p. 63-79.

Cook, E.F., 1957, Geology of the Pine Valley Mountains: Utah Geological and Mineral Survey Bulletin, v. 58, 111 p.

Cook, E.F., 1960, Geologic atlas of Utah, Washington County: Utah Geological and Mineral Survey Bulletin, v. 70, 119 p.

Cordova, R.M., 1978, Ground-water conditions in the Navajo Sandstone in the central Virgin River basin, Utah: Utah Department of Natural Resources Technical Publication No. 61, 66 p.

Cordova, R.M., Sandberg, G.W., and McConkie, W., 1972, Ground-water conditions in the central Virgin River basin, Utah: Utah Department of Natural Resources Technical Publication No. 40, 64 p.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constraints: Geology, vol. 7, p. 558-560.

Doser, D.I., and Smith, R.B., 1982, Seismic moment rates in the Utah region: Seismological Society of America Bulletin, v. 72, no. 2, p. 525-551.

Earthquake Engineering Research Institute, 1992, EERI Special Earthquake Report - St. George, Utah, September 2, 1992: Earthquake Engineering Research Institute Newsletter, v. 26, no. 10, p. 6-7.

Fillmore, R.P., 1991, Tectonic influence on sedimentation in the southern Sevier foreland Iron Springs Formation (Upper Cretaceous), southwestern Utah, *in* Nations J.D., and Eaton, J.G., editors, Stratigraphy, depositional environments, and sedimentary tectonics of the western margin, Cretaceous western interior seaway: Geological Society of America Special Paper 260, p. 9-26.

Fisher, R.V., and Schmincke, H.U., 1984, Pyroclastic rocks: Springer-Verlag, New York, p. 48-51.

Fleck, R.J., Anderson, J.J., and Rowley, P.D., 1975, Chronology of mid-Tertiary volcanism in High Plateaus region of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern Utah: Geological Society of America Special Paper 160, p. 53-62.

Grant, S.K., and Best, M.G., 1979, Geologic map of the Pinto Spring and part of the Atchison Creek quadrangles, Beaver and Iron Counties, Utah: U.S. Geological Survey Open-File Report 79-1656, 9 p., scale 1:24,000.

Grant, S.K., and Proctor, P.D., 1988, Geologic map of the Antelope Peak quadrangle, Iron County, Utah: Utah Geological and Mineral Survey Open-File Report 130, 20 p. , scale 1:24,000.

Greensfelder, R.W., Kintzer, F.C., and Somerville, M.R., 1980, Seismotectonic regionalization of the Great Basin, and comparison of moment rates computed from Holocene strain and historic seismicity: Geological Society of America Bulletin, Part II, v. 91, p. 2039-2111.

Hamblin, W.K., 1965, Origin of "reverse drag" on the downthrown side of normal faults: Geological Society of America Bulletin, v. 76, no. 10, p. 1145-1164.

Hamblin, W.K., 1970, Structure of the western Grand Canyon region, *in* Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Guidebook to the Geology of Utah, no. 23, Utah Geological Society, p. 10.

Hamblin, W.K., Damon, P.E., and Bull, W.B., 1981, Estimates of vertical crustal strain rates along the western margins of the Colorado Plateau: Geology, v. 9, p. 293-298.

International Conference of Building Officials, 1988, Uniform Building Code: Whittier, California, International Conference of Building Officials, p. 178.

Kurie, A.E., 1966, Recurrent structural disturbance of Colorado Plateau margin near Zion National Park, Utah: Geological Society of America Bulletin, v. 77, p. 867-872.

Lawrence, J.C., 1965, Stratigraphy of the Dakota and Tropic Formations of Cretaceous age in southern Utah, *in* Goode, H.D., and Robison, R.A., editors, Geology and resources of south-central Utah: Guidebook to the Geology of Utah, no. 19, Utah Geological Society, Salt Lake City, p. 71-91.

Lovejoy, E.M.P., 1973, Major early Cenozoic deformation along Hurricane fault zone, Utah and Arizona: American Association of Petroleum Geologists Bulletin, v. 57, no. 3, p. 510-519.

Mackin, J.H., 1947, Some structural features of the intrusions in the Iron Springs district: Utah Geological Society Guidebook to the Geology of Utah, no. 2, 62 p.

Mackin J.H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: American Journal of Science, v. 258, p. 81-131.

Mattison, G.D., 1972, The chemistry, mineralogy, and petrology of the Pine Valley Mountains, southwestern Utah: State College, Pennsylvania State University, Ph.D dissertation, 142 p.

Morrison, R.B., 1991, Introduction, *in* Morrison, R.B., editor, Quaternary nonglacial geology; Conterminous U.S.: [Boulder, Colorado,] Geological Society of America, The Geology of North America, v. K-2, p. 1-12.

Nairn, A.E.M., Rowley, P.D., and Anderson, J.J., 1975, Paleomagnetism of selected Tertiary volcanic units, southwestern Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 63-88.

Noweir, M.A., 1990, Structural analysis of the overthrust belt (OTB) of southwest Utah: Rolla, University of Missouri-Rolla, Ph.D dissertation, 130 p.

Peterson, Fred, and Pipiringos, G.N., 1979, Stratigraphic relations of the Navajo Sandstone to Middle Jurassic formations, southern Utah and northern Arizona: U.S. Geological Survey Professional Paper 1035-B, 43 p.

Peterson, P.R., 1974, Anderson Junction field: Utah Geological Mineral Survey, Oil and Gas Field Studies Number 13, 3 p.

Proctor, P.D., 1953, Geology of the Silver Reef (Harrisburg) mining district: Utah Geological and Mineral Survey Bulletin 44, 169 p.

Proctor, P.D., and Brimhall, W.H., 1986, Silver Reef mining district, revisited, Washington County, Utah, *in* Griffen, D.T., and Phillips, W.R., editors, Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association, Publication 15, p. 159-177.

Richardson, G.B., 1909, The Harmony, Colob, and Kanab coal fields, southern Utah: U. S. Geological Survey Bulletin 341, p. 379-400.

Ring, Uwe, Betzler, Christian, and Delvaux, Damian, 1992, Normal vs. strike-slip faulting during rift development in East Africa: The Malawi rift: Geology, v. 20, no.11, p. 1015-1018.

Rowley, P.D., Steven, T.A., Anderson, J.J., and Cunningham, C.G., 1979, Cenozoic stratigraphic and structural framework of southwestern Utah: U.S. Geological Survey Professional Paper 1149, 22 p.

Rowley, P.D., McKee, E.H., and Blank, Jr., H.R., 1989, Miocene gravity slides resulting from emplacement of the Iron Mountain pluton, southern Iron Springs mining district, Iron County, Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 70, no. 43, p. 1309.

Rowley, P.D., Anderson, R.E., Snee, L.W., and Mehnert, H.H., 1990, Geology and structural setting of the western Caliente caldera complex, Lincoln County, Nevada [abs.]: Geological Society of America Abstracts with Programs, [Cordilleran Section], v. 22, no. 3, p. 79-80.

Shubat, M.A., and Siders, M.A, 1988, Geologic map of the Silver Peak quadrangle, Iron County, Utah: Utah Geological and Mineral Survey Map 108, 13 p., scale 1:24,000.

Solomon, B.J., 1992, Geology and the indoor radon hazard in southwestern Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association, Publication 21, p. 165-172.

Stewart, J.H., 1980, Regional tilt patterns of late Cenozoic basin-range fault blocks, western United States: Geological Society of America Bulletin, v. 91, no. 8, p. 460-464.

Stokes, W.L., 1986, Geology of Utah: Utah Museum of Natural History, Occasional Paper Number 6, 309 p.

Stover, C.W., Reagor, B.G., and Algermissen, S.T., 1986, Seismicity map of the state of Utah: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1856, scale 1:1,000,000.

Strecker, M.R., Blisniuk, P.M., and Eisbacher, G.H., 1990, Rotation of extension direction in the central Kenya Rift: Geology, v. 18, p. 299-302.

Threet, R.L., 1963, Structure of the Colorado Plateau margin near Cedar City, Utah, *in* Heylmun, E.B., editor, 1963, Guidebook to the geology of southwestern Utah: Intermountain Association of Petroleum Geologists, Twelfth Annual Field Conference, p. 104-117.

Williams, H., and McBirney, A.R., 1979, Volcanology: Freeman, Cooper, and Co., San Francisco, 397 p.

Williams, J.S., and Tapper, M.L., 1953, Earthquake history of Utah, 1850-1949: Bulletin of the Seismological Society of America, v. 43, no. 3, p. 191-218.

Williams, P., 1967, Stratigraphy and petrography of the Quichapa Group, southwestern Utah and southeastern Nevada: Seattle, University of Washington, Ph.D dissertation, 141 p.

Wollard, G.P., 1958, Areas of tectonic activity in the United States as indicated by earthquake epicenters: Transactions of the American Geophysical Union, v. 39, no. 6, p. 1135-1150.

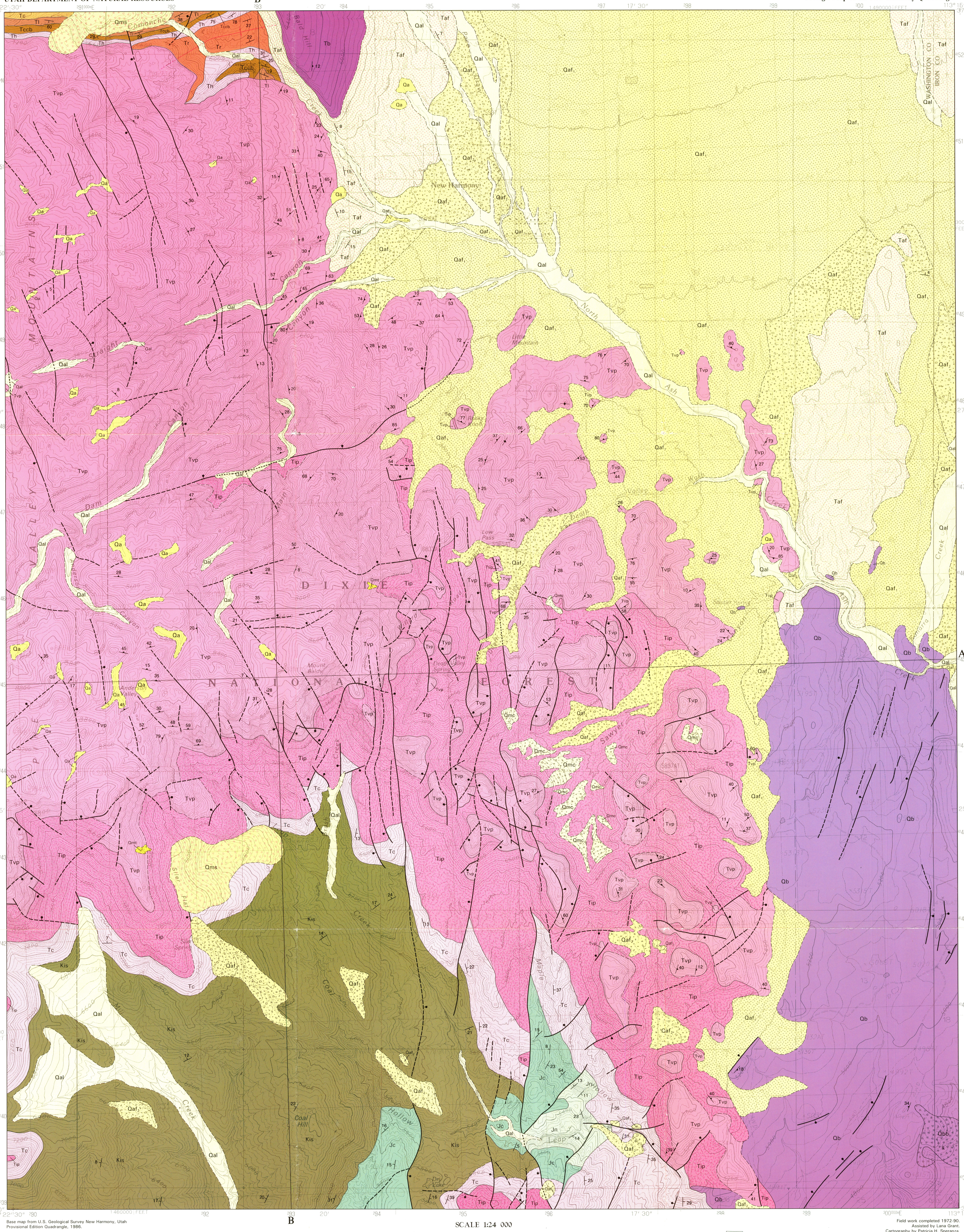
Woolley, R.R., 1946, Cloudburst floods in Utah 1850-1938: U. S. Geological Survey Water Supply Paper 994, 128 p.

UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

The Miscellaneous Publication Maps provide an outlet for authors who are not Utah Geological Survey staff. Not all aspects of this publication have been reviewed by the UGS.

Plate 1
Utah Geological Survey Miscellaneous Publication 95-2
Geologic Map of the New Harmony Quadrangle

B′



B

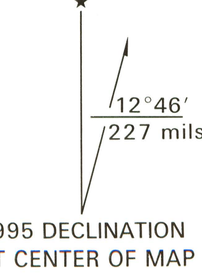
Base map from U.S. Geological Survey New Harmony, Utah Provisional Edition Quadrangle, 1986.

Field work completed 1972-90.
Assisted by Lana Grant.
Cartography by Patricia H. Speranza.

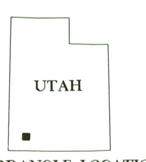
SCALE 1:24 000

1 .5 0 1 MILES
1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10 000 FEET
1 .5 0 1 2 KILOMETERS
1000 0 1000 2000 METERS

CONTOUR INTERVAL 40 FEET



1995 DECLINATION
AT CENTER OF MAP



QUADRANGLE LOCATION

1	2	3	1 Page Ranch 2 Stoddard Mountain 3 Kanarraville 4 Grass Valley 5 Kolob Arch 6 Signal Peak 7 Pintura 8 Smith Mesa
4		5	
6	7	8	

ADJOINING 7.5′ QUADRANGLE NAMES

GEOLOGIC MAP OF THE NEW HARMONY QUADRANGLE, WASHINGTON COUNTY, UTAH

by

S. KERRY GRANT

1995

MAP SYMBOLS

CONTACT--Dashed where approximately located.

FAULT--Dashed where approximate or based on lineaments on aerial photos, dotted where covered. Bar and ball on downthrown side Arrows show direction of movement. No symbol where offset unknown.

19 BEDDING--Strike and dip of bedding in sedimentary rocks and layering in ash-flow tuffs.

LAYERING--Strike and dip of layering in lava flows and flow domes.

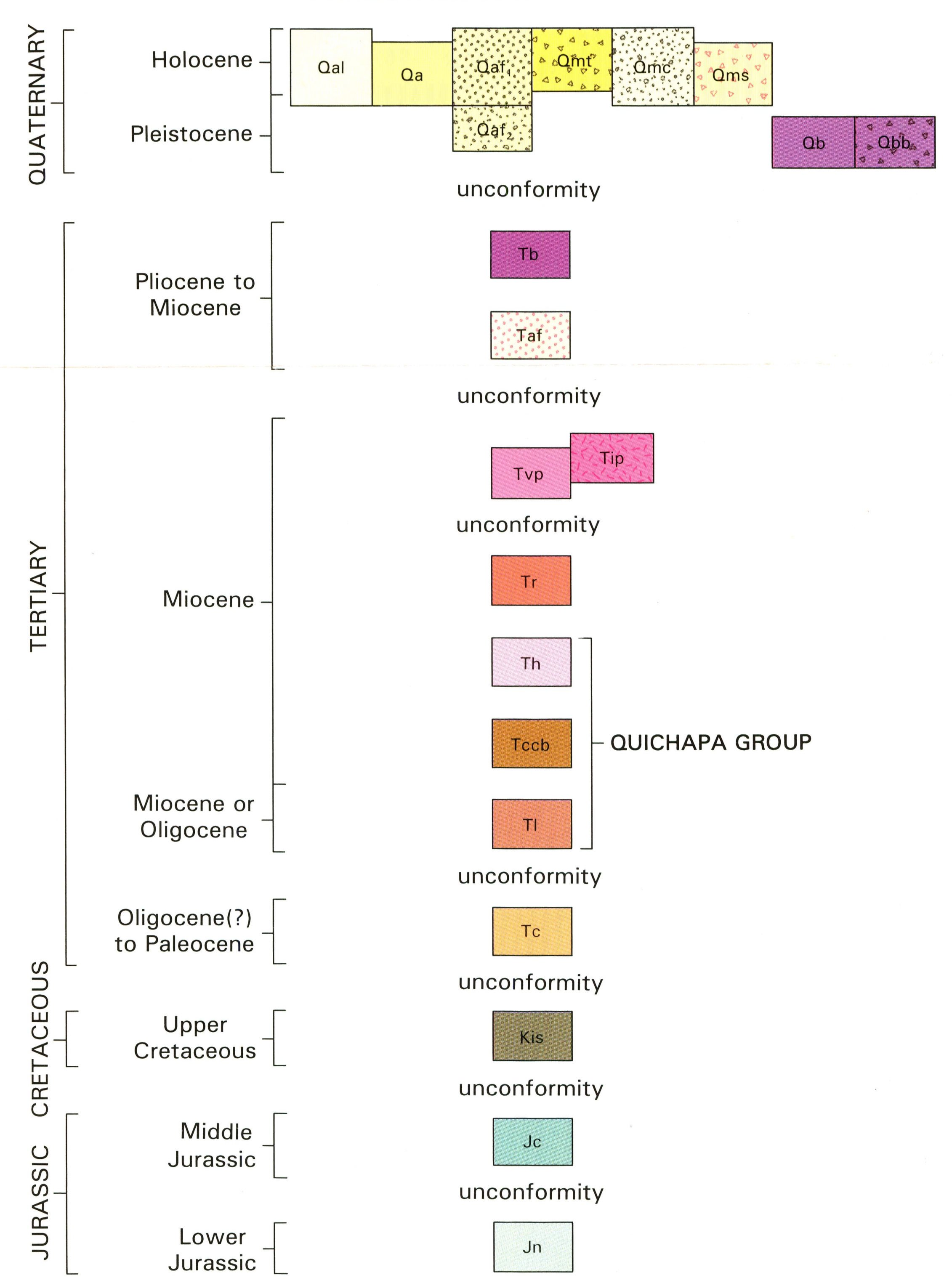
17 Inclined.

Vertical.

SYNCLINE AXIAL TRACE--Dashed where approximately located. Dotted where covered.

x PROSPECT

CORRELATION OF MAP UNITS



SYSTEM AND SERIES		UNIT	SYMBOL	THICKNESS feet, (meters)	LITHOLOGY
QUATERNARY	Holocene	Surficial deposits		0-200 (60)	
QUATERNARY	Pleistocene	Younger basalt flows	Qb	300 + (90)	
QUATERNARY	Pleistocene	Basaltic breccia	Qbb	300 + (90)	
	Pliocene to Miocene(?)	Older basalt flows	Tb	200 (60)	
	Pliocene to Miocene(?)	Oldest alluvial-fan deposits	Taf	400 + (120)	
TERTIARY	Miocene	Monzonite of the Pine Valley Mountains	Tip	1000 (300)	
TERTIARY	Miocene	Pine Valley Latite	Tvp	1700 (520)	
TERTIARY	Miocene	Rencher Formation	Tr	500 + (150)	
TERTIARY	Miocene	Quichapa Group: Harmony Hills Tuff	Th	240 (70)	
TERTIARY	Miocene or Oligocene	Quichapa Group: Bauers Tuff Mbr. of Condor Cyn. Fm.	Tccb	200 (60)	
TERTIARY	Miocene or Oligocene	Quichapa Group: Leach Canyon Formation	Tl	250 (75)	
TERTIARY	Oligocene(?) to Paleocene	Claron Formation	Tc	400-500 (120-150)	
CRETACEOUS	Upper	Iron Springs Formation	Kis	3800 (1160)	
JURASSIC	Middle	Carmel Formation	Jc	800 (240)	
JURASSIC	Lower	Navajo Sandstone	Jn	500 + (150)	

DESCRIPTION OF MAP UNITS

Qmt Talus -- *Accumulated rockfall deposits of angular blocks found downslope from bedrock. Maximum thickness about 10 feet (3 m).*

Qal Modern alluvium -- *Unconsolidated, poorly sorted sand, silt, and gravel. Mostly floodplain and channel deposits. Maximum thickness about 30 feet (10 m).*

Qaf Modern alluvial-fan deposits -- *Unconsolidated, poorly sorted silt and sand, with minor clay and gravel. Deposited in active, or recently abandoned, coalescing alluvial fans. Thickness may exceed 100 feet (30 m).*

Qa Alluvium -- *Unconsolidated sand and silt. Found typically in small basins with narrow outlets. Partially dissected. Maximum thickness about 30 feet (10 m).*

Qmc Colluvium -- *Unconsolidated, poorly sorted silt, sand, and gravel deposited by sheetwash and gravity movement on steep slopes. Occurs as dissected patches. Maximum thickness about 20 feet (6 m).*

Qms Landslide deposits -- *Poorly sorted, angular debris derived from nearby bedrock, deposited by mass-movement processes. Contains blocks of Pine Valley Latite (Tvp) as large as 30 feet (10 m) in diameter. Partially dissected. At least 200 feet (60 m) thick.*

Qaf₁ Older alluvial-fan deposits -- *Unconsolidated, poorly sorted gravel, silt, and sand deposited in abandoned alluvial fans. Dissected and partially covered by younger alluvial fans (Qaf_1). Clasts include Claron Formation upper white limestone (Tc), Leach Canyon Formation (Tl), Bauers Tuff (Tccb), Harmony Hills Tuff (Th), older basalt (Tb), and the Stoddard Mountain monzonite porphyry pluton. At least 100 feet (30 m) thick.*

Qb Younger basalt flows -- *Dark gray to black alkali olivine basalt. May exhibit columnar jointing. Age estimated to be 1 to 1.5 million years. At least 300 feet (90 m) thick.*

Qbb Basaltic breccia -- *Reddish-brown blocks of scoriaceous basalt, poorly consolidated, in partially buried cinder cones. Possible source for nearby younger basalt flows (Qb). Cones at least 300 feet (90 m) high.*

Tb Older basalt flows -- *Olivine-bearing basalt flows. Dark gray, with lighter weathering rinds 0.8 inches (2 cm) thick. Remaining thickness 200 feet (60 m).*

Taf Oldest alluvial-fan deposits -- *Poorly to moderately consolidated sandstone and conglomerate, with minor claystone. Prominent clasts include lower Claron Formation pisolitic limestone and quartzite (Tc), Pine Valley Latite (Tvp), Iron Springs Formation (Kis), and the Stoddard Mountain monzonite porphyry pluton. At least 400 feet (120 m) thick.*

Tip Monzonite of the Pine Valley Mountains -- *Intrusive monzonite porphyry forming sill or laccolith. Ranges in color from dark brown at the base to almost white at the top. Contains 30-35 percent phenocrysts of plagioclase, clinopyroxene, and biotite, with lesser sanidine and orthopyroxene. Groundmass is holocrystalline to hypocrystalline. Intrudes between Claron Formation (Tc) and Pine Valley Latite (Tvp). About 1,000 feet (300 m) thick. Age estimated at about 21 million years.*

Tvp Pine Valley Latite -- *Extrusive latite porphyry forming flows or flow domes. Gray to purple, with the same phenocrysts as associated monzonite (Tip), and traces of hornblende. Glassy groundmass. Flow layering and normal jointing perpendicular to layering. Three stratigraphic zones are present above a basal flow breccia. The lower zone has steep alternating layers, the middle zone has massive steep to gentle layering, and the upper zone has gentle layers. As much as 1,700 feet (520 m) thick. Age estimated at about 21 million years.*

Tr Rencher Formation -- *Poorly resistant, light gray to tan, slightly welded, ash-flow tuff and other volcanic and volcaniclastic rocks. Contains 25-35 percent phenocrysts of plagioclase, hornblende, and lesser biotite and clinopyroxene. Lithic fragments of quartzite and volcanic rocks constitute 15 percent of the tuff. Age is 21.5 to 21.8 million years. At least 500 feet (150 m) thick.*

Th Harmony Hills Tuff (Quichapa Group) -- *Moderately resistant, tan, moderately welded ash-flow tuff. Contains 40-45 percent phenocrysts of plagioclase, biotite, and lesser quartz, hornblende, and clinopyroxene. Thickness is 240 feet (70 m). Age is about 22 million years.*

Tccb Bauers Tuff Member of Condor Canyon Formation (Quichapa Group) -- *Resistant, pale red to pale lavender, densely welded ash-flow tuff. Contains 10-15 percent phenocrysts of sanidine and plagioclase, with lesser biotite and a little hornblende and clinopyroxene. Unit has a thin basal vitrophyre and a massive top. Thickness is 200 feet (60 m). Age is about 23 million years.*

Tl Leach Canyon Formation (Quichapa Group) -- *Resistant, purplish gray, densely welded ash-flow tuff. Contains 15-25 percent phenocrysts of quartz, sanidine, and plagioclase, with lesser biotite and minor hornblende, clinopyroxene, allanite, and sphene. Red lithic fragments with white halos constitute 5 percent of the rock. About 250 feet (75 m) thick. Age is about 24.6 million years.*

Tc Claron Formation -- *Fluvial and lacustrine sandstone, limestone, shale, and conglomerate. Mostly red and white. Prominent white limestone at top. Conglomerate at the base and in upper part. Pisolitic algal limestone in lower part. Thickness is 400 to 500 feet (120-150 m).*

Kis Iron Springs Formation -- *Sequence of alternating thin sandstone and silty shale deposited in fluvial, alluvial-plain, and paludal environments. Sandstones are buff to white. Shales are purple and gray or red, yellow, and light gray. Sandstone ledges interspersed at about 50-foot (15 m) intervals. Thickness as much as 3,800 feet (1,100 m).*

Jc Carmel Formation -- *Lower thin, red siltstone overlain by thick, platy argillaceous limestone which is overlain by an upper red siltstone and sandstone unit. Total thickness about 800 feet (240 m).*

Jn Navajo Sandstone -- *Red, massive sandstone with large-scale eolian cross-bed sets as much as 50 feet (15 m) thick. Incomplete thickness of about 500 feet (150 m).*