UTAH GEOLOGICAL AND MINERAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
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THE UNITED STATES GEOLOGICAL SURVEY

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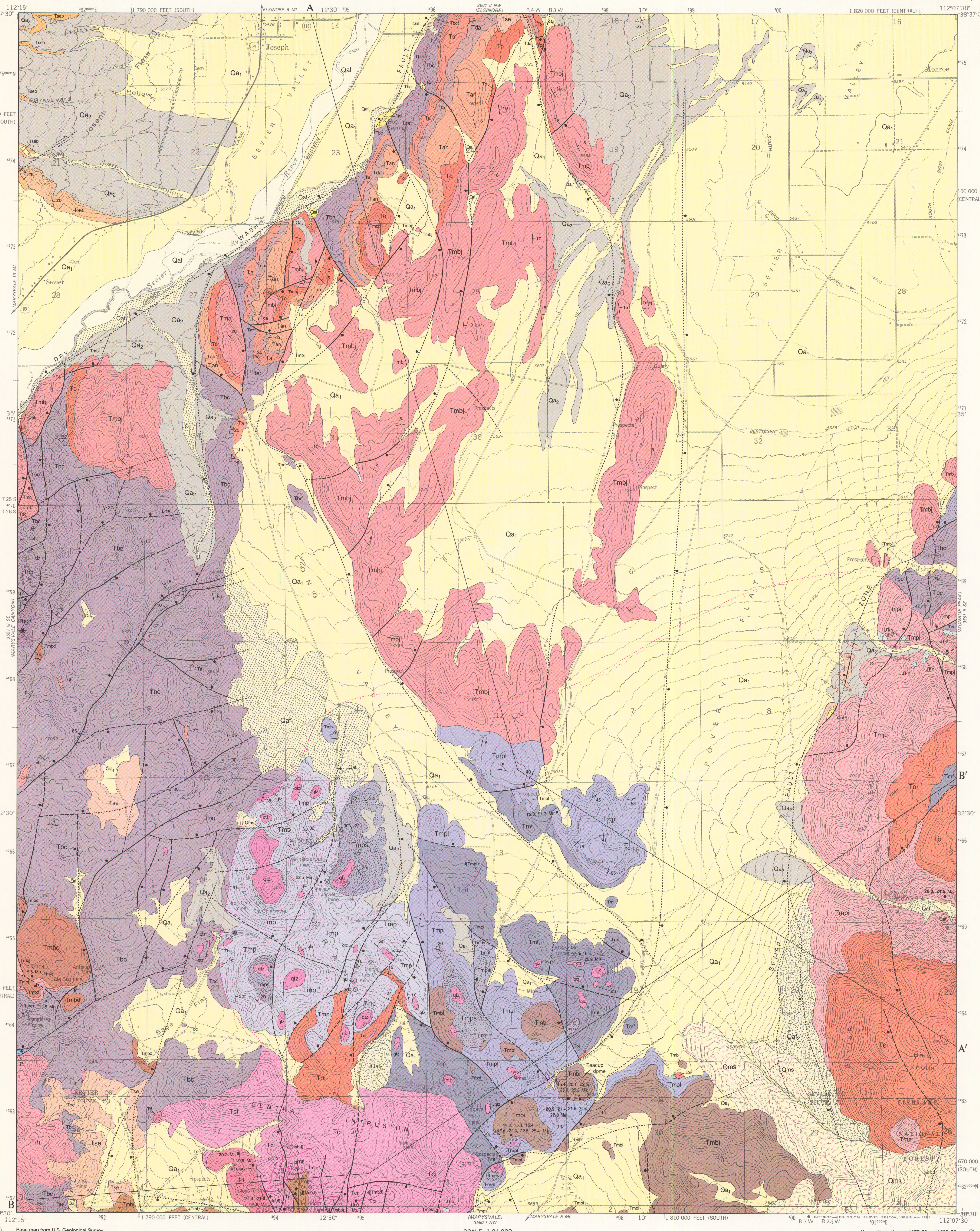
UTAH GEOLOGICAL AND MINERAL SURVEY
Genevieve Atwood, Director
606 Black Hawk Way
Salt Lake City, Utah 84108



Base map from U.S. Geological Survey,
Antelope Range Quadrangle, 1980

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Mapped by authors in 1977-79 and 1982-83
J.W. Parker, Cartographer

GEOLOGIC MAP OF THE ANTELOPE RANGE QUADRANGLE, SEVIER AND PIUTE COUNTIES, UTAH

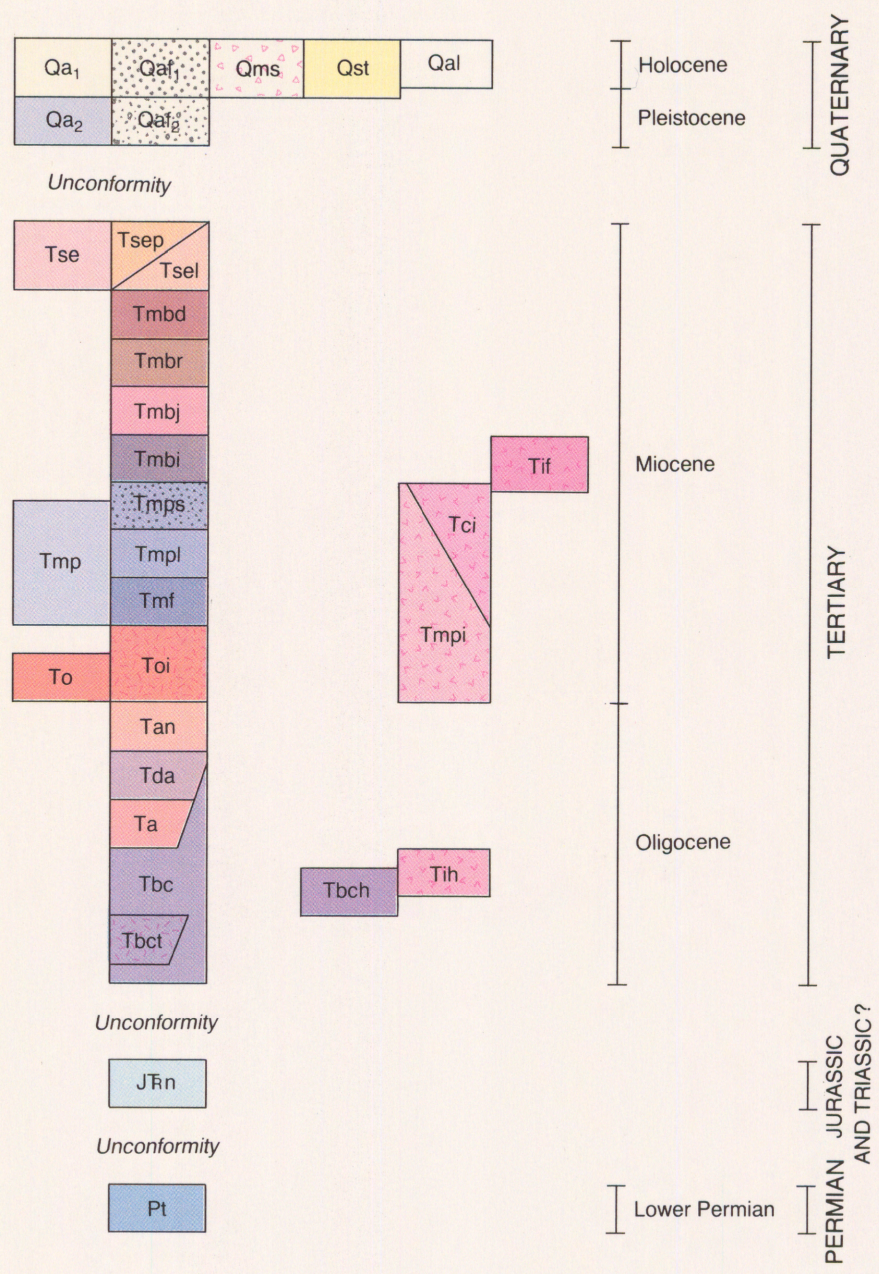
UTM GRID AND 1987 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

QUADRANGLE LOCATION

by
Peter D. Rowley, Charles G. Cunningham, Thomas A. Steven,
Harald H. Mehnert, and Charles W. Naeser

1988

CORRELATION OF MAP UNITS



MAP UNIT		SYMBOL		THICKNESS Feet(Meters)	LITHOLOGY
Surficial deposits		Qal, Qst, Qms, Qaf1, Qa1, Qaf2, Qa2		300 (90)	
Sevier River Formation		Tse		400 (120)	
Mount Belknap Volcanics	Dikes, lava flows, and plugs	Tmbd		300 (90)	
	Red Hills Tuff Member	Tmbr		200 (60)	
	Joe Lott Tuff Member	Tmbj		400 (120)	
	Crystal-rich volcanic domes and plugs	Tmbi		800 (240)	
Intracaldera rocks, Monroe Peak caldera	Sedimentary rocks	Tmp	Tmps	300 (90)	
	Lava flows of Monroe Peak		Tmpl	500 (150)	
	Lava flows of Monkey Flat Ridge		Tmf	500 (150)	
	Osiris Tuff	Toi		1200 (365)	
Basaltic andesite		Tan		55 (17)	
Antimony Tuff Mbr., Mt. Dutton Formation		Tda		60 (18)	
Tuff of Albinus Canyon		Ta		200 (60)	
Bullion Canyon Volcanics		Tbc		2500 (760)	
Three Creeks Tuff Member		Tbct		120 (36)	
Toroweap Formation		Pt		100 (30)	

DESCRIPTION OF MAP UNITS

Qa1 Piedmont-slope deposits—*Silt, sand, and gravel on piedmont slopes.*

Qaf1 Alluvial-fan deposits—*Silt, sand and gravel in alluvial fans and along streams that feed fans.*

Qms Landslide debris—*Angular, unsorted material emplaced by mass movement.*

Qst Hot spring deposits—*Tan and gray calcareous tufa and travertine.*

Qal Flood-plain deposits—*Silt, sand, and gravel in the flood plain of the Sevier River.*

Qa2 Older piedmont-slope deposits—*Dissected remnants of older piedmont-slope deposits.*

Qaf2 Older alluvial-fan deposits—*Dissected remnants of older alluvial fans.*

Tse Sevier River Formation, undivided—*Gray and tan, poorly to moderately consolidated sandstone, conglomerate, siltstone, and claystone, deposited chiefly in a fluvial environment.*

Tsep Sevier River Formation, piedmont facies—*Tan sandstone, siltstone, conglomerate, and airfall tuff deposited along margins of basins.*

Tsel Sevier River Formation, lacustrine facies—*Light-green claystone, marlstone, siltstone, and limestone deposited in the interior of a closed lake basin.*

Tmbd Dikes, lava flows, and plugs of the Mount Belknap Volcanics—*Gray and pink, flow-foliated rhyolite dikes, lava flows, and plugs.*

Tmbr Red Hills Tuff Member of the Mount Belknap Volcanics—*Red, densely welded, crystal-poor rhyolite ash-flow tuff.*

Tmbj Joe Lott Tuff Member of the Mount Belknap Volcanics—*Tan and gray, poorly welded, crystal-poor rhyolite ash-flow tuff.*

Tmbi Crystal-rich volcanic domes and plugs of Mount Belknap Volcanics—*Tan, pink, gray, and purple, crystal-rich rhyolite volcanic domes, lava flows, and intrusive feeders.*

Tif Fine-grained silicic pluton—*Gray and greenish-gray, fine-grained granodioritic to granitic intracaldera pluton.*

Tmp Monroe Peak intracaldera rocks, undivided—*Interbedded sequence of lava flows, airfall tuff, sandstone, siltstone, and conglomerate; undivided due to extensive hydrothermal alteration and silicification.*

Tmps Monroe Peak intracaldera sedimentary rocks—*Tan, gray, and yellow, soft to moderately resistant sandstone, airfall tuff and minor lava flows, siltstone, and conglomerate.*

Tmpl Lava flows of Monroe Peak—*Gray, pink and khaki, intracaldera, crystal-rich, rhyodacitic lava flows.*

Tmf Lava flows of Monkey Flat Ridge—*Gray, red, tan, and brown, intracaldera, crystal-poor rhyodacitic to dacitic lava flows.*

Tci Central intrusion—*Gray and green, porphyritic or equigranular, intracaldera quartz monzonite or monzonite.*

Tmpi Undivided intrusive rocks related to the Monroe Peak caldera—*Tan and gray, intracaldera monzonite porphyry and quartz monzonite porphyry.*

Toi Osiris Tuff, intracaldera facies—*Orange and tan, densely welded rhyodacitic intracaldera ash-flow tuff.*

To Osiris Tuff, outflow facies—*Brown and light-gray, densely welded rhyodacitic ash-flow tuff.*

Tan Basaltic andesite—*Gray, black, and brown, crystal-poor lava flows.*

Tda Antimony Tuff Member of the Mount Dutton Formation—*Purplish-gray and reddish brown, densely welded crystal-poor ash-flow tuff.*

Ta Tuff of Albinus Canyon—*Gray, pink, tan, and reddish-brown, densely welded, crystal-poor ash-flow tuff.*

Tih Hoover pluton—*Green and gray, holocrystalline, porphyritic quartz monzonite.*

Tbch Hypabyssal plug of the Bullion Canyon Volcanics—*Green and pink, flow-foliated dacitic plug.*

Tbc Bullion Canyon Volcanics—*Gray, green, and brown, heterogeneous, dacitic to rhyodacitic lava flows, and subordinate volcanic mudflow breccia and flow breccia.*

Tbct Three Creeks Tuff Member of the Bullion Canyon Volcanics—*Pink, tan, and gray, moderately welded, crystal-rich, dacitic ash-flow tuff.*

JTRn Navajo Sandstone—*Light-gray and buff, resistant, crossbedded sandstone.*

Pt Toroweap Formation—*Light-gray marble and quartzite.*

Table 1. Data for K-Ar ages of rocks and alteration minerals in the Antelope Range quadrangle, Utah

Sample no.	[1]Rock unit; [2]mineral analyzed	[3]K_2O (%)	$^*Ar^{40}$ (10^{-10}moles/g)	$^*Ar^{40}$ (%)	[4]T	[5]Reference
1. KA12b	Tmbi; B	6.03	——	63	22.3	BA
do	do	7.07	——	56	19.6	do
do	do	——	——	52	22.8	do
do	do	——	——	45	25.4	do
KA12g	Tmbi; G	2.96	——	65	11.8	do
do	do	——	——	23	16.4	do
do	do	——	——	70	15.4	do
2. KA20b	Tmbi; B	6.10	——	63	16.4	do
do	do	——	——	46	23.9	do
KA20g	Tmbi; G	3.55	——	48	20.1	do
do	do	——	——	85	22.4	do
do	do	——	——	83	25.2	do
3. KA34	Tmbd; G	4.23	——	55	12.3	do
do	do	——	——	23	15.6	do
do	do	——	——	18	14.4	do
4. M28	Tif; B	5.81	1.806	77.0	21.4 ± 0.9	ST
5. M47B	A; A	8.18, 7.99	2.639	63.0	22.5 ± 1.0	ST
6. M48	N; N	4.79, 4.84	1.155	59.0	16.6 ± 0.8	do
M48B	do	4.33, 4.36	1.116	27.6	17.7 ± 1.0	CU
7. M49B	Tmbi; S	6.33, 6.35	1.967	83.2	21.4 ± 1.0	ST
do	do	9.70, 9.55	3.053	89.9	21.6 ± 0.9	do
do	Tmbi; B	8.94, 8.95	2.805	61.5	21.6 ± 1.1	do
8. M682	N; N	0.86, 0.86	0.172	31.0	13.9 ± 0.9	CU
9. M718	Tmpl; S	7.88, 8.17	2.480	87.4	21.3 ± 0.7	TH
10. M778	N; N	2.95, 3.03	0.546	10.3	12.6 ± 2.5	CU
11. M804	A; A	4.62, 4.70	1.582	67.9	23.2 ± 1.2	do

Constants for samples 4-10: K^{40} $\lambda_{\xi} = 0.581 \times 10^{-10}$/yr; $\lambda_{\beta} = 4.962 \times 10^{-10}$/yr; $K^{40}/K = 1.167 \times 10^{-4}$; samples 1-3 recalculated by using new decay constants of Steiger and Jäger (1977)

*Radiogenic argon

—— Not determined or not published

[1]Rock unit symbols are those shown on the map; N, natroalunite veins; A, replacement alunite

[2]A, alunite; B, biotite; G, glass; N, natroalunite; S, sanidine

[3]Samples 4-10 determined by atomic absorption; samples 1-3, method of determination not known

[4]Age (Ma) ± 2σ; error figures not given by Bassett and others (1963)

[5]BA, Bassett and others (1963); CU, Cunningham, Rye and others (1984); ST, Steven and others (1979); TH, this report

SAMPLE DESCRIPTIONS

1. Glassy margin of a probable intrusive feeder to a dome, located about 1000 feet east of Papsys Hope mine; lat 38°30′29″, long 112°10′30″. Glass is considerably altered and biotite is slightly altered.
2. Fresh glassy margin of Teacup dome; lat 38°30′41″, long 112°10′35″.
3. Basal glass in lava flows northwest of Big Star mine; lat 38°31′27″, long 112°14′52″.
4. Dike of fine-grained silicic pluton 200 feet west of Freedom No. 2 mine; lat 38°30′02″, long 112°12′53″.
5. Replacement alunite from Yellow Jacket mine; lat 38°32′04″, long 112°12′30″.
6. Vein natroalunite from Al Kee Mee mine; lat 38°31′39″, long 112°10′12″.
7. Glassy margin of Teacup dome; lat 38°30′41″, long 112°10′31″.
8. Vein natroalunite from Alum King mine; lat 38°31′15″, long 112°14′54″.
9. Dacitic lava flow in dome north of Long Valley; lat 38°32′30″, long 112°10′40″.
10. Vein natroalunite from Big Star mine; lat 38°31′20″, long 112°14′44″.
11. Replacement alunite from Al Kee Mee mine; lat 38°31′39″, long 112°10′12″.

Table 2. Data for fission-track ages of rocks in the Antelope Range quadrangle, Utah

Sample no.	[1]Rock unit; [2]mineral analyzed	[3]ps	[4]pi	[5]$\phi \times 10^{15}$	[6]T	U (ppm)	[7]Reference
1. M28	Tif; Z	8.19(1137)	26.84(1864)	1.07	19.5 ± 0.7	810	ST
do	do	8.22(1484)	9.65(871)	.418	21.3 ± 0.9	740	do
2. M49B	Tmbi; Z	3.54(607)	11.05(946)	1.09	20.9 ± 1.1	330	ST
do	Tmbi; A	.136(283)	.271(565)	.930	27.8 ± 3.9	9.4	do
3. M50	Tif; Z	5.17(957)	13.00(1204)	.851	20.2 ± 0.9	490	do
4. M569	Tmpi; Z	3.58(811)	9.47(1074)	.954	21.5 ± 0.8	290	TH
do	Tmpi; A	.092(189)	.272(566)	l.00	20.0 ± 3.4	7.8	do
5. M689	Tmbd; Z	5.66(419)	18.31(678)	1.03	19.0 ± 1.0	510	CL
6. M693	Tmbd; Z	5.62(781)	17.21(1195)	1.02	19.9 ± 1.1	490	TH
7. M718	Tmpl; Z	5.78(1017)	23.07(2029)	1.02	15.3 ± 0.7	650	do

Constants: $\lambda_F = 7.03 \times 10^{-17}$/yr; K^{40} $\lambda_{\xi} = 0.581 \times 10^{10}$/yr; $\lambda_{\beta} = 4.962 \times 10^{10}$/yr; atomic abundance, $K^{40} = 1.167 \times 10^{-4}$

[1]Rock unit symbols are those shown on the map

[2]A, apatite; Z, zircon

[3]Tracks/cm^2, fossil, x 10^6; (number of tracks counted)

[4]Tracks/cm^2, induced, x 10^6; (number of tracks counted)

[5]Neutrons/cm^2

[6]age (Ma) ± 2σ

[7]CL, Cunningham, Ludwig and others (1982); ST, Steven and others (1979); TH, this report.

SAMPLE DESCRIPTIONS

1. Dike of fine-grained silicic pluton 200 feet west of Freedom No. 2 mine; lat 38°30′02″, long 112°12′53″.
2. Glassy margin of Teacup dome; lat 38°30′41″, long 112°10′31″.
3. Fresh sample of fine-grained silicic pluton from portal of Blue Eagle mine north of Central Mining Area; lat 38°30′24″, long 112°13′10″.
4. Holocrystalline quartz monzonite porphyry, from Dry Canyon, Sevier Plateau; lat 38°31′58″, long 112°07′35″.
5. Glassy dike cutting Central intrusion, from 0.8 mi northeast of Freedom No. 2 mine; lat 38°30′05″, long 112°12′16″.
6. Whilte rhyolite dike cutting fine-grained silicic pluton, northwest of Central Mining Area; lat 38°30′15″, long 112°13′05″.
7. Dacitic lava flow in dome north of Long Valley; lat 38°32′30″, long 112°10′40″.

SYMBOLS

CONTACT

85

FAULT—*Most are high-angle normal faults. Dashed where approximately located; queried where probable; dotted where concealed. Direction and angle of dip shown, where observed. Bar and ball on downthrown side, where known. Arrows indicate strike-slip displacement.*

CALDERA—*Topographic or structural wall of the Monroe Peak caldera. Dashed where approximately located; dotted where concealed.*

d(Tif)

DIKE—*Lithology indicated by symbol of equivalent rock unit, in parentheses.*

qtz

QUARTZ MASS—*White, fine- to coarse-grained, locally brecciated quartz. Formed as hot-spring sinter and as replacement masses during wallrock alteration by intrusions.*

ALTERED ROCK—*White, red, and yellow, hydrothermally altered, silicified, and locally mineralized rock. Chiefly argillic alteration to kaolinite and alunite. Propylitically altered rock not shown.*

*

VENT—*Inferred central vent area of volcano.*

CENTRAL MINING AREA—*Approximate outline of principal uranium mines.*

STRIKE AND DIP OF BEDDING

15

Inclined

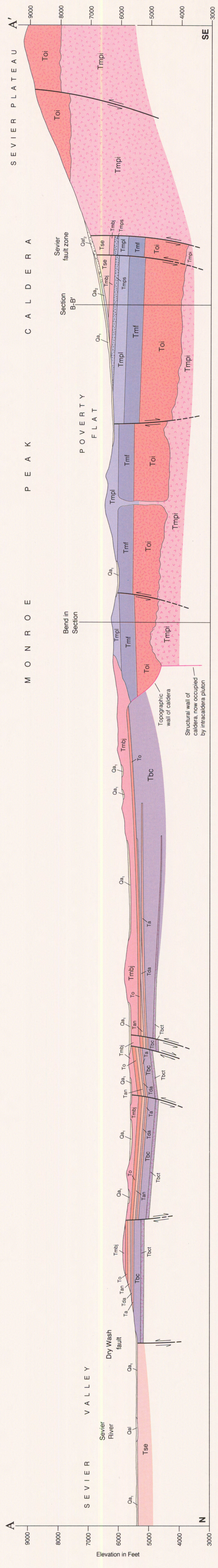
Horizontal

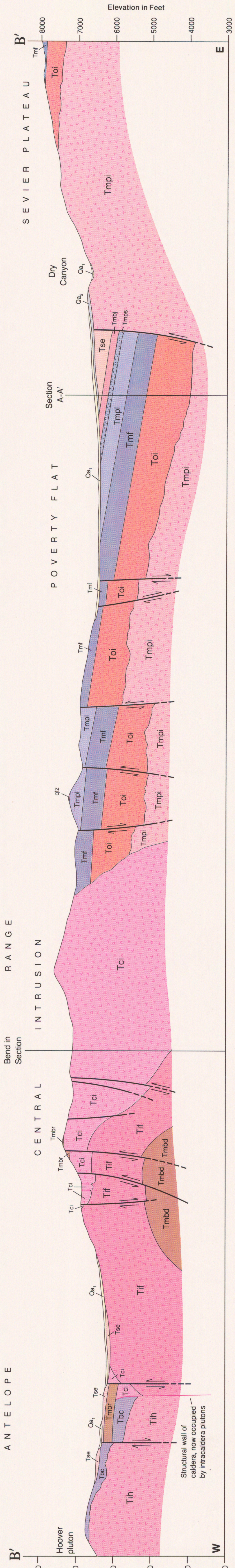
70

STRIKE AND DIP OF FLOW FOLIATION

15.3 21.3 Ma

SAMPLE LOCALITY—*Fission-track (bold) or K-Ar dated (see tables 1 and 2).*





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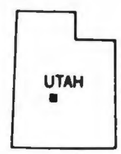

UTAH GEOLOGICAL AND MINERAL SURVEY
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MAP 106 **1988**

UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
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GEOLOGIC MAP OF THE ANTELOPE RANGE QUADRANGLE, SEVIER AND PIUTE COUNTIES, UTAH

By Peter D. Rowley[1], Charles G. Cunningham[2], Thomas A. Steven[1], Harald H. Mehnert[1], and Charles W. Naeser[1]

INTRODUCTION

The Antelope Range quadrangle is in the central part of the High Plateaus subprovince of the Colorado Plateaus physiographic province. The subprovince is structurally transitional between the block-faulted Basin and Range province to the west and the stable Colorado Plateaus to the east. The quadrangle contains a series of low hills and structural basins located between the fault-bounded Tushar Mountains west of the quadrangle and the fault-bounded Sevier Plateau on the eastern edge of the quadrangle.

The Antelope Range quadrangle is near the heart of the Marysvale volcanic field, one of the largest Tertiary eruptive piles in the western United States. Rocks of the Marysvale field were erupted from several volcanic centers within and adjacent to the quadrangle. An older and more voluminous sequence of intermediate-composition, calc-alkaline rocks is overlain by rhyolitic rocks that belong to a bimodal (rhyolite and basalt) alkaline sequence that is roughly coeval with extensional tectonism in this part of Utah. Most of the calc-alkaline rocks in the Marysvale field are lava flows, flow breccia, and volcanic mudflow breccia that formed stratovolcanos of dacitic to rhyodacitic composition ranging in age from about 32 to 22 Ma. Some rocks, however, are ash-flow tuffs whose eruption led to subsidence of calderas. The northwestern part of the Monroe Peak caldera, the largest in the Marysvale Field, is in the quadrangle. The caldera formed as a result of the eruption of the 23 Ma Osiris Tuff, the most voluminous and widespread ash-flow sheet derived from the Marysvale field. Caldera subsidence took place about 23 to 22 Ma, near the end of deposition of the calc-alkaline sequence. Thick intracaldera deposits of Osiris Tuff and of post-Osiris lava flows were erupted from local centers within the caldera that are now covered by younger rocks or obscured by the effects of pervasive hydrothermal alteration. The underlying source of these rocks and the alteration was a shallow magma chamber that evolved into a composite intracaldera batholith emplaced into the roots of the caldera.

Bimodal volcanic rocks of the Marysvale field consist mostly of rhyolitic lava flows, domes, and ash-flow tuff of the Mount Belknap Volcanics, and minor basaltic lava flows. Some Mount Belknap rocks in the quadrangle were derived from local centers near the southern margin of the quadrangle (eastern source area of Cunningham and Steven, 1979d), but ash-flow tuff of the Joe Lott Tuff Member was derived from the Mount Belknap caldera in the Tushar Mountains (the western source area; Budding and others, 1987).

The Antelope Range quadrangle is within the Marysvale mining district which contains deposits of base and precious metals, uranium, and alunite. Callaghan (1973) described in detail the geologic setting and production history of individual mines in the district. Within the quadrangle itself, most deposits are of alunite, mined chiefly during World Wars I and II, and uranium, mined principally in the 1950s and 1960s. Most alunite deposits are related to emplacement of plutons making up the intracaldera batholith of the Monroe Peak caldera. The earliest comprehensive discussion of the alunite deposits was that of Callaghan (1938). Most uranium deposits are in the Central Mining Area, the northern part of which is outlined in the southern part of the quadrangle. Although most uranium is hosted by rocks related to the Monroe Peak caldera, the origin of the uranium is genetically related to emplacement of rhyolite of the Mount Belknap Volcanics. The earliest comprehensive reports on the Central Mining Area were those of Kerr and others (1957) and Kerr (1963, 1968).

In 1975, T.A. Steven and C.G. Cunningham began detailed mapping and studies of specific deposits as part of a reappraisal of the mineral potential of the Marysvale district. They were joined by other geologists, geophysicists, and geochemists from the U.S. Geological Survey and other organizations, and the study was expanded to include geologic mapping, Bouguer gravity and aeromagnetic surveys, and geo-

[1]Geologist, U.S. Geological Survey, Denver, Colorado
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chemical and isotopic investigations of the entire Richfield 2° quadrangle. Resultant publications are too numerous to list here (over 200 to date), but some of the reports most relevant to the economic geology of the Antelope Range quadrangle are those of Cunningham and Steven (1978, 1979a) and Rasmussen and others (1985) on the Central Mining Area; Cunningham and Steven (1979b) and Beaty and others (1986) on the Deer Trail Mountain-Alunite Ridge area; Cunningham and Steven (1979c) and Budding and others (1987) on the Mount Belknap caldera; Steven and others (1981) on uranium throughout the Marysvale volcanic field; Cunningham, Ludwig and others (1982) on the geochronology of the Central Mining Area; Cunningham, Steven and others (1984) on the western and southern Tushar Mountains; Cunningham, Rye and others (1984) on Marysvale alunite deposits; Podwysocki and others (1983) and Cunningham, Steven and others (1984) on altered and silicified rocks in the Marysvale area; Miller and others (1984a, b, c) on trace-element distributions in the Marysvale area; Cook and others (1984) on the Bouguer gravity of the Marysvale area; and Campbell and others (1984) on the aeromagnetic data of the Marysvale area.

General discussions of the geology and geophysics in and near the Antelope Range quadrangle include Callaghan (1938, 1939); Callaghan and Parker (1961, 1962a, b); Willard and Callaghan (1962); Shawe and Rowley (1978); Cunningham and Steven (1979e); Steven and others (1979, 1988); Rowley, Steven and others (1979); Steven and Morris (1983, 1984); Cook and others (1984); and Campbell and others (1984). Geologic maps have been published for the areas to the north of the mapped area by Callaghan and Parker (1961) and Steven (1979); to the west by Callaghan and Parker (1962b) and Steven and Cunningham (1979); to the east by Rowley, Cunningham and Kaplan (1981); and to the south by Willard and Callaghan (1962), Cunningham and Steven (1979e), and Rowley and others (1988). Data available in 1981 were compiled by Cunningham and others (1983).

Before discovery of the Monroe Peak caldera, geologic maps of the Antelope Range quadrangle were published by Kerr and others (1957); Callaghan and Parker (1961); and Cunningham and Steven (1979a, f). The geology of the central Marysvale field (Cunningham and others, 1983) was compiled before we realized that the western edge of the Monroe Peak caldera partly underlay the area of the Antelope Range quadrangle, (Rowley, Cunningham and Kaplan, 1981; Rowley, Williams and others, 1981; Rowley and others, 1986a,b). Subsequent research described in this report has shown that the western part of the caldera extends across the Antelope Range and the adjoining Marysvale quadrangle (Rowley and others, 1988). The geology and mineral deposits of the Antelope Range-Marysvale area are thus described in the context of this interpretation. A preliminary discussion of the Monroe Peak caldera was presented by Steven and others (1984).

STRATIGRAPHY

Layered rocks exposed in the Antelope Range quadrangle are Oligocene to Holocene in age and are at least 8000 feet thick. These rocks consist largely of Tertiary volcanic rocks and Quaternary surficial deposits. Also included are scattered blocks of Permian limestone and Jurassic and Triassic(?) sandstone brought up along intrusive contacts. Of the igneous rocks, most belong to the calc-alkaline sequence. The thickest calc-alkaline unit consists of lava flows and subordinate volcanic mudflow breccia and flow breccia of the Bullion Canyon Volcanics, which belong to one or more stratovolcanos, one of which is centered at the western edge of the quadrangle. Intrusive rocks of the Hoover pluton in the southwestern corner of the quadrangle probably represent the crystallized magma source for some flows of the Bullion Canyon Volcanics. The Bullion Canyon Volcanics are overlain by ash-flow tuff, lava flows, and sedimentary rocks and are cut by intrusive rocks related to development of the Monroe Peak caldera; these younger units comprise the uppermost calc-alkaline rocks in the quadrangle. The volcanic rocks of the bimodal sequence are part of the Mount Belknap Volcanics and are derived from a western source area (Mount Belknap caldera) in the Tushar Mountains and an eastern source area in and south of the mapped area. During bimodal volcanism, regional extension formed broad basins by either warping or faulting. Uplands were eroded and the resultant continental sediments, making up older parts of the Sevier River Formation, were deposited in the basins (Steven and others, 1981). Intense basin-range faulting took place later, from latest Miocene to early Pleistocene time, and the sedimentary and volcanic rocks were broken into large, tilted, north-northeast-trending horsts and grabens. The largest of the downfaulted areas is Sevier Valley in the northwestern and northeastern part of the quadrangle and Poverty Flat in the eastern part. The grabens were largely filled with upper parts of the Sevier River Formation and by unconsolidated Quaternary sediments.

LOWER PERMIAN
Toroweap Formation

Light-gray resistant marble and quartzite are the metamorphosed equivalents of the Toroweap Formation, an interbedded sequence of dolomite, limestone, and sandstone. A small mass, about 100 feet thick, is exposed between apparent faults in the southwestern part of the quadrangle adjacent to the Hoover pluton (unit Tih). The Toroweap is interpreted to have been dragged upward and contact metamorphosed during emplacement of the Hoover pluton.

JURASSIC AND TRIASSIC?
Navajo Sandstone

The Navajo Sandstone consists of light-gray and buff, resistant, well-sorted, prominently crossbedded, fine-grained sandstone. Subrounded blocks of Navajo, as much as 300 feet long, occur primarily along intrusive margins of intracaldera plutons and were probably carried up to these positions during emplacement of the plutons.

OLIGOCENE
Bullion Canyon Volcanics

The Bullion Canyon Volcanics have not been studied in detail but appear to consist of a thick, soft to resistant, heterogeneous sequence of mostly dacitic and rhyodacitic stratovolcano deposits of several lithologies and sources. The main rock types are lava flows and subordinate volcanic mudflow breccia and flow breccia of intermediate composition; these rocks are classified as vent-facies rocks according to the concepts of Parsons (1965, 1969) and Smedes and Prostka (1972). The dominant lithology is a tan, pink, reddish-brown, gray, purple, and light-green porphyritic lava flow that contains sparse to abundant phenocrysts of plagioclase and subordinate, but conspicuous, hornblende and minor pyroxene, Fe-Ti oxides, and biotite. Less common lithologies, which mostly underlie the hornblende-bearing rocks, include brown, light-green, and red aphanitic flow rocks containing sparse to moderately abundant phenocrysts (plagioclase, pyroxene, and Fe-Ti oxides). These aphanitic flow rocks resemble rocks of the Mount Dutton Formation, which intertongues with the Bullion Canyon Volcanics south of the mapped area (Cunningham and others, 1983). A lava flow containing sparse phenocrysts of plagioclase, pyroxene, and Fe-Ti oxides in a groundmass of black glass locally occurs above the hornblende-bearing rocks in the northern Antleope Range. Pink and gray clasts of a distinctive porphyry locally are abundant in volcanic mudflow breccia low in the section just above the Three Creeks Tuff Member (unit Tbct) on the western edge of the quadrangle. These clasts were probably derived from the 26 Ma Buckskin Breccia (Anderson and Rowley, 1975). The Bullion Canyon Volcanics were defined by Callaghan (1938). The age of the formation in the quadrangle is Oligocene, but Miocene rocks are included in the formation elsewhere (Cunningham and others, 1983). In earlier studies (Rowley, Steven and others, 1979; Cunningham and others, 1983), we considered that most of the Bullion Canyon Volcanics in the quadrangle and the Marysvale Canyon area to the west predate the 30 Ma Needles Range Group. Recent field work, however, has shown that some, if not most, crystal-rich tuffs previously assigned to the Needles Range may belong to the Three Creeks Tuff Member of the Bullion Canyon Volcanics (unit Tbct) or to a local, lithologically similar unit that may be a precursor to the Three Creeks Member. Partial faulted sections of the Bullion Canyon Volcanics in the western part of the quadrangle are at least 2500 feet thick. The volcanic rocks make up one or more stratovolcanos. A probable eruptive center of one of these is a hypabyssal plug (unit Tbch); the stratovolcano deposits thin abruptly toward the northern part of the quadrangle.

Three Creeks Tuff Member of Bullion Canyon Volcanics

Poorly to moderately welded, crystal-rich ash-flow tuff that contains abundant pumice inclusions and lithic clasts is correlated with the Three Creeks Tuff Member of the Bullion Canyon Volcanics. Two moderately resistant cooling units are exposed in Marysvale Canyon (NW¼ sec. 4, T. 26 S., R. 4 W.), the lower one pink, and the upper one tan. A light-gray cooling unit is exposed southeast of Joseph. The tuff contains phenocrysts of plagioclase and subordinate hornblende and biotite, with minor quartz and Fe-Ti oxides. It petroographically resembles tuffs of the older Needles Range Group (Mackin, 1960; Best and Grant, 1987) except that it has more crystals overall, has larger crystals (reflecting the closer source), and has fewer sanidine and pyroxene crystals than the Needles Range tuffs. The map unit is correlated with Three Creeks Tuff Member on the basis of petrography, but it also could be a local, lithologically similar unit west of Elsinore and Joseph that was previously mapped as Needles Range Group (Cunningham and others, 1983) but which recent studies suggest may be a precursor to the Three Creeks Member. The source for the Three Creeks Tuff Member is an obscure caldera discovered by Steven (1981; see also Steven and others, 1984) in the Clear Creek area about 10 miles west of the mapped area. The member was defined by Steven and others (1979), who reported K-Ar and fission-track ages of about 27 Ma for it. The base of the unit is not exposed in the quadrangle, but it is about 120 feet thick at the western edge of the quadrangle.

Hypabyssal plug of Bullion Canyon Volcanics

A small, irregular body of propylitically altered, vertically flow-foliated, green and pink, resistant dacite is exposed at the western edge of the quadrangle in sec. 4, T. 26 S., R. 4 N. The rock contains abundant to sparse phenocrysts of plagioclase and subordinate hornblende and (or) pyroxene and minor Fe-Ti oxides. This plug is interpreted to be a central vent intrusion, or possibly a flank intrusion, in a stratovolcano that consists of Bullion Canyon Volcanics which thin northward away from the plug.

Hoover pluton

Rocks comprising the Hoover pluton consist of green, gray, and pinkish-gray, resistant, fine- to coarse-grained, holocrystalline, porphyritic quartz monzonite containing plagioclase and subordinate orthoclase, pyroxene, quartz, biotite, and hornblende and minor Fe-Ti oxides. The body locally contains masses and dikes of gray aplitic rock consisting of plagioclase and subordinate orthoclase, hornblende, quartz, and biotite and minor Fe-Ti oxides. The pluton intrudes the Bullion Canyon Volcanics but is considered to be generally synchronous with and a probable source for some Bullion Canyon flows. For example, thick, green, crystal-rich lava flows exposed northeast of the pluton consist of rock similar to the plutonic rock and are interpreted to have been derived from early tapping of a magma chamber, after which the magma rose higher into the eruptive pile and cooled to form the Hoover pluton. The intrusion is named after Hoover Peak, the high point of the body, located just west of the mapped area.

Tuff of Albinus Canyon

The low hills east of the Dry Wash fault expose an informal unit, tuff of Albinus Canyon, of light-purplish-gray, pink, tan, reddish-brown, red, and gray, resistant, vesicular, crystal-poor, densely welded ash-flow tuff that contains sparse small phenocrysts of labradorite and minor pyroxene and Fe-Ti oxides. It consists of at least three cooling units. Subvertical flow foliation and folds that are due to secondary flowage are conspicuous in the upper parts of cooling units. Gray pumice lenticules also are conspicuous and generally are less than 1 inch thick and several feet or more long. Vesicles that have been drawn out as much as 1 foot by flowage are present in many places. The unit locally includes interbedded soft, poorly exposed volcanic mudflow breccia and fluvial sandstone. The unit was named by Steven (1979) for exposures in Albinus Canyon in the eastern Pavant Range about 4 miles north of the mapped area. Its vent area has not been found, but the abundant fluidal features suggest that it is nearby, perhaps downfaulted beneath the Sevier Valley in the northern part or north of the mapped area, conceivably where several sharp aeromagnetic and gravity anomalies have been mapped (Cook and others, 1984; Campbell and others, 1984). The unit has a K-Ar age of 25.3 Ma (H.H. Mehnert, unpub. data), and its maximum thickness in the quadrangle is about 200 feet. The tuff becomes thinner southward in the quadrangle, presumably where it lapped onto an existing stratovolcano of the Bullion Canyon Volcanics.

Antimony Tuff Member of Mount Dutton Formation

Purplish-gray and reddish-brown, resistant, hackly weathering, vesicular, densely welded, crystal-poor ash-flow tuff that overlies the tuff of Albinus Canyon is correlated with the Antimony Tuff Member of the Mount Dutton Formation on the basis of lithology and petrography. The tuff litholigically resembles the tuff of Albinus Canyon (unit Ta) but is somewhat dissimilar petrographically. Phenocrysts are larger and more abundant than in the tuff of Albinus Canyon and they consist of plagioclase and subordinate sanidine, with sparse pyroxene and Fe-Ti oxides. Drawn-out pumice lenticules and, locally, secondary flowage structures, including drawn-out vesicles and subvertical flow foliation, are common. The base in some places is marked by a black vitrophyre as thick as 3 feet. It has a K-Ar age of 25.4 Ma (H.H. Mehnert, unpub. data). The member was defined, prior to study of the tuff of Albinus Canyon, by Anderson and Rowley (1975), for exposures near the town of Antimony, 27 miles to the south-southeast. Based on similar lithology, age, and stratigraphic position, probably the two units were derived from the same source area. Maximum thickness of the Antimony Tuff Member is about 60 feet, and it thins southward against the Bullion Canyon Volcanics.

Basaltic andesite

This informal unit consists of gray, purplish-gray, black, and medium-brown, soft to resistant, crystal-poor lava flows containing sparse phenocrysts of plagioclase and subordinate pyroxene, olivine, and Fe-Ti oxides. It contains prominent vesicles, many of them elongate. Based on similar distribution and lithology, it may be genetically related to the tuff of Albinus Canyon. The maximum thickness of the unit is about 55 feet; it is absent at the northern edge of the quadrangle, then generally thickens farther northward.

MIOCENE

Osiris Tuff, outflow facies

The outflow facies of the Osiris Tuff consists of brown (lower part) and light-gray (upper vapor-phase zone), resistant, densely welded, rhyodacitic ash-flow tuff containing moderately abundant phenocrysts of plagioclase, subordinate sanidine, and minor biotite, Fe-Ti oxides, and pyroxene. In most places it weathers to rounded bouldery masses. It contains drawn-out pumice lenticules and, in its upper part, steeply dipping foliation caused by secondary flowage. One or, locally, two simple cooling units are present in the quadrangle; the lower one in some places contains a black basal vitrophyre as thick as 2 feet. The source of the outflow facies of the Osiris Tuff is the Monroe Peak caldera of this quadrangle and adjoining areas (Rowley, Cunningham and Kaplan, 1981; Rowley, Williams and others, 1981; Rowley and others, 1986a, b; Rowley and others, 1988). After eruption of the outflow facies, the caldera subsided and was largely filled by intracaldera-facies Osiris Tuff and younger lava flows, volcanic domes, airfall tuff, and clastic sedimentary rocks (Steven and others, 1984). The tuff was first recognized and informally named by Williams and Hackman (1971); it was formally defined by Anderson and Rowley (1975). Its K-Ar age is about 23 Ma (Fleck and others, 1975)*. The maximum thickness of the outflow facies in the quadrangle is about 40 feet.

Osiris Tuff, intracaldera facies

The intracaldera facies of the Osiris Tuff is confined to the Monroe Peak caldera, from where it originated and which it partly filled. The unit consists of orange and tan, argillically altered and soft, densely welded ash-flow tuff and lava flows(?) that are petrographically similar to rocks of the Osiris Tuff outflow facies. The base of the unit is not exposed because it is intruded by cogenetic plutonic rocks. Most rocks overlying these intracaldera intrusions were intensely altered and are now poorly exposed in most places. A minimum thickness for the intracaldera facies, of about 1200 feet, is estimated from partial sections measured in the quadrangle.

Undivided intrusive rocks related to the Monroe Peak caldera

This unit consists of tan and light-gray, resistant monzonite porphyry and quartz monzonite porphyry that were the source for, and intruded, extrusive and sedimentary rocks in the Monroe Peak caldera. The unit makes up a composite intracaldera plutonic mass consisting of several discrete bodies and apophyses not mapped separately. The plutonic rocks contain moderately abundant phenocrysts of plagioclase, subordinate to minor orthoclase, pyroxene, and hornblende, and minor biotite and Fe-Ti oxides. The groundmass is mostly orthoclase, plagioclase, and quartz, and it is very fine grained near intrusive contacts but grades progressively to medium-grained rock inward in the pluton, as displayed along Dry Canyon near the eastern edge of the quadrangle. At many margins of the intrusive mass, the rock lithologically resembles the Osiris Tuff, but in interior parts it locally is holocrystalline. Where it resembles the Osiris, the pluton probably represents the unevacuated source magma of the intracaldera Osiris Tuff that either remained in place or rose higher and intruded its own ejecta in the caldera fill. Locally the intrusive rock lithologically resembles lava flows within the post-Osiris intracal-

*Where necessary, isotopic ages have been converted using the new decay constants of Steiger and Jäger (1977).

dera sequence and, thus, also probably represents the magma source for those rocks. New fission-track ages of a sample (sample M569) collected from the holocrystalline phase from Dry Canyon are 21.5 ± 0.8 Ma from zircon and 20.0 ± 3.4 Ma from apatite (table 2). The zircon age is considered to be closer to the true age. Although not statistically different from the zircon age, the apatite age is numerically younger and has a larger analytical error and may indicate resetting by an underlying intrusive source of the crystal-rich volcanic domes and plugs of the Mount Belknap Volcanics (Tmbi) that postdate the caldera.

Central intrusion

The Central intrusion underlies much of the Central Mining Area along the southern margin of the quadrangle. It is made up of gray and green, resistant, porphyritic or less commonly equigranular, quartz monzonite porphyry and monzonite porphyry. Most rocks contain abundant phenocrysts of plagioclase, subordinate hornblende, pyroxene, biotite, and orthoclase, and minor quartz and Fe-Ti oxides in a groundmass of moderately to coarsely crystalline orthoclase, plagioclase, and quartz; accessory minerals are apatite, sphene, and zircon. The pluton generally has a fine-grained chilled margin as much as 200 feet wide. The intrusion is one of the plutons related to the Monroe Peak caldera, and its margins lithologically resemble the main body of the undivided intrusive rocks related to the Monroe Peak caldera (unit Tmpi). The Central intrusion is distinguished from the undivided intrusive rocks related to the Monroe Peak caldera by a generally coarse groundmass and a more mafic composition. The pluton was informally named Central "intrusive" by Kerr and others (1957) and was mapped by Kerr and others (1957), Callaghan and Parker (1961), Willard and Callaghan (1962), and Cunningham and Steven (1979f); these geologists recognized that it is a host to many of the uranium deposits in the Central Mining Area. Dunkhase (1980) studied the chemistry of the body and reported anomalously high uranium, thorium, and zirconium. The pluton probably is about 22 Ma. Ages on the pluton itself are summarized by Rowley and others (1988). The most consistent isotopic ages related to the intrusion were obtained from adjacent contemporaneous replacement alunite bodies (Cunningham, Rye and others, 1984). These K-Ar ages were determined on alunite from the Winkleman mine (21.8 ± 4.3 Ma; Steven and others, 1979) southwest of the mapped area, and from the Yellow Jacket mine (22.5 ± 1.0 Ma; Steven and others, 1979) and Al Kee Mee mine (23.2 ± 1.2 Ma; Cunningham, Rye and others, 1984) within the quadrangle (table 1). The pluton must have been eroded and unroofed by about 19 Ma because it is unconformably overlain by the Red Hills Tuff Member of the Mount Belknap Volcanics (unit Tmbr).

Monroe Peak intracaldera rocks, undivided

This unit consists of a poorly preserved, heterogeneous, interbedded sequence of crystal-rich lava flows, crystal-poor lava flows, airfall tuff, sandstone, siltstone, and conglomerate. It is mapped only in the northwestern part of the Monroe Peak caldera where rocks are so intensely argillically and advanced-argillically altered and silicified that mapping of individual lithologic units was not possible. The maximum thickness where mapped is about 1000 feet.

Lava flows of Monkey Flat Ridge

This informal intracaldera unit of the Monroe Peak caldera consists of gray, red, brown, purple, and green, moderately resistant, vesicular to amygdaloidal, dacitic to rhyodacitic lava flows containing sparse phenocrysts of plagioclase, subordinate to minor pyroxene and sanidine, and minor Fe-Ti oxides, biotite, and olivine. Most flows are tabular but some are more bulbous and appear to form low volcanic domes. The unit locally includes minor fluvial sandstone and conglomerate, crystal-rich lava flows similar to those in the lava flows of Monroe Peak (unit Tmpl), and airfall tuff. The unit was deposited only within the Monroe Peak caldera, and it is a partial extrusive equivalent of intrusive rocks of the Monroe Peak caldera. Vent areas and contact relations are generally poorly exposed or obliterated due to pervasive hydrothermal alteration. The unit is named for exposures of fresh flow rocks at Monkey Flat Ridge about 3 miles east of the mapped area; these rocks were formerly called dacitic lava flows by Rowley, Cunningham and Kaplan (1981). The maximum exposed thickness of the unit is about 500 feet, although no complete section exists.

Lava flows of Monroe Peak

Intracaldera lava flows of Monroe Peak consist of reddish-brown, gray, khaki, and tan, moderately resistant, vesicular or amygdaloidal, rhyodacitic lava flows containing moderately abundant, locally large (as much as 0.8 inch) phenocrysts of plagioclase and subordinate sanidine, and minor pyroxene, hornblende, biotite, oxyhornblende, and Fe-Ti oxides. Some flows locally have thin, black, basal vitrophyres, and these basal zones have devitrified in places to crumbly orange rock. Most are tabular lava flows but some are bulbous and appear to form low volcanic domes such as the probable dome in sec. 18, T. 26 S., R. 3 W. This informal unit includes local minor crystal-poor lava flows and dikes similar to those in the lava flows of Monkey Flat Ridge (unit Tmf), fluvial sandstone, airfall tuff, and volcanic mudflow breccia. The unit was deposited only within the Monroe Peak caldera, and it is a partial extrusive equivalent of intrusive rocks of the Monroe Peak caldera (unit Tmpi). It was named for exposures capping Monroe Peak, about 3 miles east of the mapped area (Rowley, Cunningham and Kaplan, 1981). Vent areas and contact relations are generally poorly exposed or obscured by pervasive argillic alteration in most places. New discordant isotopic ages determined on a sample (sample M718) collected from the dome west of Poverty Flat consist of a K-Ar age on sanidine of 21.3±0.7 Ma and a fission-track age on zircon of 15.3±0.7 Ma. The 21.3 Ma age is considered to be the correct age because it agrees with isotopic ages of overlying and underlying rock units. The fission-track age indicates resetting, probably by heat from an inferred buried pluton; heat from this pluton also appears to have helped to form nearby natroalunite deposits of about the same age at the Al Kee Mee mine just to the south (Cunningham, Rye and others, 1984). The maximum exposed thickness of the unit is about 500 feet, although no complete section is exposed.

Monroe Peak intracaldera sedimentary rocks

Monroe Peak intracaldera sedimentary rocks consist of tan, gray, yellow, reddish-brown, pink, and green, soft to moderately resistant, thin- to medium-bedded, fine- to coarse-grained sandstone, siltstone, and airfall tuff, and subordinate to minor crystal-poor and crystal-rich lava flows and minor mudflow breccia and conglomerate. The sedimentary rocks are considered to be primarily of fluvial, but locally of lacustrine, origin; they were derived from erosion of highlands at, and outside of, the caldera rim and within the caldera, and were deposited in the closed basin of the Monroe Peak caldera. Tuff beds locally are rich in phenocrysts and(or) rounded pumice lapilli; they are either airfall or reworked airfall deposits. Rocks of the map unit are either argillically or advanced-argillically altered or silicified, and contact relations are generally poorly exposed or obliterated. The maximum exposed thickness of the unit is about 300 feet, although no complete section is exposed.

Fine-grained silicic pluton

The fine-grained silicic pluton consists of gray and greenish-gray, resistant, porphyritic or less commonly equigranular, fine-grained granodioritic to granitic rocks that cut the Central intrusion (unit Tci) in the Central Mining Area. The pluton contains abundant phenocrysts of orthclase, plagioclase, and quartz, and minor biotite, pyroxene, hornblende, and Fe-Ti oxides in a groundmass of finely crystalline orthoclase, plagioclase, and quartz. In most places it has a fine-grained chilled margin. The map unit also includes several dikes, some of them aplite, as much as 25 feet wide. The pluton was mapped and described by Kerr and others (1957), Callaghan and Parker (1961), and Cunningham and Steven (1979a, f). Cunningham and Steven (1978, 1979a, d, f) interpreted the body to be a fine-grained granite belonging to the bimodal sequence and perhaps a source for some of the rhyolite volcanic rocks in the eastern source area of the Mount Belknap Volcanics. Alternately, the petrographic resemblance of some parts of the pluton to the Central intrusion suggests that it may be a late-stage, more silicic, differentiated phase of the Central intrusion. The fine-grained silicic pluton is located at the intersection of the eastern source area and the wall of the Monroe Peak caldera, suggesting that it may have been localized by the caldera structural margin. Data from drilling and underground mining indicate that the pluton is larger at depth (Kerr, 1968, figure 6). The pluton is a host for many of the uranium ore bodies in the Central Mining Area (Cunningham and Steven, 1978, 1979a). K-Ar and fission-track ages cluster around 21 Ma (Steven and others, 1979; Cunningham, Ludwig and others, 1982), and include an age of 20.2 ± 0.9 Ma on the pluton in the quadrangle, and ages of 21.4 ± 0.9, 21.3 ± 0.9, and 19.5 ± 0.7 Ma (Steven and others, 1979) from a dike in the quadrangle (tables 1 and 2). Analytical data on the other ages are summarized by Rowley and others (1988).

Crystal-rich volcanic domes and plugs of Mount Belknap Volcanics

This informal unit consists of tan, salmon, pink, and gray, resistant, flow-foliated, crystal-rich, rhyolitic volcanic domes and lava flows as well as intrusive feeders for volcanic domes and flows. The unit consists of the oldest rocks of the eastern source area of the Mount Belknap Volcanics. Black and gray vitrophyres locally mark the bases of flows or the chilled margins of intrusive plugs and domes. The rock contains abundant phenocrysts of sanidine, smoky beta quartz, plagioclase, and minor biotite, hornblende, Fe-Ti oxides, pyroxene, apatite, and sphene. Fission-track and K-Ar ages of the unit cluster about 21 Ma (Steven and others, 1979; Cunningham, Ludwig and others, 1982); analytical data are given in tables 1 and 2. The discordant ages of Bassett and others (1963) are discounted because of low analytical precision. The ages of Steven and others (1979) on the Teacup dome are concordant except for one discounted fission-track age that is too old (table 2). The maximum thickness of lava flows in the unit is about 800 feet.

Joe Lott Tuff Member of Mount Belknap Volcanics

The Joe Lott Tuff Member consists of tan, gray, and yellow, moderately resistant, poorly welded, rhyolite ash-flow tuff. It contains about one percent phenocrysts of quartz, sanidine, biotite, and accessory minerals, but many lithic clasts of darker flow-foliated rocks of the Mount Belknap Volcanics. Some cooling units contain brown and black basal vitrophyres. Locally the member contains a white, soft, small-pebble conglomerate as much as 30 feet thick at the base. A dark-brown or black desert varnish characterizes weathered exposures of the unit. The tuff was defined as a formation by Callaghan (1939). Cunningham and Steven (1979d) recognized its derivation from the Mount Belknap caldera, about 7 miles west of the mapped area, in the western source area of the Mount Belknap Volcanics (Budding and others, 1987), and made it a member of the Mount Belknap Volcanics. The tuff was erupted in early Miocene time about 19 Ma, based on K-Ar ages of overlying and underlying units. Its maximum exposed thickness in the quadrangle is about 400 feet, although neither the depositional base nor top is exposed.

Red Hills Tuff Member of Mount Belknap Volcanics

The Red Hills Tuff Member consists of red, reddish-tan, and light-gray, moderately resistant, vesicular, densely welded, rhyolite ash-flow tuff. The unit contains sparse small phenocrysts of anorthoclase, quartz, plagioclase, and minor but conspicuous biotite. It also contains abundant light-gray, highly compacted pumice lenticules and sparse, small, lithic clasts. The unit was defined by Cunningham and Steven (1979d) and interpreted to have erupted from the buried Red Hills caldera just south of the mapped area (Cunningham and Steven, 1979a, e; Rowley and others, 1988), in the eastern source area. The tuff is about 19 Ma based on a K-Ar age from a basal glass (Cunningham, Ludwig and others, 1982) and on ages of underlying and overlying units. The member unconformably overlies the Central intrusion (unit Tci). It is exposed in the southwestern part of the quadrangle, just north of the Red Hills caldera, where its maximum thickness is about 200 feet.

Dikes, lava flows, and plugs of Mount Belknap Volcanics

This informal map unit, made up of rocks of similar lithologies but of several ages in the Miocene, consists of gray, pink, and light-greenish-gray, moderately resistant, flow-foliated rhyolite dikes, lava flows, and hypabyssal plugs. The distribution of these rocks partly defines the eastern source area of the Mount Belknap Volcanics. The bodies contain few phenocrysts and locally are perlitic.

The most economically significant element of this unit is a series of glassy rhyolite dikes that cut the Central intrusion (unit Tči) and the fine-grained silicic pluton (unit Tif). Uranium- and molybdenum-bearing veins occur within, and thus are genetically related to, these dikes. Cunningham, Ludwig and others (1982) suggested that the dikes pass downward into a hidden stock (unit Tmbd in section B-B') that provided the uranium metals for mineralization in the Central Mining Area. Cunningham and Steven (1978, 1979a) also proposed that the apex of this stock may contain a porphyry-type molybdenum deposit. Uranium veins cut the Red Hills Tuff Member. Two fission-track ages were determined on glassy dikes at the southern edge of the quadrangle; one cuts the Central intrusion and is 19.0 ± 1.0 Ma (Cunningham, Ludwig and others, 1982), and another cuts the fine-grained silicic pluton and is 19.9 ± 1.1 Ma (table 2). Cunningham, Ludwig and others (1982) reported two discordant fission-track ages of 23.3 ± 4.7 Ma (apatite) and 18.1 ± 0.8 Ma (zircon) on samples from a glassy dike in the area just south of the quadrangle. Cunningham, Ludwig and others (1982) favor an age of 19-18 Ma for the glassy rhyolite dikes, which agrees with ages measured on uranium minerals. The rhyolitic rocks exposed in the southwestern part of the quadrangle, called the rhyolite of Big Star by Cunningham and others (1983), appears to be a volcanic dome; its maximum thickness is about 300 feet and it has K-Ar ages of 16-12 Ma (Bassett and others, 1963). Ages of vein natroalunite in several places in the quadrangle range from 18-13 Ma (table 1); natroalunite may be due to heat from rhyolite intrusions of the map unit (Cunningham, Rye, and others, 1984).

PLIOCENE? AND MIOCENE

Sevier River Formation, undivided

The Sevier River Formation of Pliocene? and Miocene age consists of gray and tan, poorly to moderately consolidated, medium- to thick-bedded sandstone, conglomerate, and siltstone. These clastic rocks were deposited by fluvial and (locally) lacustrine processes mostly in broad downwarped basins but later in grabens. Thin patches of gravel exposed near the top of the Antelope Range in the western part of the quadrangle are pediment gravels that cap the generally flat top of the Antelope Range. The gravels were deposited before Marysvale Canyon, west of the mapped area, was carved. The formation was defined by Callaghan (1938) for exposures just north of the town of Sevier in the northwestern part of the quadrangle. Depositional landforms that controlled deposition of the Sevier River Formation are not preserved. Airfall tuff beds within the formation near Clear Creek just north and northwest of the mapped area have fission-track ages of 14 and 7 Ma, middle to late Miocene (Steven and others, 1979). The upper part of the unit, however, may be as young as Pliocene or even Pleistocene. The exposed thickness of the rocks is about 200 feet but they are doubtless considerably thicker under Sevier Valley and Poverty Flat.

Sevier River Formation, lacustrine facies

This unit consists of light-green, poorly to moderately consolidated claystone, marlstone, siltstone, and limestone deposited in the interior of a closed basin. The lacustrine facies intertongues with and locally underlies the piedmont facies (unit Tsep). The only exposure is a partial section in the northwestern part of the quadrangle, where the unit is about 250 feet thick; it is probably much thicker beneath the Sevier Valley.

Sevier River Formation, piedmont facies

This unit consists of tan and pinkish-tan, poorly to moderately consolidated sandstone, siltstone, conglomerate, and airfall tuff deposited along basin margins before integration of drainage in the area. It is exposed only in a partial section in the northwestern part of the quadrangle, where it is about 150 feet thick; it is probably much thicker beneath the Sevier Valley.

QUATERNARY

Older piedmont-slope deposits

Dissected remnants of older piedmont-slope deposits consist of gray, unconsolidated to poorly consolidated silt, sand, and gravel. Clasts commonly are coated with caliche. The unit is mostly Pleistocene but may include some Pliocene deposits. The unit's maximum exposed thickness is about 120 feet.

Older alluvial fan deposits

Dissected remnants of older alluvial fans consist of gray, unconsolidated to poorly consolidated silt, sand, and gravel. Clasts commonly are coated with caliche. The maximum exposed thickness of this Pleistocene unit is about 300 feet.

Piedmont-slope deposits

Piedmont-slope deposits consist of unconsolidated, poorly sorted silt, sand, and gravel on broad, sweeping surfaces (piedmont slopes) formed by erosion (as pediments) and deposition (as alluvial fans). The unit includes alluvium of small drainages; locally it also includes colluvium, alluvial slope wash, and talus. The maximum exposed thickness is about 100 feet for this Holocene and Pleistocene unit.

Alluvial fan deposits

Alluvial-fan deposits consist of unconsolidated, poorly sorted silt, sand, and gravel deposited at the bases of some slopes. The unit includes alluvium from streams that feed fans and local colluvium, alluvial slope wash, and talus. Its maximum exposed thickness is about 300 feet.

Landslide debris

Landslide debris consists of unconsolidated, angular, unsorted material that moved downslope, mostly off the

Sevier Plateau fault scarp, to form lobate deposits. The unit includes talus and colluvium. Its maximum thickness is about 300 feet.

Hot springs deposits

Tan and light-gray, moderately resistant, thin-bedded calcareous tufa (travertine) was derived from hot springs that issued and are continuing to issue along the Dry Wash fault and the Sevier fault zone. The maximum thickness of the unit is 50 feet.

Alluvial flood-plain deposits

Unconsolidated silt, sand, and gravel form a flood plain flanking the Sevier River. The unit includes overbank deposits as well as islands and bars exposed in the stream channel during low-water stages. Its maximum thickness is about 30 feet, its age is Holocene.

MONROE PEAK CALDERA

The Monroe Peak caldera is the largest caldera in the Marysvale volcanic field, with an east-west diameter of 16 miles and a north-south diameter of 11 miles. The caldera formed within an upland of clustered volcanos, which erupted rocks such as the Bullion Canyon Volcanics near the central part of the Marysvale field. The caldera formed during final stages of calc-alkaline volcanic activity when cupolas rose above the huge composite batholith complex that is inferred to underlie most of the volcanic field (Steven and others, 1984). The northwestern part of the caldera is exposed in the Antelope Range quadrangle; the rest of the caldera was mapped by Rowley, Cunningham and Kaplan (1981); Rowley, Williams and others (1981); Rowley and others (1986a, b); Rowley and others (1988). A summary of the geology of the caldera is provided by Steven and others (1984). The Monroe Peak caldera coincides with an aeromagnetic high and a gravity low, apparent at both regional (Zietz and others, 1976; Mabey and Virgin, 1980; Cook and others, 1975, 1981) and detailed scales (Campbell and others, 1984; Cook and others, 1984).

The Monroe Peak caldera was the source of the Osiris Tuff, the most widespread volcanic unit in the Marysvale volcanic field. The Osiris Tuff is a densely welded rhyodacitic ash-flow tuff that consists of a thin outflow facies deposited outside the caldera and a thick intracaldera facies. The outflow facies presently is exposed over an area of at least 1500 square miles, mostly in the central High Plateaus; it formerly covered most of the Marysvale field. Outflow rocks are rarely more than 50 feet thick within the main part of the Marysvale field, but as much as 300 feet are preserved north and east of the field where the tuff apparently drained down off the field and pooled in lowlands. In contrast, the thickness of the intracaldera facies is at least 1800 feet. The total volume of both facies is at least 50 miles^3.

Most of the caldera formed by rapid subsidence when the outflow facies of the Osiris Tuff was erupted about 23 Ma. Tuff from subsequent eruptions probably was largely confined to the caldera, although some outflow material probably also was produced. The caldera continued to subside in response to the continued evacuation of the magma chamber. Emplacement of the Osiris Tuff was followed by eruption of lava flows and volcanic domes at several sites within the caldera. The younger lava flows have isotopic ages of about 22 Ma. All these rocks are in turn overlain by airfall tuff and by fluvial and lacustrine sedimentary rocks deposited in the remaining parts of the topographic basin of the caldera. The post-Osiris intracaldera units complexly intertongue in parts of the caldera, especially within the Antelope Range quadrangle. The volcanic rocks represent tapping of a composite cupola that underlay the caldera and rose to shallow levels as the caldera developed. These various plutonic units have isotopic ages of about 22 Ma.

The intracaldera cupola rose to such shallow levels that it intruded the intracaldera facies of the Osiris Tuff and most other intracaldera rocks. In some places outside the mapped area, intrusive bodies extending upward from the source batholith pass gradationally into volcanic rocks, demonstrating that they breached the surface. The complex pattern of younger faults that characterize the quadrangle has obscured the answer to the question as to whether the intracaldera batholith produced minor resurgent uplift within the caldera. The presence of intracaldera sedimentary rocks concentrated near the southeastern edge of the caldera (Rowley, Williams and others, 1981; Rowley and others, 1986a) suggests that they filled a moat within the caldera on the outer flank of a resurgent uplift. However, less faulted parts of the caldera in Sevier Plateau to the east are saucer shaped, suggesting that any resurgent uplift was minor. Our interpretation is that the intracaldera rocks that formed the roof of the intracaldera batholith did not have the strength to support a structural dome owing to the shallow depth of the batholith, which was probably only several thousand feet or less below the surface.

HIGH ANGLE FAULTS

The rocks in the Antelope Range quadrangle are cut by numerous high-angle, basin-range faults that formed during regional extension of the Basin and Range province and High Plateaus. Most faults strike north-northeast or north-northwest, creating a rhombic fault pattern. Some fault planes in the area exhibit sub-horizontal slickensides (for example, southwest of Joseph, in sec. 21, T. 25 S., R. 4 W.; R. E. Anderson, oral communication, 1984), but known relative displacement for most faults in the area indicates that dip-slip displacement dominates along most faults

The greatest vertical displacement in the quadrangle is that along the Sevier fault zone, along which uplift of the Sevier Plateau took place. Topographic relief between the summit of the plateau and the Sevier Valley is more than 5000 feet, thereby giving a minimum amount for vertical displacement along the fault zone. Another major fault is the Dry Wash fault in the northwestern part of the quadrangle; vertical displacement along this fault is poorly known but, judging from the large low-gravity anomaly west of it (Cook and others, 1984), probably it is at least 1000 feet. The Dry Wash fault may also have left-lateral strike-slip movement (R. E. Anderson, oral communication, 1984). The presence of a fault along the western side of Poverty Flat is suggested by a significant gravity low (Cook and others, 1984) underlying Poverty Flat and the Sevier Valley north of it.

Ages of faulting are poorly known, but most offset seems to have taken place during latest Miocene through early Pleistocene time. In the Kingston Canyon area of the Sevier Plateau, about 22 miles south-southeast of the mapped area, the ages of rhyolites bracket the age of canyon cutting, and therefore major faulting, between 8 and 5 Ma (Rowley, Steven and Mehnert, 1981). Faulting may have begun much earlier, however, inasmuch as regional extension in Utah seems to be generally associated with compositionally bimodal (alkali basalt and alkali rhyolite) volcanism, which began about 22 Ma in neighboring quadrangles (Anderson and Rowley, 1975; Rowley, Cunningham and others, 1979; Steven and others, 1979; Best and others, 1980). Some faults in the northwestern part of the quadrangle (E½ sec. 33 and W½ sec. 34, T. 25 S., R. 4 W.) cut the Bullion Canyon Volcanics but not the Joe Lott Tuff Member of the Mount Belknap Volcanics, and therefore are older than 19 Ma. Faulting locally continued into late Quaternary time, as indicated by scarps that cut surficial sediments in some nearby areas (e.g., Rowley, Cunningham and others, 1979).

ECONOMIC GEOLOGY

The southern part of the Antelope Range quadrangle contains mineralized and hydrothermally altered rocks of several ages (Steven and others, 1979; Cunningham and others, 1983), and propylitic, argillic, and advanced-argillic alteration products are common and conspicuous (Cunningham, Steven and others, 1984). Uranium and alunite have been the main commodities mined in the quadrangle. Most uranium mines are confined to a small area, 0.7 mile north-south by 0.3 mile east-west, called the Central Mining Area (Cunningham and Steven, 1979a), which extends across the border of the Antelope Range quadrangle into the Marysvale quadrangle to the south (Rowley and others, 1988). The Central intrusion, the fine-grained silicic pluton, and the Red Hills Tuff Member are the main hosts for uranium veins in the Central Mining Area.

The oldest period of alteration and mineralization in the Marysvale area was coeval with emplacement of 27-23 Ma plutons associated with the Bullion Canyon Volcanics (Steven and others, 1979; Steven and Morris, 1984). In the Tushar Mountains, sparse pyrite-bearing quartz-carbonate veins that contain some gold and silver formed during this time, generally near the carapace of plutons, but no such productive veins have been identified in the Antelope Range quadrangle. One pluton of this age that might have associated veins of this type is the Hoover pluton; the Trinity mine just west of the mapped area is in contact-metamorphosed sedimentary rocks at the pluton margin but only thin streaks of pyrite and chalcopyrite are exposed (Callaghan, 1973). Alternativley, some of the mineralized rocks at the Trinity mine may be related to a small rhyolite stock that cut the metamorphosed rocks near the mine. The Antelope mine, near the southwestern corner of the quadrangle, contains traces of precious metals.

The next youngest period of alteration and mineralization accompanied emplacement of the intracaldera batholith, especially the Central intrusion. The principal economic commodity formed during this event was replacement alunite. Most production of replacement alunite in the quadrangle came from the Yellow Jacket, Von Hindenburg, Marys Lamb, and J and L mines; replacement alunite also occurs in small quantities at the Big Star and Al Kee Mee mine and other areas (Callaghan, 1938, 1973; Callaghan and Parker, 1961). Direct dating confirms that replacement alunite was formed 23-22 Ma (table 1), the same general age as the Central intrusion (Steven and others, 1979; Cunningham, Rye and others, 1984). The origin of replacement alunite deposits was attributed by Cunningham, Rye and others (1984) to heat from the Central intrusion that produced a series of hydrothermal convection cells of circulating ground water in the country rocks. Evaporite minerals in Mesozoic rocks at depth supplied sedimentary sulfur, which was reduced while passing through the volcanic rocks. The sulfur reacted with atmospheric oxygen near the ground surface to produce acidic solutions that altered the country rocks and developed alunite and related minerals. Alunite deposits, marking the location of the upflowing limbs of the convection cells, surround the Central intrusion (Podwysocki and others, 1983). The main products of the alteration are kaolinite, alunite, jarosite, and hematite; within each cell, the alunite zone passes laterally into kaolinite and upward into jarosite, hematite, and flooded silica zones. Propylitically altered rocks formed below the permanent water table, whereas alunite and kaolinite formed just above the water table, and jarosite, hematite, and silica formed progressively closer to the surface. The zones are best exposed in the Yellow Jacket and Al Kee Mee hydrothermal cells. The altered and alunitized rocks of the Antelope, Big Star, Alum King, and J and L mines might be due in part to emplacement of the Hoover pluton, as well as being part of another hydrothermal cell of the Central intrusion, and were reworked again in a still younger period of alteration (Cunningham, Rye and others, 1984). In places, rock in the hematite zone forms ore-grade concentrations of stalactitic and botryoidal iron and manganese, although the tonnage of such material is small. Iron and manganese deposits overlie alunite and underlie silicified rocks at the Iron Cap mine near the northwestern margin of the caldera, but apparently only small amounts of ore were shipped (Callaghan and Parker, 1961; Bullock, 1970; Callaghan, 1973). Base and precious metals related to hydrothermal cells or to deeper-level vein, replacement, or skarn deposits may also exist near the Central intrusion (Steven and Morris, 1984).

The upper flooded silica zones form numerous resistant knobs in the quadrangle. They developed when silica released during alteration migrated upward and either replaced rocks near the surface or was deposited on the surface as siliceous sinter from hot springs (Cunningham, Rye and others, 1984). When silica sealed up vents of hot springs and geysers, built-up pressure inside sinter mounds eventually was released explosively, producing hydrothermal breccia (Cunningham, Rye and others, 1984). Repeated sealing of vents and succeeding "blowouts" formed large quartz caps; especially large and well-exposed caps are east of the Yellow Jacket mine and east and north of the Iron Cap mine. In addition, ponds that formed in association with the former hot springs were filled with laminated clay, siltstone, and sandstone, which were silicified soon after deposition. These sediments exhibit soft-sediment deformation features. The depositional environments then must have resembled the ones we see now in the hot spring areas of Yellowstone National Park (Eaton and others, 1975).

Two younger periods of alteration and mineralization are related to rhyolitic magmas of the Mount Belknap Volcanics. The first deposited uranium and related lithophile elements in the Central Mining Area. Most production (1 million pounds of U_3O_8) came from nine mines (Callaghan, 1973; Steven and Cunningham, 1979a), but only the Freedom No. 2, Potts, and Cloys mines are located within the quadrangle. Most of the uranium minerals like uraninite and coffinite were precipitated in fracture-filled veins of diverse trends. Low-grade uranium values were also noted during drilling peripheral to the Central Mining Area (Steven and others, 1981; Steven and Morris, 1984). Hydrothermal alteration associated with uranium mineralization was relatively slight (Cunningham and Steven, 1978, 1979a; Steven and others, 1981). Fluid-inclusion data indicate that the fluids that deposited uranium were dilute, acidic, reducing solutions with temperatures of about 200° C and that these fluids were rich in fluorine, suggesting that uranium was carried in uranous fluoride complexes.

The uranium veins are genetically associated with rhyolite dikes of the Mount Belknap Volcanics (unit Tmbd). The veins and dikes cut the Central intrusion, the fine-grained silicic pluton, and the Red Hills Tuff Member. Isotopic ages on the dikes range from 19-18 Ma and a U-Pb isochron age of 19.0 ± 3.7 Ma on uranium and fluorine vein material and a fission-track age of 16.5 ± 4.3 Ma on quartz adjacent to pitchblende (Cunningham, Ludwig and others, 1982). Molybdenum and fluorite are associated with the uranium, and molybdenum increases in abundance downward in subsurface mine workings. Cunningham and Steven (1978, 1979a) and Steven and others (1981) suggested that the uranium and molybdenum are related to emplacement of, and distention of, overlying rocks by an underlying parent source magma body of the Mount Belknap Volcanics, and that this intrusion (unit Tmbd on cross secton B-B') also may contain a porphyry-type disseminated molybdenum deposit. Uranium also is enriched within rocks related to the Monroe Peak caldera and exceeds 50 ppm (parts per million) in fresh, silicic, intracaldera lava flows in the eastern part of the caldera (Rowley and others, 1986a,b). Dunkhase (1980) noted the anomalously high values of uranium in fresh rocks of the Central intrusion and postulated that the pluton was the ultimate source of the uranium.

The next youngest known period of alteration and mineralization produced natroalunite that is superimposed on, and whose constituents are derived from, the older replacement alunite (Cunningham, Rye, and others, 1984). Heat from plutons or feeders of the Mount Belknap Volcanics probably remobilized the natroalunite. Isotopic ages (table 1) indicate that this took place 18-13 Ma (Steven and others, 1979; Cunningham and others, 1984). Natroalunite has been mined at the Big Star and Big Chief mines and has been noted at the Al Kee Mee, Yellow Jacket, and Alum King mines. A rhyolite or granite pluton may underlie the area of the Al Kee Mee mine (Cunningham, Rye and others, 1984). The formation of natroalunite at the Alum King and Big Star mines probably resulted from emplacement of the nearby rhyolite of Big Star volcanic dome. The age of the natroalunite and rhyolite is similar to the age of precious- and base-metal mineralization, alteration, and inferred plutonism in the Deer Trail mine and Alunite Ridge area about 8 miles southwest of the mapped area (Cunningham and Steven, 1979b). Semiquantitative spectrographic analyses of samples from quartz veins at the Antelope mine, adjacent to the rhyolite, indicate anomalous values of molybdenum, silver, and copper.

The youngest period of alteration in the area is that associated with hot springs along the Dry Wash fault and Sevier fault zone. Calcareous tufa occurs at the sites of these springs. The springs have no known association with Quaternary bimodal volcanism and may have originated by deep convection along basin-range faults.

GEOMORPHOLOGY

The present topography in the Antelope Range quadrangle is the result of erosion of downwarped basins and fault blocks formed during a long phase of regional extension. One of the first products of this extension was closed basins in which the oldest parts of the Sevier River Formation were deposited. The mountains and valleys took on their present overall size and shape later, probably in late Tertiary time and perhaps in the 8 to 5 million-year-interval hypothesized for most faulting in the Kingston Canyon area to the south (Rowley, Steven and Mehnert, 1981). As subsidence and faulting continued, fluvial and lacustrine sediments of younger parts of the Sevier River Formation probably filled the faulted basins. The present drainage was superimposed on the thick fill of Sevier River Formation during destruction of closed basins and integration of drainage through much of the High Plateaus and adjacent parts of the Basin and Range. As streams cut down and the base level lowered, the soft rocks of the Sevier River Formation were selectively removed by the ancestral Sevier River. Marysvale Canyon for example, just west of the mapped area, is cut more than 1000 feet through the Antelope Range and parts of the northeastern Tushar Mountains. Eardley and Beutner (1934) ascribed the cutting of Marysvale Canyon to stream piracy of a former south-flowing river. We suggest instead that it formed by superposition through a cover of the Sevier River Formation. The flat top of the Antelope Range, with its preserved patches of Sevier River Formation, gives evidence of the minimum level to which the formation filled the basin. This flat top is an erosion surface, perhaps a pediment, cut probably during basin filling. Faulting continued during downcutting in this part of Utah; many streams probably were antecedent across active faults.

The widespread silica masses and related intracaldera volcanic, sedimentary, hydrothermally altered, and mineralized rocks that are known to have formed at or near the surface about 22 Ma are an enigma. One would not expect former erosion surfaces to be preserved for that length of time, especially where uplift and deep erosion were profound after the surfaces were formed. A similar problem was noted in the Kingston Canyon area by Rowley, Steven and Mehnert (1981). At this location, a rhyolite tuff cone and volcanic dome formed at the bottom of Kingston Canyon about 5 Ma, but there has been no incision below this level in the canyon since then. The most reasonable explanation is that the 22 Ma erosion surfaces and perhaps the 5 Ma cone were buried by the Sevier River Formation and that they only recently have been exhumed.

GEOLOGIC HAZARDS

This part of Utah is within a seismically active belt and earthquakes have been felt in the Antelope Range quadrangle in the historic past. One of Utah's largest earthquakes (magnitude 7) occurred a few miles west of the quadrangle in 1967 (Stover and others, 1986). There is no evidence to indicate that any historical earthquakes resulted from local faulting that breached the surface. No faults in the quadrangle are known to have displaced Quaternary deposits, although such sediments have been cut about 9 miles south of the mapped area (Rowley, Cunningham and others, 1979; Rowley and others, 1988). Houses, dams, or major buildings are in danger of being damaged if they are constructed on or near active faults. Buildings on poorly consolidated alluvium or thick, soft soil in valley bottoms are also prone to damage from shaking and subsidence related to earthquake activity.

One major landslide is mapped in the southeastern part of the quadrangle. There are indications of recent movement on the landslide, including fresh ridges, cracks, ponds, and bent trees. It is probable that parts of the landslide will continue to move, especially during wet periods

Flooding by the Sevier River has taken place in the quadrangle during the last several years, as well as in previous years, and thus flooding can be expected to occur in the future. Flash floods are probable along most other perennial or intermittent streams in the quadrangle. Flood hazards are particularly severe at the mouths of canyons where flood water will funnel.

WATER RESOURCES

The Sevier River provides a perennial source of water for domestic and agricultural uses in the quadrangle. Several small streams and springs issue from the mountain front of the Sevier Plateau, but they have been only partly exploited.

Warm water has issued until recently along the Dry Wash fault southeast of Joseph; the same area might contain geothermal resources at depth but apparently it has not been explored. Hot spring deposits occur south of the entrance to Live Oak Canyon, but surface spring water there is cold now. The proximity of the deposits to Monroe hot springs, about 2 miles northeast of the mapped area, suggests that several areas in the quadrangle might also contain hot water at depth; the present and former hot springs at Live Oak Canyon and Monroe are controlled by fractures of the Sevier fault zone. Exploration for hot water probably will not be undertaken in the quadrangle until energy costs rise dramatically.

SCENIC AND RECREATIONAL AREAS

The Sevier Plateau is a rugged, beautiful, heavily wooded high plateau suitable for camping, hiking, and hunting. Other parts of the quadrangle, however, are covered by sagebrush flats and hills, locally sprinkled with pinyon and juniper trees; these areas are not traditionally considered to be scenic areas, but they are lovely in their own right. In the southern part of the quadrangle, these hills contain scattered trenches, pits, adits, tunnels, and the remains of an alunite mill left from past mining and minerals exploration activity. These features may be of interest to mining and history buffs and rockhounds. In some places, mine workings are not covered or fenced off so that visitors exploring the area on foot should be careful.

ACKNOWLEDGMENTS

We are grateful to many persons for the assistance in the field work and during the evolution of ideas as the long-term study of the Marysvale mining district progressed. These include: J. R. Rasmussen, J. J. Anderson, P. L. Williams, D. R. Mabey, K. L. Cook, R. J. Fleck, and R. R. Kennedy. We received encouragement and considerable logistic support from local residents: Jim and Joan Anderson of Marysvale, Ada Hoover of Marysvale, LaWayne and Marian Hatch of Koosharem, and Dean and Sheren Pierson of Junction and Kanab deserve special mention. The manuscript was much improved by technical reviews by J. C. Cole and B. A. Skipp.

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