# A Summary of Tertiary Volcanic Stratigraphy of the Southwestern High Plateaus and Adjacent Great Basin, Utah

GEOLOGICAL SURVEY BULLETIN 1405-B

# A Summary of Tertiary Volcanic Stratigraphy of the Southwestern High Plateaus and Adjacent Great Basin, Utah

*By* PETER D. ROWLEY, JOHN J. ANDERSON,
*and* PAUL L. WILLIAMS

CONTRIBUTIONS TO STRATIGRAPHY

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*Stratigraphic setting of rocks of the south flank of the Marysvale volcanic pile and intertonguing regional ash-flow tuffs of Great Basin sources, southwestern Utah*

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# TABLE

# METRIC-ENGLISH EQUIVALENTS

| Metric unit | | English equivalent | |
|---|---|---|---|
| **Length** | | | |
| millimetre (mm) | = | 0.03937 | inch (in) |
| metre (m) | = | 3.28 | feet (ft) |
| kilometre (km) | = | .62 | mile (mi) |
| **Area** | | | |
| square metre ($m^2$) | = | 10.76 | square feet ($ft^2$) |
| square kilometre ($km^2$) | = | .386 | square mile ($mi^2$) |
| hectare (ha) | = | 2.47 | acres |
| **Volume** | | | |
| cubic centimetre ($cm^3$) | = | 0.061 | cubic inch ($in^3$) |
| litre (l) | = | 61.03 | cubic inches |
| cubic metre ($m^3$) | = | 35.31 | cubic feet ($ft^3$) |
| cubic metre | = | .00081 | acre-foot (acre-ft) |
| cubic hectometre ($hm^3$) | = | 810.7 | acre-feet |
| litre | = | 2.113 | pints (pt) |
| litre | = | 1.06 | quarts (qt) |
| litre | = | .26 | gallon (gal) |
| cubic metre | = | .00026 | million gallons (Mgal or $10^6$ gal) |
| cubic metre | = | 6.290 | barrels (bbl) (1 bbl=42 gal) |
| **Weight** | | | |
| gram (g) | = | 0.035 | ounce, avoirdupois (oz avdp) |
| gram | = | .0022 | pound, avoirdupois (lb avdp) |
| tonne (t) | = | 1.1 | tons, short (2,000 lb) |
| tonne | = | .98 | ton, long (2,240 lb) |
| **Specific combinations** | | | |
| kilogram per square centimetre ($kg/cm^2$) | = | 0.96 | atmosphere (atm) |
| kilogram per square centimetre | = | .98 | bar (0.9869 atm) |
| cubic metre per second ($m^3/s$) | = | 35.3 | cubic feet per second ($ft^3/s$) |

| Metric unit | | English equivalent | |
|---|---|---|---|
| **Specific combinations—Continued** | | | |
| litre per second (l/s) | = | .0353 | cubic foot per second |
| cubic metre per second per square kilometre [$(m^3/s)/km^2$] | = | 91.47 | cubic feet per second per square mile [$(ft^3/s)/mi^2$] |
| metre per day (m/d) | = | 3.28 | feet per day (hydraulic conductivity) (ft/d) |
| metre per kilometre (m/km) | = | 5.28 | feet per mile (ft/mi) |
| kilometre per hour (km/h) | = | .9113 | foot per second (ft/s) |
| metre per second (m/s) | = | 3.28 | feet per second |
| metre squared per day ($m^2/d$) | = | 10.764 | feet squared per day ($ft^2/d$) (transmissivity) |
| cubic metre per second ($m^3/s$) | = | 22.826 | million gallons per day (Mgal/d) |
| cubic metre per minute ($m^3/min$) | = | 264.2 | gallons per minute (gal/min) |
| litre per second (l/s) | = | 15.85 | gallons per minute |
| litre per second per metre [(l/s)/m] | = | 4.83 | gallons per minute per foot [(gal/min)/ft] |
| kilometre per hour (km/h) | = | .62 | mile per hour (mi/h) |
| metre per second (m/s) | = | 2.237 | miles per hour |
| gram per cubic centimetre ($g/cm^3$) | = | 62.43 | pounds per cubic foot ($lb/ft^3$) |
| gram per square centimetre ($g/cm^2$) | = | 2.048 | pounds per square foot ($lb/ft^2$) |
| gram per square centimetre | = | .0142 | pound per square inch ($lb/in^2$) |
| **Temperature** | | | |
| degree Celsius (°C) | = | 1.8 | degrees Fahrenheit (°F) |
| degrees Celsius (temperature) | = | [(1.8×°C)+32] | degrees Fahrenheit |

CONTRIBUTIONS TO STRATIGRAPHY

# A SUMMARY OF TERTIARY VOLCANIC STRATIGRAPHY OF THE SOUTHWESTERN HIGH PLATEAUS AND ADJACENT GREAT BASIN, UTAH

By PETER D. ROWLEY, JOHN J. ANDERSON, and PAUL L. WILLIAMS

ABSTRACT

Recent geologic mapping of the southern flank of the volcanic pile centered at Marysvale, Utah, as well as the eastern edge of the Great Basin ash-flow tuff province, has necessitated changes and additions in nomenclature of Tertiary rocks. Nine formation names are retained, and five formation names are adopted: Mount Dutton (Oligocene and Miocene), Buckskin (Miocene), Bear Valley (Miocene), Osiris (Miocene), and Horse Valley (Miocene). The Dry Hollow Formation (Miocene) is redefined. Six new formal members are adopted: the Blue Meadows Member of the Isom Formation; the Narrows and Table Butte Members of the Leach Canyon Formation; and the Beaver, Kingston Canyon, and Antimony Members of the Mount Dutton Formation. The Baldhills Member of the Isom Formation is redefined. In our area the Leach Canyon Formation, Condor Canyon Formation, and Harmony Hills Tuff are lumped together as the Quichapa Group, in accord with the usage of Williams (1967). The Sevier River Formation and overlying younger basalt flows are demonstrated to be older (Miocene) than previously thought. The name Wasatch Formation is not used in the area that we have mapped. The names Brian Head Formation and Parunuweap Formation are abandoned.

## INTRODUCTION

Changes in stratigraphic nomenclature of Tertiary volcanic rocks in southwestern Utah are necessitated by the results of a detailed mapping program, from 1963 to 1975, of 5,000 km$^2$ of the southwestern flank of the volcanic pile centered at Marysvale (fig. 1). Stratigraphic revisions summarized herein are from a more detailed discussion by Anderson and Rowley (1975).

Most published work on the Marysvale volcanic center is by Callaghan and his associates (Callaghan, 1938, 1939, 1973; Callaghan and Parker, 1961a, 1961b, 1962a, 1962b; Willard and Callaghan, 1962) and by Kerr and his students (for example, Kerr, 1963, 1968; Kerr and others, 1957). These studies concentrated on the Marysvale mining district in the center of the large Marysvale pile and on the north flank of the pile. Gregory (1945, 1949, 1950, 1951) conducted numerous reconnaissance studies south of the Marysvale area.

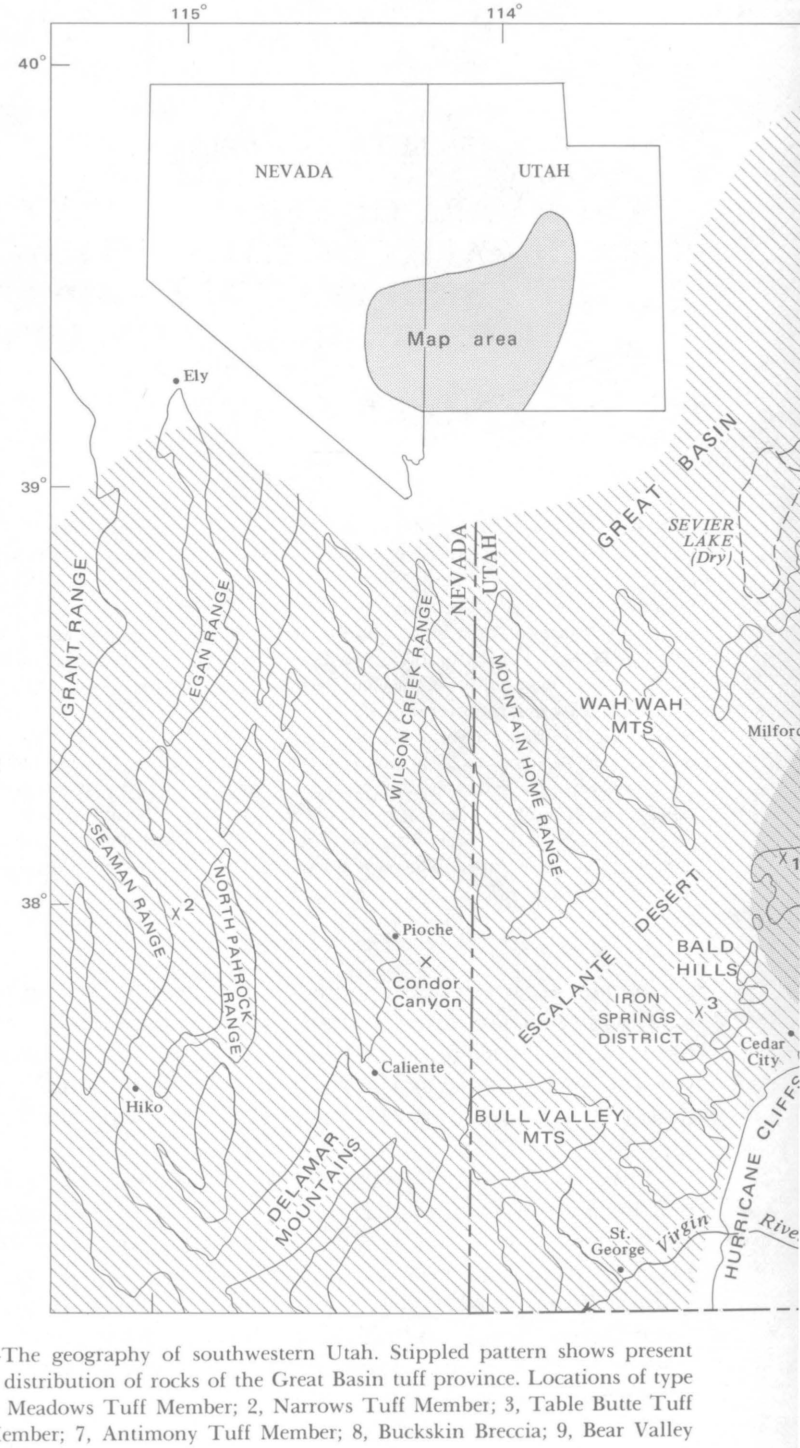


FIGURE 1.—The geography of southwestern Utah. Stippled pattern shows present present distribution of rocks of the Great Basin tuff province. Locations of type 1, Blue Meadows Tuff Member; 2, Narrows Tuff Member; 3, Table Butte Tuff Tuff Member; 7, Antimony Tuff Member; 8, Buckskin Breccia; 9, Bear Valley


distribution of rocks of the Marysvale volcanic pile; cross-hatched pattern shows sections for new stratigraphic units are identified by the following numbers: Member; 4, Mount Dutton Formation; 5, Beaver Member; 6, Kingston Canyon Formation; 10, Osiris Tuff; 11, Horse Valley Formation.

Our work is an extension of the investigations by J. Hoover Mackin and his students (among them, Mackin, 1960, 1968), who mapped in and near the Iron Springs mining district to the southwest. Most of our work has been on the southern flank of the Marysvale pile; specifically, we mapped the southern Sevier Plateau, southern Tushar Mountains, and northern Markagunt Plateau—all in the High Plateaus—and the Black Mountains in the adjacent Great Basin (Anderson, 1965, 1971; Rowley, 1968, 1972). Paleomagnetic investigations and K-Ar dating were an important part of the investigation (Nairn and others, 1975; Fleck and others, 1975). Reconnaissance mapping has been carried out on the eastern flank of the Marysvale pile (Williams and Hackman, 1971; Hackman and Wyant, 1973). Williams (1960, 1967) also conducted regional stratigraphic studies on the Great Basin ash-flow tuffs of the Quichapa Group, and Rowley recently has filled in some gaps in the detailed mapping of Mackin in the Iron Springs district.

This paper discusses only those stratigraphic units that occur in part or wholly within the southwestern High Plateaus and the Black Mountains. Thus, Great Basin volcanic units that occur adjacent to, but outside, these areas—such as the Hiko Tuff (Dolgoff, 1963; Cook, 1965) and the Rencher Formation, Kane Point, and Ox Valley Tuffs (Blank, 1959; Mackin, 1960; Cook, 1965)—are beyond the scope of this report.

### ACKNOWLEDGMENTS

The late J. H. Mackin aided and encouraged us early in the study, as did R. L. Folk, R. E. Boyer, and D. S. Barker of the University of Texas at Austin. A. E. M. Nairn of the University of South Carolina supplied paleomagnetic data, and R. J. Fleck determined K-Ar ages on the volcanic rocks. We also are grateful for assistance during the study to Eugene Callaghan of the Utah Geological and Mineralogical Survey, P. E. Damon of the University of Arizona, James Judy, Thomas Iivari, and Douglas Kohout of Kent State University, as well as Paul Averitt, R. L. Parker, and W. E. Bowers. The manuscript was reviewed by D. H. McIntyre and P. W. Lipman. The study was aided by support from the National Science Foundation (Grants GA-1098 and GA-11081), Penrose Bequest to the Geological Society of America, University of Texas at Austin, Alfred P. Sloan Foundation, Shell Oil Company, Society of Sigma Xi, and Utah Geological and Mineralogical Survey.

## GEOLOGIC SETTING

Between about 26 m.y. and about 20 m.y. ago (Miocene of Harland and others, 1964), volcanism that was centered near Marysvale inundated an area nearly 200 km in diameter to a thickness of at least 3,000 m. This complex of stratovolcanoes consisted in large part of locally derived andesitic to dacitic lava flows and volcanic breccia, with lesser silicic ash-flow tuff and intrusive rock. Dacitic lava flows were deposited on top of these rocks and in turn were capped by basaltic lava flows and thick overlying rhyolite lava flows and poorly welded ash-flow tuff; the basaltic and rhyolitic rocks were deposited about 20 m.y. ago.

Synchronous with the buildup of this Marysvale pile was emplacement of thin ash-flow tuff sheets of regional extent, derived from sources within the Great Basin. Representative sections of this ash-flow sequence are well exposed in the Iron Springs mining district (Mackin, 1960). These tuff sheets lap against and interfinger with the thick local rocks of the Marysvale pile; intertonguing relations are best seen in the Black Mountains and Markagunt Plateau. Table 1 summarizes petrologic and stratigraphic information on the volcanic units exposed in the southwestern High Plateaus and Black Mountains.

On the basis of our mapping in these two overlapping volcanic provinces, we subdivide the Cenozoic rocks into three stratigraphic sequences: lower Tertiary (includes rocks perhaps as old as Cretaceous), middle Tertiary, and upper Tertiary and Quaternary (Anderson and Rowley, 1975; fig. 2, this report). The lower Tertiary sequence consists of lacustrine-fluvial sedimentary rock (Claron Formation), unnamed local volcanic and sedimentary rock, and ash-flow tuff (Needles Range Formation); these units are continuous through the southern High Plateaus and eastern Great Basin. The middle Tertiary sequence is composed of the intertonguing volcanic rocks of the Marysvale pile and Great Basin province. Toward the close of and following deposition of the middle Tertiary volcanic rocks, block faulting began in the High Plateaus and Great Basin; erosion of upfaulted areas and deposition in downfaulted areas produced thick fluvial-lacustrine sedimentary rocks (Sevier River Formation). These rocks plus intercalated olivine basalt flows and perhaps rhyolite flows, as well as Quaternary surficial deposits, are in the upper Tertiary and Quaternary sequence.

## LOWER TERTIARY SEQUENCE

### CLARON FORMATION

The Claron Formation consists mostly of fluvial and lacustrine conglomerate, sandstone, and limestone that unconformably overlie Upper Cretaceous and older rocks. Defined by Leith and Harder (1908), the Claron Formation has been mapped throughout the Iron Springs district and adjacent parts of the Great Basin as well as throughout the southwestern High Plateaus; usage of the name Wasatch Formation in these areas is abandoned in favor of Claron Formation (Mackin, 1960). In most places the Claron Formation is 400–700 m thick. Following Mackin (1960), we informally subdivide the unit into a lower, red part and an upper, white part. The Claron Formation is Eocene and Oligocene (Gregory, 1951; Mackin, 1960), but basal strata possibly are latest Creta-

TABLE 1.—*Summary of petrologic and stratigraphic characteristics of volcanic rocks exposed in the southwestern High Plateaus and adjacent Great Basin*

[Names for chemical composition are those of Nockholds (1954, p 1012-1021)]

| Name (Maximum thickness in metres) | Dominant color | Average mode (percent) | Groundmass character | Chemical or modal(*) composition |
|---|---|---|---|---|
| Needles Range Formation (200). | Pink, pale purple, light gray. | Groundmass, 62; plagioclase, 24; amphibole, 7; quartz, 3; biotite, 2; opaque minerals, 1; pyroxene, xenoliths, and K-feldspar, trace. | Moderately welded tuff, mostly devitrified. | Dacite. |
| Isom Formation, Blue Meadows Member (15). | Pale red, pale purple. | Groundmass, 92; plagioclase, 5; pyroxene, 1; opaque minerals, 1; xenoliths, 1; K-feldspar, quartz, and amphibole, trace. | Densely welded tuff, mostly devitrified. | Dellenite. |
| Isom Formation, Baldhills Member (100). | Medium brown, purple, tan, gray. | Groundmass, 89; plagioclase, 8; pyroxene, 1; opaque minerals, 1; xenoliths, 1; quartz and amphibole, trace. | Densely welded tuff, mostly devitrified. | Dellenite, rhyodacite. |
| Isom Formation, Hole-In-The-Wall Member (30). | Pale red. | Groundmass, 92; plagioclase, 7; pyroxene, 1; opaque minerals, xenoliths, trace. | Vesicular densely welded tuff, mostly devitrified. | |
| Leach Canyon Formation, Narrows Member (100). | Salmon, white, medium brown. | Groundmass, 80; plagioclase, 6; quartz, 6; K-feldspar, 5; xenoliths, 2; biotite, 1; opaque minerals, amphibole, and pyroxene, trace. | Moderately welded tuff, mostly devitrified. | Calc-alkali rhyolite. |
| Leach Canyon Formation, Table Butte Member (200) | Salmon, white. | Groundmass, 77; plagioclase, 8, xenoliths, 6; quartz, 4; K-feldspar 4; biotite, 1; opaque minerals, amphibole, and pyroxene, trace. | Slightly welded tuff, mostly devitrified. | Dellenite. |
| Candor Canyon Formation, Swett Member (15). | Medium brown. | Groundmass, 92; plagioclase, 6; biotite, 1; xenoliths, opaque minerals, quartz, trace. | Densely welded tuff, mostly devitrified. | Dellenite. |
| Candor Canyon Formation, Bauers Member (35+). | Pale red, pale purple, reddish brown tan, light gray. | Groundmass, 86; plagioclase, 8; K-feldspar, 4; biotite, 1; xenoliths, 1; opaque minerals and pyroxene, trace. | Densely welded tuff, mostly devitrified. | Dellenite, calc-alkali rhyolite. |
| Harmony Hills Tuff (30). | Pink, tan. | Groundmass, 58; plagioclase; 26; biotite, 6; amphibole, 5; pyroxene, 2; quartz, 1; opaque minerals, 1 | Moderately welded tuff, mostly devitrified. | Dacite. |

| | | | | |
|---|---|---|---|---|
| Mount Dutton Formation, vent and alluvial facies (1,500+). | Gray, brown, tan, black, dark green. | Several phases, with average modes in the following ranges: groundmass, 38–75; plagioclase, 17–50; pyroxene, 0–9; amphibole, 0–7; opaque minerals, 0–4. | "Flow" groundmass of microlites or glass and microlites. | Andesite, doreite, dacite. |
| Mount Dutton Formation, Beaver Member (250). | Pink, gray. | Groundmass, 60; plagioclase, 25; amphibole, 11; opaque minerals, 2; biotite, 1; pyroxene, trace. | "Flow" groundmass of glass and microlites. | Dacite. |
| Mount Dutton Formation, Kingston Canyon Member (15). | Pink, pale purple. | Groundmass, 91; plagioclase, 5; xenoliths, 1; opaque minerals, 1; biotite, 1; pyroxene, K-feldspar, quartz, and amphibole, trace. | Densely welded tuff, mostly devitrified. | Dacite. |
| Mount Dutton Formation, Antimony Member (20). | Medium brown. | Groundmass, 89; plagioclase, 6; K-feldspar, 2; xenoliths, 1; pyroxene, 1; opaque minerals, 1; quartz, biotite, and amphibole, trace. | Densely welded tuff, mostly devitrified. | Dacite. |
| Buckskin Breccia (170). | Pink, tan, light gray. | Groundmass with clasts of several phases, with average modes in the following ranges: groundmass (finely holocrystalline or of glass and microlites), 53–59; plagioclase, 21–28; amphibole, trace–12; K-feldspar, trace–9; opaque minerals, trace–9; biotite, trace–7; pyroxene, trace–1; quartz, trace. | Slightly welded to nonwelded tuff, mostly devitrified. | Grandiorite, tonalite, monzonite porphryry*, tonalite porphryry*. |
| Older basalt flows (200). | Black, dark to medium gray. | Several phases, with average modes in the following ranges: groundmass, 78–89; plagioclase, 0–7; olivine, 0–11; pyroxene, 0–6; opaque minerals, 0–2. | "Flow" groundmass of microlites or glass and microlites. | Andesite, doreite, basalt*. |
| Osiris Tuff (60). | Reddish brown, light gray. | Groundmass, 78; plagioclase, 14; K-feldspar, 4; biotite, 1; opaque minerals, 1; pyroxene, 1; xenoliths, 1; quartz and amphibole, trace. | Densely welded tuff, mostly devitrified. | Rhyodacite. |
| Dry Hollow Formation (350). | Brownish red, gray, pale red. | Several phases, with average modes in the following ranges: groundmass, 69–78; plagioclase, 7–15; amphibole, 1–3; K-feldspar, 0–20; pyroxene, 0–10; opaque minerals, 1–3; biotite, 1; quartz, trace. | "Flow" groundmass of glass and microlites. | Rhyodacite, dacite. |
| Horse Valley Formation (350+). | Pink, light gray. | Several phases, with average modes in the following ranges: groundmass, 78–94; plagioclase, 5–11; amphibole, 0–9; pyroxene, 0–6; opaque minerals, 0–2; biotite, trace. | "Flow" groundmass of glass and microlites. | Rhyodacite, dellenite. |

TABLE 1.—*Summary of petrologic and stratigraphic characteristics of volcanic rocks exposed in the southwestern High Plateaus and adjacent Great Basin*—Continued

| Name (Maximum thickness in metres) | Dominant color | Average mode (percent) | Groundmass character | Chemical or modal(*) composition |
|---|---|---|---|---|
| Mount Belknap Rhyolite (350). | White, black. | Several phases with average modes in the following ranges: groundmass, 97; plagioclase, 1-3; K-feldspar, trace-1; quartz, trace-1; biotite, pyroxene, and amphibole, trace. | Glassy "flow" groundmass, partly devitrified. | Alkali rhyolite. |
| Joe Lott Tuff (35). | White, tan. | Groundmass, 94; xenoliths, 5; quartz, plagioclase, and opaque minerals, trace. | Poorly welded to nonwelded tuff, mostly devitrified. | Calc-alkali rhyolite. |
| Younger basalt flows (35). | Black, dark to medium gray. | Several phases with average modes in the following ranges: groundmass, 69–78; plagioclase, 9–23; olivine, 0–11; pyroxene, 2-6; opaque minerals, 0-4; amphibole, trace. | "Flow" groundmass of microlites or glass and microlites. | Mostly alkali basalt. |

ceous(?) or Paleocene(?) if they are correlative with the Canaan Peak, Pine Hollow, and Wasatch Formations (Bowers, 1972) of the extreme southeastern High Plateaus (Anderson and Rowley, 1975).

The upper part of the white part of the Claron Formation, together with the featheredges of several overlying named units (Needles Range, Isom, Leach Canyon, and Mount Dutton), was designated Brian Head Formation by Gregory (1945, 1949, 1950, 1951). Primarily for this reason (Threet, 1952; Anderson, 1971; Anderson and Rowley, 1975) the name Brian Head Formation is abandoned.

#### LOCAL UNIT

At scattered places in the southwestern High Plateaus and adjacent Great Basin, the Needles Range Formation is separated from the Claron Formation by an unnamed local unit composed of volcanic rocks and lesser interbedded sedimentary rocks that rarely total more than 100 m in thickness. A single K-Ar determination on one of the volcanic units is 31.1 m.y. (Fleck and others, 1975). We mapped these deposits as local volcanic and sedimentary rock of Oligocene age.

#### NEEDLES RANGE FORMATION

The Needles Range Formation consists of at least two mostly pink, pale-purple, or light-gray, silicic crystal-rich ash-flow tuff cooling units and local interbedded thin sedimentary or volcanic strata. It was defined by Mackin (1960) at a type locality in the east-central part of the Mountain Home Range (formerly called the Needle Range) of western Utah. The formation has been found over at least 50,000 km$^2$ of Utah and Nevada (Mackin, 1963; Cook, 1965); its source is presumed to be in the Great Basin. We have mapped the formation through much of the southwestern High Plateaus and adjacent Great Basin. The Needles Range Formation is Oligocene, according to numerous K-Ar age determinations that cluster around 29 m.y. (Armstrong, 1970; Fleck and others, 1975).

Mackin (1960) defined two members of the Needles Range Formation: the lower member, the Wah Wah Springs Tuff Member, and the upper member, the Minersville Tuff Member. Recently Best and others (1973) proposed that Minersville be abandoned; we believe that the reasons given do not warrant such action. We therefore retain Mackin's names.

## MIDDLE TERTIARY SEQUENCE

### ROCKS OF THE EASTERN GREAT BASIN VOLCANIC PROVINCE ADJACENT TO THE HIGH PLATEAUS

#### ISOM FORMATION

Mackin (1960) defined the Isom Formation from exposures of silicic crystal-poor ash-flow tuff characterized by secondary plastic flowage and of true lava flows in the Iron Springs district. There, where the Isom

| SEQUENCE | AGE | BLACK MOUNTAINS: SOUTHWEST | BLACK MOUNTAINS: NORTH | SOUTHERN TUSHAR MOUNTAINS | MARKAGUNT PLATEAU | SEVIER, AWAPA, AND FISH LAKE PLATEAUS |
|---|---|---|---|---|---|---|
| QUATERNARY AND UPPER TERTIARY | Holocene | Younger basalt flows | Younger basalt flows | Younger basalt flows | Younger basalt flows | Younger basalt flows |
| | Pleistocene and Pliocene | Sevier River Formation | Sevier River Formation | Sevier River Formation | Sevier River Formation | Sevier River Formation |
| MIDDLE TERTIARY | Miocene | | | Joe Lott Tuff | | Joe Lott Tuff |
| | | | Mount Belknap Rhyolite | Mount Belknap Rhyolite | | Mount Belknap Rhyolite |
| | | Quichapa Group: Harmony Hills Tuff | Horse Valley Formation | Older basalt flows | Older basalt flows | Older basalt flows |
| | | | | Dry Hollow Formation | | |
| | | ondor Canyon Fm: Bauers Tuff Member | Condor Canyon Formation: Bauers Tuff Mbr; Mount Dutton Fm (alluvial facies) | Osiris Tuff; Sandstone member | Osiris Tuff; Bauers Tuff Mbr; Condor Canyon Formation | Osiris Tuff; Mount Dutton Fm (alluvial facies) |
| | | Swett Tuff Member | Volcanic breccia member | ount Dutton Fm (vent facies); Flow–volcanic breccia member | ount Dutton Fm (alluvial facies); Volcanic breccia member | Volcanic breccia member; Antimony Tuff Mbr |

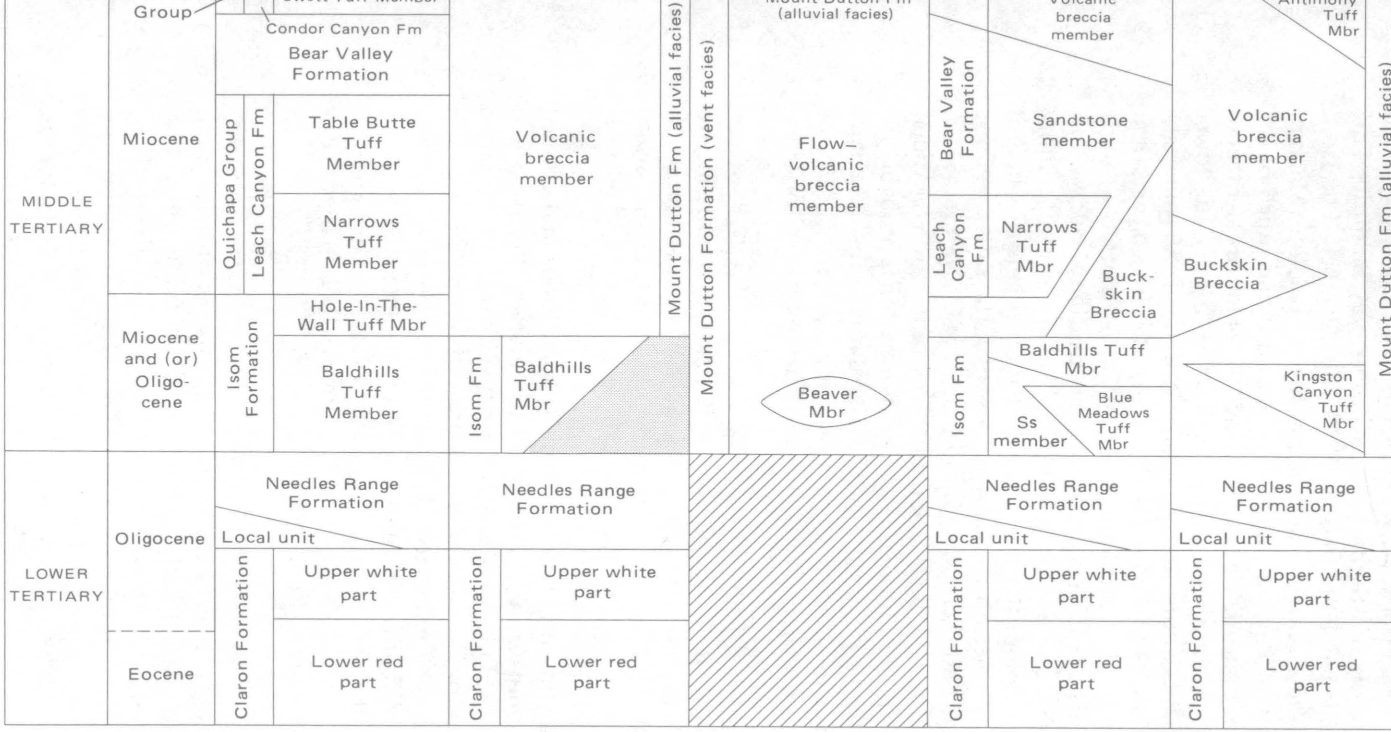


FIGURE 2.—Correlation chart of the Cenozoic stratigraphy of the southern High Plateaus and adjacent Great Basin, Utah. The absence of strata is shown by stippled pattern, but local unconformities are not shown. Absence of information is shown by cross-hatched pattern.

Formation is about 150 m thick, he recognized three members but named only the upper two, the mostly medium-brown or gray Baldhills Tuff Member and the pale-red Hole-In-The-Wall Tuff Member. The Isom Formation is exposed through much of southwestern Utah (Mackin, 1960); we mapped it in most of the Black Mountains and much of the northern Markagunt Plateau. We have redefined the Baldhills Member to include Mackin's lower unnamed member because locally his lower member includes ash-flow tuff that is indistinguishable from some ash-flow tuff in his Baldhills Member. The Baldhills Member consists of at least six cooling units, but the Hole-In-The-Wall Member is a single cooling unit. We also have defined a new member, the Blue Meadows Tuff Member, which is a single pale-red or pale-purplish ash-flow tuff cooling unit cropping out through the northern Markagunt Plateau, where it underlies the Baldhills Member. The type locality of the Blue Meadows Tuff Member is in the northern Markagunt Plateau (SE¼ NE¼ sec. 31, T. 33 S., R. 6 W.; fig. 1, loc. 1) about 11 km northwest of Panguitch (Anderson and Rowley, 1975). The source of the Isom Formation is probably the Great Basin of southwestern Utah. On the basis of numerous K-Ar dates that cluster around 25 m.y. (Armstrong, 1970; Fleck and others, 1975), the Isom Formation is considered to be latest Oligocene or earliest Miocene.

## QUICHAPA GROUP

Mackin (1960) designated as the Quichapa Formation four distinctive silicic ash-flow tuffs that occur together over much of southwestern Utah and southeastern Nevada; they were named the Leach Canyon, Swett, Bauers, and Harmony Hills Tuff Members from exposures in and near the Iron Springs district. As a result of his work in Nevada, Cook (1965) elevated Leach Canyon and Harmony Hills to formations and defined the new name Condor Canyon Formation to embrace the Swett and Bauers Tuff Members; Quichapa was not used. Williams (1967) carried out regional stratigraphic studies of these same tuffs; he used Cook's terminology except that he reinstated Quichapa by elevating it to group status. We follow Williams' terminology. Williams suggested that the source of the tuffs of Leach Canyon and Condor Canyon Formations is the Caliente, Nev., area; the source of the Harmony Hills Tuff is probably the Bull Valley Mountains (Blank, 1959).

### LEACH CANYON FORMATION

The Leach Canyon Member of Mackin (1960) consists of white, salmon, or rarely medium-brown, slightly to moderately welded ash-flow tuff. The unit was elevated to formation rank by Cook (1965). Williams (1967) divided the Leach Canyon into a Narrows Tuff Member and the overlying less-welded fragment-rich and petrographically different Table Butte Tuff Member. The type localities he proposed are (1) for the Narrows Member: the White River Narrows (fig. 1, loc. 2), T. 1 S., R. 62 E.

(unsurveyed), Lincoln County, Nev., and (2) for the Table Butte Member: Table Butte (NE¼ NE¼ sec. 5, T. 34 S., R. 14 W.; fig. 1, loc. 3) in the Escalante Desert of Utah. We accept these nomenclature additions.

Mackin, Cook, and Williams mapped the Leach Canyon Formation over large areas of Utah and Nevada. Our detailed mapping carries the formation as far east as the Black Mountains and several scattered locations in the western Markagunt Plateau. The Narrows Member consists of one or two cooling units, and the more poorly exposed Table Butte Member apparently consists of one cooling unit. The Narrows Tuff Member has an age of about 24 m.y. (Armstrong, 1970; Fleck and others, 1975).

### CONDOR CANYON FORMATION

The Condor Canyon Formation was defined by Cook (1965) from exposures at Condor Canyon, T. 1 S., R. 68 E. (unsurveyed), Lincoln County, Nev. It consists of the Swett and Bauers Tuff Members of Mackin (1960). Both are densely welded crystal-poor ash-flow tuff compound cooling units; the Swett Member is medium brown, and the Bauers Member, well-zoned, is mostly pale red, pale purple, and light gray. Williams (1960, 1967) traced both members over parts of Utah and Nevada. They are exposed at scattered places in the Black Mountains and western Markagunt Plateau. Numerous K-Ar age determinations (Armstrong, 1970; Fleck and others, 1975) indicate that the Swett Member is about 23 m.y. old and the Bauers Member is about 22 m.y. old, both early Miocene.

### HARMONY HILLS TUFF

The Harmony Hills Member (Mackin, 1960) is a pink or tan crystal-rich ash-flow tuff cooling unit; it was elevated to formation status by Cook (1965). It is similar in phenocryst composition and general appearance to the tuffs of the Needles Range Formation. Williams (1960, 1967) mapped it in Utah and Nevada. It apparently never was deposited in the Black Mountains and High Plateaus; its northeasternmost known occurrence is in the Red Hills. Armstrong (1970) published four K-Ar age determinations of about 20 to 21 m.y., or middle Miocene.

## ROCKS OF THE MARYSVALE VOLCANIC PROVINCE

### MOUNT DUTTON FORMATION

The Mount Dutton Formation, as defined by Anderson and Rowley (1975), contains most of the rock on the southern flank of the Marysvale volcanic pile. Like the other volcanic units described below, the source of the Mount Dutton Formation was within the Marysvale pile. To the west it intertongues with many units of the Great Basin volcanic province. The type section (NE¼ NE¼ sec. 9 to center sec. 15, T. 32 S., R. 4 W.; fig. 1, loc. 4), about 950 m thick, is at Mount Dutton in the southern Sevier Plateau (Anderson and Rowley, 1975). Near the center of the pile the main rock types are andesitic lava flows and autoclastic flow breccia, with lesser volcanic mudflow breccia; this material is mapped separately as the vent facies of the Mount Dutton Formation, following the concepts of Parsons (1965, 1969) and Smedes and Prostka (1973). Rocks of the vent facies are confined mostly to the Tushar Mountains; there the base of the section is not exposed but the rocks must be over 1,500 m thick. Anderson and Rowley (1975) have designated and described a reference section (SW¼ SE¼ sec. 31, T. 29 S., R. 3 W. to NE¼ NE¼ sec. 1, T. 30 S., R. 4 W.) for the vent facies about 1.5 km northwest of Junction.

On the flanks of the pile the main rock type is volcanic mudflow breccia, with minor autoclastic flow breccia and lava flows; this is mapped as the laterally correlative alluvial facies of the Mount Dutton Formation, again following the concepts of Parsons and Smedes and Prostka. Rocks of the alluvial facies occur in the Awapa Plateau, Fish Lake Plateau, Sevier Plateau, Markagunt Plateau, and Black Mountains, where they attain thicknesses of about 1,000 m; they thin and pinch out away from the center. The features of the alluvial facies may be examined at the type section of the Mount Dutton Formation (Anderson and Rowley, 1974) or at a reference section (S½ sec. 17, T. 30 S., R. 2½ W.) east of Kingston, designated and described by Anderson and Rowley (1975).

Distinctive beds within the thick vent and alluvial facies are formally named. One such unit, defined by Anderson and Rowley (1975) as the Beaver Member of the Mount Dutton Formation, occurs near the presumed base of the vent facies. This pink or gray dacitic porphyry crops out over about 50 km² of the northeastern Black Mountains and southwestern Tushar Mountains; the type section (SW¼ sec. 12, T. 30 S., R. 7 W.) is about 8 km south of Beaver (fig. 1, loc. 5). At most places the member is a lava flow and (or) ash-flow tuff about 100 m thick, but near its western and southern outcrop limit, where the base is not exposed, it is more than 250 m thick and may be intrusive.

An informal sandstone member of the Mount Dutton Formation occurs at the top of the vent facies. This member crops out over 40 km² or less in the southern Tushar Mountains, and it attains a thickness of about 70 m (Anderson and Rowley, 1975).

Two silicic ash-flow members were defined within alluvial facies rocks in the southern Sevier Plateau. The Kingston Canyon Tuff Member, made up of two cooling units of pink or pale-purple crystal-poor ash-flow tuff, occurs near the base of the alluvial facies. We have mapped it over more than 1,300 km² of the Sevier Plateau; its type section (NW¼ NE¼ sec. 16, T. 30 S., R. 2½ W.) is in Kingston Canyon east of Kingston (fig. 1, loc. 6). The other new member is the Antimony Tuff Member of the Mount Dutton Formation, which occurs higher in the alluvial facies in the Kingston Canyon area and has its type section (center sec. 29, T. 30 S., R. 2 W.) northeast of Antimony (fig. 1, loc. 7). It consists of two cooling units of medium-brown, densely welded crystal-poor ash-flow tuff.

The Mount Dutton Formation is latest Oligocene and early Miocene, according to K-Ar age determinations by Fleck, Anderson, and Rowley (1975). Lava flows near the base of the formation have been dated at 25.1 and 26.0 m.y., whereas ones from high in the formation have been dated at 20.7 and 22.9 m.y. The age of the Beaver Member and of the Kingston Canyon Member has been determined to be about 25 m.y.

### BUCKSKIN BRECCIA

The Buckskin Breccia, defined by Anderson and Rowley (1975), consists of volcanic mudflow breccia, probable autoclastic flow breccia, and (or) ash-flow tuff. All beds are characterized by the presence of abundant clasts of a distinctive local porphyry intrusion (Spry intrusion of Anderson and Rowley, 1975), which we have mapped about 25 km north of Panguitch; the source of the Buckskin Breccia is probably the vicinity of the Spry intrusion. The type section (SW¼ NE¼ sec. 26, T. 32 S., R. 6 W.) is just east of Buckskin Valley in the northern Markagunt Plateau (fig. 1, loc. 8); the unit is exposed through much of the northern Markagunt Plateau and part of the southern Sevier Plateau. The formation is most likely early Miocene because it is underlain by the Isom Formation of Oligocene or Miocene age and overlain by the Bear Valley Formation of Miocene age.

### BEAR VALLEY FORMATION

The Bear Valley Formation was defined by Anderson (1971) from a type section (from SW¼NW¼ sec. 5, T. 33 S., R. 5 W. to NE¼SE¼ sec. 32, T. 32 S., R. 5 W.; fig. 1, loc. 9) in the northern Markagunt Plateau; the formation is primarily a green, yellow, or gray sandstone exposed through the northern Markagunt Plateau, northern Red Hills, and part of the Black Mountains. The sandstone, a volcanic arenite largely of eolian origin, attains a thickness of at least 330 m; locally it contains thin intercalated beds of volcanic mudflow breccia, conglomerate, lava flow, and air-fall and ash-flow tuff. Potassium-argon ages of about 24 m.y. have been determined for several interbedded volcanic units within the formation (Fleck and others, 1975).

### OLDER BASALT FLOWS

From his work in the Marysvale area, Callaghan (1939) recognized basaltic lava flows at two stratigraphic levels. The older sequence was later included within the Dry Hollow Formation (Callaghan and Parker, 1962b). Our mapping confirms the presence of an old series of basaltic rocks. In the Sevier Plateau, Markagunt Plateau, and Tushar Mountains these black to medium-gray rocks are older than the Mount Belknap Rhyolite and mostly younger than the Osiris Tuff; some flows are characterized by olivine, pyroxene and (or) plagioclase phenocrysts. In the Awapa, Fish Lake, and Aquarius Plateaus, Williams and Hackman (1971) mapped basaltic andesite that is mostly older than the Osiris Tuff;

these dark porphyritic lava flows are characterized by plagioclase phenocrysts up to 2 cm in length. All these basalts are included in the older basalt flows (Anderson and Rowley, 1975). Although some of the rocks are classified petrographically as olivine basalt, the few chemical analyses so far determined are andesite and doreite, according to the chemical classification by Nockolds (1954). We have mapped older basalt flows at scattered places in the southern Tushar Mountains and southern Sevier Plateau; thicknesses of at least 150 m have been recorded. Samples from the unit have received K-Ar age determinations of about 22 m.y. (Fleck and others, 1975).

## OSIRIS TUFF

The Osiris Tuff is a reddish-brown or light-gray, densely welded, silicic compound ash-flow tuff cooling unit exposed at numerous scattered places through the High Plateaus. It displays conspicuous features of secondary plastic flow and is strongly zoned. Informally designated the tuff of Osiris by Williams and Hackman (1971), this unit was named Osiris Tuff by Anderson and Rowley (1975); the type section (SW¼ NW¼ sec. 2, T. 32 S., R. 2 W.; fig. 1, loc. 10) is near the abandoned community of Osiris in the southeastern High Plateaus. The unit has been dated at about 22 m.y. by Fleck, Anderson, and Rowley (1975).

## DRY HOLLOW FORMATION

The Dry Hollow Latite (Callaghan, 1939) consists of mostly brownish-red and gray porphyritic lava flows exposed through most of the Tushar Mountains and in several places in the southern Sevier Plateau. Callaghan and Parker (1962b) redefined the Dry Hollow Formation to include ash-flow tuff and basaltic lava flows. In our mapping, mostly south of the areas examined by Callaghan and Parker, we are able to map the ash-flow tuff and basaltic andesite lava flows as separate, named units, specifically the Osiris Tuff, Needles Range Formation and older basalt flows of this report. Thus, for our purposes we return to the original definition (Callaghan, 1939) for the Dry Hollow Formation. The age of the Dry Hollow Formation has been determined by K-Ar methods to be about 21.7 m.y. (Fleck and others, 1975).

## HORSE VALLEY FORMATION

The northwestern Black Mountains are underlain by a thick sequence of pink or light-gray, crystal-poor silicic lava flows, intrusive plugs, and related volcanic mudflow breccia. These were defined by Anderson and Rowley (1975) as the Horse Valley Formation. The type section (secs. 20, 21, T. 31 S., R. 12 W.; fig. 1, loc. 11) is 10 km west of Horse Valley, which is about 21 km southwest of Minersville. There an incomplete section of the unit is more than 350 m thick; the base is faulted out. Fleck, Anderson, and Rowley (1975) give K-Ar ages of 19.0, 20.6, and 21.9 m.y. for the formation.

#### MOUNT BELKNAP RHYOLITE

The Mount Belknap Rhyolite, defined by Callaghan (1939), consists of white, black, or reddish-brown rhyolite lava flows and interbedded ash-flow tuffs. Callaghan, Kerr, and their coworkers mapped the Mount Belknap in the Tushar Mountains and recorded maximum thicknesses of 1,400 and 1,700 m. Anderson and Rowley (1975) have mapped scattered thin patches of rhyolite flows similar to the Mount Belknap in the northern Black Mountains and southern Sevier Plateau; these flows are correlated tentatively with the Mount Belknap but may be younger than the Mount Belknap and, therefore, may belong to the upper Tertiary and Quaternary sequence. The Mount Belknap is the uppermost formation in the Marysvale pile for which radiometric age determinations were made (Bassett and others, 1963); these ages cluster around 20 m.y., middle Miocene. Kerr (1963, 1969), however, apparently favors an age of about 18 m.y., based upon a reinterpretation of the data.

#### JOE LOTT TUFF

The Joe Lott Tuff (Callaghan, 1939) comprises several cooling units of pink, white, and tan, slightly welded, very crystal-poor, pumice-rich rhyolite ash-flow tuff; it is the youngest formation of the Marysvale pile. Callaghan recorded thicknesses of nearly 250 m for the unit. The Joe Lott Tuff is exposed through much of the Tushar Mountains, southern Pavant Range, and central Sevier Plateau. Although the tuff has not been dated by radiometric methods, similarities in outcrop distribution and chemical composition argue strongly for a genetic tie between it and the Mount Belknap Rhyolite, as noted by Callaghan (1939).

## UPPER TERTIARY AND QUATERNARY SEQUENCE

### SEVIER RIVER FORMATION

The Sevier River Formation (Callaghan, 1938) consists of white, gray, or pink, poorly to moderately consolidated, fluvial and lesser lacustrine sedimentary rocks deposited in low downfaulted areas throughout much of the High Plateaus and adjacent Great Basin. Although exposures of the Sevier River Formation rarely exceed a few hundred metres, most of the downfaulted valleys in the High Plateaus and nearby Great Basin may be in large part filled with Sevier River rocks; if so, the formation may be many hundreds of metres thick.

Callaghan (1939) designated the Sevier River Formation as late Pliocene or early Pleistocene on the basis of diatoms and freshwater gastropods. Corroboration that some parts of the formation are as young as Pleistocene comes from K-Ar ages (Condie and Barsky, 1972; Hoover, 1974) ranging from 855,000 to 987,000 years for basalt flows interbedded with the Sevier River Formation just west of the Pavant Range. However, a K-Ar age determination of 12.6 m.y. (Damon, 1969) for a younger basalt flow (see below) that overlies a section of the Sevier River Formation in the Sevier Plateau demonstrates that at least part of the unit is Miocene as well. We believe that the Sevier River Formation is Miocene, Pliocene, and Pleistocene.

Gregory (1945, 1950) named scattered older gravel deposits in the southern High Plateaus as the Parunuweap Formation. These deposits are correlative with the Sevier River Formation, as Gregory apparently realized in some of his other publications (Gregory, 1944, 1949, 1951). We propose that Parunuweap Formation be abandoned in favor of the Sevier River Formation.

### YOUNGER BASALT FLOWS

Basalt lava flow caprocks have been mapped through the Basin and Range and parts of the Colorado Plateau. Callaghan (1939) recognized those in the Marysvale area as being distinct and younger from similar-appearing lava flows that predate the Mount Belknap Rhyolite. We mapped scattered lava flows of olivine basalt in the Sevier Plateau, Markagunt Plateau, Tushar Mountains, and Black Mountains, and we have designated them as younger basalt flows (Anderson and Rowley, 1975). Olivine basalt flows and related cinder-and-lava cones are widespread in the Awapa and Aquarius Plateaus and probably range from early to late Pleistocene in age. The younger basalt flows overlie and interfinger with the Sevier River Formation.

The oldest known flow of this unit in the map area occurs in the southern Sevier Plateau; Damon (1969, p. 47) determined a K-Ar age of 12.6 m.y. for it. Numerous other K-Ar ages of basalts in and near our map area range from 31,000 years to 1.2 m.y. (Condie and Barsky, 1972; Hoover, 1974; Fleck and others, 1975); some basalt lava flows on the Markagunt Plateau (Wilson and Thomas, 1964) have not been revegetated and are probably Holocene. The Sevier River Formation and younger basalt flows are believed to be associated with the Miocene through Holocene episode of block faulting of the southwestern High Plateaus and eastern Great Basin.

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