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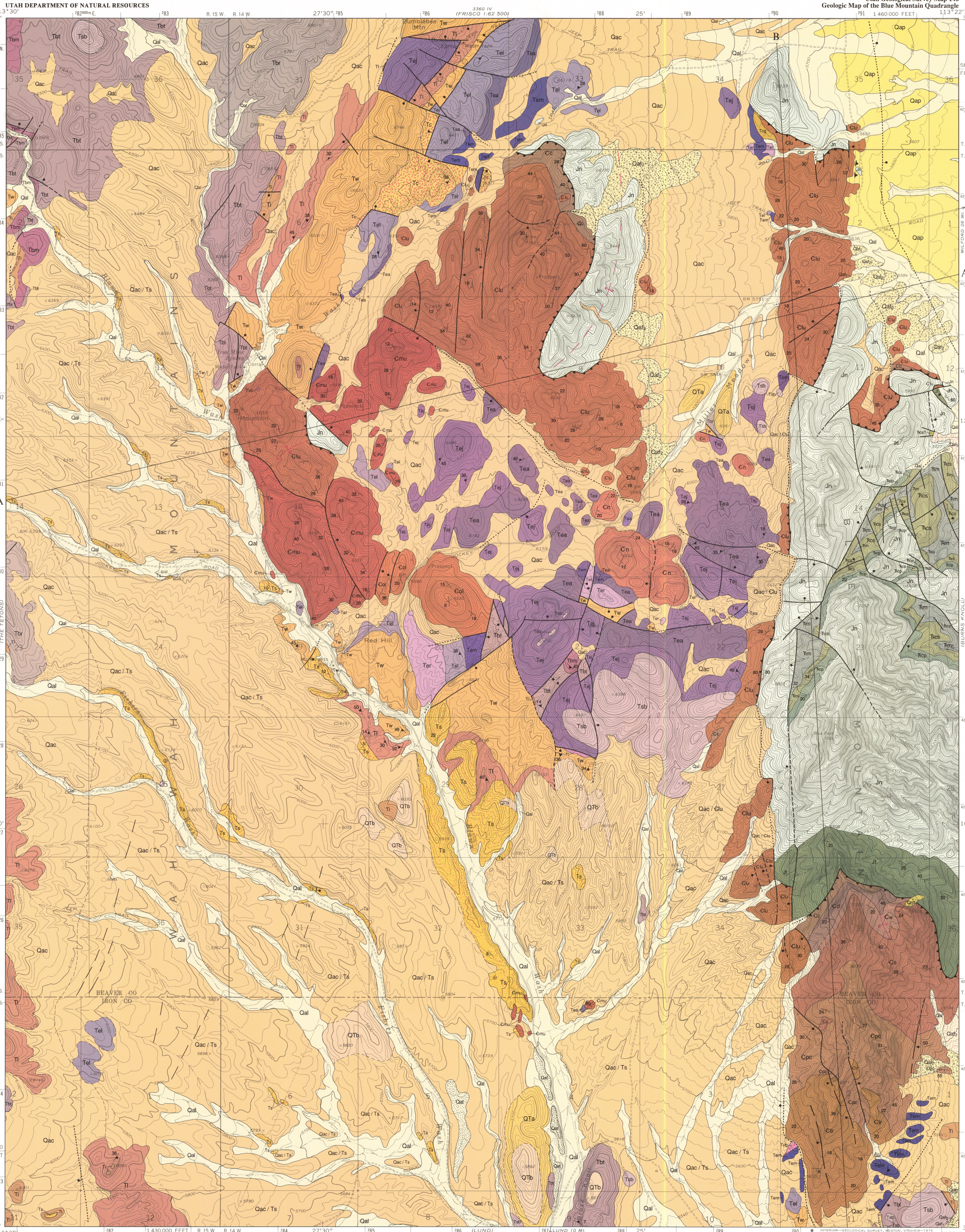


Base map from U.S. Geological Survey
Blue Mountain 7.5′ Quadrangle, 1971

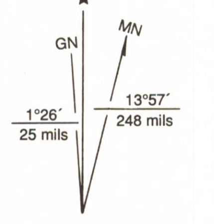
SCALE 1:24 000

1 ½ 0 1 MILE

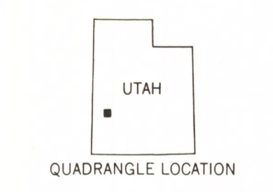
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



UTM GRID AND 1992 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET



QUADRANGLE LOCATION

GEOLOGIC MAP OF THE BLUE MOUNTAIN QUADRANGLE, BEAVER AND IRON COUNTIES, UTAH

by
Clark L. Weaver and Lehi F. Hintze
1993

Bedrock mapping by Weaver (1980)
Quaternary mapping by Hintze in 1988 and 1989
Lori J. Douglas, Cartographer

Age	Name	Symbol	Feet (meters)	Lithology	
QT	Surficial units		0 - 500 (0 - 150)		
MIOCENE	Sandstone and conglomerate	Ts	0 - 600? (0 - 180?)		
MIOCENE	Basalt flow member of Steamboat Mountain Fm.	Tsb	0 - 400 (0 - 120)		13 - 12 m.y.
MIOCENE	Blawn Fm – Rhyolite member	Tbr	400 (120)		18.3 m.y.
MIOCENE	Blawn Fm – Tuff member	Tbt	800 (240)		
MIOCENE	Blawn Fm – Mafic flow mbr	Tbm	0 - 100 (0 - 30)		23.2 m.y.
MIOCENE	Isom Formation	Ti	0 - 100 (0 - 30)		26 m.y.
OLIGOCENE	Needles Range Group – Lund Formation	Tl	200 - 800 (60 - 240)		27.9 m.y.
OLIGOCENE	Needles Range Group – Wah Wah Springs Formation	Tw	1200 (370)		29.5 m.y.
OLIGOCENE	Needles Range Group – Cottonwood Wash Tuff	Tc	0 - 1000 (0 - 300)		30.6 m.y.
OLIGOCENE	Needles Range Group – Escalante Desert Formation – Rhyolite flow mbr	Ter	0 - 580 (0 - 180)		
OLIGOCENE	Needles Range Group – Escalante Desert Formation – Lamerdorf Tuff Mbr	Tel	0 - 600 (0 - 180)		32± m.y.
OLIGOCENE	Needles Range Group – Escalante Desert Formation – Latite flow member of Jockey Road	Tej	0 - 1300 (0 - 400)		
OLIGOCENE	Needles Range Group – Escalante Desert Formation – Andesite flow member	Tea	0 - 1200 (0 - 370)		
OLIGOCENE	Needles Range Group – Escalante Desert Formation – Marsden Tuff Member	Tem	0 - 200 (0 - 60)		
OLIGOCENE	Tuff of Tower Point, Volcanic breccia, Conglomerate	Tt, Tvb, Tcg	0 - 600 (0 - 180)		34± m.y.

CENOZOIC ROCKS LIE ON REGIONAL ANGULAR UNCONFORMITY

MESOZOIC STRATA LIE BENEATH OVERTHRUST

Age	Name	Symbol	Feet (meters)	Lithology	
LOWER JURASSIC	Temple Cap Formation	Jt	1275 (0 - 389)		tan sandstone; stream-laid cross-bedding; dinosaur track
LOWER JURASSIC	Navajo Sandstone	Jn	1900 (0 - 580)		pink quartzite; eolian cross-bedding
TRIASSIC	Chinle Fm – Petrified Forest Member	Ꞧcp	280 (85)		dark hornfels
TRIASSIC	Chinle Fm – Shinarump Member	Ꞧcs	125 - 200 (35 - 60)		salt & pepper quartzite
TRIASSIC	Moenkopi Fm	Ꞧm	500+ 2000* (150+) (610*)		baked shale siltstone & mudstone

CAMBRIAN STRATA ARE THRUST OVER MESOZOIC ROCKS

Age	Name	Symbol	Feet (meters)	Lithology	
UPPER CAMBRIAN	Notch Peak Fm	Ꞓn	300+ 1800* (90+) (550*)		chert
	contact not exposed				
UPPER CAMBRIAN	Orr and Lamb Fms, undivided	Ꞓol	300+ 2000* (90+) (610*)		
	contact not exposed				
MIDDLE CAMBRIAN	Trippe Limestone	Ꞓtr	410+ 600* (125+) (180*)		interbeds of white dolomitic boundstone
MIDDLE CAMBRIAN	Pierson Cove Formation	Ꞓpc	835 1300* (255) (400*)		boundstone
MIDDLE CAMBRIAN	Swasey Limestone	Ꞓs	675 (206)		
MIDDLE CAMBRIAN	Whirlwind Fm	Ꞓw	125 (38)		*Ehmaniella*
MIDDLE CAMBRIAN	Dome Limestone	Ꞓd	130 (40)		
MIDDLE CAMBRIAN	Chisholm Fm	Ꞓc	175 (53)		*Glossopleure*

BLUE MOUNTAIN THRUST

* regional thickness

EXPLANATION OF MAP SYMBOLS

Qal Alluvial deposits of intermittent stream channels and flood plains (Holocene and upper Pleistocene): *Unconsolidated clay, silt, sand, gravel, and boulder deposits whose clast size and composition reflect stream gradient and local geologic units upstream. Thickness generally less than 20 feet (6 m).*

Qmt Mass movement - talus (Holocene and upper Pleistocene): *Angular, rocky debris on steep slopes next to bedrock source. Less than 30 feet (9 m) thick.*

Qac Alluvium and colluvium (Quaternary): *Alluvium containing a large colluvial component developed adjacent to bedrock on upland slopes. Consists of angular debris as coarse as boulders and includes local talus. Where shown with another symbol such as Qac/Ts, the second symbol, identifies the probable underlying bedrock unit. May be as much as 50 feet (15 m) thick locally.*

Qaf_1 Alluvial - fan deposits of the youngest age (Holocene): *Unconsolidated clastic deposits developed where stream channel gradient flattens upon entering Esclante Desert lowland; thickness less than 10 feet (9 m).*

Qaf_2 Alluvial - fan deposits of intermediate age (upper Pleistocene): *Unconsolidated silt, sand, gravel, and boulders. As much as 100 feet (30 m) thick.*

Qaf_3 Allùvial-fan deposits of the oldest age (Pleistocene ?): *Unconsolidated silt, sand, gravel, and boulders that form steepest upper part of alluvial apron along east side of Blue Mountain. As much as 200 feet (60 m) thick.*

Qat Alluvial terrace deposits (upper Pleistocene): *Bouldery stream - rounded gravels above present flood plains. Unit is less than 50 feet (15 m) thick.*

Qap Alluvial deposits on pediments (Pleistocene): *Silt- to gravel - size deposits that thinly overlie bedrock and include wind - blown silt. May be more than 100 feet (30 m) thick locally.*

QTa Old alluvium (Quaternary - Pliocene ?): *Unconsolidated, poorly sorted, angular to subrounded, sand- to boulder - size clasts of sedimentary and igneous rocks. Probably deposited as mudflows in paleovalley, now as hills in inverted topography. Locally is at least 150 feet (45 m) thick.*

QTb Basalt - boulder alluvium (Quaternary - Pliocene ?): *Unconsolidated, poorly sorted alluvium composed mostly of pebbles, cobbles, and boulders of Steamboat Mountain basalt. Locally as much as 100 feet (30 m) thick.*

Ts Sandstone and conglomerate (Miocene): *Pinkish-gray, variably cemented, poorly sorted sandstone, containing conglomerate interbeds with subangular to angular clasts of igneous and sedimentary rocks whose proportional composition varies widely. May be more than 600 feet (180 m) thick.*

Tsb Basalt flow member of Steamboat Mountain Formation (Miocene): *Black, vesicular to dense, jointed basalt that commonly contains olivine phenocrysts. Locally interbedded with Miocene sandstone and conglomerate (Ts). Age is 13 - 12 million years. Thickness is as much as 400 feet (120 m).*

Blawn Formation (Miocene): *Bimodal rock assemblage that is 23 to 18 million years old.*

Tbr Rhyolite member: *Light-gray to pale-purplish-gray, flow-layered lava flows. Dense and with small phenocrysts along north edge of map area; vuggy and with large sanidine and quartz phenocrysts along west edge of quadrangle. Age is 18.3 million years. Maximum thickness is about 400 feet (120 m).*

Tbt Tuff member: *Heterogeneous sequence of ash-flow tuffs, with minor thin-bedded, air-fall and pyroclastic-surge deposits, and minor fluvial deposits. Ash-flow tuffs are white, gray, orange, tan, and pink, contain pumice lapilli and volcanic lithic fragments, and generally have less than 20 percent phenocrysts of sanidine, quartz, sodic plagioclase, and biotite. Locally is as much as 800 feet (240 m) thick.*

Tbm Mafic lava flow member: *Brown to gray, porphyritic trachyandesite lava flows that contain plagioclase and pyroxene phenocrysts. Age is 23.2 million years. May be as much as 100 feet (30 m) thick.*

Ti Isom Formation (Oligocene): *Dark-reddish-brown to grayish-purple, crystal-poor, densely welded, trachytic ash-flow tuff characterized by extremely compressed pumice lapilli that show as aligned voids in weathered outcrops. Age is 27 million years. Less than 100 feet (30 m) thick.*

Needles Range Group (Oligocene): *Includes Lund, Wah Wah Springs and Escalante Desert Formations, and Cottonwood Wash Tuff.*

Tl Lund Formation: *Pink to reddish-brown, moderately to densely welded, crystal-rich, dacitic ash-flow tuff. About 40 percent phenocrysts, mainly plagioclase and lesser quartz and biotite, inconspicuous hornblende, and traces of sanidine, Fe - Ti oxides, and diagnostic sphene. Age is 27.9 million years. Thickness is 200 to 800 feet (60 - 240 m).*

Tw Wah Wah Springs Formation: *Reddish-brown to light-gray, moderately to densely welded, crystal-rich, dacite ash-flow tuff. Composition similar to Lund Formation, but contains more hornblende than biotite, less quartz, little or no augite, and no sanidine or sphene. Basal black vitrophyre is common. Age 29.5 million years. Thickness is as much as 1,200 feet (365 m).*

Tc Cottonwood Wash Tuff: *Appearance and composition similar to Lund Formation, but characterized by large biotite phenocrysts, a few percent pyroxene, and no sanidine or sphene. Age is 30.6 million years. Zero to 1,000 feet (0 - 300 m) thick in map area.*

Escalante Desert Formation: *Generally crystal-poor volcanic sequence divided into five map units in this quadrangle.*

Ter Rhyolite flow member: *Reddish-brown, purple, and gray, silica-poor rhyolite containing less than 15 percent chalky plagioclase, lesser biotite, and locally hornblende. Weathers to grus. Present only locally; is as much as 580 feet (177 m) thick.*

Tel Lamerdorf Tuff Member: *Gray, mottled red to purple, moderately to densely welded, silica-poor, rhyolitic ash-flow tuff. Contains less than 15 percent phenocrysts of plagioclase, lesser biotite, and trace of hornblende, along with light-colored pumice and dark-colored volcanic rock fragments. Age is 32 million years. May be as much as 600 feet (180 m) thick.*

Tej Latite flow member of Jockey Road: *Aphanitic to glassy, gray, red, brown, and purple latite that commonly shows liesegang banding. Invariably contains biotite, and usually hornblende. Ranges from 0 to 1,300 feet (0 - 396 m) in thickness.*

Tea Andesite flow member: *Generally non-vesicular brown to dark-gray lava flows containing phenocrysts of plagioclase and pyroxene. Occurs locally as dikes. Thickness ranges from 0 to 1,200 feet (0 - 366 m).*

Tem Marsden Tuff Member: *Pinkish-gray, light-orangish-brown, light-gray, and greenish-gray, lithic-rich, crystal-poor, moderately welded, rhyolitic ash-flow tuff. Contains 2 to 6 percent phenocrysts, mainly plagioclase and quartz, and a trace of biotite. Lithic fragments of volcanic rock, pink, red, and purple quartzite, and green phyllite are as large as 3 inches (8 cm) across and as abundant as 12 percent. Best and Grant (1987, p. 8) designated an area in the adjacent Lund quadrangle as the type area. Thickness ranges from 0 to 200 feet (0 - 61 m).*

Tt Tuff of Tower Point (Oligocene): *Green, red, and gray densely welded but weakly resistant tuff containing 25 - 30 percent phenocrysts of plagioclase and quartz, minor biotite, and traces of sanidine and hornblende. Quartz grains may exceed 0.1 inche (3 mm) across and are locally euhedral in pumice fragments. Biotite is conspicuous and visibly warped. Lithic fragments are as large as 6 inches (15 cm) near the base of the unit and include a quartz-rich volcanic rock and some Paleozoic carbonate clasts. May correlate with the Sawtooth Peak Formation (33.5 million years old, Best, and others, 1987a) but does not contain as much quartz. May be as much as 600 feet (180 m) thick in the northeast corner to the adjoining Lund quadrangle.*

Tvb Volcanic breccia: *Includes two small outcrops. Larger one on southwest flank of Blue Mountain is dark-gray andesite with white feldspar phenocrysts. Smaller outcrop is on northwest flank of Iron Mountain. Weaver (1980) described this as a brecciated plug intruded into Cambrian rocks.*

Tcg Conglomerate: *Mostly pebble- to boulder-size rounded clasts of Precambrian and Cambrian quartzites, and Cambrian carbonates with about 10 percent boulders and cobbles of dark andesite that contain chalky white feldspar phenocrysts. Thickness is about 200 feet (60 m).*

Jt Temple Cap Formation: *Interbedded reddish-brown siltstone and white, fine-grained sandstone in lowest 245 feet (74 m): interbedded white and red, fine- to coarse-grained sandstone with minor cross-bedding in middle 460 feet (140 m); medium- to fine-grained, yellowish-gray, ledge-forming sandstone in upper 570 feet (170 m). Total thickness in 1,275 feet (389 m).*

Jn Navajo Sandstone: *Red, pink, and light-brownish-gray, fine-grained, eolian cross-bedded sandstone that has been secondarily silicified to resemble quartzite. About 1,900 feet (580 m) thick.*

Ꞧcp Chinle Formation, Petrified Forest Member: *Dark-red to blackish-red hornfels, locally mottled dark greenish-black. Contains sparse petrified wood and limestone nodules. Member is about 280 feet (85 m) thick.*

Ꞧcs Chinle Formation, Shinarump Member: *Salt-and-pepper gray, quartzose sandstone that forms resistant light-gray ledges. Dark-green, quartzite-pebble conglomerate, locally near base, as much as 8 feet (2.4 m) thick; ranges from 125 - 200 feet (35 - 61 m) thick.*

Ꞧm Moenkopi Formation: *Yellowish-green, brown, and greenish-black hornfels, indurated siltstone and mudstone. Exposed thickness is about 500 feet (150 m); regional thickness, shown on cross-sections, is about 2,000 feet (610 m).*

Ꞓn Notch Peak Formation: *Dark-brownish-gray, thick-bedded, cherty dolomite that locally shows dolomitized traces of algal stromatolites. Regional thickness is about 1,800 feet (540 m). Exposed thickness is about 300 feet (90 m).*

Ꞓol Orr and Lamb Formation, undivided: *Dark-gray, thin- to thick-bedded, coarsely crystalline dolomite. Sparse dolomitized oolites and rare trilobite fragments in thin beds. Regional thickness is about 2,000 feet (610 m). Exposed thickness is about 300 feet (90 m).*

Ꞓtr Trippe Limestone: *Medium-gray mottled, medium- to thick-bedded limestone with 40 percent interbeds of light-gray to yellowish-orange, laminated, dolomitic boundstone. Regional thickness is about 600 feet (183 m). Exposed thickness is 410 feet (125 m).*

Ꞓpc Pierson Cove Formation: *Dark-gray, mottled limestone and dolomite that forms ledges and low cliffs. Basal part is tan, laminated boundstone; main body is medium-dark-gray dolomite; upper part is interbedded limestone and dolomite with occasional thin laminated boundstone beds. Regional thickness is about 1,300 feet (396 m). Exposed thickness is 835 feet (255 m).*

Ꞓmu Upper Middle Cambrian units, undivided: *Includes Trippe, and Swasey Limestones and the Pierson Cove Formation*

Ꞓlu Lower Middle Cambrian units, undivided: *Includes Whirlwind Formation, and the Dome, Swasey, and Chisholm Limestones.*

Ꞓs Swasey Limestone: *Medium-gray, massive, crystalline dolomite that characteristically forms rugged cliffs and ledges. Dolomitization is probably secondary; relict oolites are preserved locally. Thickness is 675 feet (206 m).*

Ꞓw Whirlwind Formation: *Slope-forming, light-olive-gray shale with interbeds of thin bedded medium-gray limestone that form low ledges at several horizons. Some limestone beds are nodular and olive-gray-weathering with coquinas of small heads of the trilobite Ehmaniella. Thickness is 125 feet (38 m).*

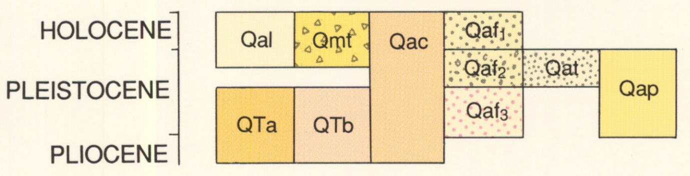
Ꞓd Dome Limestone: *Medium-gray limestone, thin bedded in the basal 20 feet (6 m), but massive and cliff-forming above. Occasional silty parting; rare oolitic and pisolitic lenses. Thickness is 130 feet (40 m).*

Ꞓc Chisholm Formation: *Interbedded olive shale and dark-gray, thin-bedded, oncolitic limestone; forms slopes and low ledges. Olive-weathering limestone nodules within shale beds are made up of Glossopleura trilobite fragments. Exposed thickness is 175 feet (53 m).*

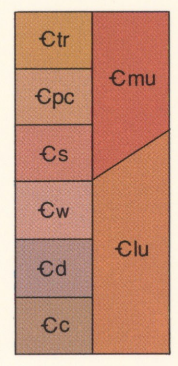
MAP SYMBOLS

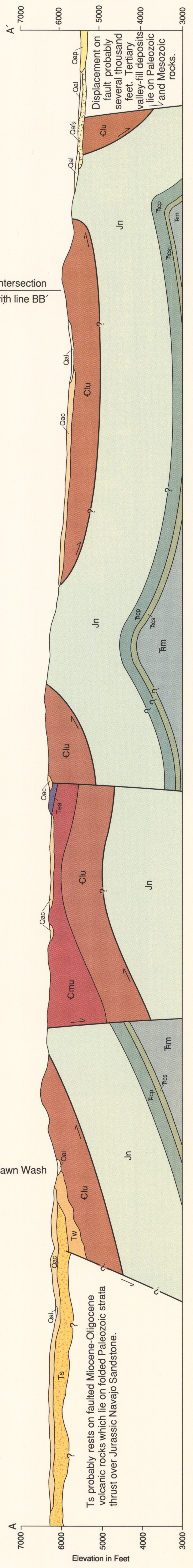
- Contact - dashed where approximate
- Normal fault - dashed where location inferred, dotted where covered. Bar and ball on downthrown side.
- Thrust fault - barbs on upper plate, dotted where covered
- Lineament - vegetation alignment that shows on aerial photographs
- 47 Strike and dip of bedding in sedimentary strata
- Horizontal bedding
- 21 Strike and dip of foliation in volcanic rocks
- Trace of axial surface of anticline - showing plunge
- Trace of axial surface of syncline - showing plunge

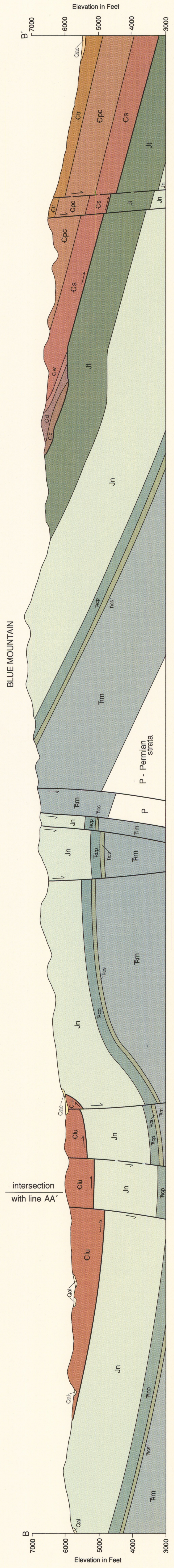
CORRELATION OF LATE CENOZOIC UNITS



CORRELATION OF MIDDLE CAMBRIAN UNITS



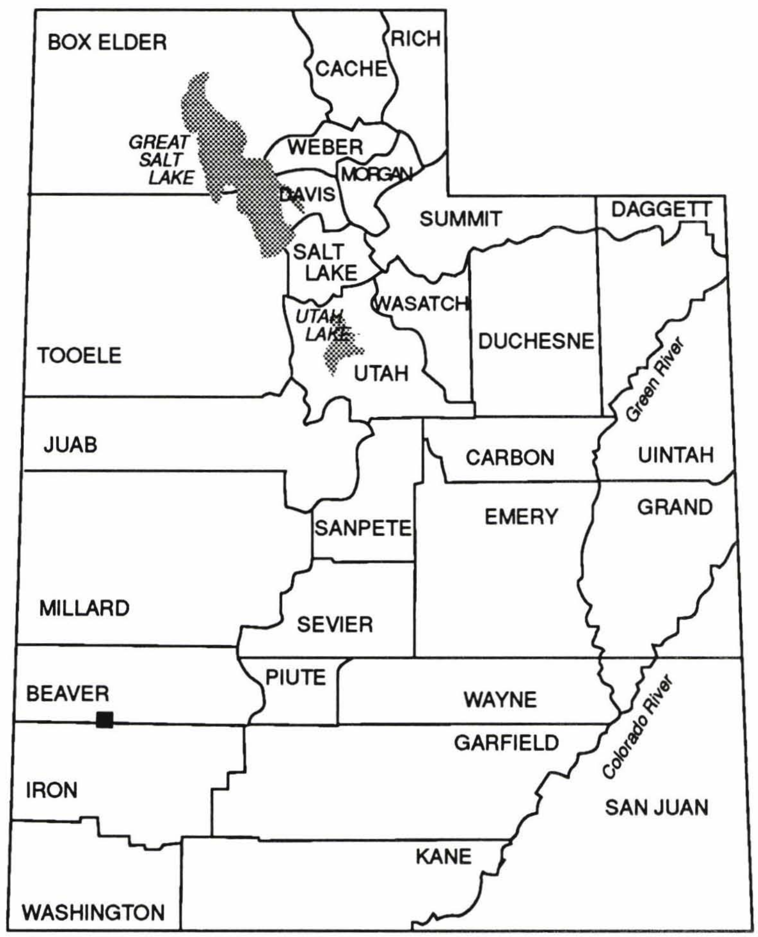




GEOLOGIC MAP OF THE BLUE MOUNTAIN QUADRANGLE, BEAVER COUNTY,UTAH

by

Clark Weaver[1] and Lehi F. Hintze[2]
[1]Union Oil Company, Sugar Land, Texas
[2]Utah Geological Survey



Map 146 **1993**
UTAH GEOLOGICAL SURVEY
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GEOLOGIC MAP OF THE BLUE MOUNTAIN QUADRANGLE, BEAVER COUNTY, UTAH

by

Clark L. Weaver[1] *and Lehi F. Hintze*[2]
[1]*Union Oil Company, Sugar Land, Texas*
[2]*Utah Geological Survey*

ABSTRACT

The Blue Mountain quadrangle lies in the southern Wah Wah Mountains, just west of the Escalante Desert, 25 miles (40 km) southwest of Milford, Utah. The oldest exposed rocks are Middle Cambrian limestone, dolomite, and shale units that are thrust over Lower Jurassic and Triassic strata of the Temple Cap, Chinle, and Moenkopi Formations and Navajo Sandstone. The overthrust is particularly well exposed on Blue Mountain, a north-south, basin-and-range horst. On Blue Mountain, and at two other localities in the quadrangle, the overthrust is folded into broad anticlines which may have formed above inferred laccolithic intrusions. Oligocene and Miocene volcanic rocks, more than 5,000 feet (1,500 m) thick, rest with moderate angular unconformity on the Paleozoic and Mesozoic strata. The oldest units in the volcanic sequence are an informally named tuff, a volcanic debris flow, and a conglomerate. These are of limited distribution, and nowhere more than a few hundred feet thick. The succeeding Needles Range Group here consists of, in ascending order, the Escalante Desert Formation, Cottonwood Wash Tuff, Wah Wah Springs and Lund Formations. The Escalante Desert Formation, 33-32 m.y. (million years old), is made up of andesite flows, rhyolite flows, and ash-flow tuffs totalling more than 2,000 feet (600 m) in thickness. The Cottonwood Wash Tuff, Wah Wah Springs and Lund Formations are ash-flow tuffs of intermediate composition, between 30.6 and 27.9 m.y.; they aggregate more than 2,000 feet (600 m) thick. These are overlain by 27 m.y. ash-flow tuffs of the Isom Formation, here about 100 feet (30 m) thick. The early Miocene Blawn Formation, 23-18 m.y., consists of mafic and rhyolite flows and ash-flow tuffs totaling about 1,000 feet (300 m) in thickness. Later Miocene deposits include poorly sorted alluvial deposits, several hundred feet thick, intercalated locally with basalt flows of the Steamboat Mountain Formation. Quaternary rocks in the quadrangle include a succession of alluvial deposits laid down in stream courses and on fans and pediments, as well as widespread colluvial cover on slopes.

All pre-Quaternary rocks are cut by normal faults. A prominent northwest-striking graben in the middle of the map area is believed to have formed during an early phase of extension in early Miocene time. The north-striking faults that bound Blue Mountain are basin-and-range faults of late Miocene to Holocene age. Hydrothermal alteration of bedrock is widespread in the quadrangle and has attracted mineral exploration efforts sporadically from the late 1800s to the present, as attested by widely scattered abandoned shallow pits, and by many boreholes drilled in 1989 on hypothetical disseminated gold targets related to the Blue Mountain overthrust. However, to date there has not been significant economic production of minerals in the quadrangle. Industrial rock and mineral resources include minor production of sand and gravel for local roads, and limited quarrying of liesegang-banded altered tuff from the Blawn Formation for decorative building stone. Because of limited precipitation, there are no perennial streams in the quadrangle. No people live within the quadrangle so the potential for loss of life due to geologic hazards such as flash floods, which are fairly frequent in summertime, or earthquakes, which probably have an occurrence frequency measured in hundreds or thousands of years, is extremely low. Except for the graded roads, there are no significant man-made structures within the quadrangle.

Figure 1. Aerial view of Blue Mountain looking southwesterly. Light-colored strata at right center are white sandstone beds of the Jurassic Temple Cap Formation, underlain in right corner foreground by darker Navajo Sandstone. Gray cliffs above are Cambrian carbonates and shales that are thrust over the Jurassic rocks. Hills in background are part of southern Wah Wah Mountains, here mostly Oligocene and Miocene volcanic rocks. West edge of the Escalante Desert shows along left edge of photo.

INTRODUCTION

Blue Mountain (highest elevation, 7,594 feet (2,315 m) rises about 2,500 feet (760 m) above the floor of the Escalante Desert some 25 miles (40 km) southwest of Milford, Utah (figure 2). It is a prominent north-south fault block about 2 miles wide (3 km) and 8 miles (13 km) long that is part of a larger sprawling group of hills forming the southern Wah Wah Mountains. Blue Mountain itself is of interest structurally for its magnificent exposure of a regional thrust, called the Blue Mountain thrust (Miller, 1966), that places drab Cambrian marine carbonate strata over brightly colored Mesozoic sandstone and shales. The southern Wah Wah Mountains have attracted mineral exploration over the past century because of widespread hydrothermal alteration that is accompanied by traces of metallic mineralization. But, to date, there has been no significant production of economic minerals from within the Blue Mountain quadrangle.

A geologic map of the southern Wah Wah Mountains was published by Miller (1966), and surrounding areas have been mapped more recently as shown on figure 2. A detailed map of the Blue Mountain quadrangle was prepared by Weaver (1980). Bedrock geology of the present map is largely taken from Weaver's map, modified in a few places by reassignment of volcanic rocks based on regional work by Best and others (1987b), and by changes incidental to mapping of Quaternary units by L.F. Hintze during 1987-89 field work. This mapping was greatly facilitated by the availability of 1:25,000 color aerial photographs of the CSR-F series, taken in 1979 in connection with Air Force evaluation of western Utah as a possible site for MX-missile deployment.

STRATIGRAPHY

Bedrock stratigraphic units are divided into three structurally separate packages of disparate ages, Cambrian, Mesozoic, and Tertiary. Cambrian rocks are marine carbonates and shales with an exposed thickness of more than 3,000 feet (900 m) and assigned to several formations, all of which are thrust upon autochthonous or parautochthonous Mesozoic strata that include the Triassic Moenkopi and Chinle Formations and the Jurassic Navajo Sandstone and the Temple Cap Formation. Exposed Mesozoic rocks are nearly 3,000 feet (900 m) thick here. Tertiary rocks, more than 6,000 feet (1,800 m) thick, lie unconform-

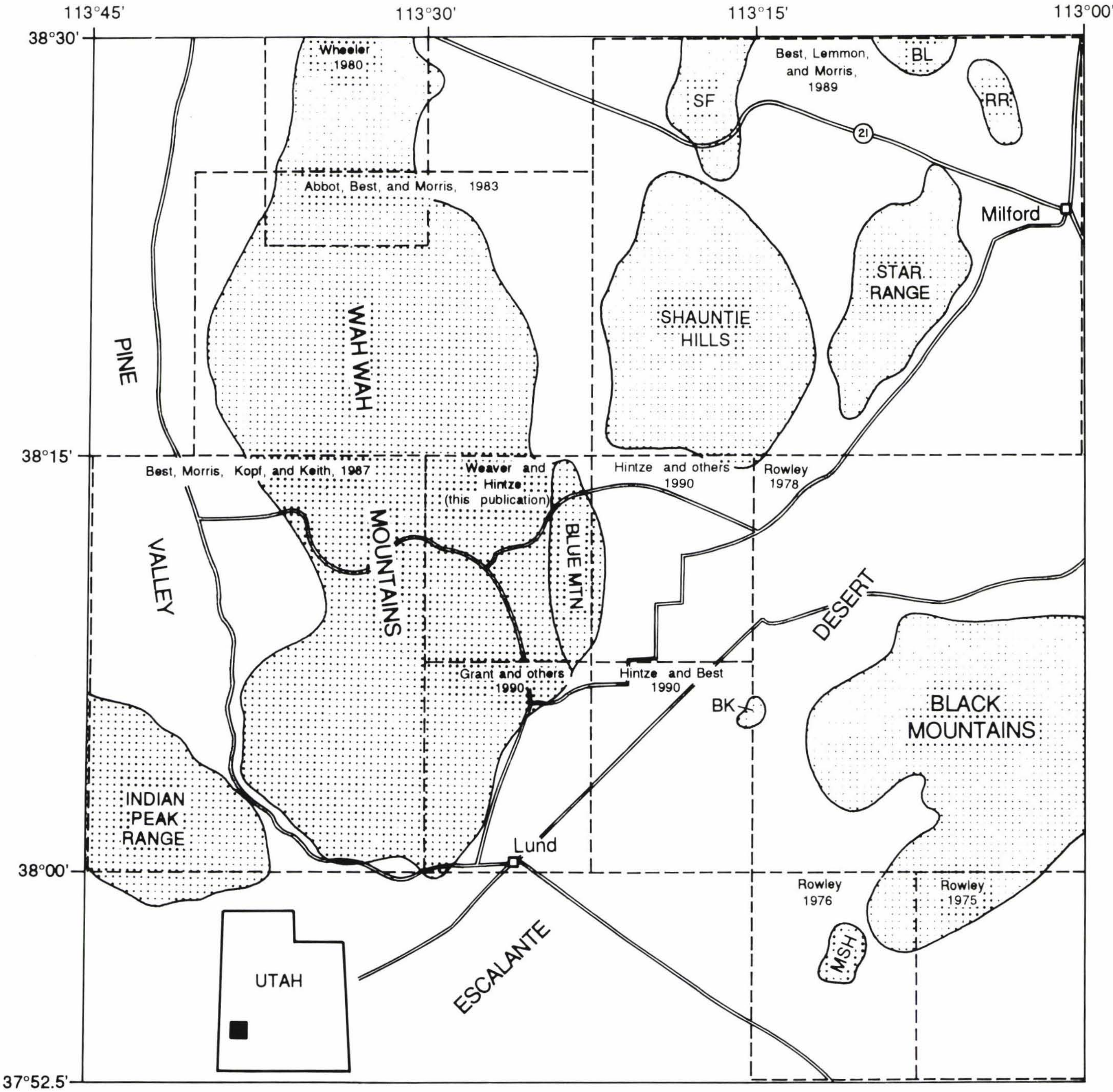

Figure 2. *Index map and published geologic maps in the vicinity of this quadrangle. SF-San Francisco Mountains, BL-Beaver Lake Mountains, RR-Rocky Range, BK-Blue Knoll, MSH-Mud Spring Hills.*

ably on all older rocks and include the Oligocene volcanic Escalante Desert, Cottonwood Wash, Wah Wah Springs, and Lund Members of the Needles Range Group, and the Isom Formation, the Miocene volcanic Blawn Formation, and Tertiary sedimentary basin-filling deposits. Quaternary rocks, a few hundred feet thick at most, include a succession of alluvial deposits that were laid down along stream courses, and on fans and pediments, as well as widespread colluvial cover on slopes.

Cambrian Strata Above The Blue Mountain Thrust

Nomenclature for Cambrian strata in this quadrangle, as shown on figure 3, was extended from the northern Wah Wah Mountains where it had been established by Hintze (1974), Hintze and Robison (1975), and Wheeler (1980). Cambrian rocks above the thrust on Blue Mountain itself are remarkably undeformed and exhibit the best Cambrian stratigraphic sequence in the southern Wah Wah Mountains. Elsewhere in the map area Cambrian rocks are generally more fractured, dolomitized, and silicified and do not present coherent sequences that allow tracing of the several formations that are identified on Blue Mountain. Weaver (1980) handled this problem by establishing a series of lettered map units, a to d; we have chosen to lump deformed Middle Cambrian strata in the western part of the map into two map units, a lower Middle Cambrian map unit that includes the Chisholm, Dome, Whirlwind, and Swasey rock types, and an upper Middle Cambrian map unit that includes the Swasey, Pierson Cove, and Trippe rock types. Most of the Middle Cambrian sequence in western Utah is composed of carbonate lithologies that are repeated in several formations, and identification of map units depends on certain unique beds. For the lower Middle Cambrian sequence the key beds are distinctive trilobite coquinas that occur within olive shales in the Chisholm and Whirlwind Formations. The upper Middle Cambrian Trippe Limestone and Pierson Cove Formation contain a distinctive lithology, white laminated dolomitic boundstone, that is not found in other parts of the Cambrian sequence. Weaver (1980) presented measured sections of all the Cambrian map units in this quadrangle, and the following discussion relies on his descriptions, supplementing them in some cases with additional observations. The reader is referred to Weaver's original measured section descriptions which are not repeated here. Because of faulting, a complete Middle and Upper Cambrian sequence is not exposed in the map area. However, a complete Cambrian sequence was described by Hintze (1974) and Wheeler (1980) in the northern Wah Wah Mountains, some 20 miles (36 km) north of Blue Mountain. All Cambrian strata exposed in the quadrangle have been transported an unknown distance from the west on the Blue Mountain thrust. If a well were drilled through the thrust and deep enough to reach the in-place (autochthonous) Cambrian rocks at depth, these Cambrian rocks would be thinner, and the nomenclature used for the allochthonous rocks at the surface would not be applicable (Hintze, 1988).

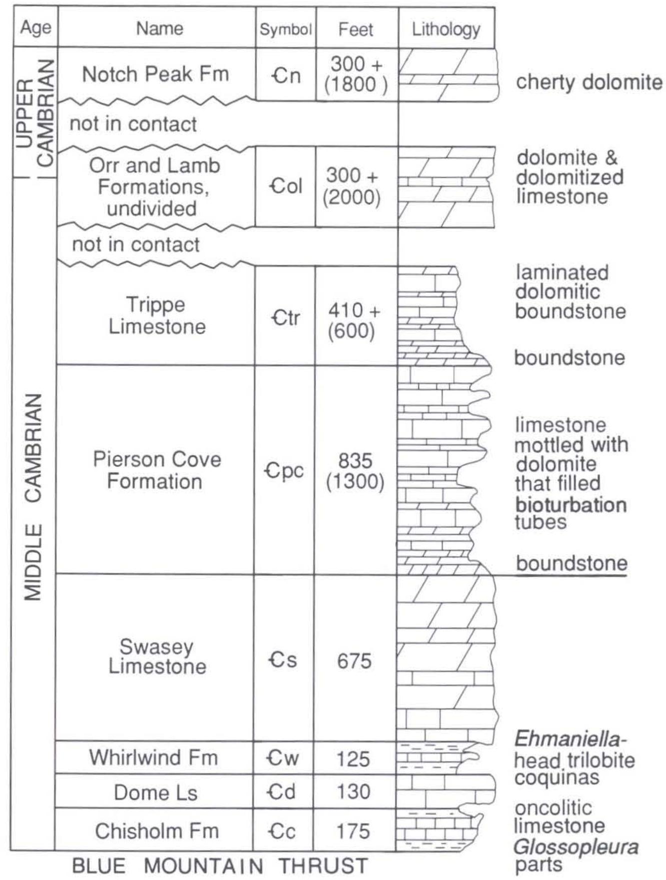

Figure 3. *Schematic lithologic column of Middle and Upper Cambrian strata in the Blue Mountain quadrangle. These rocks have been transported tens of miles on the Blue Mountain thrust to lie atop Jurassic and Triassic strata here. Upper value in thickness column shows amount of each formation exposed. Figure in parentheses is regional thickness value taken from Hintze (1974) and Wheeler (1980).*

Chisholm Formation (Ꞓc)

In southwestern Utah the Chisholm Formation generally consists of three parts: a thick, lower olive shale with abundant *Glossopleura* trilobite fragments; a middle dark-gray, oncolitic ledge-forming limestone; and a thin, upper, olive or red shale that is commonly concealed by talus from Dome Limestone cliffs. Weaver (1980) included in his Chisholm map unit both the Chisholm Shale and Peasley Limestone (Hintze and Robison, 1975; Wheeler, 1980). Weaver's (1980) measured section on Blue Mountain showed 128 feet (39 m) of lower shale, and 47 feet (14 m) of oncolitic limestone; the upper shale was not present, perhaps having been removed by bedding-plane attenuation faulting. An easily accessible place to examine a well-exposed Chisholm sequence is in the northwest quarter of section 3, T. 30 S., R. 14 W. where the small remnants of the Chisholm Formation can be found at several places where the undivided lower Middle Cambrian map unit is in thrust contact with Navajo Sandstone. But mappable Chisholm is not as widespread as was initially suggested by Weaver (1980) in the mapped distribution of his "unit c," which he showed as approximately the Chisholm equivalent. The shale and thin- to medium-bedded limestones that make up the Chisholm and Whirlwind Formations are unique within the generally more massive Cambrian carbonate units. They seem to possess the mechanical characteristics which facilitated the Blue Mountain allochthon riding on either the Chisholm or the Whirlwind throughout the quadrangle.

Dome Limestone (€d)

Weaver (1980) measured this medium-gray, cliff- and ledge-forming limestone on Blue Mountain where he found it to be about 130 feet (40 m) thick. The limestone contains sparse oolite and pisolite beds and its upper 20 feet (6 m) is thin-bedded and silty, grading into the Whirlwind Formation. Lithologies in the Dome Limestone are so similar to some in the Swasey Limestone that they cannot be differentiated in structurally complex areas. Adjacent to the thrust the lower Middle Cambrian units are often so deformed and brittlely attenuated that the Dome Limestone cannot be identified as a separate unit. Wheeler (1980) assigned 310 feet (94 m) of limestone in the Wah Wah Mountains 15 miles (24 km) to the northwest (see figure 2 for location) to the Dome Limestone.

Whirlwind Formation (€w)

The Whirlwind Formation forms a shaly slope between the cliffs of the Dome and Swasey Limestones. It consists of pale yellowish-orange, fissile shale with interbeds of thin-bedded, silty, medium-gray limestone. Some limestone beds are coquinas of small heads of the trilobite *Ehmaniella,* the sure key to the identification of the Whirlwind Formation. A few limestone layers are intraformational conglomerate. Weaver's (1980) measured section indicated a thickness of 125 feet (38 m) for the Whirlwind Formation on Blue Mountain. The Blue Mountain thrust plate rides on disorganized Whirlwind Formation at some locations on the west side of Blue Mountain and around the anticlinal nose of the folded thrust in section 9, T. 30 S., R. 14 W. It seems to form an alternative thrust glide surface above the shaly Chisholm Formation.

Swasey Limestone (€s)

Only the basal 80 feet (24 m) of this formation is limestone; the upper 595 feet (181 m) is medium- to light-gray dolomite that forms massive cliffs. Weaver's (1980) measured section on Blue Mountain shows a very-light-gray dolomite band, about 25 feet (8 m) thick, at the base of the dolomite sequence. Regionally the Swasey is typically all limestone (Hintze and Robison, 1975). Dolomitization of the formation in the map area is believed to be the result of secondary hydrothermal alteration as discussed in the economic geology section of this report. Relict oolites are preserved locally. The contact with the overlying Pierson Cove Formation was taken at the base of a light-tan, laminated dolomitic boundstone that is easily distinguished on aerial photographs.

Because Swasey Limestone lies near the bottom of the Cambrian sequence on the overthrust sheet, it is commonly complexly fractured and folded. In addition to dolomitization, hydrothermal alteration produced widespread silicification; silica fills fractures in the dolomite creating boxwork structures in many places. These are particularly common in Cambrian rocks at the north end of Blue Mountain.

Pierson Cove Formation (€pc)

The Pierson Cove Formation is characterized by its generally dark-gray color which is conspicuously darker than the Trippe Limestone and also differs markedly in color and topographic expression from the underlying Swasey Limestone. It includes a light boundstone about 70 feet (21 m) thick at its base which shows prominently as a white band on aerial photographs. The main body of the formation consists of medium-dark-gray dolomite, alternately thin-bedded to massive; the massive units form low cliffs and the thin-bedded units form breaks in slope between cliffs. The upper part of the formation includes some limestone beds and, more rarely, laminated dolomitic boundstone. Mottling, probably caused by bioturbation penecontemporaneous with deposition, is common in massive units throughout, but particularly pronounced in upper limestone layers. The contact between the Pierson Cove and Trippe units was taken at the base of a 120-foot (36-m) thick laminated dolomitic boundstone unit in which intraformational flat-pebble conglomerate is locally common. Weaver's (1980) measured section showed the Pierson Cove Formation to be 835 feet (255 m) thick on Blue Mountain. Wheeler (1980) found the Pierson Cove to be nearly 1,300 feet (400 m) thick in the Wah Wah Mountains 15 miles (24 km) north of Blue Mountain.

Trippe Limestone (€tr)

As exposed at the south end of Blue Mountain, the Trippe Limestone is a sequence of light-colored, laminated dolomitic boundstones interbedded with medium-gray limestone and dolomite. Weaver (1980) measured 410 feet (125 m) of Trippe Limestone here. However, the section is incomplete, lacking the top part of the formation. Unit d in Weaver's (1980) Miller Meadows measured section is more than 1,100 feet (335 m) thick and includes not only most of the Trippe Limestone, but also higher Cambrian strata that probably belong to the Wah Wah Summit Formation as mapped by Wheeler (1980) 15 miles (24 km) north of Blue Mountain. However, the identity of Weaver's unit d is not certain enough to warrant showing the Wah Wah Summit Formation as a separate map unit on this quadrangle.

The boundstone beds that make up nearly half of the unit form light-colored slopes which make the Trippe Limestone show up from a distance and on aerial photographs as conspicuously lighter than adjacent formations. The Fish Springs Member of the Trippe Limestone, described by Hintze and Robison (1975) as a widespread marker bed, has not been found in the southern Wah Wah Mountains.

Lower Middle Cambrian units, undivided (€lu)

Because of structural complexities induced in Cambrian strata in this quadrangle by thrusting, subsequent normal faulting, and hydrothermal alteration, the formational identity of these rocks are obscured to the extent that we feel it would be misleading to users of this map if we attempted to segregate individual Cambrian formations in many parts of the map. We are, in this respect, even more cautious than Weaver (1980) who used lettered Cambrian units a to d. The relatively unbroken patterns of the a and b units on Weaver's map, we now believe, suggest more regularity in the stratigraphic units found at the base of the thrust plate than, in fact, exists. Accordingly, we now show only two lumped units: a "lower Middle Cambrian units, undivided", and an "upper Middle Cambrian units, undivided".

Lower Middle Cambrian units, undivided, includes parts of the Chisholm, Dome, Whirlwind, and Swasey rocks. This unit is in thrust contact with the Jurassic Navajo Sandstone, and in several places remnants of shale beds from the Chisholm or the Whirlwind Formations can be found among the distorted rocks. In three locations Chisholm shale exposures are large enough to be identified specifically on the map. The bulk of this map unit is limestone, commonly dolomitized, and thought to be mostly Swasey and Dome Limestones. It includes Weaver's (1980) Cambrian units a, b, and the lower part of c. He showed the measured thickness of this interval to be about 1,000 feet (305 m).

Upper Middle Cambrian units, undivided (€mu)

This unit includes beds that belong to the Swasey, Pierson Cove, and Trippe units, and may also include some higher beds that Wheeler (1980) mapped as the Wah Wah Summit Formation in the Wah Wah Mountains 15 miles (24 km) north of Blue Mountain. The key lithology that identifies this unit is light-colored, laminated dolomitic boundstone, a lithology that is common in the Pierson Cove Formation and Trippe Limestone but virtually absent in the lower part of the Cambrian sequence. This unit includes the upper part of Weaver's (1980) Cambrian unit c, and all of his unit d. He measured this interval to be about 1,800 feet (540 m) thick.

Orr and Lamb Formations, undivided (€ol)

This map unit is separated by faults from other Cambrian strata. Its lower part consists of thin- to thick-bedded, medium-dark-gray, coarsely crystalline dolomite similar to the Lamb Dolomite elsewhere in west-central Utah (Hintze and Robison, 1975). Its upper part is grayish-brown, fine-grained, silicified dolomite. Weaver (1980) noted that in the southeastern edge of the main exposure of this unit he found an oolitic limestone lens with abundant, but unidentifiable, trilobite fragments. This occurrence suggests identification of this part of the unit as the Big Horse Limestone Member of the Orr Formation. The Big Horse was mapped by Best and others (1987a) in exposures located 6 miles (9.6 km) west of the outcrops on the Blue Mountain quadrangle. Weaver (1980) assigned this entire unit to the Orr Formation and calculated it to be about 300 feet (90 m) thick.

Notch Peak Formation (€n)

The rocks here identified as Notch Peak Formation are structurally separated from other Cambrian strata. They are dark-brownish-gray cherty dolomites, generally thick bedded, with traces of large algal stromatolites in some beds. As with other Cambrian rocks in this quadrangle, these dolomite beds show secondary silicification which obscures their primary features to a considerable extent. However, the presence of what is thought to be primary chert and the large algal structures suggest the assignment of this dolomite to the Notch Peak Formation as described by Hintze (1974) in the northern Wah Wah Mountains, 30 miles (48 km) north of Blue Mountain. Total exposed thickness of Notch Peak strata in this quadrangle is about 300 feet (90 m).

Mesozoic Strata Below The Blue Mountain Thrust

Triassic rocks on Blue Mountain (figure 4) are the westernmost representatives of rocks of this age at this latitude in Utah. This is also the westernmost occurrence of the Lower Jurassic Temple Cap Formation. The Navajo Sandstone, however, is exposed again 2 miles (3 km) beyond the west edge of this quadrangle as described by Best and others (1987a). Description of Mesozoic map units is taken in part from Miller (1966) and Weaver (1980). All Mesozoic strata on Blue Mountain have undergone low-grade thermal metamorphism that probably was produced by a concealed pluton.

Moenkopi Formation (₸m)

Only the uppermost 500 feet (150 m) of the Moenkopi Formation is exposed on Blue Mountain. Regionally in southwestern Utah, the Moenkopi Formation is about 2,000 feet (610 m) thick (Hintze, 1988) and is divided into five members. Most Moenkopi rocks exposed at Blue Mountain probably represent the uppermost regional member, called the "upper red member," typically composed of red sandstone and siltstone. The top of the underlying Shnabkaib Member, a gypsiferous and dolomitic siltstone, may also be represented here. On Blue Mountain the lowest Moenkopi exposures are metamorphosed green lenticular siltstones. Miller (1966) reported that thin-sections of these rocks show abundant actinolite and chlorite porphyroblasts. Epidote is present in some bands and along fractures indicating that the original sediments were somewhat calcareous. Other beds in the Moenkopi are dense, olive-gray, siliceous shales that show splintery fracturing. Moenkopi rocks range widely in color, from black and green to pale greenish-yellow and yellowish-brown. They are generally thin bedded and weather to platy or blocky rubble. Moenkopi rocks on the east side of Blue Mountain are broken by many normal faults. The most complete Moenkopi sequence is on the west side of Blue Mountain where strata about 500 feet (150 m) thick are exposed. The Moenkopi Formation is Lower Triassic in age (Hintze, 1988).

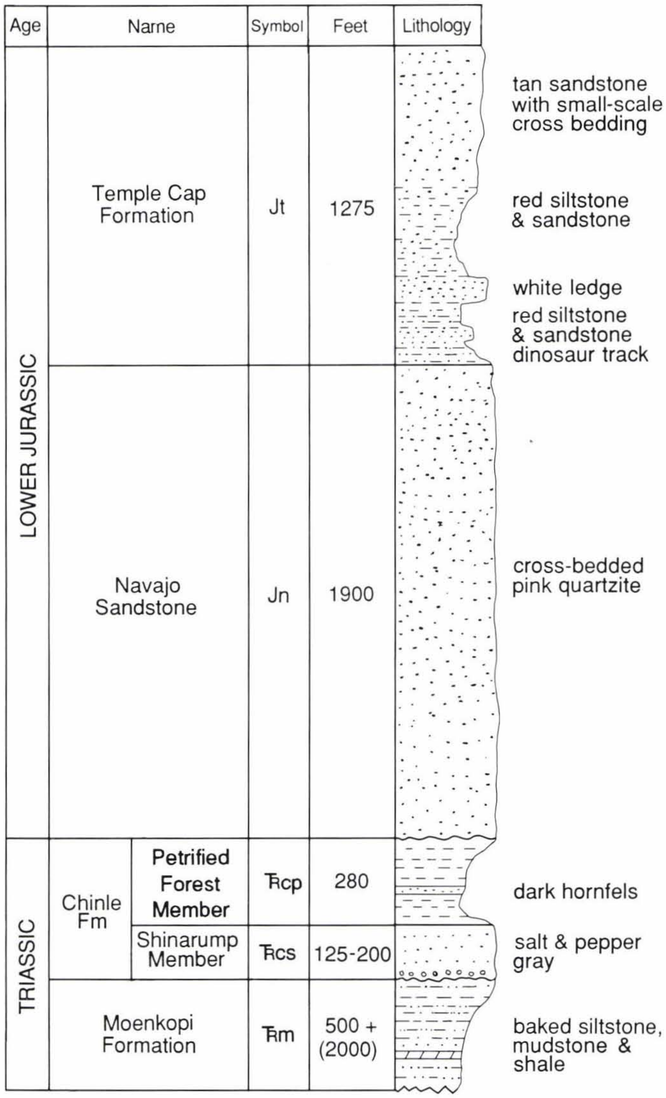

Figure 4. *Schematic lithologic column of Lower Jurassic and Triassic strata in the Blue Mountain quadrangle. These strata lie beneath the Blue Mountain thrust. The Triassic rocks and the Navajo Sandstone appear to have been metamorphosed by heat, probably from a buried intrusion. Number in parentheses is regional thickness.*

Chinle Formation, Shinarump Member (TRcs)

The Shinarump is the basal member of the Upper Triassic Chinle Formation in southwestern Utah. In many places it is conglomeratic; on Blue Mountain it is mostly sandstone, but includes a quartzite pebble conglomerate, that ranges from 1 to 8 feet (0.3-2.4 m) in thickness, near its base. This basal conglomerate fills paleostream channels cut into the Lower Triassic Moenkopi Formation. The basal conglomerate grades upward into coarse-grained quartz sandstone containing some scattered pebbles. Most of the Shinarump is a gray, salt-and-pepper sandstone that appears conspicuously lighter in color on aerial photographs than the adjacent Moenkopi or upper Chinle units. Petrified wood collected from the Shinarump on Blue Mountain was identified as *Araucarioxylon arizonicum*, a species common in the Chinle Formation in southern Utah and Arizona. Fluvial cross-bedding is common in the Shinarump Member, particularly in its upper part. The Shinarump Member ranges from 125 to 200 feet (35-60 m) thick on Blue Mountain.

Chinle Formation, Petrified Forest Member (TRcp)

The upper Chinle on Blue Mountain is commonly a dark hornfels that shows up well on aerial photographs because of its dark color. Regionally this part of the Chinle Formation is known as the Petrified Forest Member. Limestone nodules, a minor regional characteristic of the member, occur sparsely on Blue Mountain. The Petrified Forest Member includes much bentonitic ash that forms varicolored muddy clay beds in unmetamorphosed areas. These bentonitic beds were particularly susceptible to silicification and thermal metamorphism and are now seen as hornfels in the upper Chinle on Blue Mountain. Despite Miller's (1966) suggestion that the upper part of this map unit might include Moenave or Kayenta Formation equivalents, we believe it does not, and that it is best regarded as entirely equivalent to the Petrified Forest Member. It is 280 feet (85 m) thick on Blue Mountain.

Navajo Sandstone (Jn)

Navajo Sandstone consists of fine- to medium-grained, pinkish- or yellowish-gray, quartz sand that has been silicified to the extent that it resembles a quartzite. Large-scale cross-beds and frosted grains attest to its largely eolian origin. Miller (1966) noted the occurrence of a few thin silty beds in the upper part of the formation that suggest minor aqueous deposition. Navajo Sandstone is one of the most widely distributed formations in Utah. Its thickness of about 1,900 feet (580 m) on Blue Mountain is typical for exposures at the western edge of its occurrence beneath overthrust plates in western Utah (Hintze, 1988).

Temple Cap Formation (Jt)

The red and white sandstone and siltstone beds that lie conformably above the Navajo Sandstone on Blue Mountain were called "Carmel Formation" by Weaver (1980) and "Winsor Formation and San Rafael Group, undifferentiated" by Miller (1966). Present stratigraphic usage in southwestern Utah (Hintze, 1986, 1988) suggests that Temple Cap Formation is a more appropriate name for this entirely clastic unit. We remeasured the section described by Miller (1966) on the south slope of the saddle on Blue Mountain and found the following:

Temple Cap beds lie beneath overthrust Cambrian strata.

Unit	Thickness/feet (m)
9. Sandstone, yellowish-gray, medium- to fine-grained, mostly small-scale cross-bed, fluvial, weakly cemented, forms conspicuous ledges and cliffs at top of exposed Temple Cap section	570 (173.7)

8. Interbedded red silty sandstone and white sandstone, forms ledges beneath unit 9 . . . . 205(62.5)
7. Brick-red silty sandstone, thin-bedded, forms small saddle between more resistant units 40 (12)
6. Sandstone, medium- to coarse-grained, white, with small-scale cross-bedding, forms dipslope above more resistant unit 5 . . . . 105 (32)
5. Sandstone, medium-grained, white, forms prominent cliffs and ledges, small-scale cross-beds, top cliff obvious on aerial photographs 110 (33.5)
4. Red silty sandstone with 40 percent interbeds of white calcareous sandstone that forms flaggy talus. Unit forms a pink slope as seen from a distance 100 (30.5)
3. Sandstone, white, fine-grained, thick-bedded, with 40 percent interbeds of brick-red, thin-bedded silty sandstone, forms lowest ledge in Temple Cap 50 (15)
2. Interbedded, white, flaggy sandstone and thin-bedded red siltstone, forms low ledges and slopes . . . . 30(9)
1. Siltstone and fine-grained sandstone, brick-red, thin-bedded, forms slope. Miller (1966) reported a single imprint of a small three-toed bipedal dinosaur track from this unit. Base appears conformable on Navajo Sandstone 65 (19.8)

Total thickness 1,275 (388.6)

Tertiary Volcanic And Sedimentary Deposits

Weaver (1980) subdivided the volcanic rocks in this quadrangle for the first time. More recently, Best and Grant (1987), and Best and others (1987b) presented summaries of regional relationships in Oligocene and Miocene volcanic rocks in southwestern Utah. They modified the stratigraphic nomenclature of these rocks, and gave isotopic ages, regional distributions, sources, and volumes for the various volcanic units. In the following pages we follow their nomenclature for most of our map units. A few units are local to this quadrangle and were not treated by the regional studies listed above.

Figure 5 shows that Tertiary rocks in the map area are more than 6,000 feet (1,800 m) thick, and range in age from about 34 to 10 million years old. The oldest rocks are limited to small outcrops at the north and south ends of Blue Mountain. They have not been isotopically dated; their age is inferred from the observation that no volcanic rocks older than 34 million years old have been reported from anywhere in southwestern Utah (Hintze, 1988). The succeeding Needles Range Group here includes the Cottonwood Wash Tuff, the Escalante Desert, Wah Wah Springs, and Lund Formations. The uppermost Oligocene unit is the Isom Formation, a widely distributed ash-flow tuff. Miocene deposits include the volcanic Blawn Formation, 23 to 18 million years old, which is unconformably overlain by an unnamed local sandstone and conglomerate unit that includes interbedded basalt flows assigned to the Steamboat Mountain Formation, 13 to 12 million years old.

Many volcanic rocks in this quadrangle are so hydrothermally altered that their identity is uncertain and obtaining isotopic dates from them is unreliable. In addition, some of the units are of only local occurrence, and many units range considerably in thickness either because of their original mode of distribution or because of the unevenness of the paleoterrains upon which they

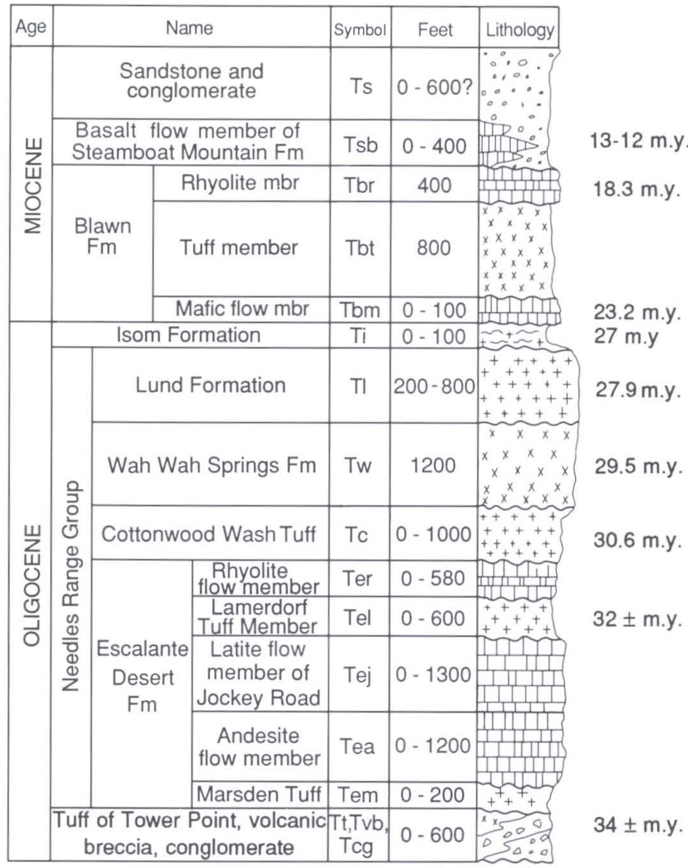

Figure 5. *Schematic lithologic column of Tertiary volcanic and sedimentary deposits in the Blue Mountain quadrangle. These deposits lie unconformably on all older rocks, and many disconformities occur within this sequence.*

were deposited. The even stacking of units on figure 5 may give readers unacquainted with such schematic diagrams an impression of greater regularity in the distribution and thickness of the volcanic units than actually exists.

Conglomerate (Tcg)

This conglomerate is exposed at only one locality in the quadrangle, at the north end of Blue Mountain in section 34, T. 29 S., R. 14 W., where it appears to rest uncomformably on steeply dipping Cambrian carbonate rocks. Half of the clasts in the conglomerate are rounded quartzite pebbles, cobbles, and boulders up to 2 feet (0.6 m) in diameter; they are mostly white or tan, similar to the lithology of the Lower Cambrian Prospect Mountain Quartzite, but some are purplish-red suggesting late Precambrian Mutual Formation quartzite like that exposed in the southern Wah Wah Mountains some 10 miles (16 km) to the northwest (Abbott and others, 1983). About 40 percent of the clasts are Cambrian carbonate boulders and cobbles. The remaining 10 percent of the clasts are dark-gray to dark-red andesite cobbles and boulders that contain small, white, chalky feldspar phenocrysts. Some exposures of andesite associated with this conglomerate are large enough to suggest the possibility that they might be intrusive dikes. The conglomerate dips about 40 degrees westward and has a thickness of about 200 feet (60 m).

Volcanic breccia (Tvb)

Two small outcrops are included under this designation. The larger is on the west side of the south end of Blue Mountain. The rock there is a dark-gray andesite with about 20 percent white, boxy feldspar phenocrysts, some as much as 0.2 inches (0.5 cm) long. Although Weaver (1980) showed it as being in fault contact with the Marsden Tuff Member, we now believe it lies unconformably beneath the Marsden. It is more than 100 feet (30 m) thick. The second outcrop is on the northwest flank of Iron Mountain in section 7, T. 30 S., R. 14 W. Weaver (1980) described this as a brecciated igneous plug intruded into surrounding Cambrian carbonate rock. Some hydrothermal alteration surrounds this plug, and prospect pits have been dug nearby.

Tuff of Tower Point (Tt)

This unit is more extensively exposed in the Lund quadrangle (Grant and others, 1990) south of Blue Mountain. Just the northern tip of a larger body extends into the southeastern corner of the quadrangle in section 11, T. 31 S., R. 14 W. The rock is a red and gray, densely welded, but weakly resistant tuff with 25 to 30 percent phenocrysts of plagioclase and quartz, minor biotite, and traces of sanidine and hornblende. Quartz grains may exceed 0.1 inch (3 mm) across and are locally euhedral in pumice fragments. Biotite is conspicuous and visibly warped. This unit is as much as 600 feet (180 m) thick in the northeast corner of the adjoining Lund quadrangle (Grant and others, 1990). It may correlate with the Sawtooth Peak Formation of the Indian Peak Range (Needles Range) (Best and others, 1987b), but does not contain as much quartz. The Sawtooth Peak Formation is about 33.5 million years old.

Escalante Desert Formation

Best and Grant (1987) added this formation to the Needles Range Group "because the magmas that created it were derived from essentially the same area, and from the same magma system that produced the other formations in the group." The Escalante Desert Formation has been divided into five members in this quadrangle: in ascending order, Marsden Tuff Member, andesite flow member, latite flow member of Jockey Road, Lamerdorf Tuff Member, and rhyolite flow member.

Marsden Tuff Member (Tem): This member was named by Best and Grant (1987) for rocks at Marsden Spring in the Lund quadrangle just south of the Blue Mountain quadrangle. The Marsden Tuff is variously pinkish-gray, light orange brown, light gray, or greenish gray; it is a lithic-rich, crystal poor, moderately welded, rhyolitic ash-flow tuff that contains 2 to 6 percent phenocrysts, mainly plagioclase and quartz, and a trace of biotite. Lithic fragments include volcanic rocks, quartzite, and green phyllite; some are as large as 8 inches (20 cm) across and in places make up more than 10 percent of the rock. Marsden rocks have been so hydrothermally altered throughout the map area that none of the exposures have yielded samples suitable for isotopic dating. Thickness ranges from 0 to 200 feet (0-60 m) in the map area. Its source is the Pine Valley caldera (Best and others, 1987b).

Andesite flow member (Tea): This informal member forms low rounded hills in the northwest-striking graben near the center of the map area. The andesite is black to gray, aphanitic to glassy, and includes small phenocrysts of pyroxene and plagioclase. Thickness ranges from 0 to 1,200 feet (0-370 m).

Latite flow member of Jockey Road (Tej): Weaver (1980) applied this informal name to latite flows apparently found only in this quadrangle. The rock is aphanitic to glassy, grayish red, grayish brown, or grayish red-purple; it commonly shows liesegang banding and weathers to blocky talus. The latite invariably contains some biotite; most samples include some hornblende phenocrysts, and in some samples hornblende is abundant. The variable phenocryst composition and presence of intramember vitrophyres suggest multiple extrusions, probably from local vents. Map distribution shows a close relationship with the underlying andesite member. Thickness ranges from 0 to 1,300 feet (0-400 m).

Lamerdorf Tuff Member (Tel): This ash-flow tuff is mottled reddish- or purplish-gray, is generally densely welded, and contains 10 to 15 percent plagioclase, 1 to 5 percent biotite, and trace amounts of hornblende, quartz, sanidine, and Fe-Ti oxides. Light-colored, flattened pumice lapilli and dark volcanic fragments, which make up as much as 25 percent of the member near its base, cause the mottled appearance of the rock. Best and Grant (1987) reported a K-Ar age of 32.3 ± 1.1 Ma on biotite from the Lamerdorf Tuff Member. Thickness in this quadrangle ranges up to about 600 feet (180 m), and its source is the Pine Valley caldera (Best and others, 1987c).

Rhyolite flow member (Ter): Weaver (1980) called this unit his "upper quartz latite flow member." It occurs at only one locality east of Red Hill. It is an altered rock that is mottled reddish or brownish gray and weathers to grus. It contains 10 to 15 percent phenocrysts of plagioclase, quartz, and biotite, and is up to 580 feet (180 m) thick.

Cottonwood Wash Tuff (Tc)

This member of the Needles Range Group appears to be a crystal-rich, simple ash-flow tuff cooling unit which is characterized by large, euhedral biotite phenocrysts (10-15 percent); plagioclase (25 percent); a small percentage of large, embayed quartz phenocrysts; and minor hornblende, green augite, and Fe-Ti oxides. Lithic fragments are rare, and flattened pumice lapilli are present, but not conspicuous. The biotite phenocrysts are commonly aligned producing a foliated rock texture. Age is 30.6 million years (Best and Grant, 1987). Thickness ranges from 0 to 1,000 feet (0-300 m). The source caldera is not well defined.

Wah Wah Springs Formation (Tw)

All of this formation in this quadrangle belongs to the ash-flow tuff member of the Wah Wah Springs Formation as redefined by Best and Grant (1987). This is a simple, densely welded, crystal-rich ash-flow tuff cooling unit that originated from the Indian Peak caldera a few miles west of this quadrangle. It is reddish-brown to light-gray, and contains abundant plagioclase, prominent hornblende, lesser biotite, minor quartz, augite, and Fe-Ti oxides. Flattened pumice lapilli are conspicuous in some places, and a basal black vitrophyre is common. Average age is 29.5 million years (Best and Grant, 1987). Thickness is at least 1,200 feet (370 m).

Lund Formation (Tl)

All of this formation in this quadrangle belongs to the tuff member of the Lund Formation as redefined by Best and Grant (1987). This is a simple cooling unit of densely welded ash-flow tuff that originated from the White Rock caldera astride the Utah-Nevada border about 15 miles (24 km) west of the map area. The tuff member of the Lund Formation is crystal rich and contains abundant plagioclase, relatively abundant (5-10 percent) quartz, more biotite than hornblende, and, most diagnostic of all, trace amounts of sphene. Average age is 27.9 million years (Best and Grant, 1987). Thickness ranges from 200 to 800 feet (60-240 m).

Isom Formation (Ti)

This is a crystal-poor, dark-reddish-brown to grayish-purple, densely welded trachytic ash-flow tuff that is characterized by extremely compressed pumice lapilli that often appear as aligned voids in weathered outcrops. The Isom is thin and discontinuous in this quadrangle despite the inferred nearby location of its source caldera along the Utah-Nevada border about 10 miles (16 km) southwest of this map area. The tuff contains less than 12 percent phenocrysts of plagioclase, and minor pyroxene and magnetite. Its age is about 27 million years old, and it is generally less than 100 feet (30 m) thick in the map area.

Blawn Formation

This is a bimodal rock assemblage that ranges in age from 23 to 18 million years old (Best and others, 1987b).

Mafic lava flow member (Tbm): This brown or brownish-gray trachyandesite contains a small percentage of pyroxene and plagioclase phenocrysts. In hand sample this rock resembles the andesite flow member of the Escalante Desert Formation. Stratigraphic relations of adjacent units help determine the identity of these similar units. Best and others, (1987b) reported an age of 23.2 ± 1.0 Ma for Blawn mafic rocks. Blawn mafic flows are thin and discontinuous in the map area, ranging from 0 to about 100 feet (0-30 m) in thickness.

Tuff member (Tbt): This consists of a heterogeneous sequence of ash-flow tuffs, with minor thin-bedded, air-fall, pyroclastic-surge, and minor fluvial deposits that are well exposed on the southwest side of Broze Knoll. Ash-flow tuffs are white, gray, orange, tan, and pink, and contain light-colored pumice lapilli, dark-colored lithic lapilli, and generally less than 20 percent phenocrysts of sanidine, quartz, sodic plagioclase, and biotite. Where unaltered, tuffs are generally weak and poorly exposed. However, the tuffs are commonly silicified and iron-stained, and their resistant colorful outcrops show up well on aerial photographs. The tuff member is as much as 800 feet (240 m) thick locally.

Rhyolite member (Tbr): This member consists of light-gray to pale-purplish-gray, flow-layered rhyolite lava flows. The large outcrop along the north margin of the map is dense rhyolite with small phenocrysts of quartz and sanidine. Elsewhere the rhyolite is vuggy and contains large sanidine and quartz phenocrysts. Best and others (1987b) recorded an age of 18.3 ± 0.7 Ma for Blawn rhyolite a few miles northwest of this map. Maximum thickness in this quadrangle is about 400 feet (120 m).

Basalt flow member of Steamboat Mountain Formation (Tsb)

These flows are black, vesicular to dense, and commonly contain olivine phenocrysts. They occur interbedded near the base of the late Tertiary sandstone and conglomerate sequence that covers most of the western third of the map area. Steamboat Mountain basalt clasts of all sizes are a common constituent, not only of the Tertiary sandstone and conglomerate, but also of all Quaternary alluvial deposits. Best and others (1987b) indicated an isotopic age of 13-12 Ma for Steamboat Mountain mafic rocks. Thickness of the basalt member in this quadrangle is as much as 400 feet (120 m).

Sandstone and conglomerate (Ts)

This unit is widespread in the western third of the quadrangle. It is pinkish-gray, variably cemented, poorly sorted sandstone that contains interbeds of conglomerate made of subrounded to angular clasts (figure 6) that include some very large boulders but are mostly pebble or cobble size. Clasts are mostly of local Cambrian carbonate and Tertiary volcanic rocks; conglomerate ranges from 90 percent carbonate clasts to 90 percent volcanic clasts in places. In most outcrops this unit shows dips of less than 10 degrees, but in some places it dips as much as 40 degrees. Because the unit is generally covered by reworked indigenous colluvium or alluvium its structure is only partly understood. Wherever it can be seen or inferred, its basal contact is an angular unconformity of as much as 15 degrees. This unit is interbedded locally with basalt flows of the Steamboat Mountain Formation which fix its age as Miocene. In both general appearance and in age relationships it is similar to the Muddy Creek Formation near Gunlock, Utah and Mesquite, Nevada (Hintze, 1986). Both appear to be early basin-and-range extensional basin-fill deposits that have been subsequently elevated and partially

Figure 6. *Outcrop of Tertiary sandstone and conglomerate (Ts) in NW section 4, T. 31 S., R. 14 W. Hammer is 12 inches (30 cm) long. Note poor sorting and angularity of clasts.*

exposed by late Cenozoic erosion. Discontinuous exposures do not permit measurement of a complete stratigraphic section of this unit, but it is possibly more than 600 feet (180 m) thick locally.

Quaternary - Tertiary deposits

Two map units, QTa and QTb, have been tentatively assigned a latest Pliocene to early Pleistocene age because their geologic relationships suggest that they are younger than the sandstone and conglomerate unit (Ts), and their physiographic relationships suggest they are older than other Quaternary alluvial and colluvial units.

Old alluvium (QTa): The three hills on the map that are identified as covered with this old alluvium all rise slightly above surrounding areas covered with younger Quaternary alluvial or colluvial deposits. The unit consists of poorly sorted, angular to subrounded, sand- to boulder-size clasts of both sedimentary and igneous rocks. This alluvium may have been deposited as slugs of debris flows or mudflows in former valleys; QTa now caps hilltops because of the resistance of the coarse material to erosion. The unit is probably more extensive than shown; some deposits shown as alluvium and colluvium (Qac) may actually be QTa. It is locally at least 150 feet (45 m) thick.

Basalt-boulder alluvium (QTb): This alluvial deposit is similar in most respects to QTa except that it contains a high percentage of basalt clasts derived from the Steamboat Mountain Formation. In some exposures the clasts are all basalt. This unit shows on aerial photographs as areas darker than adjacent units. In most of its exposures QTb caps hilltops. But south of the largest exposure of Steamboat Mountain basalt (Tsb) near the center of the map, it appears to constitute a local bed near the base of alluvial and colluvial deposits shown as Qac/Ts on the map. Outcrops of Steamboat Mountain Formation, which are no longer present, must have been available as the source for this distinctive alluvial deposit. QTb is locally at least 100 feet (30 m) thick.

Quaternary Deposits

The geologic map shows alluvial deposits along the main active streams (Qal), in alluvial fans (Qaf_1, Qaf_2, and Qaf_3), on pediment surfaces (Qap), and underlying stream terraces (Qat). Colluvium is combined with alluvial deposits of minor stream courses in the widespread undifferentiated unit Qac. A small area of colluvial talus on Blue Mountain is shown as Qmt. Colluvial units range in age from early Pleistocene to Holocene as shown on the correlation diagram accompanying the map. Age estimates used here are somewhat subjective, but the relative ages of the various Quaternary units is based on standard principles of superposition and cross-cutting relationships. No isotopic dates are available to support the age interpretations. Quaternary units are not discussed in the order of their inferred ages, rather in the order in which they are shown on the correlation diagram on plate 2.

Alluvium (Qal)

The map unit Qal consists of unconsolidated clay, silt, sand, gravel, and boulder deposits whose clast size and composition reflect local bedrock, stream gradient, and topographic relief. Thickness is generally 20 feet (6 m) or less.

Mass-movement talus (Qmt)

This unit is shown only on the east side of Blue Mountain where a sloping accumulation of angular rock fragments from Cambrian limestone cliffs covers the trace of the Blue Mountain thrust. Small talus accumulations elsewhere on the map are included within map unit Qac. The talus is probably less than 30 feet (9 m) thick.

Alluvium and colluvium, undivided (Qac)

Undivided alluvium and colluvium is widely mapped in the western two-thirds of the quadrangle where it consists of alluvium of minor streams that merges with loose soil and rock debris deposited by rainwash or downslope creep on the upland slopes between stream courses. Where this symbol is combined with another, such as "Qac/Ts," it means that the bedrock unit, Ts, is veneered with Qac, and that the Qac is largely composed of reworked Ts material. Although this undivided alluvium-colluvium unit is still actively forming on some interstream uplands, it is also being actively dissected by streams. The oldest Qac deposits are probably pre-Holocene in age. Locally Qac may be as much as 50 feet (15 m) thick.

Alluvial-fan deposits of the youngest age (Qaf_1)

These consist of unconsolidated deposits of silt, sand, gravel, and boulders. Qaf_1 is shown only in the southeast corner of the map where the northwest edge of a large active fan cuts across a tiny portion of this quadrangle. These youngest fan deposits cover extensive areas just east of the Blue Mountain quadrangle (Hintze and Best, 1990).

Alluvial-fan deposits of intermediate age (Qaf_2)

These are unconsolidated deposits of silt, sand, gravel, and boulders that accumulated along the east flanks of Mine Mountain and Blue Mountain. Based on degree of dissection (Christenson and Purcell, 1985) they are probably of late Pleistocene age. These deposits may be as much as 100 feet (30 m) thick.

Alluvial-fan deposits of the oldest age (Qaf_3)

The oldest fan deposits on the east flank of Blue Mountain form steep cones, the apexes of which lap onto the east edge of this quadrangle. These fan deposits are extremely coarse, consisting mostly of angular boulder-size material, in some places resembling rock glaciers. Their steep slope and coarseness suggest rapid deposition probably triggered by basin-range uplift of Blue Mountain along the fault at its eastern base in the adjacent Burns Knoll quadrangle. These deposits may be as much as 200 feet (60 m) thick.

Alluvial-terrace deposits (Qat)

Alluvial-terrace deposits are mapped only near the south edge of the map along Blawn Wash and Fishers Wash where they form benches along hillsides above present flood plains. They consist of bouldery gravel with subrounded to rounded clasts. These deposits are less than 50 feet (15 m) thick. Elsewhere in the quadrangle smaller terrace deposits are included with either Qal or Qac.

Alluvial deposits on pediment (Qap)

Pediment-mantle deposits, widespread on the adjacent Burns Knoll quadrangle (Hintze and others, 1990) extend into the northeast corner of this map area where they consist of silt- to gravel-size materials that mantle a pediment surface which slopes southward from the Shauntie Hills towards the Escalante Desert (figure 1). Low hills of bedrock that rise slightly above the alluvial cover in the Burns Knoll quadrangle attest to the thinness of the alluvium on the pediment surface. Eolian silt, blown northward from the desert, is incorporated into the pediment alluvial cover. Thickness of alluvial deposits on the pediment is unknown, but locally may be more than 100 feet (30 m).

GEOLOGIC HISTORY

Understanding geologic relationships in the map area may be facilitated by a brief review of the sequence of depositional and tectonic events. See also Best and others (1987b); Hintze (1988); Best and others (1989a, b). Table 1 lists the chief events, youngest at the top.

Table 1. *Summary of geologic history pertinent to this map area.*

m.y.	
0	
	Quaternary alluvial, lacustrine, and eolian deposition, influenced by the Ice Ages. Quaternary basin-range faulting.
2	
	Pliocene-late Miocene extension of the Great Basin, resulting in block-fault uplift of Blue Mountain and southern Wah Wah Mountains, and down-faulting of the Escalante Desert area. Alluvial deposits derived from uplift of the mountains are largely buried beneath the Escalante Desert. West of Blue Mountain early basin-range alluvial sedimentation (Ts) took place in a local fault basin.
12	
	Steamboat Mountain Formation volcanism and concurrent alluvial sedimentation.
13	
	Steamboat Mountain alluvial sedimentation (Ts), and volcanism in western Utah outside of this quadrangle.
18	
	Blawn Formation volcanism. Intrusive doming of Blue Mountain probably occurred during this interval, as inferred by comparison with 22 million-year-old laccolithic intrusions in the nearby Iron Springs mining district (Rowley and Barker, 1978; age corrected for new decay constants).
23	
	Hiatus, represented in other parts of southwestern Utah by local fresh-water lake deposition (Hintze, 1986).

25 -
Isom Formation volcanism. Isom ash-flow tuffs are intercalated with fresh-water lake deposits in other areas south of this map (Hintze, 1986).

27 -
Hiatus, local deposition in fresh-water lakes in nearby areas (Hintze, 1986).

28 -
Needles Range Group volcanism: eruption of lava flows and regionally extensive ash-flows that formed the Lund, Wah Wah Springs, and Escalante Desert Formations and Cottonwood Wash Tuff. Collapse of associated calderas in Indian Peak caldera complex.

33 -
Deposition of local pre-Needles Range Group rocks: tuff of Tower Point (Tt), volcanic breccia (Tvb), conglomerate (Tcg), and other volcanic units of this age deposited in Shauntie Hills and Indian Peak Range.

34 -
Probable hiatus of unknown duration. Deposition of the Claron Formation in other parts of southwest Utah is considered to have been of Eocene and Oligocene age (Rowley and others, 1979), but few isotopic and paleontologic data exist to define its exact age (Mullett, 1989).

60 -
Thrust-related deposition of Grapevine Wash Formation and perhaps the lower parts of the Claron Formation (Goldstrand, 1989). The Grapevine Wash Formation is a local conglomeratic deposit related to the Square Top Mountain thrust about 56 miles (90 km) south of Blue Mountain (Hintze, 1986). Over a wide region in southern Utah the Claron Formation is generally conglomeratic at its base, but grades upwards into finer lacustrine sediments. Goldstrand (1989) suggested that some basal Claron conglomerates may be of Late Cretaceous or Paleocene age and were derived partly from distant source areas to the south and from nearby source areas related to the Wah Wah - Blue Mountain thrust plates. Ages of the Grapevine Wash and basal Claron are not well constrained.

75 -
Compression during Sevier orogeny moved thrust sheets of Paleozoic marine strata which had originally been deposited west of the map area, tens of miles southeastward over autochthonous or parautochthonous Jurassic and earlier strata. The Blue Mountain thrust fault, upon which this movement took place in the area, is presumed to have been a substantially unfolded surface at the end of the thrusting; its present domical configuration is interpreted to be a result of uplift related to laccolithic(?) intrusive activity about 22 million years ago. Erosion of the highlands formed by Sevier compression produced thick Upper Cretaceous deposits in eastern Utah. These deposits constrain the age of the thrusting to an interval sometime between 100 and 75 million years ago.

100 -
Hiatus. No deposits of Late Jurassic or Early Cretaceous age have been recognized in southwestern Utah. Erosional debris from the map area are probably represented in the Morrison and Cedar Mountain Formations in eastern Utah.

160 -
Cambrian through mid-Jurassic sedimentation comprised mostly shallow marine or coastal-plain deposition with numerous brief periods of non-deposition.

570 -

STRUCTURAL GEOLOGY

The following section is an organized sequence of occurrences, with the oldest structural deformation discussed first.

Blue Mountain thrust and related compressional structures: Paleozoic, Triassic, and Jurassic strata had accumulated in a comformable stack 6 miles (10 km) thick prior to deformation by Sevier orogenic compressional forces in Late Cretaceous time. The Blue Mountain thrust fault is the most conspicuous product of this deformation in the map area. On this fault, Cambrian strata from the bottom of the sedimentary sequence have been emplaced over Jurassic strata near the top of the sequence. Very little evidence of ramping is observed within the exposed segment of the Blue Mountain thrust. The upper plate soles on the shale-bearing Chisholm Formation, or on immediately superjacent strata, from Blue Mountain to an unnamed hill 2 miles (3 km) west of the edge of this map (Best and others, 1987c) over an east-west distance of about 10 miles (16 km); at its easternmost exposed edge the thrust ascends onto a higher Cambrian unit, the Swasey Limestone. Because of its lateral continuity, the thrust surface is thought to have been nearly horizontal at the end of the Cretaceous thrusting; its present deformation in anticlinal structures is believed to have been caused later by concealed lower Miocene laccolithic (?) intrusions, as discussed below. The Blue Mountain thrust fault on the west side of Blue Mountain is nearly vertical where exposed locally in stream cuts. Beds in the upper and lower plates also dip steeply there, so the fault is represented on the map as a folded thrust. Generally, rocks immediately above and below the thrust are fresh and unaltered, although in a saddle on Blue Mountain, a thin zone exists in the upper plate where Cambrian shale and limestone have undergone a slight color change. Where the thrust ramps up through the Dome Limestone, the contact shows no baking or brecciation. Throughout the map area, lower plate Mesozoic rocks are generally less affected by deformation associated with thrusting than upper plate Cambrian rocks. In some places, Cambrian rocks just above the thrust surface are complexly deformed; minor folds of various styles and orientations are too small to show at the map scale. Near the thrust-fault plane, some competent units exhibit evidence of ductile deformation. Such features suggest that, in this portion of the thrust belt, the rocks have been subjected to sufficiently high temperatures and/or confining pressures to inhibit brittle behavior. This conclusion leads to the further extrapolation that, if the rocks on Blue Mountain were sufficiently deep to inhibit brittle behavior, the up-dip continuation of the thrust may extend a considerable distance to the east, with at least a portion of the Escalante Desert underlain by the Blue Mountain thrust. Van Kooten (1988) gave seismic and drill-hole evidence for thrusting beneath the Iron Springs area 30 miles (50 km) southeast of Blue Mountain. Weaver (1980) noted some minor faults, too small to map, that he thought were tear faults that formed concurrently with thrusting. These minor faults strike S. 30° E., supporting Miller's (1966) assertion that the upper plate of the Blue Mountain thrust moved to the southeast.

The Blue Mountain thrust is the lower of two regional thrusts identified by Miller (1966). A structurally higher thrust, the

Figure 7. Brecciated Cambrian carbonate rocks in NW section 4, T. 31 S., R. 14 W. Hammer is 12 inches (30 cm) long. Weaver (1980) suggested that the brecciation might be Tertiary in age, perhaps related to volcanic disturbance or normal faulting. Alternatively, they may be breccias produced by Mesozoic thrusting.

Wah Wah thrust, places Late Precambrian strata over Paleozoic strata of the Blue Mountain thrust plate at Rose Spring Canyon in the Wah Wah Mountains about 12 miles (19 km) northwest of Blue Mountain (Abbott and others, 1983). When estimating distance of horizontal offset produced by the thrusting, it is significant to note that Cambrian stratigraphy on the Blue Mountain plate is virtually the same as that on the Wah Wah thrust plate. Miller (1966) gave a minimum horizontal displacement of 9 miles (14 km) for the Blue Mountain thrust; its total horizontal displacement is probably several times this amount.

Oligocene caldera development: The Indian Peak caldera complex, located west of the map area astride the Utah-Nevada line, was the source of regionally extensive ash-flows of the Needles Range Group and Isom Formation (Best and others, 1989a) that covered large areas of southwestern Utah and southeastern Nevada. Variation in thickness of ash-flow sheets is associated with unevenness of the terrain on which they were deposited and with distance from source. No major extensional or compressional features whose origin could be ascribed to caldera development, or to unrelated tectonic events concurrent with caldera collapse, have been identified within the map area.

Middle Tertiary extensional structures: On the basis of the orientations of dikes, Best (1988) concluded that the direction of least principal stress in southwestern Utah during the early Tertiary was northerly until sometime in the early Miocene. West-northwest- to west-southwest-striking normal faults in the northern third of the map area may reflect this state of stress. The most prominent middle Tertiary fault in the quadrangle strikes west-northwesterly across Blue Mountain and continues northwest for about 5 miles (8 km). It and a fault that parallels it 1 mile (1.5 km) to the south form a graben. Several shorter faults of the same orientation can be seen on the map. All Oligocene rocks and most Miocene units are cut by middle Tertiary faults. An exception is that the Blawn Formation rhyolite member appears to postdate this faulting. Displacements produced by this early extensional system range from less than 160 feet (50 m) to more than 1,000 feet (300 m).

Inferred lower Miocene intrusion under Blue Mountain: Doming of the Blue Mountain thrust on Blue Mountain and in areas west of there (see also Best and others, 1987c) is deemed to be the result of a post-thrust event. Miller (1966) postulated that this doming was the result of emplacement of a Tertiary intrusion. An unpublished aeromagnetic map of the Richfield 2-degree quadrangle prepared by the USGS for the Richfield CUSMAP folio shows a 200 gamma magnetic high centered over Blue Mountain that is part of an east-west belt of magnetic anomalies that runs across the Richfield 2-degree quadrangle and defines the Pioche-Marysvale mineral belt. The Blue Mountain magnetic high supports the probability that there is a concealed igneous body beneath Blue Mountain. Additional evidence is found in the thermal metamorphism and silicification of Triassic and Jurassic sedimentary rocks on Blue Mountain and in the silicification of Cambrian carbonate rocks north of Blue Mountain. These units are also complexly faulted, as might be expected over the roof of an intrusion. Actinolite and chlorite, mimetic after the original bedding, were produced in the Moenkopi and Chinle Formations by the thermal metamorphism which also introduced epidote along fracture surfaces in the Shinarump sandstones (Miller, 1966). The age of the intrusion that produced the doming of the thrust on Blue Mountain may be about 22 million years based on analogy with isotopic ages on Blawn Formation volcanic activity and intrusions in the Iron Springs area (Rowley and Barker, 1978). Folding of the Blue Mountain thrust might, alternatively, have been caused by movement on a hidden, deeper thrust system.

Late Cenozoic extensional block-faulting: Late Miocene to Holocene regional uplift and extensional block-faulting is responsible for most of the topographic relief in this area, and indirectly responsible for basin-fill deposits beneath the Escalante Desert. Evidence for the continuing nature of this activity is provided by Quaternary fault scarps that cut Holocene deposits along the west side of the Escalante Desert in the Lund quadrangle (Grant and others, 1990). Identifying which of the many minor normal faults shown on the Blue Mountain quadrangle were formed by late Cenozoic extension, as opposed to those that may have formed earlier, is not everywhere possible. One generally north-south-striking, down-to-the-west fault on the west flank of Blue Mountain cuts rocks as young as the basalt member of the Steamboat Mountain Formation and may be a late Cenozoic fault related to block-faulting. Normal faults on both sides of the Blue Mountain horst more or less follow this north-south orientation (see also Hintze and others, 1990). Late Cenozoic range-front faults in western Utah that have cumulative displacement as much as several thousand feet mostly strike north-south, but diagonal offsets along them are common, so north-south orientation alone cannot be used to identify late Cenozoic faults.

ECONOMIC GEOLOGY

Although there has never been any significant mineral production from the Blue Mountain quadrangle, the widespread signs of hydrothermal alteration and small shows of iron, manganese, and base-metal mineralization have attracted prospectors sporadically for the past century. Weaver (1980) briefly reviewed the history of exploration for metals in the quadrangle. Iron gossans and minor shows of psilomelane, pyrite, barite, and copper oxides have received the most attention. Bullock (1970) reported that the Emma mine (sec. 7, T. 30 S., R. 14 W.) produced several hundred tons of gossanous fluxing ore that contained 55 percent iron and assayed $5.00/ton gold in surface samples. Ore at the Emma mine occurs along high-angle faults just above the Blue Mountain thrust. A small copper vein was found at the 100-foot (30 m) level of the Emma shaft. Bullock also reported a few tons of stockpiled ore at the Iron Duke prospect (sec. 17, T. 30 S., R. 14 W.), developed from a gossan deposit along a high-angle fault. Crittenden (1951) reported that the Susie Q claims, located in the northern part of sec. 16, T. 30 S., R. 14 W., (also called the Iron Lily) produced flux ore shipped to Frisco, and in 1943 produced six tons (5,500 kg) of ore containing 40 to 45 percent manganese shipped to the Metals Reserve Company stockpile in Delta. Ore consisted of brecciated and silicified limestone with abundant iron/manganese oxides. The area was also prospected, unproductively, for mercury and uranium during the uranium boom of the 1950s. Thrust fault contacts were extensively drilled in the map area during 1989 in an apparent attempt to evaluate the possibility of low-grade gold occurrence. No exploratory wells for oil and gas have been drilled within the map area. In summary, no significant economic development of metals or hydrocarbons has yet occurred. More subsurface exploration will be required to determine if any economic mineral development is possible within the quadrangle.

Rock alteration: Alteration in volcanic rocks within the quadrangle is nearly ubiquitous, although the intensity of alteration varies widely, it is most intense in the northwest-trending graben. Some areas show only slight alteration; in other areas, only quartz phenocrysts survive, leaving a porous rock of phenocryst casts. Locally intense argillization has reduced volcanic rocks to clay. Chloritization also occurs locally.

Silicification is the most widespread type of alteration, both in sedimentary and in volcanic rocks. Secondary silica fills fractures in Cambrian carbonate rocks particularly in the northeast quarter of the map; secondary silica boxworks are common in Cambrian rocks at the north end of Blue Mountain. Mesozoic clastic rocks have also been silicified on Blue Mountain and in exposures of the Navajo Sandstone west of Blue Mountain. Moenkopi and Chinle shales have been widely altered to hornfels, and Shinarump and Navajo sandstones have mostly been converted to quartzite.

Iron gossans: Gossans are numerous throughout carbonate rocks in the northern half of the quadrangle. Nearly every iron-stained rock has been prospected, but most workings are small. Calcite, psilomelane, hematite, and limonite are the introduced minerals most commonly found in the prospect pits. In the Iron Mountain area (Emma mine), two shafts were sunk and several adits, drifts, and stopes were developed. Another shaft was sunk in the southwest quarter of section 4, T. 30 S., R. 14 W.

Sulfide mineralization: Weaver (1980) reported only one locality where he found fresh pyrite. It occurs, along with barite, in the northeast quarter of section 5, T. 30 S., R. 14 W.

Building stone: The tuff member of the Blawn Formation has been quarried in small tonnages for building and ornamental stone, from outcrops on the east edge of section 20, T. 30 S., R. 14 W., where it shows attractive liesegang banding (figure 8).

Clay resources: Van Sant (1964) reported a clay resource located in section 17, T. 30 S., R. 14 W., that might be suitable for use in heavy-clay products. Clay bodies occur both as veins and as tabular replacements in volcanic rocks.

Figure 8. *Liesegang banding in the tuff member of the Blawn Formation, exposed in a small quarry in NE section 20, T. 30 S., R. 14 W. Hammer is 12 inches (30 cm) long.*

WATER RESOURCES

Because of limited precipitation, this portion of the southern Wah Wah Mountains is typically dry, with small winter snowfall, and summer rainfall largely restricted to August and early Septermber thunderstorms. No perennial streams exist in the quadrangle; however, a small perennial trickle does flow in upper Blawn Wash west of the quadrangle boundary.

There are two springs in the map area. One, Iron Mine Spring, generally does not have water except early in the year. The other, Bumblebee Spring, has been developed for livestock watering and generally has a small amount of water throughout the summer. Both springs are located along fault zones.

Small wells, developed for livestock watering, tap ground water in alluvial materials along Blawn Wash. McKnight's Well has a windmill and holding tank near the center of the map area. Leigh Well, a quarter mile south of the map in the north edge of the Lund quadrangle, is similarly developed. When these water supplies are insufficient, local ranchers haul water from sources near Lund, about 8 miles (12 km) south of the Blue Mountain quadrangle.

GEOLOGIC HAZARDS

The map area is uninhabited; the only nearby permanent residents are a few people who live in Lund, 8 miles (12 km) south of the map area. The chief natural hazard is late summer cloudburst flooding, particularly along Fishers Wash and Blawn Wash. The only works of man that are likely to suffer flood damage are the graded gravel roads along which traffic is ordinarily limited to a few vehicles a day.

Earthquakes are a possible, but extremely infrequent, hazard. Recent fault scarps along the east side of the southern Wah Wah Mountains were noted by Anderson and Bucknam (1979). Stover and others (1986) showed three historic earthquakes of magnitude 3 or less in the vicinity of Lund for the period 1931-1975. The area is on the west edge of the Intermountain seismic belt. Almost no historic seismic activity is known in Utah west of the map area. The quadrangle is in seismic zone U-2 (Ward, 1979), more specifically in zone 2b on the 1988 Uniform Building Code Zone Map published by the International Conference of Building Officials, Whittier, California. Because of the lack of human inhabitants or significant structures within the area, there is little possibility of significant loss of life or property damage from geologic hazards, however infrequent they may be.

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