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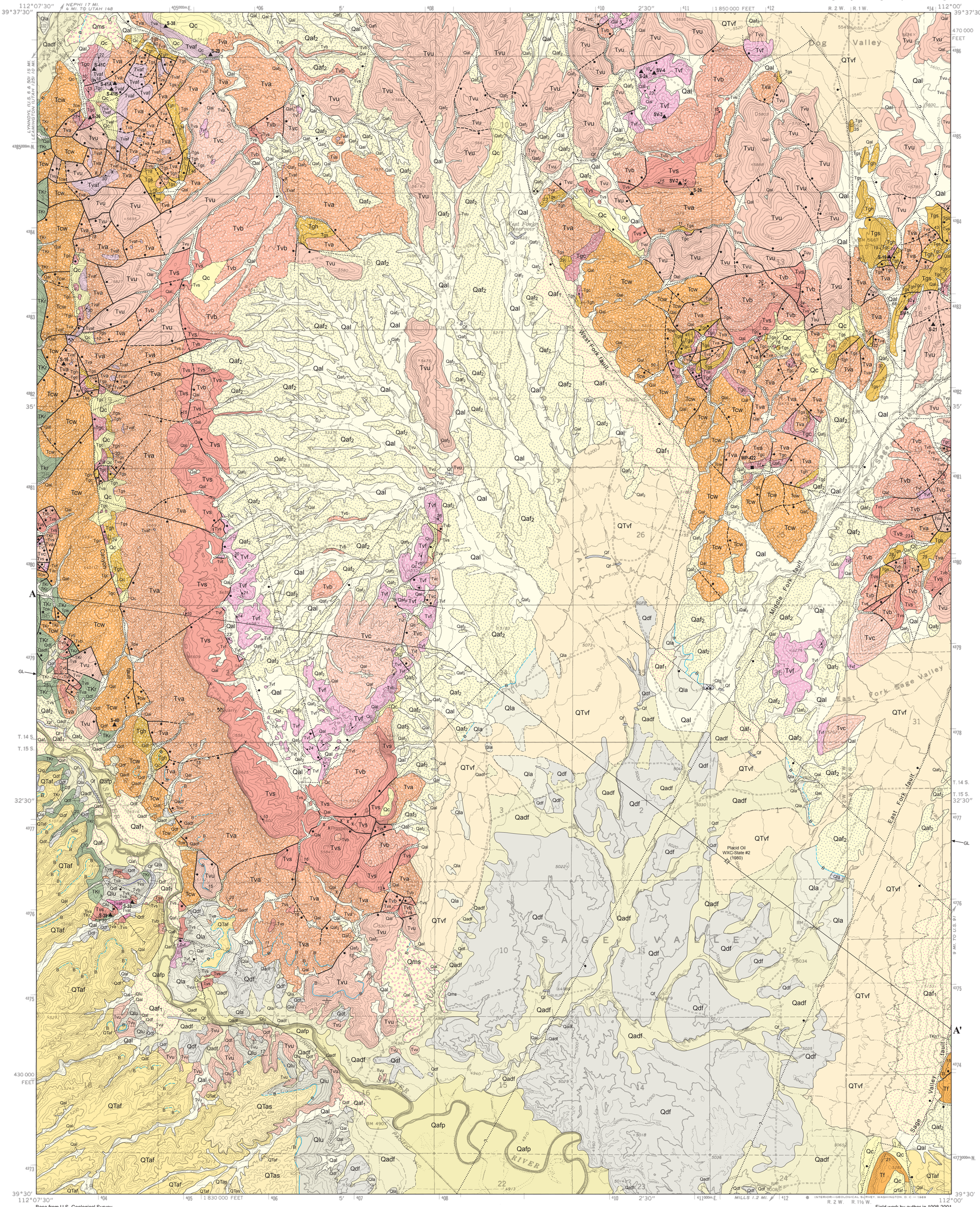


Base from U.S. Geological Survey, Sage Valley 7.5' quadrangle, 1967

SCALE 1:24,000

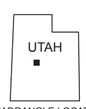
1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

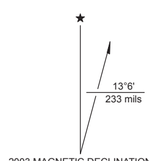
1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Field work by author in 1998-2001
Robert F. Biek, Project Manager
Digital cartography by James Parker and Kent Brown,
Utah Geological Survey



QUADRANGLE LOCATION



2003 MAGNETIC DECLINATION AT CENTER OF SHEET

1	2	3	1. Jericho 2. Furner Ridge 3. Sugarloaf 4. Champlin Peak 5. Juab 6. Fool Creek Peak 7. Mills 8. Skinner Peaks
4		5	
6	7	8	

ADJOINING 7.5' QUADRANGLE NAMES

GEOLOGIC MAP OF THE SAGE VALLEY 7.5' QUADRANGLE JUAB COUNTY, UTAH

by

Donald L. Clark

2003

DESCRIPTION OF GEOLOGIC UNITS

Alluvial deposits

Qafp Flood plain alluvium (late Pleistocene to Holocene) - Fine-grained deposits with local coarse lags along the Holocene Sevier River; total thickness unknown, up to 10 feet (3 m) exposed.

Qal Stream alluvium (late Pleistocene to Holocene) - Fine- to coarse-grained, poorly-sorted alluvium in ephemeral stream valleys and on larger valley and canyon floors; locally includes some slopewash deposits; thickness variable and probably less than 20 feet (6 m) in most places, but possibly over 100 feet (30 m) in Sage Valley.

Qaf_1 Younger alluvial-fan deposits (Holocene) - Poorly sorted sand and gravel with fines included in active alluvial fans and surfaces adjacent to steeper uplands; composed of locally-derived rock types; thickness probably less than 100 feet (30 m).

Qaf_2 Older alluvial-fan deposits (late Pleistocene to Holocene?) - Similar in composition to younger alluvial fans, but higher in elevation and more deeply incised; locally abuts bedrock surfaces at headward margins; up to 100 feet (30 m) exposed, total thickness unknown.

QTaf Oldest alluvial-fan deposits (Pliocene to early Pleistocene) - Fine- to coarse-grained, poorly sorted, dissected surface of alluvium shed from Canyon Mountains and developed on an erosionally truncated bedrock surface southwest of the Sevier River; includes solitary fan mass in eastern Sage Valley; predominantly quartzite and carbonate clasts, and locally volcanics; locally consolidated; includes mixed alluvial and lacustrine deposits at distal margins below Bonneville shoreline; contains Alturas volcanic ash (about 4.8 million years old); up to 130 feet (40 m) exposed, total thickness unknown.

QTvf Valley-fill deposits (Pliocene to Holocene) - Poorly sorted, unconsolidated, coalesced alluvial fans and other alluvial materials in Sage and Dog Valleys; grades to fans and alluvial deposits at valley margins; thickness unknown, maximum estimated at 400 to 600 feet (120-180 m).

QTas Sevier River sand and gravel deposits (Pliocene to Pleistocene) - Well to moderately sorted sand and gravel deposited by the Sevier River; gravel clasts mostly pebbles of volcanic rocks, black chert, and sedimentary rocks derived from upstream in the Sevier River basin; overlies and laterally interfingers with older alluvial fan deposits; approximately 100 feet (30 m) thick.

Deltaic and lacustrine deposits

Qdf Deltaic (estuarine) fines (Pleistocene) - Fine sand, silt, and clay; thinly to very thickly bedded; local layered appearance; forms an upward-fining sequence; deposited by the Sevier River estuary of Lake Bonneville about 15,000 years ago; to about 120 feet (35 m) exposed, total thickness uncertain.

Qlg Lacustrine gravels (Pleistocene) - Well sorted and rounded, sandy, pebble-size gravel composed of locally derived rock fragments; beach gravel deposited at the margin of Lake Bonneville; thickness probably less than 20 feet (6 m).

Qlu Undifferentiated lacustrine deposits (Pleistocene) - Fine-grained sediment and gravel deposits present in Sevier Canyon below the Bonneville Level shoreline; deposits derived from local rocks and deposits (notably QTas) and typically form a thin mantle over bedrock; thickness likely less than 25 feet (8 m).

Colluvial deposits

Qc Colluvial deposits (Pleistocene to Holocene) - Slopewash deposits of clay- to boulder-size, locally derived sediments deposited on upland slopes adjacent to drainages; generally less than 20 feet (6 m) thick.

Mixed-environment deposits

Qadf Alluvial and delta-fine deposits (Pleistocene to Holocene) - Poorly to moderately sorted, clay- to sand-size sediment present in and adjacent to drainages developed within areas of deltaic-fine deposits in Sage Valley and Sevier Canyon; thickness estimated to be less than 50 feet (15 m).

Qla Lacustrine and alluvial deposits (Pleistocene to Holocene) - Clay- to boulder-size deposits that consist of pre-Lake Bonneville alluvial fans partially reworked in the lake, and Lake Bonneville deposits partially reworked by post-Bonneville alluvial activity; thickness less than 120 feet (30 m).

Mass-movement deposits

Qms Landslide deposits (Pleistocene to Holocene?) - Two areas consisting of poorly sorted clay- to boulder-size debris derived from adjacent uplands; fan-shaped morphologies with hummocky surfaces; developed from poorly consolidated volcanic conglomerate on steeper slopes; thickness unknown, probably less than 100 feet (30 m).

Human-made deposits

Qf Artificial fill (Holocene) - Local earth materials used to construct dams for stock ponds and berms to divert drainages; thickness 0 to 20 feet (6 m).

QTu Quaternary-Tertiary deposits undifferentiated - Shown on cross section only

Volcanic rocks of Sage Valley (late Eocene to early Oligocene) - Divided into:

Tvu Volcanic conglomerate unit undifferentiated - Conglomerate belonging to units A, B or C, but where the position within the volcanic rocks of Sage Valley cannot be determined; thickness unknown, possibly to 500 feet (150 m).

Tvc Volcanic conglomerate unit C - Poorly consolidated, brownish gray to moderate brown weathering volcanic conglomerate and breccia, with dark gray to dark pink, angular to subrounded volcanic clasts and minor carbonate and quartzite clasts; similar to unit B and unit A; rubbly exposures; likely alluvial deposits and lahars shed southward from the Tintic Mountains area; up to approximately 400 feet (120 m) present.

Tvf Fernow Quartz Latite - Light to medium gray, porphyritic, moderately to densely welded, rhyolitic ash-flow tuff in a simple cooling unit; crystal rich (about 50%) with phenocrysts of quartz, plagioclase, sanidine, biotite, and hornblende in a glassy groundmass; locally contains black to gray glassy fiamme forming a eutaxitic texture, with lapilli and up to block-sized lithic fragments; crops out as cliffs and large boulders; $^{40}Ar/^{39}Ar$ age of 34.83 ± 0.15 Ma; source likely caldera in Furner Ridge and Tintic Mountain quadrangles to the north; from 200 to 450 feet (60-140 m) exposed in quadrangle.

Tvb Volcanic conglomerate unit B - Similar to unit C and unit A; poorly consolidated, brownish gray to moderate brown weathering volcanic conglomerate and breccia, with dark gray to dark pink, angular to subrounded volcanic clasts and minor carbonate and quartzite clasts; rubbly exposures; from about 350 to 450 feet (110-140 m) present.

Tvs Tuff of Little Sage Valley - Grayish pink to light gray, poorly to moderately welded, dacitic ash-flow tuff; primarily phenocrysts of plagioclase, quartz, sanidine, and conspicuous biotite (10%); $^{40}Ar/^{39}Ar$ age of 37.43 ± 0.18 Ma; source unknown; exposures vary from poor to good; approximately 100 to 500 feet (30-150 m) thick.

Tva Volcanic conglomerate unit A - Similar to units B and C; poorly consolidated, brownish gray to moderate brown weathering volcanic conglomerate and breccia, with dark gray to dark pink angular to subrounded volcanic clasts and minor carbonate and quartzite clasts; matrix of tuffaceous sandstone and ash; generally forms rubble-covered hills and slopes, consolidated exposures south in Sevier Canyon; includes lava flows and tuffs interbedded with conglomerate to the west; thickness ranges from 175 to 1,000 feet (55-300 m).

Volcanic conglomerate unit A - Western exposures further divided into:

Tvaf Lava flow member - Lava flows generally aphanitic, of intermediate composition, and highly fractured; flow(s) range from pink to bluish gray to dark gray and weather to various shades of brown and gray; present at northwestern portion of map area, decreasing in thickness to the south; at least two flow units present; thickness of flows from 0 to 200 feet (0-60 m).

Tvat Tuff member - One area of white to light pink, dacitic, crystal-rich tuff southwest of Sevier River; moderately consolidated and crudely layered; exposed thickness of tuff about 100 feet (30 m).

Goldens Ranch Formation (late Eocene) - Divided into (after Meibos, 1983):

Tgs Sage Valley Limestone Member - Yellowish gray to light olive gray, thinly- to thickly-bedded, lacustrine limestone, lesser interbedded clay and mudstone, locally minor conglomerate; ledge-forming limestone contains plant remains, chert, vugs, gastropods; good marker unit; original member of Muessig's (1951a) Goldens Ranch Formation; from 0 to 250 feet (0-75 m) thick.

Tgh Hall Canyon Conglomerate Member - Gray, poorly consolidated conglomerate and volcanic conglomerate; clast composition varies from quartzite-carbonate to volcanic; clasts are angular to subrounded pebbles to boulders; typically forms rubbly slopes; from 0 to 300 feet (0-90 m).

Tgc Chicken Creek Tuff Member - Grayish pink to light gray to yellowish gray, poorly welded, vitric, dacitic ash-flow tuff; about 30% crystals in a glassy and calcitic matrix; phenocrysts of plagioclase, sanidine, quartz, and biotite; obvious pumice lapilli and lithic fragments; generally not well exposed; $^{40}Ar/^{39}Ar$ age of 38.61 ± 0.13 Ma; source unknown; named for exposures southwest of Chicken Creek Reservoir; about 200 feet (60 m) thick.

Tgu Goldens Ranch Formation undivided - Shown only on cross section

Tcw Conglomerate of West Fork Reservoir (middle or late Eocene?) - Poorly consolidated conglomerate weathering greenish gray, brownish gray and pinkish gray; includes predominantly quartzite clasts (Mutual and Prospect Mountain) and andesitic volcanic clasts, locally Paleozoic carbonates; clasts are subangular to subrounded cobbles and boulders; exposed above West Fork Sage Valley and in Sevier Canyon; appears limited in lateral extent; a western or northern source suggested; from 0 to maximum of approximately 1,300 feet (400 m) exposed.

Tf Flagstaff Limestone (late Paleocene to early Eocene?) - Pastel-colored limestone and dolomite, multicolored mudstone, siltstone, sandstone; present in cuesta and fault block of West Hills; no local age determination data available; about 400 feet (120 m) exposed in quadrangle.

TKn? North Horn Formation (Late Cretaceous to early Eocene?) - Moderate reddish orange and moderate reddish brown quartzite-clast conglomerate, mudstone, sandstone; upper part of unit present at base of cuesta of West Hills; no local age determination data available; only about 50 feet (15 m) exposed in quadrangle.

TKr Red beds of Sevier Canyon (Late Cretaceous to Eocene?) - Poorly to moderately consolidated, moderate reddish orange weathering, quartzite-clast conglomerate, sandstone and mudstone; overlain by tan and red sandstone, pebble and cobble conglomerate, mudstone, and a thin platy limestone with gastropods; apparently overlies Canyon Range Conglomerate of Lawton and others (1997); exposed in Sevier Canyon; age and correlation uncertain, possibly correlates with North Horn Formation and/or Flagstaff Limestone to east; about 600 feet (185 m) exposed, total thickness unknown.

TKu Tertiary-Cretaceous rocks undifferentiated - Shown only on cross section

Ku Cretaceous rocks undifferentiated - Shown only on cross section

Kc Canyon Range Conglomerate (after Lawton and others, 1997) - Subsurface, shown only on cross section

Jtg Twist Gulch Formation (Jurassic) - Subsurface, shown only on cross section

Ja Arapien Shale (Jurassic) - Subsurface, shown only on cross section

Jtc Twin Creek Limestone (Jurassic) - Subsurface, shown only on cross section

Jn Nugget Sandstone (Jurassic) - Subsurface, shown only on cross section

Ŧa Ankareh Formation (Triassic) - Subsurface, shown only on cross section

Ŧt Thaynes Formation (Triassic) - Subsurface, shown only on cross section

Ŧw Woodside Shale (Triassic) - Subsurface, shown only on cross section

Ppc-Pdc Park City Formation and Diamond Creek Sandstone undivided (Permian) - Subsurface, shown only on cross section

Pk Kirkman Limestone (Permian) - Subsurface, shown only on cross section

Є-D? Cambrian to Devonian (?) rocks undivided - Subsurface, shown only on cross section

GEOLOGIC SYMBOLS

Contact - dashed where approximately located

High-angle normal fault - dashed where inferred, dotted where concealed, queried where uncertain due to poor exposures or cover; bar and ball on downthrown side; arrows show relative direction of movement on cross section

Low-angle thrust fault (on cross section only) - queried where uncertain; arrow shows relative direction of movement

Reactivated thrust fault (on cross section only)

Unconformity (on cross section only) - dashed where inferred

Lake Bonneville shoreline - dashed where poorly developed

S-16 Location of rock sample analyzed and described in this study (analytical results in appendix)

WP-422 Location of rock sample analyzed and described in other studies (analytical results in appendix)

GL GL Gravity profile of Wang (1970)

A A' Line of cross section

Strike and dip of bedding in sedimentary rocks -

17 inclined

12 approximate

approximate strike and dip direction

Strike and dip of layering in extrusive volcanic rocks -

14 inclined

11 approximate

approximate strike and dip direction

Drill hole (dry hole, abandoned)

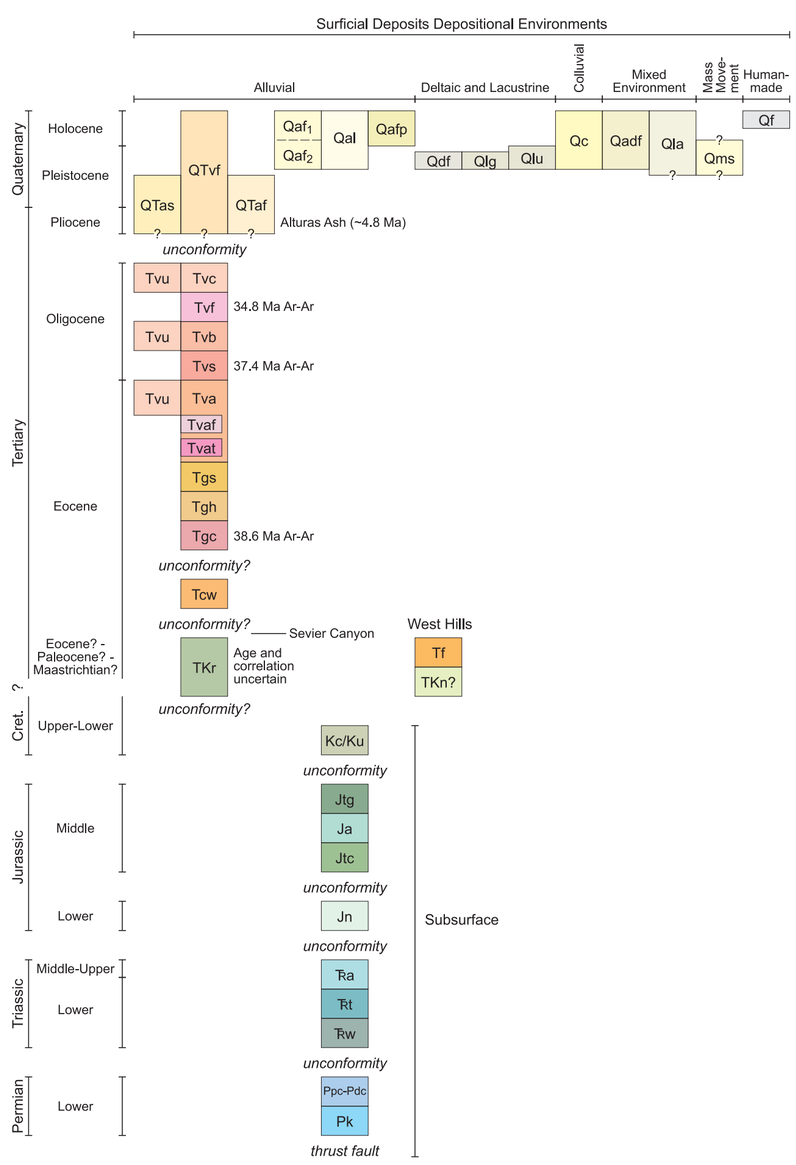
Water well

Quarry

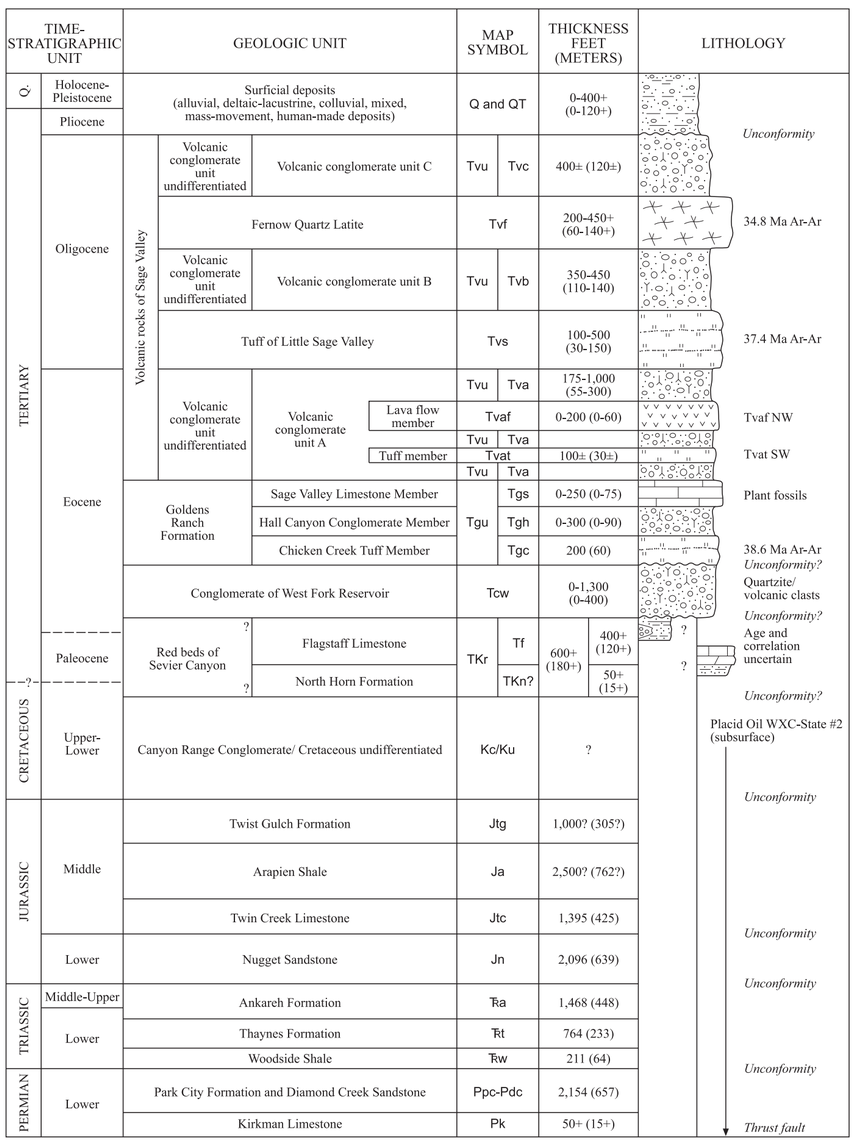
Prospect pit

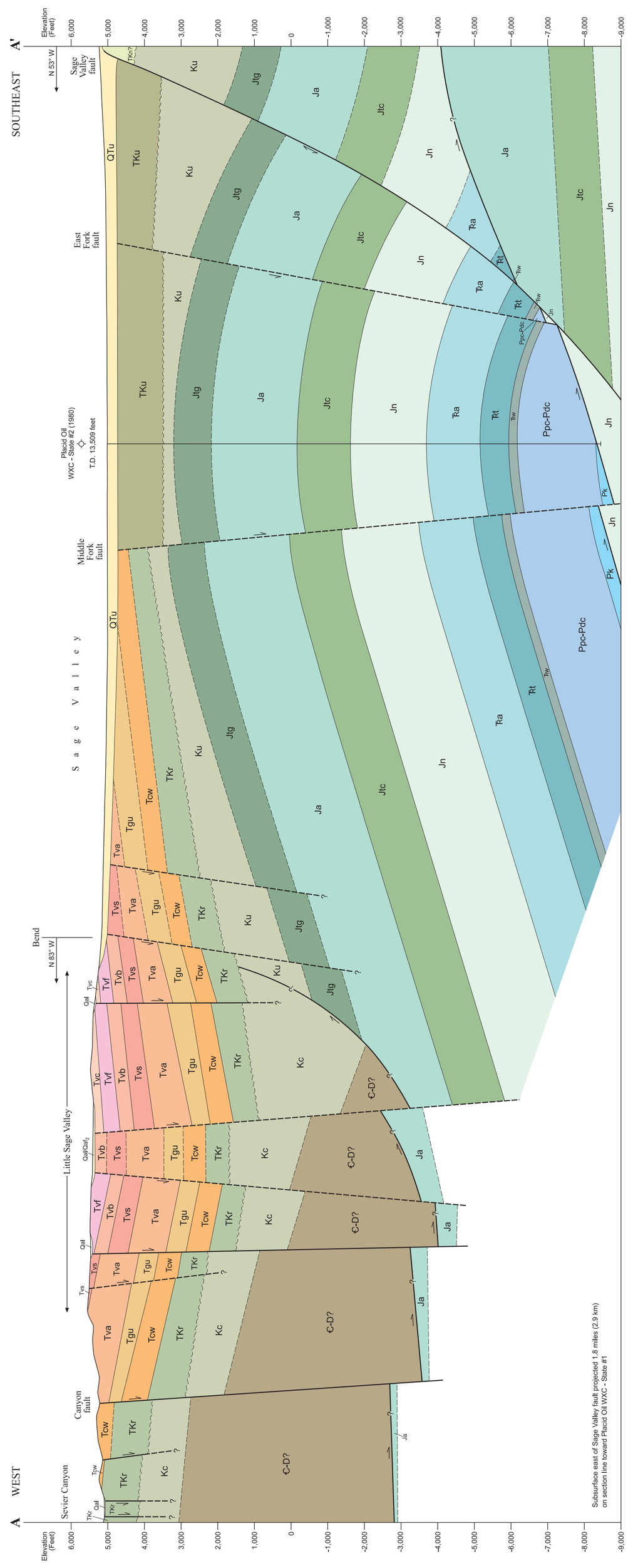
Gravel / road fill pit

CORRELATION OF GEOLOGIC UNITS



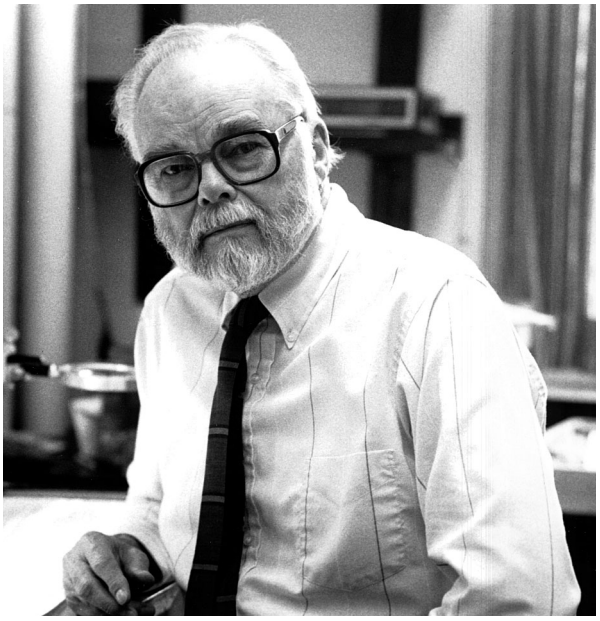
LITHOLOGIC COLUMN





GEOLOGIC MAP OF THE SAGE VALLEY QUADRANGLE, JUAB COUNTY, UTAH

by
Donald L. Clark



DEDICATION

This mapping project is dedicated to the memory of Malcolm "Mac" Weiss. Mac studied and elucidated on central Utah geology over a 48-year period (1953 to 2001). While at The Ohio State University and later Northern Illinois University, he guided numerous students, myself included, in mapping, stratigraphic, and structural studies within Utah. Mac was revered by colleagues, peers, and friends for his knowledge, generosity, enthusiasm, work ethic, and wit.

The Miscellaneous Publication Series of the Utah Geological Survey provides non-UGS authors with a high-quality format for papers concerning Utah geology and paleontology. Although reviews have been incorporated, this publication does not necessarily conform to UGS technical, policy, or editorial standards.

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Utah Department of Natural Resources
2003

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12/03

GEOLOGIC MAP OF THE SAGE VALLEY QUADRANGLE, JUAB COUNTY, UTAH

by

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ABSTRACT

The Sage Valley quadrangle is in the eastern Basin and Range Province of central Utah, and in an area of overlapping structural elements. Through geologic time, this area was also located along "Utah's hingeline," within the Sevier thrust belt, on the southern margin of the East Tintic Mountains volcanic field, and within an estuary of Lake Bonneville.

Subsurface data indicate the presence of nearly 8,100 feet (2,470 m) of Jurassic through Permian strata comprising part of a folded thrust sheet. A synorogenic deposit, the Canyon Range Conglomerate, developed on Sevier thrust plates in this portion of the thrust belt from the Early to Late Cretaceous. The conglomerate was on-lapped by continental and lacustrine strata of probable Late Cretaceous to early Eocene age during the latter stages of the Sevier orogeny. These clastic and carbonate rocks are represented in the quadrangle by the red beds of Sevier Canyon to the west, and North Horn Formation and Flagstaff Limestone of the West Hills on the east.

There may have been a hiatus during the Eocene until deposition of the overlying volcano-sedimentary succession. The quadrangle may contain some of the oldest exposed volcanic and volcaniclastic products of the East Tintic Mountains volcanic field, or possibly other local sources. The lower portion of the succession consists of the conglomerate of West Fork Reservoir and three-member Goldens Ranch Formation, which includes the lower Chicken Creek Tuff, middle Hall Canyon Conglomerate, and upper Sage Valley Limestone. Above is a mass of volcanic conglomerate interlayered with intermediate composition lava flows and two prominent ash-flow tuffs – the tuff of Little Sage Valley and Fernow Quartz Latite. The rock formations above the Goldens Ranch have been grouped here as the volcanic rocks of Sage Valley. Radiometric ($^{40}Ar/^{39}Ar$) ages show the volcano-sedimentary sequence ranges from greater than 39 to about 35 million years old (late Eocene to early Oligocene). The bedrock has an extensive cover of Tertiary and Quaternary surficial deposits derived from alluvial, deltaic and lacustrine (Lake Bonneville high stand), colluvial, mixed, and mass-wasting environments.

Abundant normal faults offset the bedrock units and are related to regional extension, known to have begun in the early to middle Miocene based on regional studies. Some of the faults may have involved reactivation of Sevier-age thrust faults and others the result of localized evaporite diapirism. Extensional tectonism has been important in development of the present surface topography, notably Sage Valley and Sevier Canyon.

The principal geologic resources in the quadrangle are sand and gravel, stone, and aragonite; there are also possibilities for metallic minerals and hydrocarbons. Presently, the agricultural value and water rights are the most used resources, and the area is an important transportation and utility corridor. Geologic hazards that could pose future problems include earthquakes, mass movements, problem soils and rocks, flooding, and radon.

INTRODUCTION

The Sage Valley 7.5-minute quadrangle is approximately 17 miles (27 km) southwest of Nephi in eastern Juab County, central Utah. The quadrangle lies in the eastern Basin and Range physiographic province, near the transition to the Middle Rocky Mountains and Colorado Plateaus provinces. Utah Highway 132 crosses the far northwest corner of the map area. The Sevier River flows northwestward in Sevier Canyon across the southwestern quadrant of the map area. The Sage Valley quadrangle is bordered by the West Hills (east), Furner Ridge and East Tintic Mountains (north), Gilson Mountains (northwest), and northern Canyon Mountains (west and southwest). Sage Valley joins Mills and Little Valleys to the south across the Sevier River (figure 1).

The quadrangle includes several lowlands including portions of the East and Middle Forks of Sage Valley, the West Fork of Sage Valley, Little Sage Valley, southernmost Dog Valley, and portions of Dog Valley Wash and Sevier Canyon, as well as unnamed adjacent uplands. A small portion of the West Hills is present at the southeast corner (figure 2). The topography of the quadrangle varies from a low of 4,880 feet (1,488 m) along the Sevier River to a high of 5,967 feet (1,819 m) between Sage and Dog Valleys, with total relief of

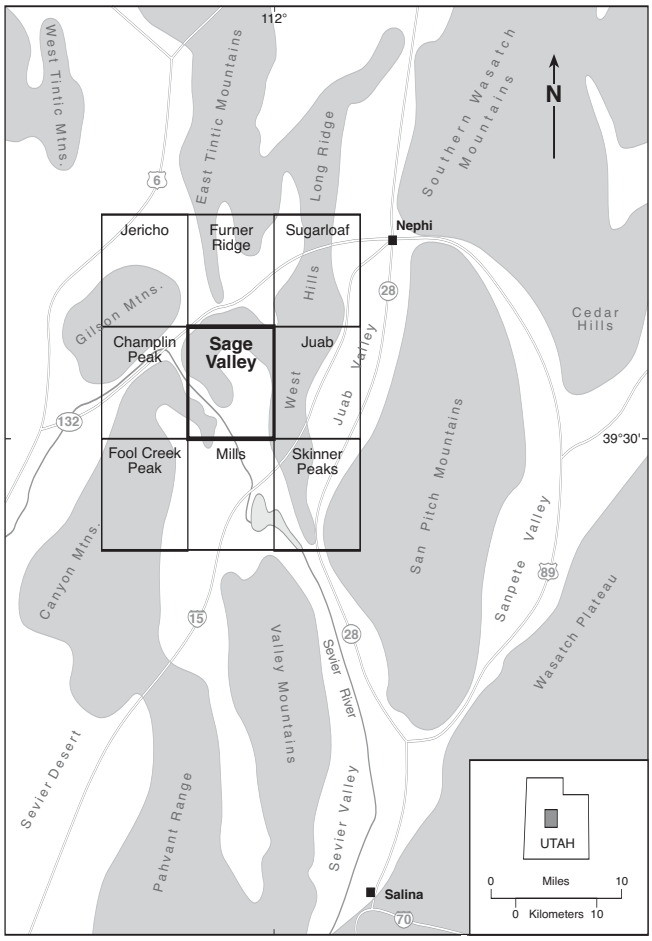

Figure 1. *Index map showing the location of the Sage Valley quadrangle, adjacent quadrangles, and other features of interest in central Utah.*

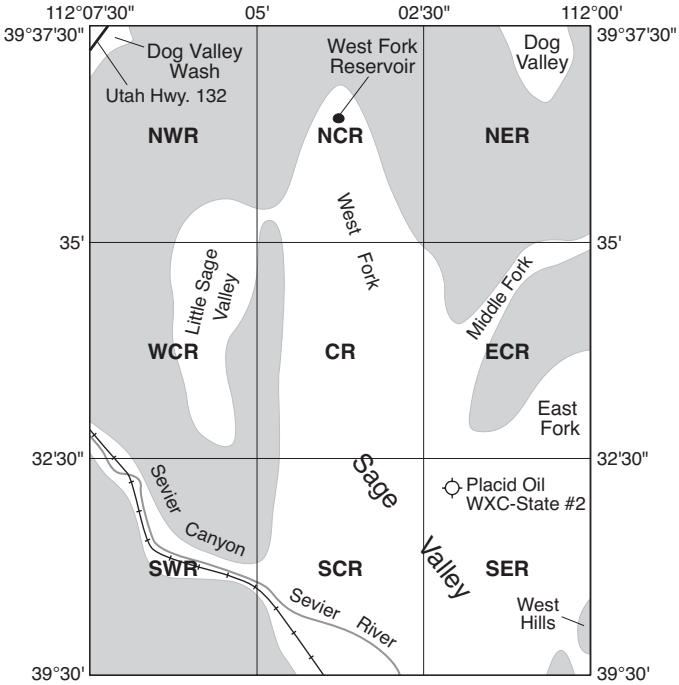

Figure 2. *Sage Valley 7.5-minute quadrangle with major features and divided into rectangles. The rectangles assist in locating geologic features discussed in the text. The village of Mills is located 1.2 miles (1.9 km) south of the SER (south-east-right portion).*

1,087 feet (331 m). The quadrangle is aptly named due to the abundance of sagebrush (*Artemisia*) in the lowlands. Junipers and grasses dominate the vegetation of the uplands; however, range fires in recent years have reduced the viable juniper population.

The area is uninhabited by humans, but is used for cattle ranching and various outdoor recreational activities. The area carries two large overhead electric transmission lines, underground natural gas and fiber optic lines, and a rail line. The quadrangle contains a mixture of federal, state, and privately owned land.

To aid in the discussion of the locations of geologic features, the 7.5-minute quadrangle is divided into nine rectangles with intervals of 2.5 minutes of latitude and longitude (figure 2). The rectangles are referred to as Northeast Rectangle (NER), and so forth, throughout the quadrangle. Locations of features discussed in the text are specified by such rectangles, or by a cadastral survey section or sections within a rectangle.

Field mapping was conducted over intervals from 1998 to 2001. Field data was placed on U.S. Department of Agriculture black-and-white aerial photographs (dated September 14, 1965) and transferred by hand from the photos (approximately 1:20,000 scale) to the topographic base map (1:24,000). Chemex Labs in Sparks, Nevada performed geochemical analyses. Radiometric dating was conducted by the New Mexico Geochronology Research Laboratory in Socorro, New Mexico. Mr. Harold G. Pierce of O'Neill, Nebraska provided paleontologic expertise. Chemical classification of volcanic rocks is based on the Total Alkali-Silica (TAS) diagram after Le Bas and others (1986). Discussions of geologic time refer to the time scale after Hansen (1991).

Geologic mapping data is presented on plates 1 and 2. Rock sample locations are provided in tables 1 and 2, and are also shown on plate 1.

PREVIOUS WORK

Siegfried Muessig (1951a), a Ph.D. student of Dr. Edmund Spieker at The Ohio State University, conducted the first detailed mapping in the vicinity. His map included what is now known as the West Hills and Long Ridge from near Mills Gap northward to Goshen at 1:31,680 scale on a planimetric base. Muessig's map included a few small areas along the eastern border of the Sage Valley quadrangle. His work was fundamental to the present study and included definition of the Golden's Ranch Formation (1951b).

Christiansen (1952) and Campbell (1979) undertook mapping (1:62,500 scale) in the Canyon Mountains (formerly referred to as Canyon Range). This mapping extended northward to the Sevier River and included the southwestern portion of the Sage Valley quadrangle. Lawton and others (1997) conducted more recent mapping of the Canyon Mountains.

Geologic investigations of the Tintic Mining District began in the late 1800s. Hal Morris with the U.S. Geological Survey (USGS) performed the most comprehensive study of the East and West Tintic Mountains (Tintics) and adjacent areas from the 1950s to 1980s. The Sage Valley quadrangle is included on the preliminary geologic map of the Delta 1 x

2-degree quadrangle (1:250,000) by Morris (1978, 1987). Hannah and Macbeth (1990), Keith and others (1989, 1991, in preparation), and Stoeser (1993) subsequently revised the stratigraphy of the Tintics.

Pampeyan (1989) compiled the most detailed prior mapping of Sage Valley at 1:100,000 as part of the Lynndyl 30 x 60-minute quadrangle. The geology of immediately adjacent areas has also been mapped at 1:100,000 scale. Witkind and Weiss (1991) prepared the Nephi sheet (east); Witkind and others (1987) produced the Manti sheet (southeast); Hintze and Davis (2002) compiled the Delta sheet (south).

Adjacent geologic mapping of 7.5-minute quadrangles (1:24,000 scale) (figure 1) includes Champlin Peak (Higgins, 1982), Furner Ridge (Morris, 1977), Sugarloaf (Meibos, 1983), Juab (Clark, 1987, 1990), Skinner Peaks (Felger, 1991), Mills (Hintze, 1991a), Fool Creek Peak (Hintze, 1991b).

Other studies are important to the understanding of geology in the quadrangle. Lambert (1976) and Vorce (1979) conducted stratigraphic studies in the West Hills. Oviatt (1992) conducted surficial deposit mapping just to the south in Mills, Little and Scipio Valleys. Witkind and Marvin (1989), de Vries (1990), Delclos (1993), and Moore (1993) evaluated volcaniclastic rock units in the vicinity. Data from unpublished work (M.S. theses) in Sage Valley and nearby areas by the latter three authors is included herein.

STRATIGRAPHY AND MAP UNITS

The bedrock units of the quadrangle range from late Permian to early Oligocene in age and can be grouped into three packages through structural and stratigraphic considerations. The Permian to late Cretaceous strata are present under the cover of younger rocks and deposits, and record the marine, marginal marine, and continental conditions that predate and are coeval with the compressional deformation in the region. Secondly, Late Cretaceous? to early or middle Eocene fluvial and lacustrine sediments were subsequently deposited during the latter stages of the Sevier orogeny. The third rock package is composed of late Eocene to early Oligocene volcanic and volcaniclastic strata infilling and adjoining the western margin of Lake Uinta. These rocks are overlain by surficial deposits of late Tertiary to Holocene age in Sage Valley, Sevier Canyon, Dog Valley, and other drainages. Surficial deposits consist largely of alluvial and lacustrine sediments, or mixtures thereof.

Paleozoic and Mesozoic

Approximately 8,100 feet (2,470 m) of Permian through Jurassic strata are known to exist in the subsurface of the quadrangle based on state records from the 1980 Placid Oil Company WXC-State #2 drill hole (section 1, SER) (table 3, cross section A-A′). According to Douglas Sprinkel (oral communication, May 21, 2001), the bore hole was advanced on the southwest flank of a seismic anomaly. The units logged do not crop out in the quadrangle, but are known to be present in the vicinity in the West Hills, Canyon Mountains, southern Wasatch Mountains, and Pahvant Range.

The upper 2,640 feet (805 m) of the bore hole was cased and not logged. This part of the hole passed through probable Cretaceous strata, Jurassic Twist Gulch (Jtg) and Arapien Shale (Ja) units, and into the Twin Creek Limestone (Jtc), where the first formation top was picked at 5,252 feet (1,601 m) in depth. Other underlying units logged include the Jurassic Nugget Sandstone (Jn); the Triassic Ankareh Formation (Ŧa), Thaynes Formation (Ŧt), and Woodside Shale (Ŧw); and the Permian [Park City Formation] and Diamond Creek Sandstone (Ppc-Pdc), and Kirkman Limestone (Pk). A section was cored at a depth near 13,390 feet (4,082 m) that passed a thrust fault into vertical Nugget Sandstone (Douglas Sprinkel, oral communication, May 21, 2001). The hole was terminated at a depth of 13,509 feet (4,119 m) in the Nugget. The Park City Formation was not logged in this bore hole, but its presence is indicated by regional exposures and thickness relations.

Placid Oil also drilled the State #1 bore hole in the adjacent Skinner Peaks quadrangle. Data from the State #2 and #1 drill holes (table 3) were used to construct cross section A-A′ for the Sage Valley quadrangle.

Cretaceous? and Tertiary

Red beds of Sevier Canyon (TKr)

A sequence of primarily red-colored clastic and carbonate strata is present in Sevier Canyon along the western edge of the map area, and referred to here as the red beds of Sevier Canyon (TKr). This informal name is used because there is little information to determine the age of these rocks and correlation with other named units is problematic.

These rocks have previously been included with the Conglomerate of Leamington Pass by Higgins (1982), and the Canyon Range Formation of Stolle (Pampeyan, 1989). Working west of the Sevier River in the adjacent Canyon Mountains, Lawton and others (1997) subdivided the thick conglomerate units into several lithosomes under the Canyon Range Conglomerate (their unit Kc). Several workers (noted below) observed that the massive conglomerate units of the Canyon Mountains are overlain by a finer-grained clastic and carbonate sequence. Lawton's group mapped rocks above the Canyon Range Conglomerate as Tertiary red conglomerate, sandstone and limestone (their map symbol Tr, no rock unit name), tentatively correlated with the North Horn Formation. These finer clastics and carbonates were not extensively studied by Lawton east of the Sevier River. Their Tr unit has been also referred to as Unit B of the Canyon Range Formation (Stolle, 1978), and the North Horn and Flagstaff Formations (Hintze, 1991a, 1991b; Hintze and Davis, 2002).

Exposures of the red beds of Sevier Canyon (TKr) in the northern part of the quadrangle are poor. Red to tan-colored soil littered with quartzite and locally minor carbonate clasts is the norm. Locally, a few more resistant ledges of channelform conglomerate and sandstone are exposed. Better exposures exist closer to the Sevier River.

The lower or westernmost exposures (west of the Sevier River) consist of moderate reddish orange sandstone and conglomerate. The conglomerate contains primarily pebbles, cobbles, and locally boulders of quartzite clasts. Purple and banded purple clasts are derived from the Precambrian Mutual Formation, whereas pinkish gray to tan clasts are probably from the Cambrian Prospect Mountain Quartzite. These units are exposed to the west in the Canyon Moun-

tains. Gray carbonate clasts, derived from Paleozoic rocks are locally present. Covered intervals may include less resistant sandstone and mudstone. To the south and east, the upper portion of the unit contains ledges of red and tan sandstone and conglomerate beds, some with a reddish purple and yellow mottled appearance. The sandstones are fine to coarse grained and contain gritty and conglomeratic lenses (typically up to pebble size). The southernmost exposure west of the river also includes (at the top of the section) a few feet of whitish tan platy limestone beds with gastropods.

The unit appears to have developed under alluvial and local lacustrine conditions, based on the lithologies observed. These environments are similar to the North Horn Formation and Flagstaff Limestone described below.

The eastward-dipping sequence of the red beds of Sevier Canyon appears to underlie the conglomerate of West Fork Reservoir (Tcw) in several areas; however, this contact is difficult to locate due to poor exposures and the quartzite-rich clast composition of the two units. The red beds of Sevier Canyon are also in fault contact with the conglomerate of West Fork Reservoir over a significant area. To the south near the river (WCR, SWR), the conglomerate of West Fork Reservoir is locally absent and tuff and volcanic conglomerate units directly overlie the red beds of Sevier Canyon. A maximum exposed thickness of approximately 600 feet (180 m) was determined from the map. The lower contact is not exposed in the quadrangle. The lower contact of the red beds of Sevier Canyon may be marked by an angular unconformity with the Canyon Range Conglomerate (Hintze, 1991b; Douglas Sprinkel, oral communication, May 21, 2001). In the Canyon Mountains, Stolle (1978) stated that the contact between his Canyon Range Formation Unit A and Unit B may be slightly angular or conformable. Stolle measured 1,761 feet (537 m) of Unit B of the Canyon Range Formation. Thickness estimates were not provided by Lawton and others (1997) for Tr, or by Hintze (1991a, 1991b) for the Flagstaff Formation (Tf). Hintze and Davis (2002) estimated thicknesses for the Flagstaff Formation (Tf) and North Horn Formation (TKn) in the Canyon Mountains; Tf is from 1,300 to 2,460 feet (395-750 m) and TKn is >3,900 feet (>1,200 m).

Samples of the limestone containing gastropods were submitted for paleontologic analysis. Mr. Harold Pierce recognized molds from two taxa: (1) *Biomphalaria aequalis* (White 1880), range from North Horn Formation to Colton/Green River Formations, and (2) *Sphaerium* n. sp., unknown range. No beds considered favorable for possible palynologic analysis were located.

As indicated by prior workers (Lawton, Stolle, Hintze), these primarily clastic strata may correlate with the North Horn and/or Flagstaff to the east. At the San Pitch Mountains (located 18 miles [29 km] east), the North Horn is latest Cretaceous to early Eocene in age, whereas the Flagstaff is probably early Eocene (Weiss and others, 2001). The Canyon Range Conglomerate, which appears to underlie the red beds of Sevier Canyon, may range from Barremian(?) to Maastrichtian or Paleocene in age, and may correlate with the Cedar Mountain Formation, San Pitch Formation, Indianola Group, and North Horn Formation to the east in the San Pitch Mountains (DeCelles and others, 1995; Lawton and others, 1997; Sprinkel and others, 1999).

North Horn Formation (TKn?)

The North Horn Formation was defined by Spieker (1946, 1949) at the Wasatch Plateau (45 miles [72 km] southeast) for a succession of terrestrial sediments (riverine, floodplain, lacustrine, deltaic). Lawton developed a specific lithostratigraphy and sedimentary history indicating that the unit developed in the final stages of Sevier thrusting and onset of Laramide tectonics (Lawton and Trexler, 1991; Lawton and others, 1993; Lawton and Weiss, 1999).

A very small portion of a rock unit mapped as the North Horn Formation is along the eastern border of the map area in the West Hills. About 50 feet (15 m) of these brick red (heavily oxidized) clastic rocks are present along the base of the cuesta bordering Sage Valley and are truncated by the Sage Valley fault in section 11, SER. Muessig (1951a), Pampeyan (1989), Clark (1990), and Witkind and Weiss (1991) mapped this unit as North Horn, because of the lithologic and chromatic differences with the overlying carbonate-clastic strata mapped as Flagstaff. Although the North Horn label has been applied, no age information corroborates this designation, so the query is included on the map symbol (TKn?).

This unit concordantly underlies the conspicuous carbonate-clastic unit capping the largest (western) cuesta of the West Hills. Muessig (1951a), Lambert (1976), Vorce (1979), and Clark (1987, 1990) previously described these rocks in detail. The outcrop in the quadrangle consists of beds of moderate reddish brown and moderate reddish orange sandstone and mudstone. The bulk of the North Horn of the West Hills consists of channel-form conglomerate and sandstone interbedded with mudstone. The conglomerate includes predominantly quartzite clasts (75 to 100 percent) with subordinate carbonate clasts.

As stated, no age determination has been made; therefore, the TK age label has been applied. The North Horn to the east in the San Pitch Mountains ranges from late Campanian to early Eocene (Lawton and Weiss, 1999; Weiss and Sprinkel, 2000). Possible correlation with the red beds of Sevier Canyon has been considered, but such a correlation is presently unclear due to lack of continuous exposures and age identifiers.

Tertiary

Flagstaff Limestone (Tf)

Like the North Horn, the Flagstaff Limestone was defined on the Wasatch Plateau by Spieker and Reeside (1925) and Spieker (1946). Stanley and Collinson (1979) divided the Flagstaff there into three members. However, the strata at the West Hills (deposited along the western margin of Lake Flagstaff) differ from the more typical exposures to the east. The lithologic differences lead to the use of the name Flagstaff Formation by previous workers (Muessig, 1951a; Clark, 1990; Felger, 1991; Hintze, 1991a, 1991b), and a conglomeratic lateral equivalent was recognized by Meibos (1983) and Clark (1990). However, use of the nomenclature "Flagstaff Formation" is not considered correct (North American Stratigraphic Code, 1983), so Flagstaff Limestone is used herein.

A relatively small portion of the Flagstaff Limestone is at the southeastern portion of the map area where the West Hills join eastern Sage Valley. These rocks are present in the

cuesta bordering Sage Valley and in a horst to the south bounded by the Sage Valley fault. These rocks are lower Flagstaff strata; the upper portion of the unit is not exposed in the Sage Valley quadrangle.

Lambert (1976), Vorce (1979), Clark (1987, 1990), and Felger (1991) measured and described sections in the Juab quadrangle. The Flagstaff here consists of pastel-colored limestone and dolomite, interbedded with multicolored mudstone, siltstone and sandstone. The largest outcrop in the horst block in the quadrangle is primarily fractured and weathered carbonate and mudstone.

The unit was deposited in a large lake and bordering marshes present in central Utah (Stanley and Collinson, 1979). The location of Lake Flagstaff's western margin is indicated by the increase in clastic lithologies, the transition to the Orme Spring Conglomerate (named by Meibos, 1983), and lack of relatively thick carbonate units to the west. Clark (1990) described the northward transition from lacustrine and fluvial (Flagstaff) to piedmont lithofacies (Orme Spring Conglomerate) in the adjacent Juab quadrangle. The Orme Spring Conglomerate contains carbonate-clast conglomerates and pale-colored mudstones.

A maximum of about 400 feet (120 meters) of Flagstaff Limestone is present at the horst block in section 14, SER. A lesser thickness exists along the eastern quadrangle border. The Flagstaff conformably overlies the North Horn Formation in the West Hills cuesta (Clark, 1990).

As with the underlying North Horn, paleontologic evidence has not defined the age of the Flagstaff in the West Hills. The Flagstaff Limestone to the east is from late Paleocene to early Eocene in age; the main body of the Flagstaff Limestone is early Eocene (Jacobsen and Nichols, 1982). Therefore, a late Paleocene to early Eocene age is here assigned.

The Flagstaff has been shown to be the lateral equivalent of the Orme Spring Conglomerate (Meibos, 1983; Clark, 1990). The Flagstaff may correlate westward with the red beds of Sevier Canyon or other strata overlying the Canyon Range Conglomerate, but such correlations cannot presently be confirmed.

Conglomerate of West Fork Reservoir (Tcw)

The informal name, conglomerate of West Fork Reservoir, has been applied to a poorly consolidated conglomerate unit exposed in parts of the northeastern and western map area. The areas mapped as conglomerate of West Fork Reservoir have been included by Pampeyan (1989) with the Goldens Ranch – Agglomerate, Fernow Quartz Latite, and Canyon Range Formation of Stolle, and by Higgins (1982) in part with the conglomerate of Leamington Pass. The unit has not been mapped in adjacent areas; its presence may be difficult to detect.

This conglomerate unit appears to be confined to the Sage Valley quadrangle and the area immediately adjacent on the west, and is exposed along the eastern margin of the West Fork of Sage Valley and in the eastern portion of Sevier Canyon. At the surface, it is unconsolidated and exists as rubble-strewn hills. One exception is an outcrop of white to gray tuffaceous sandstone in section 23, NER (note attitude symbol). Better exposures are present in roadcuts along the West Fork of Sage Valley, and a cut bank on the Sevier River (NW1/4 section 8, SWR). These exposures show the unit is very crudely bedded and the matrix consists of tuffaceous sand and finer particles. The matrix varies from greenish gray, brownish gray, and pinkish gray. Clasts range from pebbles to boulders, but cobbles and boulders are most prevalent. The largest clasts are approximately two feet (0.6 meters) in diameter; clasts are subangular to rounded.

Quartzite clasts include purple Mutual and tan Prospect Mountain varieties. Green-colored clasts may be from the Ophir Formation (Douglas Sprinkel, oral communication, May 21, 2001). Several types of volcanic clasts are present (typically gray and green aphanitic and porphyritic extrusive rocks, apparently of intermediate composition), and gray Paleozoic carbonate clasts are locally present. Quartzite clasts are most prevalent, with volcanics and carbonates varying up to about 50 percent of the total.

In Sevier Canyon east of the river, the conglomerate of West Fork Reservoir overlies the red beds of Sevier Canyon (TKr); the nature of the contact there is unclear, but map relations suggest it may be concordant. The section in Sevier Canyon appears to be nearly complete at 600 feet (180 m) thick. The unit is anomalously absent in certain locations in Sevier Canyon over a short distance from relatively thick exposures. The upper portion of the unit is seen under the Chicken Creek Tuff Member of the Goldens Ranch Formation at the West Fork of Sage Valley (section 14, NCR, NER); a maximum of about 1,300 feet (400 m) appears to be present, but the lower part of the conglomerate is truncated and concealed by a fault. The unit does not crop out east of the Middle Fork of Sage Valley, so the conglomerate is not seen in contact with the Flagstaff Limestone or North Horn Formation. In the East Fork of Sage Valley, lacustrine and clastic deposits mapped as Green River Formation appear to exist under the Chicken Creek Tuff (Clark, 1990).

Geochemical analysis indicates a volcanic clast from the lower part of the unit is an andesite (figure 3, table 6). The trace and minor element composition of the clast (figure 5, table 7) has affinities with other volcanic units mapped in the Sage Valley quadrangle that may have erupted from the southern East Tintic Mountains volcanic field.

The source of the conglomerate of West Fork Reservoir is unclear, but westward or northward sources are more likely. Considering the clast content, the quartzites may have come from the Canyon Mountains and/or Tintics. The most likely source of volcanic clasts is the Tintics. On the other hand, Tcw is similar to several members of the Little Drum Formation mapped by Hintze and Oviatt (1993), and regional drainage during the late Eocene may have been eastward to the Uinta Basin (Baer and Hintze, 1987). However, the distance between the Little Drum Mountains and Sage Valley is estimated to have been significant (about 30 miles [50 km]) before regional extension occurred.

The unit is underlain by the red beds of Sevier Canyon, of uncertain, but possibly late Cretaceous to early Eocene age. The conglomerate of West Fork Reservoir is older than the overlying Chicken Creek Tuff, which has been dated during this study (table 4). A volcanic clast from the lower portion of the unit produced a suspect $^{40}Ar/^{39}Ar$ biotite age of 35.72 ± 0.61 Ma (table 4 and appendix B). Unfortunately, this age does not concur with the stratigraphy and other Ar-Ar dates obtained through this study. Laboratory data indicate that sample has likely undergone alteration and argon loss; therefore, the date is suspect.

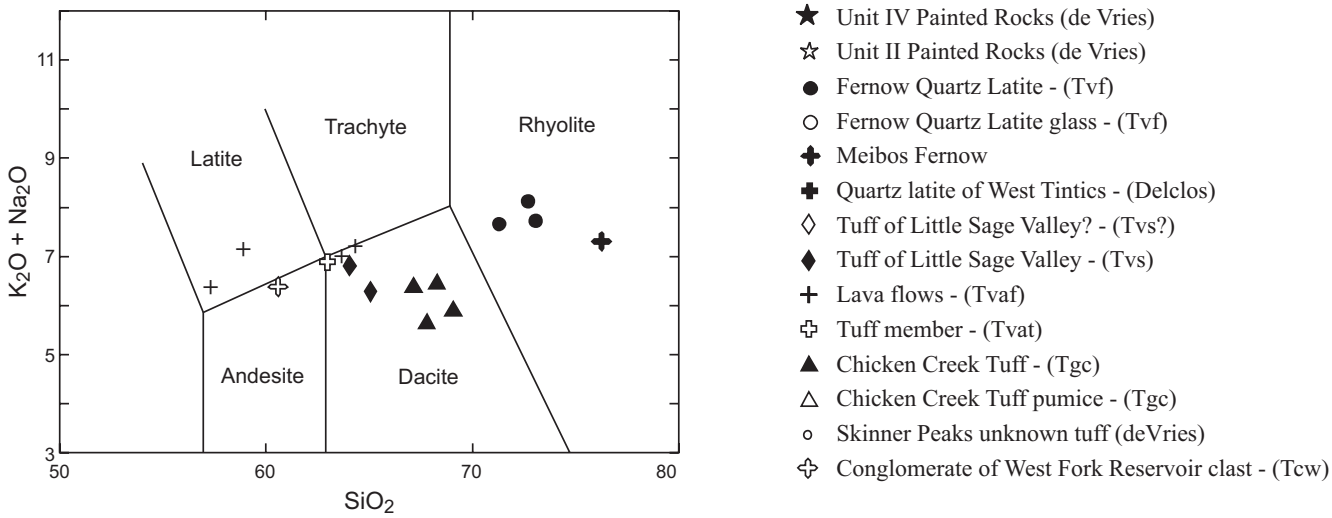

Figure 3. *Total alkali ($Na_2O + K_2O$) versus silica (TAS) diagram for volcanic rocks in the Sage Valley quadrangle and adjacent areas collected by the author. Compositional fields for volcanic rocks from Le Bas and others (1986). Data is normalized to 100% after loss on ignition (LOI) subtracted. Table 6 lists the non-normalized major-element whole-rock geochemical analyses. Tables 1 and 2 list sample locations. Symbols also apply to figures 4 and 5.*

The unit may be middle to late Eocene in age, based on the available information. If the volcanic clasts in the conglomerate of West Fork Reservoir are indeed from the Tintics, they may represent some of the oldest igneous rocks associated with that district, making the onset of volcanism older (>39 million years ago) than the previously documented 32-35 million years old (early Oligocene) (Morris and Lovering, 1979; Keith and others, in preparation).

Stratigraphic relations suggest the conglomerate of West Fork Reservoir may be laterally equivalent to the Green River Formation lacustrine-fluvial beds mapped by Clark (1990) in the Juab quadrangle. The age of the Green River Formation was not constrained by Clark (1990), but to the east in Sanpete Valley and the Wasatch Plateau, $^{40}Ar/^{39}Ar$ and fission track dates ranging from 42 to 46 million years before present indicate a middle Eocene age (Sheliga, 1980; Bryant and others, 1989), and the unit may extend into the late Eocene to the south near Salina (Willis, 1986).

Goldens Ranch Formation

Muessig (1951a, 1951b) defined the Goldens Ranch Formation (originally Golden's Ranch Formation) to include volcanic conglomerate, tuff, bentonite, sandstone, other sediments, and a limestone member. Meibos (1983) revised the definition of the formation to include only the lower portion of Muessig's formational strata, subdivided the formation into three members, and designated a type section in NW1/4 section 18, T. 14 S., R. [1] W. (Juab and Sage Valley quadrangles) (MacLachlan and others, 1996). Witkind and Marvin (1989) subsequently conducted K/Ar dating and revised the areal extent of the unit (MacLachlan and others, 1996); the recommended vertical extent of the formation was similar to Muessig's original definition and mapping. Felger (1991) proposed further subdivision of the Chicken Creek Tuff Member into four units. For this mapping project, the UGS chooses to retain the nomenclature used by Meibos (three-member Goldens Ranch Formation) and the overlying units are informally grouped under the name "volcanic rocks of Sage Valley."

The origin of the formational name was only described by Muessig as a ranch located in the South Fork of Dog Valley. The best exposures of the formation were located in the Middle Fork of Sage Valley (Muessig, 1951a, p. 89). Muessig intended to designate a type area for the formation, which was located near uninhabited ranch land owned by the Golden family of Nephi (Malcolm Weiss, oral communication, May 15, 1998). The "Golden's ranch" was located in section 6, T. 14 S., R. 1 W. (northwestern corner of the Juab quadrangle) (Gary Golden, oral communication, May 28, 1998).

Goldens Ranch Formation terminology has been applied east of Juab Valley by some workers (Black, 1965; Jefferson, 1982; Le Vot, 1984; Auby, 1991). However, the accepted practice is to use Goldens Ranch within and west of Juab Valley and Moroni Formation to the east (Witkind and Weiss, 1991; Hellmut Doelling, verbal communication, May 21, 2001).

Chicken Creek Tuff Member (Tgc): The lower portion of Muessig's Golden's Ranch Formation contained tuff units at the Middle Fork of Sage Valley and well exposed in roadcuts southwest of the Chicken Creek Reservoir in Juab Valley (Skinner Peaks quadrangle). The tuff at the reservoir locality was sampled for radiometric dating purposes by Everenden and James (1964) and Mackin (see Armstrong, 1970), and referred to as the Chicken Creek Tuff. Meibos (1983) designated these strata the lower member of the revised Goldens Ranch Formation.

In the Skinner Peaks-Painted Rocks area, located 10 miles (16 km) to the southeast of Sage Valley, Vogel (1957) and Neihaus (1956) mapped Golden's Ranch Formation (undivided), where recent mapping by Felger (1991) proposed subdivision of the Goldens Ranch Formation into five units. Units I through IV were thought to correspond (stratigraphically) to Meibos' Chicken Creek Tuff Member, and Unit V was the Hall Canyon Conglomerate or its equivalent. Felger and others (1990) initially suggested that Unit IV was the Chicken Creek Tuff, but this distinction is not described by Felger (1991). de Vries (1990) stated that the Chicken Creek Tuff should be stratigraphically near the position of Unit IV.

The Chicken Creek Tuff Member crops out in the northern half of the Sage Valley quadrangle from the Middle Fork of Sage Valley, westward above the West Fork of Sage Valley, in a fault valley in Sevier Canyon, and adjacent to Dog Valley Wash. Elsewhere, the tuff member is present in limited exposures in the Sugarloaf and Juab quadrangles. The best exposures are at the Chicken Creek Reservoir locality. The extent of the unit southeast of the reservoir toward Painted Rocks is not known; the tuffs at Painted Rocks appear different and will be discussed in more detail below. The Chicken Creek Tuff Member is generally not well exposed in the Sage Valley quadrangle and crops out as rounded ledges or knobs.

The Chicken Creek Tuff is a grayish pink to light gray to yellowish gray, poorly to moderately welded, vitric, dacitic ash-flow tuff. Plagioclase and biotite, pumice lapilli and lithic fragments are obvious in hand sample. Where present, pumice lapilli are up to 2 inches (5 cm) in length, and can be flattened. Lithic inclusions are comprised of volcanic rocks, quartzite, and carbonate up to pebble size. In general, the unit is crudely layered, but locally, layering is distinct and may be as thin as a few inches.

Clark (1987, 1990) and de Vries (1990) described the petrography of the tuff. Modal analyses of three samples by de Vries are included (table 5). Phenocrysts are up to 2 mm in length and most are fragmented. Phenocrysts comprise about 30 percent of the rock including plagioclase (20%), sanidine (2-4%), quartz (2-4%), biotite (1-2%), hornblende (<1%), magnetite (<1%), and accessory minerals (trace). Lithic inclusions can also comprise about 5% or less of the rock. The remainder of the tuff consists of a groundmass composed of glass shards and pumice (40-50%), and calcite (25-30%). The calcite is a secondary alteration product. Whole-rock geochemical analyses indicate that the Chicken Creek Tuff is a dacite (figures 3 and 4, table 6).

In the map area, the Chicken Creek Tuff is approximately 200 feet (60 m) thick. Meibos (1983) reported a thickness for the tuff of 0 to 50 feet (0 to 15 m). The maximum exposed thickness in the Juab quadrangle should be closer to 100 feet (30 m) rather than 640 feet (195 m) (Clark, 1990), which was overstated due to misidentification of the tuff of Little Sage Valley. The base of the unit is not exposed in the Middle Fork of Sage Valley. In exposures to the west, the tuff member overlies the conglomerate of West Fork Reservoir. The Chicken Creek Tuff is typically overlain by the Hall Canyon Conglomerate Member, except where the Hall Canyon pinches out near West Fork Sage Valley, and where both upper members of the Goldens Ranch Formation are absent adjacent to Dog Valley Wash.

Muessig (1951b) suggested a middle Eocene age for the Golden's Ranch Formation based on plant debris identified by Roland Brown of the USGS. A subsequent potassium-argon (K-Ar) age of 33.2 Ma was obtained from the reservoir locality, and review of the fossil evidence by MacGinitie lead to his conclusion that the flora from the Sage Valley Limestone could range from middle Eocene to upper Oligocene (Everenden and James, 1964).

Witkind and Marvin (1989) conducted reconnaissance sampling and K-Ar dating of volcanic units they referred to as Goldens Ranch and Moroni Formations. The Goldens Ranch samples were from the Dog Valley, Sage Valley, Chicken Creek Reservoir, and Skinner Peaks-Painted Rocks areas. They conceded that the stratigraphic position of most samples was not known with much certainty, so their data are of limited use. I attempted to locate the western sample locations vertically based on the current stratigraphy. The sample in Sage Valley (WP-422) was collected from the Chicken Creek Tuff, as was WP-421 at the Chicken Creek Reservoir (Skinner Peaks quadrangle). Based on the given locations, other samples in the Sugarloaf (WP-468) and Furner Ridge

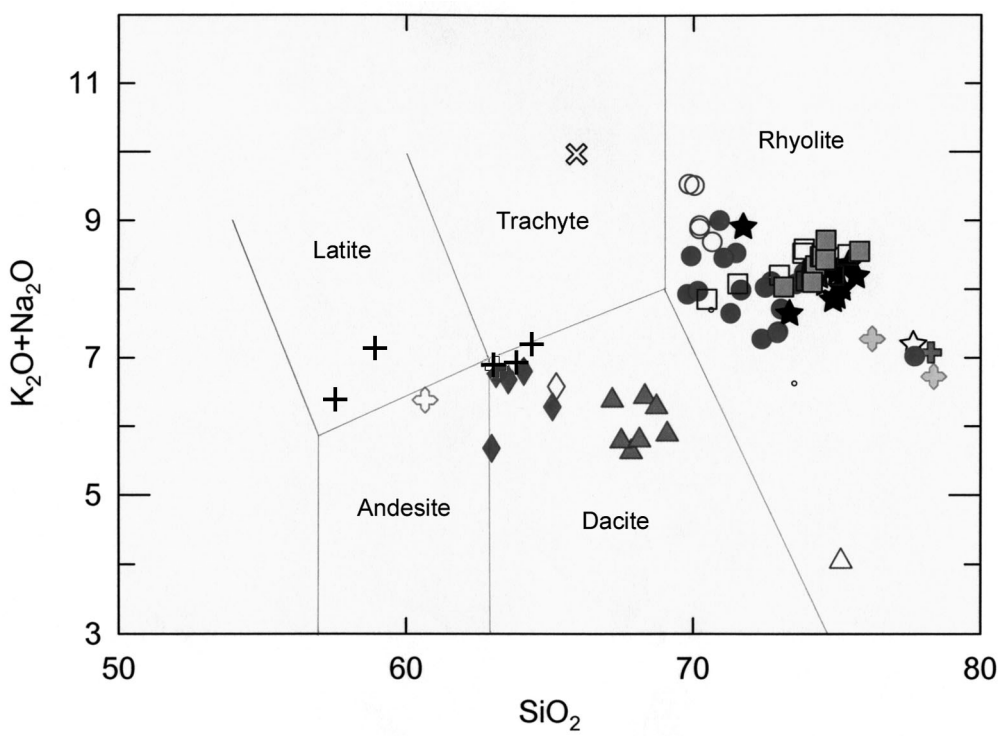

Figure 4. *Total alkali ($Na_2O + K_2O$) versus silica (TAS) diagram for volcanic rocks in the Sage Valley quadrangle and adjacent areas collected by the author and others. Compositional fields for volcanic rocks from Le Bas and others (1986). Data are normalized to 100% after loss on ignition (LOI) subtracted. Table 6 lists the non-normalized major-element whole-rock geochemical analyses. Tables 1 and 2 list sample locations. Symbols are listed in figure 3.*

(WP-473 and WP-469) quadrangles appear to be from volcanic conglomerate units or surficial deposits located stratigraphically above the Chicken Creek Tuff. The K-Ar ages reported by Witkind and Marvin (1989) for the two Chicken Creek Tuff samples were from 30.9 ± 0.7 to 38.5 ± 1.4 Ma (table 4).

For the present study, a sample of the Chicken Creek Tuff Member from the Middle Fork of Sage Valley was dated at 38.61 ± 0.13 Ma using the $^{40}Ar/^{39}Ar$ method on biotite (table 4 and appendix B). The tuffs at the Middle Fork and Dog Valley wash areas have been correlated with the Chicken Creek Reservoir outcrops through stratigraphic position, similar lithic inclusions, petrography, and geochemical analysis (figures 3, 4, and 5).

The source of the Chicken Creek Tuff has not been identified. Pumice size and abundance in the tuff unit appears to decrease to the west in the quadrangle. The East Tintic Mountains volcanic field is a possible source from which the tuff may have erupted, but no vent or correlative unit has been identified. A local eruptive center could be associated with the Levan monzonite intrusives, described by John (1972), Auby (1991), Felger (1991), and Weiss and others (2001) (located largely in the Levan and Chriss Canyon quadrangles, 10 miles [15 km] to the east-southeast of Sage Valley). K-Ar ages on these intrusions are about 23 million years old (Witkind and Marvin, 1989; Auby, 1991), but considering the altered nature of the outcrops and accuracy of the K-Ar method, these rocks could be considerably older (Eric H. Christiansen, written communication, February 8, 2002). Available geochemical data (John, 1972) are not useful for correlation purposes. An interesting possibility is that the Levan intrusions may have fed the extrusive rocks mapped as Goldens Ranch Formation at the nearby Skinner Peaks-Painted Rocks area, or the Moroni Formation present to the northeast. However, further research is needed to verify this hypothesis.

Neither tuffs at Painted Rocks or within the Moroni Formation appear to correlate geochemically with the Chicken Creek Tuff, as both of the former units are rhyolitic (de Vries, 1990) (figures 4 and 5, tables 6 and 7). de Vries (1990) recognized that the tuffs at Painted Rocks are lithologically, petrographically, and geochemically different from the Chicken Creek Tuff found at the reservoir locality and Sage Valley. Tuffs at the Painted Rocks-Skinner Peaks area have K-Ar ages from 30-35 million years old (Witkind and Marvin, 1989) (table 4).

Through this study, the Chicken Creek Tuff was determined to be older than the dated volcanic units erupted from the East Tintic Mountains volcanic field (Morris and Lovering, 1979; Keith and others, in preparation). Therefore, the correlation proposed by Morris (1964, 1975, 1977) of the Chicken Creek Tuff with the Fernow and Packard Quartz Latites is not considered valid. The Chicken Creek Tuff may be coeval with part of the Moroni Formation of the Cedar Hills area located 25 miles (40 km) to the northeast. K-Ar ages on ash-flow and stream-laid tuffs and volcanic breccia of the Moroni Formation range from 33 to 38 million years before present (Witkind and Marvin, 1989); the Moroni Formation is also cut by the Salt Creek dike with K-Ar ages of 36.0 ± 1.3 and 33.6 ± 1.4 Ma (Witkind and Marvin, 1989; Banks, 1991). Witkind and Marvin (1989) concluded that the Goldens Ranch and Moroni Formations were correlative

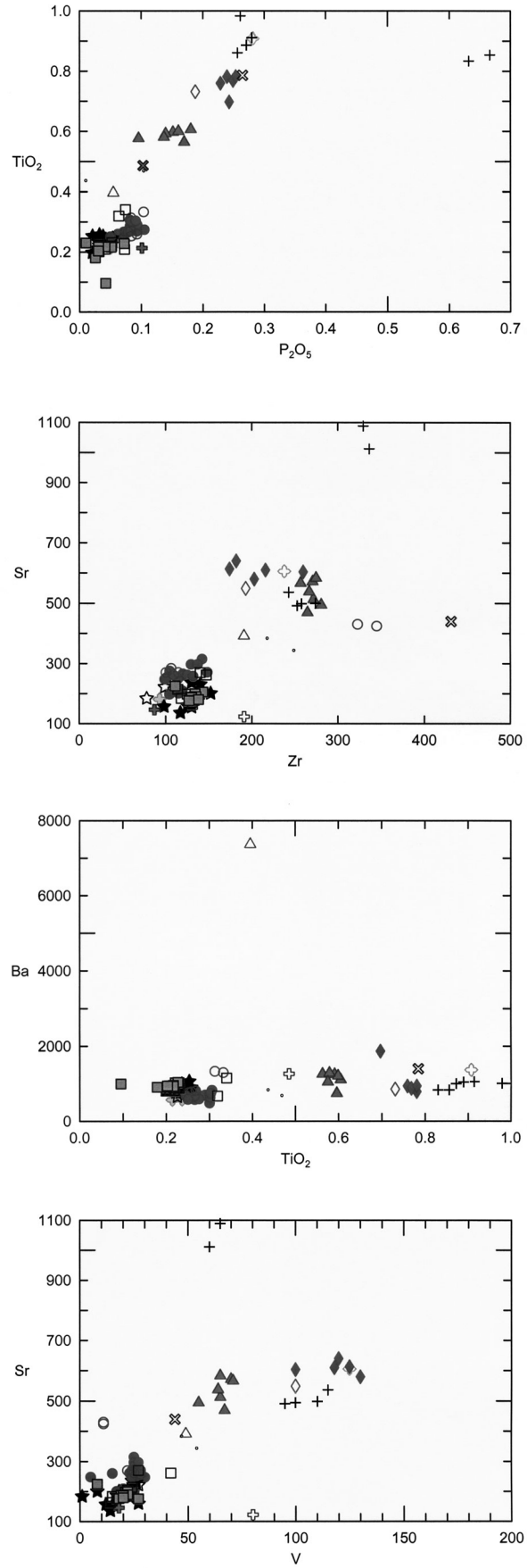

Figure 5. *Geochemical variation diagrams based on the normalized major- and trace-element geochemical data included in tables 6 and 7. Symbols are listed in figure 3.*

based on geochronology and stratigraphic relations; however, I believe this conclusion requires further study. de Vries (1990) concluded that the volcanic units in the Goldens Ranch and Moroni Formations were not correlative. This conclusion was based on differences in petrography and geochemistry; however, temporal correlation has not yet been ruled out. More recent dates from the Moroni Formation in the Cedar Hills area show $^{40}Ar/^{39}Ar$ ages <37.5 million years old from sedimentary units, and 34.3 million years old from an ash-flow tuff unit (Albrecht, 2001). K-Ar ages on the formation of Aurora (overlies the Green River and Crazy Hollow Formations near Salina) are similar to the Chicken Creek Tuff ranging from 38 to 40 million years old (Willis, 1986, 1988).

The more precise dating of the Chicken Creek Tuff has important implications, for the tuff appears to be in stratigraphic contact with (or very near) the Green River Formation at the Chicken Creek Reservoir-Mills Gap area (Juab and Skinner Peaks quadrangles). These data indicate that the Green River Formation does extend to the late Eocene there. There does not appear to be any intervening Crazy Hollow Formation present.

Some of the questions raised by Clark (1990), de Vries (1990) and Felger (1991) about the relations of the Goldens Ranch Formation and East Tintic volcanic rocks have been answered through the present study. Further research is ongoing regarding the stratigraphic relations and correlation of the Painted Rocks-Skinner Peaks volcanic section. Additional subdivision of the Goldens Ranch Formation may be warranted (Malcolm Weiss, oral communication, June 6, 2001).

Hall Canyon Conglomerate Member (Tgh): Meibos (1983) designated the conglomerate overlying the Chicken Creek Tuff, the Hall Canyon Conglomerate Member, for exposures in Hall Canyon of the Sugarloaf quadrangle. He further divided the member into Q and V units, based on clast type, that "…indeterminately grade into one another" (p. 47). However, the Q/V subdivision was not used by Clark (1990), or in the present study, as it does not appear to be useful for mapping purposes. Pampeyan (1989) included the Hall Canyon with his Goldens Ranch Formation–Agglomerate unit. Higgins (1982) mapped this rock unit as Copperopolis Latite–Middle Agglomerate Member following Morris' terminology.

Through the present study, refinement of the stratigraphy has occurred, and some of what was mapped by Clark (1990) as the Hall Canyon Member is now thought to be stratigraphically higher (younger) volcanic conglomerate units. In Skinner Peaks, Felger (1991) stated that Unit V of the Goldens Ranch was the Hall Canyon Conglomerate or its equivalent. Much of the South Hills area there has been mapped as Unit V?

In the Sage Valley quadrangle, the Hall Canyon Conglomerate is relatively thin (< 50 feet [<15 m]) where present between the upper and lower members of the Goldens Ranch Formation in the Middle Fork of Sage Valley. The Hall Canyon is absent immediately west of the type section but crops out westward in Sevier Canyon. The conglomerate member is also present below the Sage Valley Limestone in Leamington Canyon.

The Hall Canyon Member consists of gray, poorly consolidated conglomerate and volcanic conglomerate. Meibos described the clast composition as varying from quartzite-carbonate (65%-35%) [Unit Q] to quartzite-carbonate-volcanic (50%-15%-35%) [Unit V]. Quartzite includes the Prospect Mountain and Mutual types; carbonates appear to be from Paleozoic units; volcanic fragments are grayish to reddish andesite. Locally, greater proportions of volcanic clasts (approaching 100 percent) were observed in Sage Valley. Clasts are angular to subrounded pebbles to boulders, and most are less than six inches (15 cm) across. The matrix of the conglomerates consists of poorly consolidated tuffaceous sand, silt, and clay.

The unit is expressed as rubbly slopes and clast-strewn hills. The Hall Canyon can be lithologically similar to the volcanic conglomerate units above the Sage Valley Limestone Member, so where the Sage Valley Limestone is absent, differentiating the Hall Canyon is difficult.

The stratigraphic relations have previously been discussed with the Chicken Creek Tuff. The Hall Canyon Conglomerate Member ranges from 0 to 300 feet (0-90 m) in Sage Valley. The maximum thickness is in Sevier Canyon. The unit appears thicker in the Sugarloaf quadrangle where Meibos stated a thickness near 820 feet (250 meters) for both of his Q and V units. In the Champlin Peak quadrangle, 0 to 33 feet (10 m) is reported as a slope below the Sage Valley Limestone (Higgins, 1982). In the Juab quadrangle, the thickness should be on the order of 100 feet (30 m) or less, rather than 0 to 400 feet (122 m) (Clark, 1990), based on my re-evaluation of the section.

There is no direct age information on the Hall Canyon, but it is bracketed by radiometric ages on the underlying Chicken Creek Tuff (38.61 ± 0.13 Ma) and overlying tuff of Little Sage Valley (37.43 ± 0.18 Ma). A late Eocene age is assigned.

The source of the Hall Canyon is most likely from the East Tintic Mountain volcanic field, as indicated by a thicker section and larger clasts present in the Sugarloaf quadrangle to the northeast. Unfortunately, exposures are poor, so the presence of directional indicators is difficult to observe. The unit appears to record the initial stages of alluvial and lahar deposition prograding southward during the construction of stratovolcanoes in the East Tintic volcanic field.

The Hall Canyon Conglomerate Member may correlate with similar volcaniclastic strata of the Painted Rocks-Skinner Peaks area (Felger, 1991), and the Moroni Formation present in the southern Cedar Hills area (Muessig, 1951a; Witkind and Marvin, 1989, Albrecht, 2001). Biek (1991) and Auby (1991) mapped similar rocks along the northwestern and western flanks of the San Pitch Mountains. Due to uncertainties of source and age, Biek mapped these rocks as Tertiary volcanics, while Auby mapped them as Goldens Ranch Formation in northern exposures and volcaniclastic rocks of unknown affinity in limited, more southern exposures.

Sage Valley Limestone Member (Tgs): The Sage Valley Limestone was originally designated as a member of Muessig's Golden's Ranch Formation. He stated that the best exposures of this unit are near southern Dog Valley (Furner Ridge and Sugarloaf quadrangles) (Muessig, 1951a). This rock unit was also included as a member of the Copperopolis Latite in adjacent quadrangles by Morris (1977) and Higgins (1982), and Pampeyan (1989) included the Sage Valley Limestone as a member of the Goldens Ranch Formation. Meibos (1983) designated the limestone as the upper member of the revised Goldens Ranch Formation.

The Sage Valley Limestone Member is an excellent marker unit as it aids in identifying stratigraphic and structural relations among a relatively thick series of poorly consolidated volcanic conglomerate and conglomerate units. The member is present in southern Dog Valley, Sage Valley, and westward to Leamington Canyon.

This member contains limestone with clay or mudstone and locally minor conglomerate. The limestone dominates and is yellowish gray to light olive gray and thinly to thickly bedded. It is finely to coarsely crystalline (sparite), and often fractured and vuggy, weathering to a rough, pitted surface. It also contains abundant fossilized plant remains and locally chert and gastropods. The chert is found in thin discontinuous layers and patches with colors ranging from medium light gray to moderate reddish brown to white. White to orange yellow clay and mudstone form slopes between limestone ledges; these strata are calcareous and earthy. Minor conglomerate is included at the type area. The unit forms a series of ledges easily recognizable from units above and below it.

The Sage Valley Limestone is underlain by either the Hall Canyon Conglomerate or Chicken Creek Tuff Members, except for one location (section 23, NER) where the limestone lies directly on the conglomerate of West Fork Reservoir. Volcanic conglomerate unit A overlies the limestone, where present.

In the quadrangle, the Sage Valley Limestone is thickest (250 feet [75 m]) at the type area. Similar to the Hall Canyon, the limestone member thins to zero west of the type area (section 24, NER and ECR), but is present over the Chicken Creek Tuff in sections 23 and 24, NER. In Sevier Canyon, the member thins from about 20 feet (6 m) to zero. The thickness in the Sugarloaf quadrangle is about 260 feet (80 meters). In the Furner Ridge quadrangle, 0 to 300 feet (0-90 m) is present (Morris, 1977), and 0 to 100 feet (0-30 m) exists in Leamington Canyon (Higgins, 1982).

Prior studies regarding the age of the Sage Valley Limestone have been previously discussed under the Chicken Creek Tuff herein. Like the Hall Canyon, the age of the limestone member is bracketed by ages from tuff units – the Chicken Creek Tuff below (late Eocene) and tuff of Little Sage Valley above (early Oligocene) (table 4).

Muessig (1951a) reported the following leaves and stem fragments identified by Roland Brown (USGS): *Equisetum* sp. (horsetail), *Sabalities* sp. (palm), *Koelreuteria nigricans*, fragments of other dicotyledons, as well as some freshwater mollusks. Meibos (1983) obtained a collection of fossil leaves and twigs from the unit that were not identified. In addition, a gastropod was tentatively identified *Lymnaea*, species indeterminate. Clark (1990) similarly reported the presence of unidentified plant remains and gastropods.

The series of interbedded limestone and clay, with plant remains and gastropods suggests that the Sage Valley Limestone formed in a lake or series of freshwater lakes. The lake(s) apparently developed on some of the earliest volcanic and volcaniclastic deposits of the East Tintic volcanic field. Work by the USGS indicates that locally warm springs may have fed the lake or lakes (Clark, 1987). The reason for the lake basin topography is unclear. Possibly the water body could be a remnant of Lake Uinta, may have developed in a caldera, or formed as a result of damming of drainages by volcanic edifices.

Kim (1988) included lacustrine rocks mapped in the East Tintic Mountains as Goldens Ranch, but later references to these rocks excluded the Goldens Ranch name (Keith and others, 1991). The lacustrine rocks mapped by Keith and others (in preparation) appear to be much younger than the Sage Valley Limestone in the quadrangle.

Volcanic rocks of Sage Valley

The volcano-sedimentary and extrusive volcanic rock units present above the three-member Goldens Ranch Formation have been informally grouped here as the volcanic rocks of Sage Valley. The five primary units were informally designated as formations to maintain a consistent rank with the Fernow Quartz Latite. This group of strata primarily consists of volcanic conglomerates (units A, B, C, and undifferentiated) interleaved with two ash-flow tuffs, which include a little known unit (the tuff of Little Sage Valley) and the regional Fernow Quartz Latite. Lava flow and tuff members are included in the lower volcanic conglomerate (unit A). Of importance, is that relatively complete sections of the volcanic rocks of Sage Valley were recognized overlying the Goldens Ranch Formation in two locations: (1) the northeast quadrant of the quadrangle (sections 14 and 11, NER), and (2) along the eastern quadrangle border (section 19, ECR) extending to Hill 5825 in the Juab quadrangle.

The majority of this group of rocks (volcanic rocks of Sage Valley) was originally referred to as part of the Golden's Ranch Formation by Muessig (1951a) and later Witkind and Marvin (1989), as the Copperopolis Latite by Morris (1977), and as the Cazier Canyon Agglomerate of Meibos (1983). Morris and Lovering (1979) called the Copperopolis Latite the lower formation of the Tintic Mountain Volcanic Group.

The UGS has decided to use this new informal unit terminology rather than existing rock names, because recent mapping has revised the stratigraphy in Sage Valley and the East Tintic Mountains that is not all consistent with prior work. It is our opinion that the use of existing names could lead to confusion regarding stratigraphy, age, and correlation.

The terms agglomerate, volcanic breccia, volcanic conglomerate, and lahar could be applied to the coarse volcaniclastic deposits. Muessig (1951b) originally referred to the bulk of these rocks as volcanic conglomerates and noted that they grade laterally to flows and volcanic breccias (to the north on Long Ridge). Several of these rocks have been referred to as agglomerates by Morris, and later by Meibos and Pampeyan. I prefer the term volcanic conglomerate to agglomerate. The term agglomerate suggests a pyroclastic origin and has been variously defined over time (Jackson, 1997).

The Fernow Quartz Latite is an important rock unit included in this group. It is known to be located near the bottom of the exposed volcanic pile in the southern East Tintic Mountains and thought to correlate to other tuffs on the north side of that range. In Sage Valley, however, the Fernow is near the top of the section, suggesting that some of the oldest rocks derived from the Tintics are present below.

Volcanic conglomerate unit A (Tva)

The lower formation of the volcanics of Sage Valley is

named here volcanic conglomerate unit A. The formation corresponds with the lower parts of the Cazier Canyon Agglomerate of Meibos, and Morris' Copperopolis Latite–Middle Agglomerate Member. Of all of the rock units present in the map area, unit A appears to cover the most surface area. It is present in many parts of the quadrangle where rock is exposed. More extensive exposures exist in section 24 (NER, ECR) over the Chicken Creek Tuff, and comprising the eastern wall of Sevier Canyon (east of the subsidiary Canyon fault valley) from the Sevier River northward to Dog Valley Wash.

Unit A consists of gray to brown volcanic conglomerate and breccia, with dark gray to dark pink, angular to subrounded volcanic clasts and minor carbonate and quartzite clasts. The volcanic clasts appear andesitic and are aphanitic and porphyritic, but no analyses were made to verify composition. No cobble counts were performed, but the clast percentages reported by Meibos for the Cazier are similar to my estimates: volcanic (90-100%), limestone (0-1%), quartzite (0-10%). The unit is largely matrix supported. The matrix consists of ash, silt, and sand, with colors varying from light gray to medium gray to moderate brown, and locally blue gray and red gray. In some places, the matrix fines have been subsequently winnowed away leaving a lag of coarse clasts, while in other places, a light gray powdery matrix exists with few scattered clasts. The unit is poorly to moderately consolidated. Where more weathered, it develops rubble-covered hills and slopes. The better exposures in southern Sevier Canyon develop ledges and slopes.

Delclos (1993) measured sections in the Sevier Canyon-southern Little Sage Valley area (WCR). Using Pampeyan's map as his guide, Delclos discussed sections of rock that Pampeyan included with the Fernow Quartz Latite, but are now mapped as volcanic conglomerate unit A, tuff of Little Sage Valley, and Fernow. The lower parts of Delclos' sections refer to fluvial and debris-flow members, which correspond to volcanic conglomerate unit A. Delclos described the fluvial member as consisting of several layers of fluvially deposited ash, fine sand, silt, and volcanic boulders (which range up to 1.6 feet [0.5 m] in diameter) with cross bedding and channeling present. The debris flows consist of a matrix-supported deposit of cobbles and boulders of volcanic rocks, limestone, and quartzite within a volcanic matrix (lithologically similar to the Fernow). Some Paleozoic boulders are up to 6.6 feet (2 m) in diameter, and the rock is poorly sorted.

Locally, lava flows and tuff units are included with the volcanic conglomerate. These rocks are mapped separately as members and described below. Unit A also includes lava flows too small to be mapped separately. In addition, limited exposures of possible pyroclastic-fall (or fall-out) tuff lenses were observed in volcanic conglomerate unit A near the section 8 and 9 boundary (SWR) in Sevier Canyon. The apparent tuffs consist of white to yellow powdery fines with pumice included, and are poorly to moderately consolidated. Although not mapped separately, they are discussed here for completeness.

Volcanic conglomerate unit A is generally present above the Sage Valley Limestone, or the other two members of the Goldens Ranch Formation. Unit A is capped by the tuff of Little Sage Valley. Near the river, unit A can unconformably overlie the red beds of Sevier Canyon (figure 6). The formation is 375 feet (115 m) thick in the northeast quadrant section, but is obviously thinner (about 175 feet [55 m]) between the Middle and East Forks of Sage Valley. In Sevi-

Figure 6. *View to northeast in Sevier Canyon of sections 7 and 5, SWR. In the foreground is the oldest alluvial-fan deposit (QTaf). At the left center the red beds of Sevier Canyon (TKr) are unconformably overlain by volcanic conglomerate unit A (Tva) and the tuff of Little Sage Valley (Tvs). Near the photo center is the tuff member of volcanic conglomerate unit A (Tvat). Across the Sevier River is the conglomerate of West Fork Reservoir (Tcw) in the lowest hills in fault contact with Tva (slope) and Tvs (at ridgetop).*

er Canyon, approximately 1,000 feet (300 m) crops out.

The better exposures of volcanic conglomerate unit A indicate the unit was water laid, likely as alluvial fans or plains and lahars. The rock unit may record the continued southward progradation of alluvial systems and lahars, which were initially indicated by the conglomerate of West Fork Reservoir and the Hall Canyon Conglomerate. The presence of lava flows and ash-flow tuffs in the stratigraphic column suggest the development of a volcanic center(s) from which the coarse and finer fractions could be derived. The volcanic clasts are probably from some of the earliest igneous activity in the East Tintic Mountains – none of which are now exposed, due the thick layers of volcanic rocks present. Subordinate carbonate and quartzite clasts could be from Paleozoic rocks underlying the volcanic section there, or exposed outboard from the stratovolcanoe(s). The coarse fraction suggests that considerable surface gradients had developed to carry such a load.

The radiometric ages on the Chicken Creek Tuff bound the lower age range for unit A; no detailed age data have been obtained on the upper two members of the Goldens Ranch Formation. The tuff of Little Sage Valley, which overlies unit A, has been dated in this study and is discussed later. Available information points to a late Eocene age for unit A. As stated, unit A appears to correspond with part of the Cazier Canyon Agglomerate, and part of Morris' Middle Agglomerate Member of the Copperopolis Latite. Correlations to Painted Rocks and Moroni Formation volcaniclastic rocks are considered possible.

Lava flow member (Tvaf): The prior reconnaissance mapping had not recognized lava flow units in the northwestern portion of the quadrangle. These flows are interstratified with the lowest volcanic conglomerate (unit A), and do not appear to be present in any other stratigraphic horizon. This map unit is exposed at the surface as far east as section 9 (NWR) and as far south as section 30 (WCR). The flows are often recognized as blocks and chips of talus draped on hillslopes. In some cases, the unit caps hills where it is more resistant than the enclosing volcanic conglomerate.

These rocks are predominantly aphanitic and the surfaces weather from light reddish brown, moderate brown to dark brown, and medium dark gray with rust-colored spots, and on fresh surfaces varies from bluish gray, medium dark gray, pink, and moderate yellowish brown. Petrographic analysis was not conducted to confirm that these rocks were lava flows rather than tuffs, but available field evidence points to the lava flow origin.

Whole-rock geochemical analyses were done for six samples from this unit (figure 3, table 6). The results indicate the existence of two separate lava flow units. Four of the samples are geochemically similar and plot near the intersection of the latite-trachyte-andesite-dacite fields on a TAS diagram. The two other samples are latites, and come from the relatively thick flow outcrop north of the drainage in sections 5 and 6, NWR. This flow outcrop appears to be a different flow based on composition. There are several lava flow outcrops in the quadrangle and only a few have been tested geochemically. Because of the uncertainty, the flows have been mapped as one unit (Tvaf). These lava flows provide an area for further study.

The lava flow units are interlayered with volcanic conglomerate. The thickness of the flow remnants notably decreases from north to south. The thickest and best exposed flow is located on the south side of the hill (sections 5 and 6, NWR) in the drainage to Dog Valley Wash (figure 7). Here, a complete flow unit up to 200 feet (60 m) thick is apparent, with the base exposed at the creek bed and upper surface at the ridge crest. The flow exposures to the south are more difficult to map and describe because they are generally fractured and poorly exposed. Locally, the flow unit has fractures that are partially filled with white aragonitic masses. The larger masses have all been prospected and are discussed further under the Economic Resources section herein.

The vents for the lava flows are likely not far, and are probably to the north or northwest of the quadrangle's outcrops. No other similar lava flows are known to the north or northwest (Morris, 1977; Pampeyan, 1989). The source(s) may be buried under younger volcanic rocks of the East or

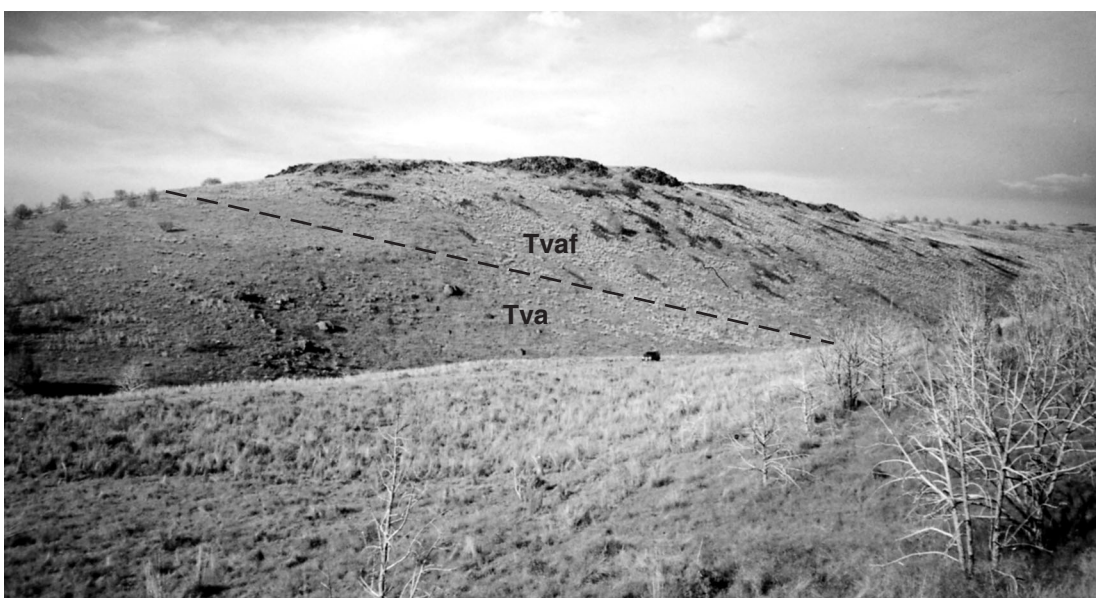

Figure 7. *View to the northeast in sections 5 and 6, NWR of the lava flow member (Tvaf) within volcanic conglomerate unit A (Tva). Vehicle near photo center for scale.*

West Tintic Mountains, or alluvium of Tintic Valley. Higgins (1982) mapped intrusions just to the west across Leamington Canyon. She described these intrusions as glass-rich porphyritic basalt sills within the Permian rocks. Meibos (1983) mapped lenses of apparent lava flow in the northern portion of the Sugarloaf quadrangle with a similar description to the lava flows in the Sage Valley quadrangle. He called this rock the Copperopolis Latite–Upper Flow Member in accordance with Morris' terminology.

Because the lava flow member is intercalated with volcanic conglomerate unit A, their ages are believed to be similar (late Eocene).

Tuff member (Tvat): There is one area southwest of the Sevier River (section 7, SWR) with two outcrops of a white to light pink ash-flow tuff unit on both sides of a drainage. The outcrops in this area have been mapped as Tertiary Volcanics by Christiansen (1952), as Packard and Fernow Quartz Latite by Campbell (1979), and as Goldens Ranch-Agglomerate by Pampeyan (1989). The rock contains phenocrysts of quartz and feldspar with minor biotite in a pale pink to white, fine-grained and possibly glassy matrix. The unit is moderately consolidated and crudely layered.

Nearly 100 feet (30 m) of the tuff member is exposed. The tuff is overlain by thin volcanic conglomerate and the tuff of Little Sage Valley (figure 6). The lower contact is not exposed. The unit appears to be located in the stratigraphic position of volcanic conglomerate unit A. The composition is similar to the lava flow member on TAS (figure 3, table 6), but its trace and minor element composition (table 7) differs from the lava flow member, indicating a different eruptive event. The age of the tuff member is believed to correspond with the volcanic conglomerate and associated lava flow member (late Eocene).

Tuff of Little Sage Valley (Tvs)

The tuff of Little Sage Valley is a mappable rock unit informally designated here for exposures located in and bordering Little Sage Valley. This unit was, in part, mapped by Higgins (1982) as grayish pink andesite crystal tuff. The tuff was differentiated from other extrusive rocks by de Vries (1990), who referred to it as a mafic tuff and biotite-rich tuff. This unit has previously been mapped with the Fernow Quartz Latite (Morris, 1977; Pampeyan, 1989) and Chicken Creek Tuff Member of the Goldens Ranch (Clark, 1990), and has been identified as Chicken Creek Tuff by Felger (in de Vries, 1990, p. 69). Delclos (1993) recognized that this rock differed from the Fernow Quartz Latite (p. 30, p. 108), but was relying on Pampeyan's reconnaissance mapping work. Difficulties in differentiating this tuff from other pyroclastic rocks have been due to lithologic similarities, and structural and stratigraphic relations.

The tuff of Little Sage Valley is of limited lateral extent, and is known to be present in portions of the Champlin Peak, Furner Ridge, Sage Valley, and Juab quadrangles. Exposures of this rock vary from poor to good, and are dependent on the degree of welding and other factors such as structure and topography. The tuff crops out as rounded ledges and knobs. The better exposures are along the western and southern margins of Little Sage Valley, and in the two relatively complete volcanic sections previously described. The unit conspicuously caps the southern portion of the ridge separating Little Sage Valley and Sevier Canyon (figure 6).

The tuff of Little Sage Valley is a grayish pink to light gray, poorly to moderately welded, dacitic, ash-flow tuff. There are phenocrysts of plagioclase, quartz, sanidine, and conspicuous biotite, but obvious pumice fragments are lacking. Whole-rock geochemistry from six samples indicates the tuff is a dacite (figures 3 and 4, table 6). Biotite compositions are discussed by de Vries and Delclos.

de Vries (1990) and Delclos (1993) presented rock and petrographic descriptions, although not referred to as the tuff of Little Sage Valley. Modal analyses of three samples are included in table 5. The general rock description provided by Higgins (1982) concurs with the tuff of Little Sage Valley; however, her petrographic description does not. There are differences in the two geologic maps, and my evaluation of the tuff outcrops along the map border indicated similar lithologies with Tvs.

Delclos (1993) described sample Fs17 (considered here to be Tvs) as a partially welded, crystal-rich, quartz-rich tuff. Major minerals include plagioclase (25%), quartz (20%), sanidine (15%), and biotite (10%), and minor minerals identified include clinopyroxene (1%), Fe-Ti oxides (1%), amphibole (1%), sphene (<1%), and apatite (<1%). Plagioclase was observed to be more abundant than quartz. Apatite was present as inclusions in biotite phenocrysts. The percentage of phenocrysts is about 10% higher than the Fernow. This rock contains a partially devitrified groundmass. Matrix alteration is present along microfractures and comprises approximately 10% to 15% of the groundmass.

Complete thicknesses of the unit are present in several locations in Sage Valley. A maximum of about 500 feet (150 m) exists in southern Little Sage Valley (section 4, SWR). In sections 11 and 12, NER, the formation is 225 feet (70 meters) thick, but appears to thin to the northeast toward 100 feet (30 m). On the east border (section 30, ECR) approximately 350 feet (90 m) is present. Higgins (1982) indicated a thickness up to 165 feet (50 m). Less than 20 feet (6 m) is present in a roadcut on Utah Highway 132 in the Furner Ridge quadrangle. The tuff of Little Sage Valley is seen between volcanic conglomerate units A and B in most locations. However, in Sevier Canyon, the tuff locally appears to lie unconformably on the red beds of Sevier Canyon (figure 6).

The vent for the tuff of Little Sage Valley is unknown. Like the Chicken Creek Tuff, based on its composition and location, it may have emanated from the East Tintics, from a local vent area that has subsequently been covered, or from a vent not yet identified.

Direct dating of the tuff was conducted during this study through $^{40}Ar/^{39}Ar$ on biotite. The tuff of Little Sage Valley provided an age of 37.43 ± 0.18 Ma (table 4 and appendix B), corresponding to the early Oligocene.

Volcanic conglomerate unit B (Tvb)

Volcanic conglomerate unit B is very similar to unit A below and unit C above. This rock unit consists of poorly consolidated, brownish gray- to moderate brown-weathering volcanic conglomerate and breccia, with dark gray to dark pink, angular to subrounded volcanic clasts, and minor carbonate and quartzite clasts. Otherwise, the lithology is similar to volcanic conglomerate unit A, and is not restated.

Unlike unit A where some consolidated outcrops are present, only unconsolidated exposures were observed. Unit B forms rubbly slopes and hills between the tuff of Little

Sage Valley and Fernow Quartz Latite. Complete thicknesses range from about 350 feet (110 m) thick in section 11, NER, to near 450 feet (140 m) on the east border (section 30, ECR).

Morris (1977) mapped an agglomerate unit overlying the Fernow Quartz Latite and referred to it as Copperopolis Latite–Middle Agglomerate Member. He described this unit as a massive boulder agglomerate composed of rounded clasts of dark-gray latite embedded in a matrix of tuff and volcanic gravel, equivalent to the lower part of the Golden's Ranch Formation of Muessig. As discussed by Hannah and Macbeth (1990) and observed by me, agglomerate also exists beneath the Fernow in the Furner Ridge quadrangle.

Unit B may be partly equivalent to Meibos' Cazier Canyon Agglomerate. Tvb may correlate with some of the volcaniclastic sediments unit in the Tintic Mountain quadrangle (Keith and others, in preparation). The age of unit B is constrained by the tuff units on either side, indicating an early Oligocene age.

Fernow Quartz Latite (Tvf)

This noticeable tuff unit was first referred to as the Fernow rhyolite (Tower and Smith, 1899) for exposures near Furner Canyon in the Tintic Mountain Quadrangle (shown as Fernow Canyon or Ferner Canyon on some maps). Morris (1957) later formally defined this rock unit as the Fernow Quartz Latite. Morris applied the Quartz Latite rock name due to the reported petrographic similarity to the Packard Quartz Latite of the northern East Tintics, although no published petrographic or geochemical data substantiated this conclusion. The Packard was referred to as a quartz latite by plotting normative quartz-orthoclase-albite+anorthsite using the classification of Johannsen (1932) (Morris and Lovering, 1979). Using the TAS classification scheme and current chemical modal data shows the Fernow is a rhyolite, but the "quartz latite" name is firmly entrenched.

The Fernow is an ash-flow sheet present over the southern portion of the East Tintic Mountains and southward to the Sage Valley area. Readily accessible exposures are present along Utah Highway 132 in the adjacent Furner Ridge quadrangle. In the Sage Valley quadrangle, the Fernow has been mapped in the northeast quadrant, between the Middle and East Forks of Sage Valley, in southern Little Sage Valley, and in limited exposures in Sevier Canyon. It is more welded than other tuffs, and outcrops as cliffs and large boulders (figure 8).

The Fernow is a conspicuous rock unit that has undergone more study than other rocks in the quadrangle. Morris (1957, 1975, 1977), Gutscher (1989), de Vries (1990), Hannah and MacBeth (1990), Delclos (1993), and Moore (1993) provided rock descriptions; de Vries, Delclos and Moore also provided petrographic descriptions. The Fernow Quartz Latite is light to medium gray, porphyritic, moderately to densely welded, rhyolitic ash-flow tuff. It is crystal-rich with about half of the rock consisting of phenocrysts of smoky bipyramidal quartz (~35%), plagioclase (~15%), sanidine (~10%), with lesser biotite (~5%) and amphibole (~1%). Minor constituents usually present include apatite, sphene, Fe-Ti oxides, and lithic fragments (<2%). The Fernow has a glassy groundmass, contains black to gray glassy fiamme forming a eutaxitic texture, and locally includes lapilli, and lithic inclusions up to block size. Modal analyses on four samples are included in table 5. Whole-rock geochemical analyses show the Fernow is a rhyolite (figures 3 and 4, table 6). In addition to the welded tuff, Morris (1975, 1977) mapped a basal air-fall unit of the Fernow, but this pyroclastic unit was not recognized in the map area.

Meibos (1983) and Moore (1993) discussed ash-flow tuff units referred to as the Fernow Quartz Latite. These tuffs along with the quartz latite of the West Tintics (Delclos, 1993) plot together on TAS (figures 3 and 4, table 6), with a lower alkali and higher silica content than the other Fernow samples. Yet, trace element plots (figure 5, table 7) show

Figure 8. *Exposure of Fernow Quartz Latite (Tvf) in section 11, NER. Rock hammer in left center of photo for scale.*

they group together reasonably well with the Fernow.

Chemical analyses of rhyolitic tuffs from the northern East Tintic Mountains (including the Packard Quartz Latite, quartz latite of Allens Ranch, and tuff of Chimney Rock) are similar to the Fernow in and near Sage Valley, and suggest that some of these tuffs may correlate with it (see Morris and Lovering, 1979; Keith and others, 1989; de Vries, 1990; Delclos, 1993, Moore, 1993). This geochemical data are not included on the TAS plots in the present study for the sake of clarity.

The Fernow is seen with volcanic conglomerate unit B below and unit C above in the quadrangle. Meibos (1983) mapped the tuff unit he called Fernow Quartz Latite directly on the Sage Valley Limestone. Rather than a flow directly overlying the limestone, I interpret Meibos' tuff exposure to be a lens of ash-flow tuff near the hilltop underlain by volcanic conglomerate and the Sage Valley Limestone (Hill 5934, SE$^1/_4$ section 24, T. 13 S., R. 2 W.).

The exposed thickness of the Fernow in the map area ranges from a maximum of 450 feet (140 m) in section 11, NER, to a minimum of 200 feet (60 m) at the west margin of Sage Valley (section 33, CR). The unit is likely thicker, but the 450-foot section is truncated by a fault. Other exposures are thinner, incomplete, and difficult to measure. To the north, Morris (1975, 1977) reported Fernow thicknesses of 0 to 1,500 feet (0-460 m).

Surprisingly, there has been little direct radiometric dating of the Fernow Quartz Latite (see table 4). The age of the Fernow was apparently first based on K-Ar ages of 32.7 ± 1.0 and 32.8 ± 1.0 Ma from the Packard Quartz Latite in the Eureka quadrangle (Laughlin and others, 1969). A K-Ar age of 33.8 ± 0.7 Ma is reported by Armstrong (1970) on the Leamington Tuff (location matches Fernow outcrop in Furner Ridge quadrangle), which was apparently overlooked by many. Dating of the Fernow appears to have been conducted (34.6 ± 0.2 Ma reported in abstract by Hannah and others, 1995), but the data were never published in a report and apparently are not available. Villien (1984) also reported a date on the Fernow from the Champlin Peak quadrangle (38.82 ± 1.92 Ma [sample number incorrect]), which is also not considered reliable as it is a whole-rock analysis.

In an effort to clarify the age of the Fernow, $^{40}Ar/^{39}Ar$ dating of a sample from the Sage Valley quadrangle was conducted; sanidine yielded an age of 34.83 ± 0.15 Ma, which agrees within error of a biotite age (table 4). Radiometric ages on the Fernow Quartz Latite and other rhyolitic tuffs are included in table 4.

The source of the Fernow has been elusive, and workers have pointed to the East Tintics and other locations as probable sources. Morris (1975), Gutscher (1989), and Hannah and Macbeth (1990) discussed evidence for a single "Tintic caldera" as the origin of East Tintic and outlying volcanics. With different viewpoints, Delclos (1993) suggested a source southwest of the Fernow outcrops, based on lateral chemical variations and lithologic evidence, and Stoeser (1993) reported the possibility that the Fernow could be outflow of a "Maple Peak caldera" in the West Tintic Mountains. These ideas are superseded by the more recent research of Keith and others (in preparation).

Keith and others (in preparation) discuss the existence of three distinct, nested calderas, extending into the Eureka, Furner Ridge and McIntyre quadrangles. The oldest caldera is associated with the eruption of the Fernow Quartz Latite; a subsequent caldera developed through eruption of the andesite of Rattlesnake Peak; the final caldera was created by the Copperopolis Latite Tuff eruption. The partial extent of the Fernow caldera is indicated by the outcrop pattern and a possible ring fault structure at the southwestern corner of the Tintic Mountain quadrangle (Jon King, oral communication, January 26, 2001). The northern extent of the Fernow caldera was destroyed by the eruption of the andesite of Rattlesnake Peak. The collapse of the Fernow caldera walls is indicated by the entrainment of blocks of Paleozoic rocks within the andesite flows. The proposed Fernow caldera is roughly centered on the Little Dog and Big Dog Canyon area in the south-central portion of the Tintic Mountain quadrangle. The Copperopolis Latite caldera is placed 1 to 2 miles (2-3 km) north of Morris' proposed caldera; the basis for this location is the distribution of several intrusive units, the contact of the Copperopolis Latite Tuff with andesite flows of Rattlesnake Peak, and differences in tuff thicknesses.

Morris (1975) believed that the Packard and Fernow Quartz Latites and lithologically equivalent units were formed from the initial eruptions of the Tintic caldera. The more distal correlative volcanic units included the tuffs of Chimney Rock Pass (northeastern East Tintics), lower units of the Moroni Formation, and "tuffs of Chicken Creek and Sage Valley in the Long Ridge area." The lens of tuff (called Fernow by Meibos, 1983) was placed above the revised Goldens Ranch Formation. Hannah and Macbeth (1990) hinted that the Fernow (and Packard?) could be younger than the Goldens Ranch Formation. Correlating outlying volcanic rocks to those in the central part of the East Tintic volcanic field has been challenging. The Fernow Quartz Latite is a key unit that can be traced from the bottom of the volcanic pile in the southern East Tintics to near the top of the volcanic section in Sage Valley. The stratigraphic relations established and radiometric ages acquired in this study show that the Fernow Quartz Latite is definitively younger than the three-member Goldens Ranch Formation.

The Fernow Quartz Latite has been tentatively correlated with rhyolitic tuffs in the East and West Tintic Mountains including the Packard Quartz Latite (Morris 1957, 1975), quartz latite of Allens Ranch (Hannah and Macbeth, 1990; Delclos, 1993), and rhyolitic welded tuff or quartz latite of the West Tintics (Stoeser, 1993; Delclos, 1993). Delclos concluded that the tuff of Chimney Rock and quartz latite of Cedar Valley were probably from small eruptions of the northern East Tintic Mountains or farther north, but did not discuss correlation with the Fernow. Based on paleomagnetic data obtained in the East Tintics, Gutscher (1989) concluded that the Fernow and Packard were probably not contemporaneous. The data further suggest correlation of his informal "Latite 2" (Delclos reports as quartz latite of Allens Ranch) with the Fernow.

To the east, the Moroni Formation could be temporally equivalent with the Fernow, but the pyroclastic units within the Moroni appear less likely to have been ejected from the same source as the Fernow. The relations of the Fernow Quartz Latite to the tuffs at the Skinner Peaks-Painted Rocks area in eastern Juab Valley are presently uncertain.

Volcanic conglomerate unit C (Tvc)

Volcanic conglomerate unit C is quite similar to the

underlying units B and A, so further detailed description is not warranted. The unit is mapped where it can be distinguished above the Fernow Quartz Latite in sections 2 (NCR), 8 (NWR), 33 and 28 (WCR, CR); there are no consolidated exposures. Up to approximately 400 feet (120 m) of unit C is present in Little Sage Valley. The exposures to the north are thinner. Unit C is also present along the East Fork of Sage Valley.

Morris reported a thickness of 0 to 1,000 feet (0-305 m) in Furner Ridge for the Copperopolis Latite–Middle Agglomerate Member, which is likely equivalent to units B and C. Unit C may also be partly equivalent to Meibos' Cazier Canyon Agglomerate. Tvc may correlate with the volcaniclastic sediments unit in the Tintic Mountain quadrangle (Keith and others, in preparation), which appears to overlie the Fernow and underlie the Latite Ridge Latite. There is possible correlation with the Middle Tuff Breccia Member of the Copperopolis Latite in the Slate Jack Canyon quadrangle (Jensen, 1984), north of the Sugarloaf quadrangle, originally mapped by Muessig as the Laguna latite series on Long Ridge.

Unit C is the youngest rock unit in the quadrangle, overlying the Fernow Quartz Latite (34.83 ± 0.15 Ma). In the East Tintic Mountains, the equivalent to unit C (volcaniclastic sediments) appears to underlie the Latite Ridge Latite (Keith and others, in preparation), with no published age.

Volcanic conglomerate unit undifferentiated (Tvu)

Determination of the specific volcanic conglomerate unit (A, B or C) present at certain locations is possible due to stratigraphic relations with other strata of the volcanic rocks of Sage Valley or Goldens Ranch Formation. However, at other locales, it is not possible to determine which conglomerate unit is present due to the lithologic similarity, unconsolidated nature of these units, and extent of normal faulting in the quadrangle. Therefore, these rocks have been mapped as volcanic conglomerate unit undifferentiated. Large areas of undifferentiated volcanic conglomerate have been mapped in the northern portion of the quadrangle and adjacent to the Sevier River. The thickness is not known with certainty, but may be up to 500 feet (150 m).

Tertiary and Quaternary

Much of the quadrangle consists of relative lowlands conducive to accumulating sediment; therefore, roughly half of the surface area of the Sage Valley quadrangle is covered with surficial deposits. These deposits have been divided into 15 units for mapping purposes based on morphology, lithology, and stratigraphic relations. The deposits have been grouped by depositional environment including: alluvial, deltaic and lacustrine, colluvial, mixed environment, mass movement, and human made. The surficial deposits range in age from Pliocene to Holocene. Many of the unit designations follow the work of Oviatt (1992).

Because the Sevier River capture hypothesis (Oviatt, 1992) has geomorphic implications for this region, it is summarized here. A different course for the Sevier River has been indicated by Costain (1960) and Oviatt (1987). This path would apparently have been eastward through Mills Gap and northward in Juab Valley. The possible diversion of the river to its present course, known as river capture, is attributed to growth of a large alluvial fan in Juab Valley (Four Mile Creek Fan) and headward erosion in Leamington Canyon. Oviatt (1992) presented an alternative hypothesis suggesting that the Sevier Canyon area has always been the outlet for the Sevier River. Lowering of base level would have lead to headward erosion in Leamington Canyon and associated downcutting of the Sevier River and Chicken Creek tributary.

Alluvial Deposits

Oldest alluvial-fan deposits (QTaf): The oldest alluvial-fan deposits form a broad surface of low relief (bajada) emanating from the Canyon Mountains and sloping toward the Sevier River. These fan gravels lie on a pediment (erosionally truncated bedrock surface), which is visible near the river. The fan material is coarse grained, poorly sorted, and derived from local rocks including Precambrian and Cambrian quartzite, Paleozoic carbonates, Cretaceous-Tertiary limestone and sandstone, and Eocene-Oligocene volcanics. Locally, the volcanics are abundant, as in section 6, WCR. Higgins (1982) mapped the adjacent area as post-Oligocene conglomerate (Tcv). QTaf is higher in elevation and more deeply incised than younger fan levels. The fan gravels are locally consolidated and possess a pink to light red color from an oxidized matrix, as in sections 17, 18, 19, 20, SWR. Consolidated ledges are seen a few feet or more below the fan surface.

Oviatt (1992) observed that QTaf has a stage IV calcic soil at its surface (indicating part of it is at least young as early Pleistocene). Also, about 0.85 mile (1.4 km) south of the southwest corner of the quadrangle (Oviatt's locality M), a lens of the Alturas volcanic ash was found within the fan gravels. This ash layer is approximately 4.8 million years old (early Pliocene). The age of QTaf is therefore thought to range from early Pliocene to early Pleistocene. In the map area, up to about 130 feet (40 m) of this oldest fan deposit is exposed; the total thickness is unknown.

At certain locations along the Sevier drainage (sections 6, 7, 17, 18, SWR), the distal portions of QTaf have been reworked by Lake Bonneville. However, because the former lake's shoreline is only locally preserved, and because of inadequate morphologic differences developed on the fan deposits above and below the shoreline, mixed alluvial and lacustrine deposits (if present) have not been mapped as a separate unit.

In addition to the QTaf surface emanating from the Canyon Mountains, there is a solitary mass of QTaf located at the unnamed canyon mouth in section 14, SER. As this fan straddles the border of four quadrangles, it has been previously mapped by Clark (1990), Felger (1991), and Hintze (1991a). Clark mapped this fan as Qaf_3, but the QT label appears more appropriate as it is highly dissected and may be faulted, although this is difficult to determine. The older fan material stands above the surrounding fan gravels mapped as Qaf_2, and contains an abundance of carbonate clasts, probably derived from the Flagstaff Limestone in the adjacent canyon. QTaf is thought to be at least 50 feet (15 m) thick at this location.

Valley-fill deposits (QTvf): Large expanses of coalesced alluvial fan and other alluvial materials have been mapped as

valley fill in the East and West Forks of Sage Valley, and southernmost Dog Valley. These deposits consist of poorly sorted, unconsolidated sediment (gravels to clays) forming broad, gently sloping surfaces. This alluvial debris grades to alluvial fans and alluvial deposits at valley margins, where it can be separated into various map units. The upper surfaces of QTvf overstep lacustrine, mixed lacustrine, and alluvial deposits in central Sage Valley, but a young fan surface (Qaf_1) spills over QTvf in the East Fork (SER). Some of the valley-fill surfaces have been cultivated.

The thickness of QTvf is not known, but Muessig (1951a) reported 400 feet (120 m) of surficial deposits in a drill hole in Sage Valley (section 12, SER). These alluvial deposits are Holocene at the surface and thought to range in age to late Tertiary, possibly Pliocene, at depth.

Sevier River sand and gravel deposits (QTas): There is a deposit of distinctive sand and gravel predominantly located in sections 17 and 20 (SWR). Oviatt (1992) referred to these deposits as Sevier River sand and gravel. This map unit contains well to moderately sorted sand and gravel; the gravel clasts are mostly pebbles of volcanic rocks, black chert, and sedimentary rocks derived from upstream in the Sevier River basin. The black chert is a distinguishing feature; its source is likely from the Crazy Hollow Formation (Grant Willis, oral communication, May 21, 2001), which is exposed in uplands adjacent to the Sevier Valley southward to near Richfield (Weiss and Warner, 2001).

QTas in the Sage Valley quadrangle is the northern extent of several deposits present in Mills Valley extending to Yuba Dam at the Sevier Bridge Reservoir. The sand and gravel deposits in the quadrangle lie on volcanic conglomerate bedrock (Tvu), and in addition, overlie and laterally interfinger with QTaf. Oviatt observed that QTas is also associated with fine-grained basin-fill deposits (mud and sand) to the south. The eastern and northern margins of the QTas outcrops have been cut by Lake Bonneville, and the resulting deposits have been mapped as a separate unit herein (Qlu). Hintze (1991a) mapped the exposure straddling the quadrangle border (section 20 and 21, SWR) as Qap (pediment alluvium), and justifiably so since truncated volcanic bedrock is near the surface. But, the relationship between QTaf and QTas in the map area indicates they are roughly of the same age – probably Pliocene to early Pleistocene. From map observations, the Sevier River sand and gravel in the quadrangle appears to be about 100 feet (30 m) thick.

Older alluvial-fan deposits (Qaf_2): Alluvial fan deposits, referred to as Qaf_2, appear to be intermediate in age between the oldest fans (QTaf) and youngest fans (Qaf_1). These deposits form a dissected surface through much of Little Sage Valley, into the West Fork and parts of the Middle and East Forks, extending toward Dog Valley Wash, and above the river in section 31, WCR. Qaf_2 is likely late Pleistocene to possibly Holocene in age. Like other fans, both fine and coarse sediments are included. These surfaces are higher in elevation and cut by numerous ephemeral stream channels indicating they are older than level 1 fans and the active upper surfaces of QTaf. In addition, in the West Fork, Qaf_1 is seen prograding over Qaf_2. The distal margins of level 2 fans can grade into QTaf and some were submerged in Pleistocene Lake Bonneville, whereas the headward margins often abut bedrock surfaces. Up to about 100 feet (30 m) of these older alluvial-fan deposits are exposed, but the total thickness is uncertain.

Younger alluvial-fan deposits (Qaf_1): The lowest and youngest level of fan deposits is called Qaf_1. These deposits are present as coalesced surfaces bordering the West Hills (SER) and emanating from the eastern margin of the West Fork. Solitary fans have also been mapped where they issue from drainages near the Middle Fork (ECR) and in Sevier Canyon. These Holocene alluvial fans are comprised of poorly sorted sand and gravel with finer material included, depending on the source. These level 1 fans overlap and merge into valley-fill deposits (QTvf), and mixed lacustine and alluvial deposits (Qadf). The younger fan deposits are estimated to be less than 100 feet (30 m) thick.

Stream alluvium (Qal): Stream alluvium is mapped along narrow to broad valley floors where modern stream channels incise upland bedrock and older alluvial, colluvial, and lacustrine sediments. The alluvium is unconsolidated, poorly sorted, clay- to boulder-size sediment. It is largely fine grained, but locally contains significant amounts of gravel. Qal is laterally gradational with QTvf and Qaf_1 in Sage and Dog Valleys, Qaf_1 and Qadf in Sevier Canyon, and Qc in some upland areas. This map unit can locally have a considerable slopewash component that could alternatively be mapped as mixed alluvium and colluvium. I chose to maintain the Qal designation throughout. The thickness is variable, and probably less than 20 feet (6 m) in most places, but may approach 100 feet (30 m) in Sage Valley. The age of the stream alluvium unit is late Pleistocene to Holocene.

Flood plain alluvium (Qafp): Alluvial deposits along the Holocene Sevier River have been mapped as a separate unit. Although they are similar in composition to Qal, the extent of the river's flood plain is readily mapped, and records the recent meanderings of the river (also see Oviatt, 1992). This feature is wide and flat to the south in Mills Valley, but narrows abruptly upon entering Sevier Canyon. The river cuts lacustrine and mixed lacustrine-alluvial deposits before entering the canyon, adding fine-grained materials to the sediment load. These fines may also contribute to the river's greenish color. The unit's total thickness is unknown, but up to 10 feet (3 m) of these deposits are exposed. Similar to Qal, Qafp is considered late Pleistocene to Holocene in age.

Deltaic and Lacustrine Deposits

Deltaic (Estuarine) fines (Qdf): Fine-grained deposits cover extensive areas in the central portion of Sage Valley (roughly 6 square miles [10 sq km]) and form scattered outcrops in Sevier Canyon. Large deposits of fine clastics incised by alluvium also lie north of the Sevier Bridge Reservoir forming The Washboard (Mills and Skinner Peaks quadrangles). These sediments are thought to have been deposited during the transgression of Lake Bonneville to its highest level and maximum lateral extent (known as the Bonneville Level) in an estuary that developed along the Sevier River Valley. From the main body of the lake that lay to the west, an estuary extended to the east and south through Leamington and Sevier Canyons, into Mills and Sevier Valleys to near Redmond. Related deposits are present as far south as Gunnison (Mattox, 1992). Oviatt (1992) referred to these deposits as deltaic (estuarine) fines and this terminology is retained herein. An upward-fining sequence of fine sand,

silt, and clay is recognized. Qdf is thinly to very thickly bedded and can possess a striped or layered appearance due to grain size and matrix color, which varies from shades of white, gray, yellow, and brown.

Other fine-grained deposits are present downstream along the Sevier River to west of the Canyon Mountains where a large delta complex developed at the mouth of the Sevier River (Oviatt, 1992). Hence, Oviatt used the deltaic depositional terminology. Estuary extensions to the east and south into portions of Juab Valley are reported based on appropriate elevation, but the presence of deltaic or lacustrine deposits is not easily discernable (Clark, 1990; Biek, 1991).

Oviatt based the age of Qdf in the Mills-Sage Valley area on: (1) stratigraphic relations and soil development, (2) amino-acid ratios of mollusk shells, and (3) the presence of the Pahvant Butte volcanic ash interbedded in Qdf. This information indicates an age of about 15,000 years before present (late Pleistocene). Dating of snail shells near Fayette by Mattox (1992) yielded a younger age, which is attributed to carbonate contamination.

Some patches of deltaic fines are only a few feet thick in Sevier Canyon, but the maximum exposed thickness is present where these deposits have been cut by the river (section 15, SCR). There, Qdf ranges to over 120 feet (35 m) thick; the total thickness is not known.

Lacustrine gravels (Qlg): A few deposits of lake gravels have been mapped. They are discerned on aerial photos by their bench-like shape and proximity to the Bonneville shoreline, more so than from inspection of their surfaces. These beach deposits are elongated parallel to and adjoining the shoreline, and contain well-sorted and rounded, sandy, pebble-size gravel composed of local rock materials. The best exposure is where the road on the border of sections 35 and 36 (ECR) passes through, and excavation has occurred. As with the deltaic fines, the lake gravels are of late Pleistocene age, and their thickness is probably less than 20 feet (6 m).

The Bonneville shoreline records the high stand of the lake, and has been mapped regionally by Gilbert (1890) and Currey (1982). Currey (1982) determined a shoreline elevation in central Sage Valley (his location 62) of 5,113 ± 7 feet (1,559 ± 2 m) from air photo and map interpretation. Oviatt (1992) stated that the highest level of the lake was about 5,115 feet (1,559 m). Portions of the Bonneville Level shoreline are shown on the map at an elevation near 5,115 feet (1,559 m) (plate 1). There does not appear to be any significant variation in the shoreline elevation across the quadrangle.

Undifferentiated lacustrine deposits (Qlu): This unit includes deposits southwest of the Sevier River where a thin mantle of surficial sediments overlie bedrock below the Bonneville shoreline. These deposits are comprised of gray, fine-grained and gravel sediments from local sources. The sediments appear to have been reworked by the lake and redeposited. Notably, pebbles of black chert are present, probably from reworking of QTas in the quadrangle or upstream. Qlu is relatively thin, likely less than 25 feet (8 m) thick. Because Qlu is associated with lacustrine deposition, it is considered to be late Pleistocene.

Qlu has been differentiated from Qla, which is comprised of an alluvial substrate. Sediments similar to Qlu and Qla are locally present at the margins of QTaf. However, because the shoreline cannot be continuously mapped and because of poor morphologic expression, it is difficult to segregate Qlu or Qla from the oldest alluvial fans, so these deposits have been included with QTaf.

Colluvial Deposits

Colluvial deposits (Qc): Several areas of slopewash deposits have been mapped as colluvium. These masses of material are typically developed on upland slopes adjacent to drainages. The unit consists of locally derived, intermixed clay- to boulder-size sediment. Clasts can be angular or subangular due to minimal transport. Qc is less than approximately 20 feet (6 m) thick, and is probably of late Pleistocene to Holocene age.

Mixed-Environment Deposits

Alluvial and delta-fine deposits (Qadf): Extensive areas of deltaic (estuarine) fines are located in central and southern Sage Valley and adjacent to the Sevier River flood plain. These fine-grained deposits have been incised and reworked by stream action. The deltaic fines and alluvial debris at the surface, present in and adjacent to the drainages, has been mapped as the mixed unit Qadf. These sediments are believed to have been deposited from the late Pleistocene to Holocene. The sediment is composed of poorly to moderatedly sorted, clay- to sand-size particles. The Lake Bonneville estuary also extended northward along Dog Valley Wash at the northwest corner of the map area. Although no Qdf is present at the surface in the northwest corner of the quadrangle, sediments exposed in the ephemeral stream cutbanks there appear to be a mix of alluvial and deltaic fines. Qadf is estimated to be less than 50 feet (15 m) thick.

Lacustrine and alluvial deposits (Qla): Undivided lacustrine and alluvial deposits are located below the Bonneville shoreline in Sevier Canyon and Sage Valley. This Pleistocene and Holocene unit consists of locally derived clay- to boulder-size sediment. These areas consist of pre-Lake Bonneville alluvial fans (level 2 and QTaf) that have been partly reworked by the lake. The fans retain their morphology, but surface modification by lake processes is evident on aerial photos and by field inspection. Subsequent stream downcutting has further modified these sediments. The thickness of these combined sediments appear to be less than 120 feet (35 m).

Mass-Movement Deposits

Landslide deposits (Qms): Due to the comparatively low relief of the area, there are few mass-movement deposits, but two similar landslide deposits have been mapped. They developed from poorly consolidated volcanic conglomerate units on steeper slopes. The larger one is located at the western margin of Sage Valley near the head of Sevier Canyon (section 9, SCR); the smaller one extends into Dog Valley Wash in section 6, NWR. The poorly sorted clay- to boulder-size debris from the adjacent uplands possess fan-shaped morphologies with hummocky surfaces. The landslide deposits have been dissected and eroded along their margins. The northern slide appears to have been cut by Lake Bon-

neville; it is difficult to discern if the lake reworked the southern slide. Because of these relations, these slides are thought to have developed in the Pleistocene, possibly extending into the Holocene. The landslide deposits are probably less than 100 feet (30 m) thick.

Human-placed Deposits

Artificial fill (Qf): Local earth materials have been used to construct dams for stockponds in Sage Valley and berms to divert drainages in Sevier Canyon. Although relatively small features, the fill material is mappable, with a thickness up to 20 feet (6 m).

STRUCTURE

The quadrangle is located in an area of overlapping structural elements in the eastern Great Basin geologic province, within the Sevier thrust belt, and along "Utah's hingeline" (Hintze, 1988). The structural complexity is largely concealed by Tertiary and Quaternary surficial deposits, and large masses of Tertiary conglomerate that typically poorly display bedding and faults. However, refinement of the stratigraphy has increased structural detail.

The area is presently a relative lowland, a structural graben (or fault valley), between the relatively high-standing and thrusted Canyon and Gilson Mountains (west) and West Hills horst (east). The following discussion proceeds from subsurface structure to surface structure.

Thrust Faults

Prior interpretations of the subsurface at the latitude of Sage Valley envisioned a stack of thrust sheets. Several thrust systems developed during the Sevier orogeny in central Utah, which occurred from the Late Cretaceous to Eocene (see, for example, Willis, 1999). At least 74 miles (120 km) of east-west shortening was accommodated by four major thrust systems (DeCelles and others, 1995). An eastward-breaking sequence of underlying thrusts has been recognized as follows. The Canyon Range thrust is the oldest and highest. It is present to the west in the Canyon Mountains, placing Cretaceous, Cambrian and Precambrian rocks over lower Paleozoic units (Lawton and others, 1997). The Pahvant thrust, carrying Devonian through Cambrian sedimentary strata over Jurassic-Triassic and Carboniferous sedimentary rocks, has been detected in seismic data underlying the Canyon Mountains (Lawton and others, 1997; Douglas Sprinkel, oral communication, May 21, 2001). Progressively younger and lower thrusts include the Paxton and Gunnison (Lawton and others, 1997). In addition, Morris (1983) mapped the Tintic Valley thrust in the Gilson and East Tintic Mountains, north of the Leamington Canyon fault. The Charleston-Nebo thrust is well expressed in the southern Wasatch Mountains near Nephi (Biek, 1991; Willis, 1999).

The eastward extent of the Pahvant thrust is not known with certainty. It has been placed near the longitude of the West Hills by various workers. There is little control under the surface cover of the western portion of the quadrangle to constrain the structure, but a thrust has been inferred to have propagated there in the Arapien Shale. The Arapien Shale, in particular, has acted as a fault–gathering unit in response to compressional deformation.

Seismic and drilling data in the eastern part of the quadrangle confirms the presence of a relatively high section of Jurassic through Permian rocks and a thrust fault. This thrust may extend eastward to the Placid Oil State #1 (southern West Hills), which penetrated a thrust fault and partly duplicated section of Jurassic strata (Sprinkel, 1982; Standlee, 1982).

The thrust fault in the State #2 may be offset by the Sage Valley fault. Several workers (including Villien and Kligfield, 1986; DeCelles and others, 1995) suggest the range-bounding Sage Valley fault is a west-dipping listric normal fault merging with a thrust surface. This may be similar to the possible character of the Wasatch fault, where it bounds the eastern margin of Juab Valley and the Great Basin (Zoback, 1983). This fault surface (the Sage Valley fault) appears to fit with the available subsurface data, and gravity data from Wang (1970).

The thrusts indicated on cross section A-A′ have not been named, because of the uncertainty of the relations and timing. It is possible that they are subsidiary to the primary thrusts described above. The relations of the thrusts indicated in Sage Valley to the two thrusts mapped by Meibos in the northern West Hills are not clear. Meibos (1983) labeled the southernmost thrust fault as the Nebo-Charleston on his cross section, but this terminology may not be appropriate for present-day use.

East of Sage and Scipio Valleys, the subsurface structure has been interpreted to consist of an imbricate fan involving blind thrusts and some extensional reactivation along older thrust surfaces merging with listric normal faults (Standlee, 1982; Villien and Kligfield, 1986; Mattox and Weiss, 1987).

Leamington Canyon Fault Zone

The thrust structure of the central Utah portion of the Sevier belt ends at a structural cross-strike discontinuity present in Leamington Canyon, which may best be referred to as the Leamington Canyon fault zone (Douglas Sprinkel, written communication, April 5, 2001). Costain (1960) and Higgins (1982) previously mapped this structural element as the Leamington Canyon fault. Morris (1983) referred to the Leamington Canyon fault as a transcurrent fault. Thrust plates with different hanging-wall stratigraphies and kinematic histories are located on either side of the discontinuity (Lawton and others, 1997).

The covered trace of the Leamington Canyon fault zone crosses the northwest portion of the map area (from section 13, NWR to section 4, NCR, trending about N. 80° E. over a distance of 3 miles [5 km]), as indicated by the adjacent mapping of Higgins (1982) and Morris (1977). There is no obvious surface evidence of the Leamington Canyon fault zone there, but the strike of normal faults in this area appear to be sub-parallel to the apparent trend of the fault zone, which may indicate breakage on prior zones of weakness.

According to Higgins (1982), the Leamington Canyon fault has a steep southward dip in Leamington Canyon. The discontinuity has recently been interpreted to be the near-vertically folded northward edge (or lateral ramp) of the Canyon Range thrust, and may be better explained as a fault zone rather than a single break (Lawton and others, 1997; Kwon

and Mitra, 2001). The age of this folded thrust edge is thought to be early Late Cretaceous (Lawton and others, 1997).

Folds

There is no obvious surface folding in the quadrangle; the bedding attitudes can be explained by tilting of fault blocks. In the West Hills segment, rock units strike to the north-northeast and dip east-southeast. In the northeast quadrant, the primary strike is to the north and northeast with dips to the west and northwest. Strata of the western half of the quadrangle are mainly trending north and northwest and dip east and northeast, with the exception of eastern Little Sage Valley with beds striking to the northeast and dipping northwest.

The outcrop pattern in southern Little Sage Valley initially suggests the existence of a gently north-plunging syncline, but detailed mapping points to relations associated with normal fault displacements. Cross-section construction indicates that the Tertiary strata comprising Little Sage Valley have a synclinal form, which could be attributed to paleotopography or folding. Folding might be accounted for by lateral movement on the Leamington Canyon fault zone subsequent to deposition of the volcanic rocks.

Meibos (1983) and Clark (1990) refer to an anticlinal structure in Tertiary rocks near the border of the Sugarloaf and Juab quadrangles. These attitudes are attributed to basin-and-range style faulting or salt tectonics, and considered post-Goldens Ranch in age.

There is an inferred fold in the subsurface of eastern Sage Valley. An anticlinal fold is interpreted to have developed on a thrust ramp. This thrust fault may be offset by the Sage Valley fault, considered to merge with a thrust and reactivated during the period of regional extension. The evidence for this fold is the relatively high Mesozoic and Paleozoic section encountered in Placid's State #2 drill hole and seismic data that lead to Placid's drilling investment. Seismic data were not available to me for review. Standlee (1982) noted that seismic data west of the San Pitch Mountains are uniformly poor. Wang's (1970) interpretation of his gravity data does not reveal the presence of this fold, but suggests that a west-dipping feature dominates the profile (considered here to likely be the Sage Valley fault). Bankey and Cook's (1989) bouger gravity data indicate a gravity low in central Sage Valley.

Other interpretations of the subsurface near this latitude (Villien and Kligfield, 1986; DeCelles and others, 1995) indicate a mass or eastward-thickening wedge of Cretaceous and Tertiary-Quaternary strata and deposits adjoining the range-bounding faults of the West Hills and Valley Mountains. This interpretation does not fit the data from the Placid State #2 well, which suggests that the Cretaceous and Tertiary section may thin over a structural high.

Irving Witkind, USGS retired, advanced the concept that large-scale salt diapirism was the primary cause of structural complexity in central Utah. He included the West Hills as a probable diapiric fold, one of the 12 he reportedly recognized (Witkind, 1983, 1994). Witkind (in Witkind and Weiss, 1991) cites the anticlinal configuration and presence of salt in the Placid - Howard #1A bore hole (southern portion of Sugarloaf quadrangle) as supporting evidence. Of the drill holes in the West Hills area, the Howard #1A has the thickest section of salt in the Jurassic Arapien Shale, about 550 feet (170 m), while others have much smaller amounts (Sprinkel, 1982; Standlee, 1982; Witkind and Weiss, 1991). Otherwise, there are no additional lines of evidence, as described by Witkind, supporting the presence of a diapiric fold.

Based on field relations, geophysical and subsurface data, the majority of geologists working in central Utah (myself included) believe that thrusting and block faulting with localized and limited evaporite diapirism have been the primary factors leading to the existing structural geometry. The diapir model does not explain the required shortening to produce structures observed, does not extrude through younger units, and major deformation has not been continuous since deposition of the Arapien Shale (Lawton and Weiss, 1999).

Normal Faults

Normal faults are the primary structural features observed at the surface of the quadrangle. The primary faults are discussed in two groups: (1) the Sage Valley fault system, and (2) Little Sage Valley-Canyon fault system. Subsidiary fault sets are also present.

Sage Valley Fault System

The Sage Valley fault system is comprised of the Sage Valley fault (named by Muessig, 1951a), and other faults referred to here as the East Fork fault, Middle Fork fault, and West Fork fault.

The Sage Valley fault in the quadrangle is the southward extension of the well-expressed down-to-the-west normal fault at the margin of Sage Valley and the West Hills in the Juab quadrangle. The Sage Valley fault is inferred to continue southward along the west side of a block of Flagstaff into the Mills quadrangle. It may also continue northward into Sugarloaf as the East Spring Canyon fault. There appears to be significant vertical displacement on the Sage Valley fault, likely on the order of 1,500 feet (460 m). As discussed above, the fault is an important structural feature interpreted as merging with a reactivated thrust surface.

The East and Middle Forks of Sage Valley are thought to be fault controlled. The drainages are quite linear (trending about N. 25° E.), nearly parallel to the West Hills horst, and different strata are juxtaposed across the drainages. The throw on these faults is much less than the Sage Valley fault, probably near 300 feet (90 m). These concealed faults extend several miles in the Sage Valley, Juab, and possibly Sugarloaf quadrangles. Their continuation on the south past the Sevier River is not known, and they were not mapped in the Mills quadrangle by Hintze (1991a).

The West Fork of Sage Valley is likely bounded on the east by a down-to-the-west normal fault. The West Fork fault strikes to the northwest and jogs to the south prior to the possible truncation by another inferred fault near the Middle Fork Sage Valley. There may be less separation on the West Fork fault farther to the northwest. The presence of this concealed fault is inferred from the relief, abrupt truncation of bedrock units, and active fan surface building into the valley. The valley block must have dropped at least 400 feet (120 m) to produce the existing topography. Map relations suggest that the West Fork fault predates the Middle Fork, East Fork,

and Sage Valley faults.

A concealed northwest-trending fault and the Sage Valley fault are inferred to have down-dropped the southern portion of Sage Valley (SER). The presence of the northwest fault is indicated by: (1) the lack of bedrock exposures in southern Sage Valley (SER), and (2) northwest-trending faults which break the West Hills cuesta near the southwest corner of the Juab quadrangle. The NW-trending fault is also assumed to be older than the NNE fault set.

Little Sage Valley-Canyon Fault System

Other prominent fault sets exist in Little Sage Valley and Sevier Canyon. These faults consist of three north-northwest-trending faults (the Canyon fault and two faults in Little Sage Valley), and a northeast-trending fault set on the south and east sides of Little Sage Valley.

The Canyon fault is one of the most recognizable faults in the project area with its associated fault valley, and was included as a lineament on the Lyndyll sheet (Pampeyan, 1989). The fault extends for a distance of 6 miles (10 km) from near the Sevier River to Dog Valley Wash and strikes roughly N. 10° W. The Goldens Ranch Formation and volcanic conglomerate unit A (Tva) are primarily dropped on the east against the conglomerate of West Fork Reservoir (Tcw), and the throw is not great, less than 400 feet (120 m). The fault loses its linearity northward, closer to Dog Valley Wash, as it is broken by numerous faults in the NWR.

Little Sage Valley contains two faults with a similar north-northwest orientation. The western floor of the valley is defined by a down-to-the-east normal fault that places Fernow Quartz Latite against the tuff of Little Sage Valley, with about 600 feet of vertical separation. This fault exists over a distance of 4.5 miles (7.5 km). The structure of Little Sage Valley is to a large extent due to an additional down-to-the-west fault located 0.4 mile (0.6 km) to the east. This fault is largely concealed beneath surficial deposits, but the attitude of the Fernow changes abruptly at the south end of the valley. The fault is thought to be 2 miles (3 km) long with vertical displacement near 400 feet (120 m). Map relations and cross section A-A′ indicate that these three north-northwest-oriented faults are high-angle.

The eastern and southern portions of Little Sage Valley are controlled by a set of northeast-striking normal faults. These faults may explain the existing structural configuration through faulting rather than folding. Fault blocks are dropped in both directions; however, the larger concealed faults are down-to-the-northwest and are inferred to extend into the West Fork of Sage Valley some distance. There is no evidence (field or geophysical) for a prominent fault bounding the western margin of Sage Valley.

The interpretation of the gravity line of Wang (1970) corresponds relatively well with the structural attitudes on cross section A-A′, except for the eastern portion, where the Sage Valley fault may dominate the profile. The horizontal gravity gradient data of Bankey and Cook (1989) appear to coincide with the Canyon fault.

Secondary Fault Systems and Faults

There are subsidiary sets of faults to the primary ones described above. These fault sets are not as extensive laterally and most have smaller throws, but retain similar approximate trends: N. 25° E., N. 45° W., N. 10° W., and N. 45° E. The northeastern portion of the quadrangle contains all four orientations, whereas the western part contains the north-northwest, northwest and northeast sets. The northeast-directed set is most obvious in the northwestern quadrant of the map area. The predominant fault sets of the West Hills are observed to be the north-northeast- and northeast-striking ones.

Determining the relative ages of the fault sets is not straightforward in this area. However, in general, the north-northeast- and northeast-trending fault sets appear to be younger than to the north-northwest- and northwest-oriented sets.

The normal faults mapped appear to be of the high-angle variety near the surface, as they cut across topography, and the juxtaposition of rock units indicates primarily vertical movement. These faults are thought to be planar to a depth near 6 miles (10 km), then changing to a listric character below (Douglas Sprinkel, written communication, April 5, 2001). Although unconformable surfaces have been recognized, they appear to represent hiatuses and none appear to exhibit an angular relationship indicating tectonic movement between placement of the involved rock units.

Locally in the quadrangle, the presence of good marker units (i.e., tuffs and limestones) has allowed for the mapping of a significant density of block faulting. The distribution of these markers requires the presence of faults. However, portions of the quadrangle contain masses of conglomerate and some other included units with virtually no exposed structural attitudes. It is a logical assumption that fault density in these areas would be similar to other portions of the quadrangle, but is not as readily discernable. I included some normal faults in these "structureless areas" based on the topography. Because their presence is uncertain, these faults have been mapped with dashed and/or queried symbols.

An alternative interpretation to the significant number of mapped faults is that paleotopography or stratigraphic relations of volcaniclastic rocks could also account for some of the field relations observed. These types of stratigraphic units can possess varying thicknesses and be affected by depositional or erosional discontinuities, with conformable contacts rather than fault contacts. Some examples include the Hall Canyon and Sage Valley Limestone Members of the Goldens Ranch Formation, and the lava flow member of volcanic conglomerate unit A. These units were observed to have variable thicknesses and are locally absent. However, the generally poor exposures make geologic interpretations within the quadrangle difficult.

Origin and Timing of Deformation

The structural deformation of rock units in the quadrangle appears to be associated with a compressional episode associated with the Sevier orogeny, and a later extensional regime referred to as basin-and-range style. Regional extension has been inferred to include reactivation of preexisting Sevier structural surfaces.

The period of compressional deformation lead to the thrust faults and folds observed in the region and interpreted in the subsurface of the map area. The timing of the Sevier-related deformation has been identified by prior studies in this region as extending from the early Cretaceous (Neoco-

mian) to Eocene (130 to 40 million years ago) (DeCelles and others, 1995; Willis, 1999).

The normal faults mapped cut all of the bedrock units present at the surface. One of the youngest dated rock units displaying offset, the Fernow Quartz Latite, is about 35 million years old. Although there are no apparent fault scarps in surficial deposits in the Sage Valley quadrangle, range-front morphology suggests that the Sage Valley fault may have Quaternary offset (Hecker, 1993), and new mapping here similarly suggests that the West Fork fault may have Quaternary offset. These faults were not shown by Bucknam and Anderson (1979). In addition, in Little Valley to the south (Mills quadrangle), Hintze (1991a) and Oviatt (1992) mapped normal faults offsetting the older alluvial fan surface (QTaf), shown to be early Pliocene (about 4.8 million years old), and younger Quaternary deposits. The onset of basin-and-range extension is reported as 17-14 million years old, or early to middle Miocene, and extensional tectonism has probably continued in the region to the present day (Hintze, 1988).

ECONOMIC GEOLOGY

The primary geologic resources within the quadrangle are sand and gravel, stone, and aragonite. There are also possibilities for metallic minerals and hydrocarbons.

Industrial Minerals and Rock

Sand and Gravel

There are several sources of sand and gravel in the map area. Sources such as Sevier River sand and gravel deposits (QTas) and lacustrine gravels (Qlg) would require less sorting and washing than the remaining alluvial and colluvial sources (QTvf, QTaf, Qaf_2, Qaf_1, Qal, Qc), but are not as voluminous. Sand is present in deltaic fines (Qdf) and alluvial and delta-fine deposits (Qadf), but would have to be separated from the larger fraction of fines.

Road gravel is actively removed from a pit in older alluvial-fan deposits (Qaf_2) in section 10, NCR. There is another gravel pit about 0.5 mile (0.8 km) to the north, which has not been used as recently. An exposure of Qlg is conveniently located (section 35, ECR) and has been excavated to provide sand and gravel for the road network as well (table 8).

Crushed Stone and Dimension Stone

Tuff in the Goldens Ranch Formation has been quarried in the Painted Rocks area (Hells Kitchen Canyon Southwest quadrangle) by the Azome Utah Mining Company. The tuff has been crushed and used as poultry grit, a soil mineralizer and conditioner, and domestic animal feed additive (Vogel, 1957; Pratt and Callaghan, 1970; Tripp, 1985). The Chicken Creek Tuff and less-welded exposures of the tuff of Little Sage Valley from the Sage Valley quadrangle could provide similar uses.

Carbonate rock of the Sage Valley Limestone and Flagstaff Limestone along with some of the volcanic rocks (Fernow Quartz Latite, tuff of Little Sage Valley) could also be crushed and used for aggregate. Cobbles and boulders from the poorly consolidated conglomerate units could be collected or removed, sorted and applied to a variety of uses. Some of the more indurated and thickly bedded rocks could be used for dimension stone and riprap, including the Fernow, tuff of Little Sage Valley, Sage Valley Limestone, and Flagstaff Limestone.

Cement Rock

The Sage Valley Limestone and Flagstaff Limestone might be candidates for cement production. However, their calcium carbonate content is not known and the surface volumes are limited in the map area. There are prospects in the Sage Valley Limestone in section 23, NER (table 8) that may have been tested by others.

Mineralized Rock

There are four areas in the western portion of the quadrangle containing masses of calcium carbonate (aragonite) as fracture- and vein-filling material (table 8). Two are indicated as quarries on the topographic map and the others are indicated by prospect symbols. No additional large masses were located during this mapping project. This material is of similar description to aragonite reported in a fault zone in the Green River Formation near Sterling (locality 8 of Pratt and Callaghan, 1970), which occurs "… principally as a white crystalline material filling thin fractures and lining cavities, concentric bands, mammilary forms, and massive, translucent, structureless material" (p. 52). The aragonite is thought to be used for poultry grit (Hellmut Doelling, oral communication, May 21, 2001), and has been used in Nephi as decorative stone and lapidary material. The prospecting and quarrying activities do not appear to be presently active. A claim marker in the north quarry refers to annual labor in 1998 for Little Gem 66 Nos. 1 and 2, UMB 143418-143419.

Prospecting for green amorphous mineralization was observed in the eastern portion of the quadrangle (sections 24 and 18, NER) in tuff and volcanic conglomerate (table 8). A sample from one of these pits was submitted for geochemical analysis (table 9). The results appear ordinary except for elevated chromium (309 ppm). The average concentration of chromium in rock is 100 ppm (Alloway, 1990). The mineralized zones appear to be secondary features (vein-fillings) and are very limited in extent at the ground surface.

There is a potential for metallic minerals associated with the mineralized zones described above. It is not known if these zones have been thoroughly tested. Stream-sediment sampling for geochemical analyses, as part of USGS' Delta CUSMAP work, did not include any data collection in the map area (Arbogast and others, 1990).

Hydrocarbons

Exploration for oil and natural gas through seismic surveys and drilling has taken place in the vicinity of the quadrangle. State records indicate that a wildcat well (the Sage Valley Oil Company 1) was drilled in Sage Valley (SE1/4NW1/4 section 12, T. 15 S., R. 2 W.) and plugged in 1947. According to Muessig (1951a), the hole encountered 400 feet (120 m) of alluvium followed by about 1,400 feet (430 m) of volcanics. A limestone was reportedly present at 1,795 feet (547 m) in depth, where drilling was terminated

with no shows or production.

In the late 1970s and early 1980s, Placid Oil Company and others conducted stratigraphic tests through drilling in and near the study area (Sprinkel, 1982). Placid Oil drilled a wildcat well in Sage Valley in 1980. The WXC-State #2 was located at SW$^1/_4$SW$^1/_4$ section 1, T. 15 S., R. 2 W. State records indicate that the well was a dry hole that reached a total depth of 13,509 feet (4,119 m) and encountered Jurassic through Permian strata and a thrust fault at depth (table 3). Shows of oil and gas were detected by Placid in the Howard #1 drill hole located in the adjacent Sugarloaf quadrangle (about 7.5 miles [12 km] north-northeast of the State #2 drill hole). Another hole (Howard #2) was advanced updip, but with no petroleum returns (Douglas Sprinkel, oral communication, May 21, 2001).

The subsurface work targeted the Nugget or Navajo Sandstone reservoir rock. The drilling in central Utah has yielded important stratigraphic data, but so far no economic reservoirs. The subsurface geology of this area of central Utah indicates the presence of structural relations similar to the producing overthrust belt of Wyoming and northern Utah.

WATER RESOURCES

The agricultural value and water rights are presently the most used resources of the quadrangle. The Sage Valley quadrangle is located in a semiarid desert region with average annual precipitation near 13 inches (33 cm). The quadrangle is crossed by the Sevier River and several intermittent streams. Surface drainage is primarily southward or westward to the river, except in the northern quarter of the map area where it first passes through Dog Valley and Dog Valley Wash before draining to the river at the junction of Sevier and Leamington Canyons.

The most recent research on water resources in the map area is a USGS study on this portion of the Sevier River basin (Bjorklund and Robinson, 1968). Data collected in the quadrangle in March 1963 (section 7, SWR) indicated that the river flow was 38.3 ft^3/s (108.5 l/s), and about 94 percent of the total flow was from ground-water discharge. Water-quality data were reported as follows: sodium and potassium (107 ppm), bicarbonate (296 ppm), carbonate (0 ppm), sulfate (166 ppm), chloride (184 ppm), hardness as $CaCO_3$ (442 ppm), noncarbonate hardness as $CaCO_3$ (199 ppm), sodium (35%), sodium adsorption ratio (2.2), specific conductance (1,290 micromhos per cm at 25°C), and pH (7.4).

USGS stream-flow data at Yuba Dam (about 14 river miles [23 km] upriver) indicate an annual mean flow ranging from a low of 94.2 ft^3/s (266.8 l/s) in 1961 to a high of 1,366 ft^3/s (3,869 l/s) in 1984. USGS also maintains water-quality data.

Several catchment basins have been constructed across ephemeral streams to collect sporadic precipitation and runoff for cattle and wildlife use. The largest of these basins is the West Fork Reservoir, indicated on the topographic map in section 15, NCR. Another relatively large catchment was recently constructed in section 25, ECR. The U.S. Bureau of Land Management (BLM) has water rights for stock watering on a portion of the Sevier River (Utah Division of Water Right's database).

Ground water occurs in unconsolidated deposits and rock units of the quadrangle. The principal aquifers exist in more permeable alluvial deposits; the bedrock units are generally not favorable for storing or transmitting water, except where fractures or solution features exist (Bjorklund and Robinson, 1968). Utah State water-well records indicate the water table is lower in elevation (depth increases) away from the Sevier River. While only a few to tens of feet deep in the immediate vicinity of the river, water is present at depths greater than 260 to 290 feet (80-90 m) in Sage Valley (section 35 and 36, ECR), and exceeds 455 feet (140 m) in southern Dog Valley (section 1, NER). Recharge areas are mainly at the valley margins and alluvial lowlands, and the Sevier River acts as both a recharge and discharge area depending on the stretch and climatic conditions.

Two water wells were observed in the field. The Placid Oil WXC-State #2 drill hole (section 1, SER) has been converted to a stock-water well. A well exists in section 18, NER and has a pump apparatus to lift water to an adjacent stock tank. Several wells are reportedly located near the Sevier River with depths from 60 to 300 feet (18-90 m) (Utah Division of Water Right's database). Well discharge rates and ground-water quality in the vicinity are discussed by Bjorklund and Robinson (1968). The principal uses for ground water in the quadrangle, in decreasing order of use, are stock watering, irrigation and domestic supply (Utah Division of Water Right's database).

No springs are indicated on the topographic map, and none were observed in the field. Three small springs, located just east of the quadrangle boundary (section 19, ECR) are directed to a stock tank located in the quadrangle.

GEOLOGIC HAZARDS

Although the Sage Valley quadrangle is largely undeveloped, geologic hazards associated with earthquakes, mass movements, problem soils and rocks, flooding, and radon are known in the quadrangle and the surrounding area. The discussion below identifies potential problem areas, but should not be used in place of site-specific investigations.

Earthquakes

The quadrangle lies within the Intermountain seismic belt, a zone of shallow seismicity that, in Utah, follows the boundary between the Basin and Range and the Colorado Plateaus and Middle Rocky Mountains physiographic provinces. The Intermountain seismic belt is roughly centered on the Wasatch and Hurricane fault zones (Christenson and others, 1987; Smith and Arabaz, 1991). The Wasatch fault zone is located 10 miles (16 km) to the east of the quadrangle. The Wasatch fault zone has documented Holocene movement, but has a general lack of associated strong historical seismicity (Christenson and others, 1987).

Records of earthquakes in the quadrangle have documented diffuse, small-magnitude ($M_L < 4.0$) events. The largest earthquake in the immediate vicinity is a 1963 magnitude 4.4 with an epicenter in western Juab Valley (Cook and Smith, 1967; Arabaz and others, 1980; McKee and Arabaz, 1982). To the west, seismicity tends to decrease in the Basin and Range (Christenson and others, 1987).

The quadrangle is located in the highest seismic risk zone in Utah (zone 3) (International Conference of Building Officials, 2000). The primary seismic hazards are associated with moderate- to large-magnitude earthquakes ($M_L > 4.0$); these hazards include ground shaking, surface fault rupture, slope failure, liquefaction, tectonic subsidence, and flooding (Christenson and others, 1987).

In the map area, there is a potential for damage from ground shaking to man-made structures including the overhead electrical transmission lines, natural gas line and fiber optic cable (Williams Energy), railway (Union Pacific), roadways, and water wells. Liquefaction could possibly be a concern in the Sevier River flood plain, composed of granular, saturated alluvial deposits.

Mass Movements

There is some possibility for the development of mass movements in the area, particularly where there are low-strength geologic materials in areas of greater topographic relief as in Sevier Canyon and Dog Valley Wash. Although there is no evidence of recent mass movement activity, two older landslide deposits have been mapped. Both developed on steeper slopes in poorly consolidated volcanic conglomerate strata. The southern slide at the head of Sevier Canyon covers roughly 120 acres (50 hectare), and the northern one in Dog Valley Wash is about 37 acres (15 hectare) in area. The area in Sevier Canyon between these two landslides offers the greatest risk for future movement because of the slope angles, exposures of poorly consolidated bedrock units, and limited vegetation. Mass movements may occur as landslides (slides, slumps and flows), debris flows, and/or rock falls.

Problem Soils and Rocks

Expansive soils and rocks contain clay minerals that swell conspicuously when wet and shrink upon drying. This expansion and contraction can cause difficulties with foundations, road beds, and can damage underground utilities (Mulvey, 1992). In the quadrangle, the deltaic fines (Qdf) and mixed alluvium-deltaic fines (Qadf) units mapped possess a high clay content and are susceptible to shrink-swell. The lake beds are notorious as seemingly bottomless dust or mud depending on the season. There could be problems for construction of roads and other structures on or within these units. There is a possibility that soils formed on some of the volcanic rock units may also be expansive. The condition of a portion of Interstate Highway 15, constructed in 1985 in the Juab quadrangle, may have been affected by expansive materials within the underlying Goldens Ranch Formation.

There is also the potential for hydrocompaction to occur in collapsible soils such as alluvial-fan deposits. Hydrocompaction occurs when soils are saturated for the first time since deposition, and causes subsidence (Mulvey, 1992).

Flooding

Flooding is of principal concern along the Sevier River. The river meanders greatly across a broad flood plain between Sage and Mills Valleys, and to a much lesser extent where the gradient increases through Sevier Canyon. Problems due to flooding there could affect the rail line with associated service road, and pasture land. The rail line crosses the river at three locations in the map area. The larger tributaries to the river in Sevier Canyon that have the potential to adversely impact the rail line through flow of water or debris, have been diverted by earthen berms and trenching. There is also potential for damage to the road network throughout the quadrangle during periods of increased runoff through erosion or debris flows. The possibility exists for flash floods in smaller drainages during cloudburst storms. The shallower water table near the Sevier River could possibly cause construction problems.

Radon

Radon is an odorless, tasteless, colorless, radioactive gas that is found in small concentrations in nearly all rocks and soil. Radon can become a health hazard when it accumulates in sufficient concentrations in enclosed spaces such as buildings. A variety of geologic and non-geologic factors combine to influence radon concentrations indoors; these include soils and rocks with naturally elevated levels of uranium, soil permeability, ground-water levels, atmospheric pressure, building materials and design, as well as other factors. Indoor-radon concentrations can differ dramatically within short distances due to both geologic and non-geologic factors.

The radon hazard has been depicted in only a general way for the Sage Valley quadrangle (Spinkel and Solomon, 1990; Black, 1993). These generalized maps, which should not be used in place of site-specific studies, show that the Sage Valley quadrangle has a moderate to high radon hazard potential. This hazard potential may be due to the possibility for elevated uranium concentrations in volcanic rocks. It should be noted that a quantitative relationship between geologic factors and indoor-radon levels does not exist, and that localized areas of higher or lower radon potential are likely to occur in any given area. Actual indoor-radon levels can vary widely over short distances, even between buildings on a single parcel of land.

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APPENDIX A

Table 1. *Summary of rock samples collected during the present study for laboratory analysis. Also refer to plate 1 for sample locations in the Sage Valley quadrangle. Analysis dates for argon dating not provided.*

Sample No.	Sample Date	Purpose	Rock Unit	Map Symbol	Quadrangle	Location	Latitude (N)	Longitude (W)	Analysis Date
S-16	5/26/98	Geochem	Lava flow	Tvaf	Sage Valley	SENWNW1/4 S19-T14S-R2W	39°35'15"	112°07'13"	7/28/98 & 7/30/98
S-3	5/17/98	Geochem	Chicken Creek Tuff		Skinner Peaks	NESWSE1/4 S19-T15S-R1W	39°29'12"	111°58'11"	12/21/99
S-19	6/13/99	Geochem	Chicken Creek Tuff	Tgc	Sage Valley	S18-T14S-R1W	39°35'57"	112°00'30"	12/21/99
S-24	6/15/99	Geochem	Fernow Quartz Latite	Tvf	Sage Valley	NENENW1/4 S11-T14S-R2W	39°37'08"	112o02'32"	12/21/99
S-26	6/15/99	Geochem	Tuff of Little Sage Valley	Tvs	Sage Valley	SWSESE1/4 S11-T14S-R2W	39°36'25"	112°02'12"	12/21/99
S-29	6/16/99	Geochem	Lava flow	Tvaf	Sage Valley	SW1/4 S5-T14S-R2W	39°39'13"	112°06'08"	12/21/99
S-33	6/17/99	Geochem	Tuff Member	Tvat	Sage Valley	NWNENE1/4 S7-T15S-R2W	39o31'51"	112°06'44"	12/21/99
S-34	6/18/99	Geochem	Meibos Fernow		Sugarloaf	SE1/4 S24-T13S-R2W	39°39'38"	111°59'20"	12/21/99
S-36	10/13/99	Geochem	Chicken Creek Tuff	Tgc	Sage Valley	SE1/4 S7-T14S-R2W	39°36'49"	112°07'05"	12/21/99
S-21	6/13/99	Geochem	Green Prospect		Sage Valley	S18-T14S-R1W	39°35'35"	112°00'07"	12/16/99
SV21701-1	2/17/01	Geochem	Chicken Creek Tuff	Tgc	Sage Valley	S18-T14S-R1W	39°35'36"	112°00'23"	3/12/01
SV21701-1	2/17/01	Dating	Chicken Creek Tuff	Tgc	Sage Valley	S18-T14S-R1W	39°35'36"	112°00'23"	
SV21701-2	2/17/01	Geochem	Tuff of Little Sage Valley	Tvs	Sage Valley	SWSESE1/4 S11-T14S-R2W	39°36'25"	112°02'13"	3/12/01
SV21701-2	2/17/01	Dating	Tuff of Little Sage Valley	Tvs	Sage Valley	SWSESE1/4 S11-T14S-R2W	39°36'25"	112°02'13"	
SV21701-3	2/17/01	Geochem	Fernow QL (base of unit)	Tvf	Sage Valley	SESWNE1/4 S11-T14S-R2W	39°36'50"	112°02'21"	3/12/01
SV21701-4	2/17/01	Geochem	Fernow Quartz Latite	Tvf	Sage Valley	SENWNWNE1/4 S11-T14S-R2W	39°37'07"	112°02'26"	3/12/01
SV21701-4	2/17/01	Dating	Fernow Quartz Latite	Tvf	Sage Valley	SENWNWNE1/4 S11-T14S-R2W	39°37'07"	112°02'26"	
S-38	5/21/01	Geochem	Lava flow	Tvaf	Sage Valley	NESW1/4 S5-T14S-R2W	39°37'25"	112°06'27"	8/27/01
S-39	5/22/01	Fossil Identification	Limestone in TKr	TKr	Sage Valley	SENWNE1/4 S7-T15S-R2W	39°31'47"	112°06'55"	1/3/02
S-40	5/22/01	Geochem	Volcanic clast in Cgl of WFR (bottom)	Tcw	Sage Valley	SWSE1/4 S31-T14S-R2W	39°32'59"	112°06'52"	8/27/01
S-40	5/22/01	Dating	Volcanic clast in Cgl of WFR (bottom)	Tcw	Sage Valley	SWSE1/4 S31-T14S-R2W	39°32'59"	112°06'52"	
S-41A	5/22/01	Geochem	Lava flow (top)	Tvaf	Sage Valley	NWNE1/4 S7-T14S-R2W	39°37'03"	112°06'52"	8/27/01
S-41B	5/22/01	Geochem	Lava flow (middle)	Tvaf	Sage Valley	NWNE1/4 S7-T14S-R2W	39°37'01"	112°06'54"	8/27/01
S-41C	5/22/01	Geochem	Lava flow (bottom)	Tvaf	Sage Valley	NENW1/4 S7-T14S-R2W	39°37'05"	112°07'03"	8/27/01

Table 2. *Summary of rock samples and locations collected by others for geochemistry, but referred to in this study. Rock sample data of de Vries (1990), Delclos (1993), Moore (1993) from unpublished M.S. theses. Some of the sample location data of de Vries and Delclos is limited in accuracy.*

Source	Sample No.	Rock Unit	Quadrangle	Location	Latitude (N)	Longitude (W)
de Vries	CCT-DC	Tuff of LSV	Juab	S19-T14S-R1W	39°34'39"	111°59'43"
de Vries	F-1	Tuff of LSV?	Furner Ridge	NE1/4 S31-T14S-R2W	~39°38'28"	~112°05'10"
de Vries	F-2	Welded Fernow	Furner Ridge	NE1/4 S31-T14S-R2W	~39°38'35"	~112°04'57"
de Vries	F-2-G	Fernow glass	Furner Ridge	NE1/4 S31-T14S-R2W	~39°38'35"	~112°04'57"
de Vries	F-3-Ga	Fernow glass	Furner Ridge	NE1/4 S31-T14S-R2W	~39°38'35"	~112°04'57"
de Vries	F-5	Air Fall Fernow	Furner Ridge	S19-T13S-R2W	~39°39'43"	~112°05'57"
de Vries	SVC	Meibos Fernow	Sugarloaf	NE1/4 S11-T14S-R2W	~39°39'38"	~111°59'19"
de Vries	CCT-1a	CCT-CCR	Skinner Peaks	SW1/4 S19-T15S-R1W	~39°29'20"	~111°58'30"
de Vries	CCT-1P	CCT-CCR Pumice	Skinner Peaks	SW1/4 S19-T15S-R1W	~39°29'20"	~111°58'30"
de Vries	CCT-1c	CCT-CCR	Skinner Peaks	SW1/4 S19-T15S-R1W	~39°29'20"	~111°58'30"
de Vries	CCT-3a	CCT-SV	Juab	S30-T14S-R1W	~39°34'12"	~111°59'42"
de Vries	PR-2	PR-Unit II	HKCSW	PRS ~209' above base		
de Vries	PR-2A	PR-Unit II	HKCSW	PRS ~209' above base		
de Vries	PR-4A	PR-Unit IV	HKCSW	PRS ~322' above base		
de Vries	PR-4B	PR-Unit IV	HKCSW	PRS ~359' above base		
de Vries	PR-4AP	PR-Unit IV	HKCSW	PRS ~322' above base		
de Vries	PR-4BN	PR-Unit IV	HKCSW	1/4 mile N of PRS		
de Vries	PR-5A	PR-Unit IV	HKCSW	PRS ~400' above base		
de Vries	PR-5AE	PR-Unit IV	HKCSW	1/4 mile E? of PRS		
de Vries	PR-5BE	PR-Unit IV	HKCSW	1/4 mile E? of PRS		
de Vries	PR-5BNP	PR-Unit IV	HKCSW	1/4 mile N of PRS		
de Vries	PR-5C	PR-Unit IV	HKCSW	PRS ~475' above base		
de Vries	PR-5CE	PR-Unit IV	HKCSW	1/4 mile E? of PRS		
de Vries	CCT-4A	Unknown Tuff	Skinner Peaks	NE1/4 S33-T16S-R1W	~39°22'36"	~111°55'28"
de Vries	CCT-4B	Unknown Tuff	Skinner Peaks	NE1/4 S33-T16S-R1W	~39°22'36"	~111°55'28"
de Vries	MH-1	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-1B	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-1C	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-2	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-3	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-3A	Moroni (hill area)	Moroni	SW1/4 S4-T15S-R3E		
de Vries	MH-4	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-4A	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-5A	Moroni (hill area)	Moroni	S3&4?-T15S-R3W		
de Vries	MH-5B	Moroni (hill area)	Moroni	SW1/4 S4-T15S-R3E		
de Vries	MH-6	Moroni (hill area)	Moroni	W1/2 S3-T15S-R3E		
de Vries	MC-4	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-3C	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-3B	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-3A	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-2C	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-2B	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-2A	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-1A	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	MC-1	Moroni (cliff area)	Moroni	S11 to 14?-T14S-R3E		
de Vries	SCD	Salt Creek dike	Fountain Green N.	SESWSW1/4-S28-T13S-R2E	39°44'29"	111°42'45"
Delclos	Fs3	Fernow	Furner Ridge	S19-T13S-R2W	39°39'41"	112°05'58"
Delclos	Fs6	Fernow	Furner Ridge	S33-T13S-R2W	39°38'26"	112°03'04"
Delclos	Fs7	Fernow	Furner Ridge	S33-T13S-R2W	39°38'15"	112°03'26"
Delclos	Fs9	Fernow	Furner Ridge	S18-T13S-R2W	39°40'39"	112°05'53"
Delclos	Fs10	Fernow	Tintic Mtn.	S24-T12S-R21/2W	39°45'52"	112°06'44"
Delclos	Fs11	Fernow	Tintic Mtn.	S24-T12S-R21/2W	39°45'48"	112°06'24"
Delclos	Fs12	Fernow	Furner Ridge	S29-T13S-R2W	39°39'23"	112°04'19"
Delclos	Fs13	Fernow	Furner Ridge	S20-T13S-R2W	39°39'24"	112°04'19"
Delclos	Fs14	Fernow	Furner Ridge	S29-T13S-R2W	39°39'24"	112°04'13"
Delclos	Fs15	Fernow	Furner Ridge	S19-T13S-R2W	39°39'39"	112°05'44"
Delclos	Fs17	Tuff of LSV	Sage Valley	S32-T14S-R2W	39°33'25"	112°06'19"
Delclos	Fs18	Tuff of LSV	Sage Valley	S32-T14S-R2W	39°33'25"	112°06'19"
Delclos	Fs19	Fernow?	Sage Valley	S32-T14S-R2W	39°33'29"	112°05'56"
Delclos	Fs20	Fernow?	Sage Valley	S32-T14S-R2W	39°33'37"	112°05'57"
Delclos	Fs21	Fernow?	Sage Valley	S29-T14S-R2W	39°33'46"	112°05'57"
Delclos	Fs22	Fernow	Sage Valley	S32-T14S-R2W	39°33'10"	112°05'52"
Delclos	Wts4	QL of W. Tintics	Sabie Mtn.	S5-T11S-R4W	39°53'44"	112°18'59"
Moore	TD45	Fernow	Tintic Mtn.	SW1/4 S13-T12S-R21/2W	39°45'37"	112°06'49"

HKCSW is Hells Kitchen Canyon SW
PRS is Painted Rocks Section
PRS Location: SW1/4 s. 32, T. 16 S., R. 1 W.
PRS begins at ~ 39°22' 14" (N), 111°57' 02" (W) and ends at ~ 39°22' 06" (N), 111°57' 29" (W), dip is 20° WSW
CCT is Chicken Creek Tuff
CCR is Chicken Creek Reservoir
LSV is Little Sage Valley

Table 3. *Simplified logs of exploratory drill holes in and near the Sage Valley quadrangle. Data from state records and Douglas Sprinkel.*

Operator	Well Name	Location	Ground Elevation (feet)	Formation Name	Drilled Depth (feet)	Elevation (feet)	Thickness (feet)
Placid Oil	WXC-State #2	SWSW1/4 s. 1, T. 15 S., R. 2 W. Sage Valley quadrangle	5,034	Valley fill	0	5,034	?
				(not logged)			
				Twin Creek	5,252	-218	1,395
				Navajo	6,647	-1,613	2,096
				Ankareh	8,743	-3,709	1,468
				Thaynes	10,211	-5,177	764
				Dinwoody-Woodside	10,975	-5,941	211
				Diamond Creek [& Park City]	11,186	-6,152	2,154
				Kirkman	13,340	-8,306	50
				thrust fault	13,390	-8,356	
				Navajo (Nugget)	13,390	-8,356	119
				T.D.	13,509	-8,475	
Placid Oil	WXC-State #1	NENW1/4 s. 36, T. 15 S., R. 1 1/2 W. Skinner Peaks quadrangle	5,173	Green River	0	5,173	300
				Colton, Flagstaff	?		
				North Horn	300?	4,873	1,703
				Price River	2,003	3,170	677
				Indianola	2,680	2,493	530
				Curtis (Cedar Mountain)	3,210	1,963	1,000
				Twist Gulch	4,210	963	640
				Arapien	4,850	323	2,018
				Twin Creek			
				Watton Canyon Mbr.	6,868	1,695	224
				Boundary Ridge Mbr.	7,092	-1,919	148
				Rich Mbr.	7,240	-2,067	250
				Slide Rock Mbr.	7,490	-2,317	320
				Gypsum Springs Mbr.	7,810	-2,637	285
				thrust fault	8,095	-2,922	
				Twist Gulch	8,095	-2,922	149
				Twin Creek			
			Arapien equivalents	Giraffe Creek Mbr.	8,244	-3,071	66
				Leeds Creek Mbr.	8,310	-3,137	3,346
				Watton Canyon Mbr.	11,656	-6,483	207
				Boundary Ridge Mbr.	11,863	-6,690	158
				Rich Mbr.	12,021	-6,848	255
				Slide Rock Mbr.	12,276	-7,103	299
				Gypsum Springs Mbr.	12,575	-7,402	343
				Navajo (Nugget)	12,918	-7,745	963 (976?)
				T.D.	13,881	-8,708	
					(13,894?)	(-8,721?)	

Table 4. *Summary of radiometric ages for volcanic rocks in the vicinity of Sage Valley. Refer to table 1 and plate 1 for locations of samples dated during present study. HKCSW is Hells Kitchen Canyon SW.*

Rock Unit	Map Symbol	Sample Number	Quadrangle	Mineral/ Method	Age (Ma)	Reference
Leucomonzonite sill		LE-Tlm	Levan	biotite/K-Ar	23.5 ± 1.0	Auby, 1991
Monzonite porphyry		Thmp-5	Levan	hornblende/K-Ar	23.3 ± 1.2	Auby, 1991
Monzonite porphyry		WP-481	Levan	biotite/K-Ar	23.8 ± 0.9	Witkind and Marvin, 1989
Leucomonzonite intrusion		WP-482	Levan	biotite/K-Ar	23.3 ± 0.8	Witkind and Marvin, 1989
Volcanic breccia		WP-468	Sugarloaf	plagioclase/K-Ar	34.8 ± 4.9	Witkind & Marvin, 1989
Stream laid volcanic detritus		WP-473	Furner Ridge	biotite/K-Ar	34.5 ± 1.0	Witkind & Marvin, 1989
Ash-flow tuff		WP-469	Furner Ridge	plagioclase/K-Ar	37.2 ± 2.3	Witkind & Marvin, 1989
		WP-469	Furner Ridge	biotite/K-Ar	38.8 ± 1.4	Witkind & Marvin, 1989
Rhyolitic ash-flow tuff		WP-480	Skinner Peaks	biotite/K-Ar	29.9 ± 1.1	Witkind & Marvin, 1989
Rhyolitic ash-flow tuff		WP-479	Skinner Peaks	biotite/K-Ar	34.9 ± 1.3	Witkind & Marvin, 1989
		WP-479	Skinner Peaks	sanidine/K-Ar	32.7 ± 1.2	Witkind & Marvin, 1989
Ash-flow tuff (Painted Rocks)		WP-381	HKCSW	biotite/K-Ar	34.3 ± 1.2	Witkind & Marvin, 1989
		WP-381	HKCSW	sanidine/K-Ar	33.3 ± 0.9	Witkind & Marvin, 1989
Moroni Fm. (volcanic breccia)		WP-461	Payson Lakes	plagioclase/K-Ar	32.8 ± 3.3	Witkind and Marvin, 1989
Moroni Fm. (ash-flow tuff)		WP-435	Birdseye	plagioclase/K-Ar	37.7 ± 2.4	Witkind and Marvin, 1989
		WP-435	Birdseye	hornblende/K-Ar	37.8 ± 2.2	Witkind and Marvin, 1989
Moroni Fm. (latite?)		WP-478	Fountain Green N.	biotite/K-Ar	33.6 ± 1.2	Witkind and Marvin, 1989
Moroni Fm. (ash-flow tuff)		WP-485	Moroni	biotite/K-Ar	35.4 ± 1.3	Witkind and Marvin, 1989
		WP-485	Moroni	sanidine/K-Ar	30.6 ± 1.1	Witkind and Marvin, 1989
		WP-485	Moroni	plagioclase/K-Ar	35.2 ± 2.2	Witkind and Marvin, 1989
Moroni Fm. (ash-flow tuff)		WP-433	Moroni	biotite/K-Ar	35.2 ± 1.3	Witkind and Marvin, 1989
Moroni Fm. (ash-flow tuff)		99-3-2	Moroni	biotite/Ar-Ar	34.3 ± 0.1	Albrecht, 2001
Salt Creek dike		FGN-1	Fountain Green N.	biotite/K-Ar	33.6 ± 1.4	Banks, 1991
Salt Creek dike		WP-475	Fountain Green N.	biotite/K-Ar	36.0 ± 1.3	Witkind and Marvin, 1989
Rhyolitic tuff		SP192	Soldiers Pass	sanidine/Ar-Ar	34.18 ± 0.24	Moore, 1993
Rhyolitic tuff		SP292	Soldiers Pass	biotite/Ar-Ar	34.71 ± 0.19	Moore, 1993
Rhyolitic welded tuff		?	Maple Peak	biotite/Ar-Ar	34.6 ± 0.1	Stoeser, 1993 (Snee)
		?	Maple Peak	sanidine/Ar-Ar	34.4 ± 0.05	Stoeser, 1993 (Snee)
Packard Quartz Latite		TAD-6-67	Eureka	biotite/K-Ar	32.8 ± 1.0	Laughlin et al, 1969
		TAD-6-67	Eureka	sanidine/K-Ar	32.7 ± 1.0	Laughlin et al, 1969
		?	unknown	?/Ar-Ar	35.2 ± 0.1	Hannah, Stein & Snee, 1995
Fernow Quartz Latite		172B	Furner Ridge	biotite/K-Ar	33.8 ± 0.7	Armstrong, 1970 (Mackin)
		GM 131	Champlin Peak	whole rock	38.82 ± 1.92	Villien, 1984
		?	Furner Ridge	?/Ar-Ar	34.6 ± 0.2	Hannah, Stein & Snee, 1995
	Tvf	SV-4	Sage Valley	sanidine/Ar-Ar	34.83 ± 0.15	present study
Tuff of Little Sage Valley	Tvs	SV-2	Sage Valley	biotite/Ar-Ar	37.43 ± 0.18	present study
Chicken Creek Tuff		KA 837	Skinner Peaks	biotite/K-Ar	33.2	Everenden & James, 1964
		171	Skinner Peaks	biotite/K-Ar	35.8 ± 0.7	Armstrong, 1970 (Mackin)
		WP-421	Skinner Peaks	plagioclase/K-Ar	32.0 ± 4.9	Witkind & Marvin, 1989
		WP-421	Skinner Peaks	biotite/K-Ar	38.5 ± 1.4	Witkind & Marvin, 1989
		WP-422	Sage Valley	sanidine/K-Ar	30.9 ± 0.7	Witkind & Marvin, 1989
		WP-422	Sage Valley	biotite/K-Ar	33.6 ± 1.2	Witkind & Marvin, 1989
	Tgc	SV-1	Sage Valley	biotite/Ar-Ar	38.61 ± 0.13	present study
Conglomerate of West Fork Reservoir	Tcw	S-40	Sage Valley	groundmass/Ar-Ar	35.72 ± 0.61 (age suspect)	present study

Table 5. *Modal analyses for selected rock units. Refer to table 2 for sources of data. Proportions are calculated on the basis of 100% and represent 500 point counts; tr=trace, np=not present.*

Sample No.	Map Unit	Ground-mass	Plagioclase	Sanidine	Quartz	Biotite	Hornblende	Clino-pyroxene	Fe-Ti Oxides	Sphene	Zircon	Apatite	Lithics	Glass Shards	Pumice
F-5	Tvf	50.8	23.0	tr	12.8	2.6	tr		tr	tr	tr	tr	tr	tr	8.6
F-2	Tvf	52.4	17.6	tr	18.6	1.2	1.8		tr	tr	np	np	1.6	4.4	2.2
Fs10	Tvf	36.4	11.0	7.2	36.8	5.7	1.0	np	3.0	0.5		tr	1.0		
Fs7	Tvf	35.7	12.8	9.3	35.3	5.8	tr	np	3.1	tr		tr	1.5		
Fs17	Tvs	27.0	28.1	3.7	16.2	12.3	2.3	2.3	5.6	1.8		tr	2.5		
CCT-DC	Tvs	45.6	24.2	8.2	tr	6.8	8.8		1.6	np	tr	tr	tr	3.2	tr
F-1	Tvs?	53.6	16.2	tr	tr	10.4	tr		2.4	tr	np	np	3.0	13.0	1.4
CCT-1a	Tgc	50.8	18.0	2.6	tr	tr	tr		1.4	np	tr	tr	1.0	13.8	13.4
CCT-1c	Tgc	37.6	19.0	np	np	2.8	np		tr	np	tr	tr	1.0	23.2	21.0
CCT-3a	Tgc	40.6	21.0	tr	tr	3.4	tr		tr	np	tr	tr	7.0	15.2	16.4
CCT-4a	Unknown tuff	61.0	12.2	2.2	tr	2.8	np		1.8	np	tr	tr	5.4	8.0	6.2
PR-2a	PR-Unit II	64.4	8.0	15.6	11.0	1.0	tr		tr	tr	tr	tr	tr	np	np
PR-4a	PR-Unit IV	72.8	1.8	tr	1.0	1.6	1.0		1.0	tr	np	tr	3.2	13.8	4.8
PR-5c	PR-Unit IV	40.0	4.0	1.8	np	1.6	tr		tr	tr	tr	tr	1.0	15.4	35.4

Table 6. *Whole rock geochemical data (major elements) for volcanic rocks in the vicinity of Sage Valley. Data include samples from the present study and from deVries (1990), Delclos (1993), and Moore (1993). Analyses for UGS by Chemex Labs in Sparks, Nevada. Results in weight percent. Data is not normalized to 100 percent. HKCSW is Hells Kitchen Canyon SW*

Source	Quadrangle	Rock Unit	Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O_3	LOI	Total %
Clark	Skinner Peaks	Tgc	S-3	62.58	0.55	15.35	4.02	0.04	1.41	3.37	1.92	3.27	0.14	< 0.01	6.39	99.04
Clark	Sage Valley	Tvaf	S-16	61.69	0.84	16.09	5.28	0.09	2.22	4.87	3.13	3.63	0.25	< 0.01	1.53	99.62
Clark	Sage Valley	Tgc	S-19	64.27	0.53	14.99	3.53	0.03	0.96	3.92	2.27	3.78	0.16	< 0.01	4.83	99.27
Clark	Sage Valley	Tvf	S-24	70.68	0.25	13.95	1.89	0.07	0.54	2.07	3.34	4.54	0.07	< 0.01	1.68	99.08
Clark	Sage Valley	Tvs	S-26	61.64	0.66	13.44	5.04	1.49	1.55	5.19	2.75	3.20	0.23	< 0.01	3.42	98.61
Clark	Sage Valley	Tvaf	S-29	56.64	0.82	17.10	7.38	0.19	1.41	5.84	3.45	3.42	0.64	< 0.01	2.02	98.91
Clark	Sage Valley	Tvat	S-33	61.07	0.47	9.49	3.44	0.05	6.09	9.82	1.05	5.6	0.10	< 0.01	1.83	99.01
Clark	Sugarloaf	Meibos Fernow	S-34	74.06	0.23	11.84	1.72	0.04	0.27	2.04	2.76	4.31	0.07	< 0.01	1.85	99.19
Clark	Sage Valley	Tgc	S-36	63.24	0.57	15.88	3.99	0.03	0.90	3.75	2.50	3.50	0.17	< 0.01	4.51	99.04
Clark	Sage Valley	Tgc	SV-1	64.27	0.55	14.93	3.71	0.04	0.96	3.33	2.13	3.34	0.13	0.01	5.38	98.78
Clark	Sage Valley	Tvs	SV-2	61.56	0.75	15.27	5.67	0.07	1.68	4.83	3.07	3.46	0.23	0.01	1.87	98.47
Clark	Sage Valley	Tvf	SV-3	67.77	0.26	14.04	2.06	0.07	0.85	2.82	2.87	4.40	0.10	0.02	3.72	98.98
Clark	Sage Valley	Tvf	SV-4	71.34	0.26	14.34	1.95	0.06	0.49	1.80	3.22	4.31	0.07	0.01	1.30	99.15
Clark	Sage Valley	Tvaf (N)	S-38	56.58	0.82	16.81	7.39	0.19	2.25	6.17	3.40	7.39	0.62	< 0.01	2.27	99.61
Clark	Sage Valley	Tcw clast	S-40	58.17	0.87	15.93	6.31	0.11	3.09	5.67	2.88	6.31	0.27	< 0.01	2.32	99.10
Clark	Sage Valley	Tvaf (top)	S-41A	60.67	0.88	16.21	5.26	0.07	2.09	4.73	3.04	5.26	0.27	< 0.01	1.39	98.39
Clark	Sage Valley	Tvaf (middle)	S-41B	61.37	0.84	16.04	4.46	0.05	0.75	5.16	3.22	4.46	0.26	< 0.01	2.58	98.56
Clark	Sage Valley	Tvaf (bottom)	S-41C	61.08	0.94	16.45	4.44	0.04	0.51	5.77	3.08	4.44	0.25	< 0.01	3.45	99.75
de Vries	Juab	Tuff LSV	CCT-DC	60.55	0.73	16.30	5.49	0.09	2.67	5.18	2.94	2.52	0.22			96.69
de Vries	Furner Ridge	Tuff LSV?	F-1	62.46	0.70	15.29	5.00	0.09	2.07	4.16	2.78	3.52	0.18			96.25
de Vries	Furner Ridge	Welded Fernow	F-2	70.21	0.26	14.21	1.61	0.07	0.62	2.16	3.15	4.62	0.09			97.00
de Vries	Furner Ridge	Fernow glass	F-2-G	67.76	0.30	15.39	1.74	0.10	0.48	1.90	3.16	5.17	0.08			96.08
de Vries	Furner Ridge	Fernow glass	F-3-Ga	67.55	0.32	15.57	1.73	0.10	0.50	1.97	3.33	5.21	0.10			96.38
de Vries	Furner Ridge	Air Fall Fernow	F-5	70.30	0.25	14.37	1.44	0.04	0.86	2.09	2.97	4.14	0.06			96.52
de Vries	Sugarloaf	Meibos Fernow	SVC	76.77	0.21	11.44	1.31	0.02	0.31	1.41	2.67	3.92	0.05			98.11
de Vries	Skinner Peaks	CCT-CCR	CCT-1a	63.06	0.56	15.87	3.65	0.04	1.57	3.49	2.09	3.31	0.15			93.79
de Vries	Skinner Peaks	CCT-CCR Pumice	CCT-1P	68.36	0.36	12.7	2.47	0.04	1.28	2.29	1.52	2.16	0.05			91.23
de Vries	Skinner Peaks	CCT-CCR	CCT-1c	64.65	0.55	16.16	3.41	0.03	1.50	3.31	2.10	3.40	0.13			95.24
de Vries	Juab	CCT-SV	CCT-3a	64.46	0.54	15.36	3.50	0.03	0.96	3.33	2.18	3.71	0.09			94.16
de Vries	HKCSW	PR-Unit II	PR-2	72.7	0.22	13.2	1.44	0.05	0.46	1.61	2.97	4.91	0.05			97.61
de Vries	HKCSW	PR-Unit II	PR-2A	74.6	0.20	11.6	1.3	0.03	0.32	1.39	2.78	4.13	0.02			96.37
de Vries	HKCSW	PR-Unit IV	PR-4A	56.7	0.2	11.9	1.34	0.05	0.74	1.17	1.98	5.06	0.03			79.17
de Vries	HKCSW	PR-Unit IV	PR-4B	68.5	0.23	13.3	1.42	0.05	1.22	1.62	2.11	5.03	0.05			93.53
de Vries	HKCSW	PR-Unit IV	PR-4AP	71	0.22	13	1.28	0.06	0.71	1.03	2.05	5.42	0.03			94.80
de Vries	HKCSW	PR-Unit IV	PR-4BN	70.8	0.21	13	1.29	0.05	0.78	1.12	1.98	5.44	0.03			94.70
de Vries	HKCSW	PR-Unit IV	PR-5A	71.1	0.23	12.9	1.31	0.04	0.61	1.67	2.17	5.66	0.03			95.72
de Vries	HKCSW	PR-Unit IV	PR-5AE	70	0.24	12.4	1.36	0.04	0.55	1.17	1.97	5.49	0.03			93.25
de Vries	HKCSW	PR-Unit IV	PR-5BE	69.9	0.22	12.3	1.22	0.04	0.53	1.39	2.07	5.62	0.03			93.32
de Vries	HKCSW	PR-Unit IV	PR-5BNP	72.4	0.19	13	1.02	0.04	0.52	0.89	1.98	6.05	0.02			96.12

Table 6. *(continued)*

Source	Quadrangle	Rock Unit	Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O_3	LOI	Total %
de Vries	HKCSW	PR-Unit IV	PR-5C	70.6	0.24	13	1.2	0.04	0.51	1.15	2.24	5.85	0.02			94.85
de Vries	HKCSW	PR-Unit IV	PR-5CE	72.7	0.20	13.1	1	0.04	0.52	0.91	1.98	5.89	0.02			96.35
de Vries	Skinner Peaks	Unknown Tuff	CCT-4A	67.81	0.45	14.4	2.8	0.02	0.84	2.48	1.48	5.91	0.1			96.29
de Vries	Skinner Peaks	Unknown Tuff	CCT-4B	70.71	0.42	13.09	2.33	0.03	0.62	2.83	1.33	5.04	0.01			96.41
de Vries	Moroni	Moroni (hill)	MH-1	71.01	0.2	13.44	1.01	0.06	0.61	1.72	2.39	5.44	0.04			95.92
de Vries	Moroni	Moroni (hill)	MH-1B	67.3	0.3	14.2	1.91	0.06	0.87	1.96	2.97	4.63	0.06			94.26
de Vries	Moroni	Moroni (hill)	MH-1C	66.3	0.32	14.5	2.27	0.08	1.14	2.24	2.8	4.59	0.07			94.31
de Vries	Moroni	Moroni (hill)	MH-2	71.24	0.22	13.59	1.27	0.07	0.6	1.29	2.43	5.85	0.03			96.59
de Vries	Moroni	Moroni (hill)	MH-3	71.44	0.21	13.87	1.29	0.07	0.53	1.24	2.57	5.68	0.03			96.93
de Vries	Moroni	Moroni (hill)	MH-3A	71.25	0.2	13.53	1.16	0.07	0.62	1.31	2.61	5.36	0.07			96.18
de Vries	Moroni	Moroni (hill)	MH-4	69.67	0.22	14.23	1.13	0.07	0.65	1.72	2.46	5.37	0.05			95.57
de Vries	Moroni	Moroni (hill)	MH-4A	71.7	0.19	12.5	1.16	0.06	0.36	1.16	2.69	5.4	0.03			95.25
de Vries	Moroni	Moroni (hill)	MH-5A	70.45	0.19	12.96	1.06	0.06	0.61	1.92	2.57	5.28	0.03			95.13
de Vries	Moroni	Moroni (hill)	MH-5B	71	0.21	13.12	1.23	0.06	0.72	1.99	2.61	5.19	0.05			96.18
de Vries	Moroni	Moroni (hill)	MH-6	71.8	0.21	13.1	1.08	0.04	0.6	1.23	2.61	5.26	0.03			95.96
de Vries	Moroni	Moroni (cliff)	MC-4	69.55	0.21	14.22	1.23	0.07	0.87	1.4	2.43	5.21	0.03			95.22
de Vries	Moroni	Moroni (cliff)	MC-3C	71.11	0.22	13.54	1.18	0.06	0.44	1.35	3.11	4.88	0.01			95.9
de Vries	Moroni	Moroni (cliff)	MC-3B	71.75	0.22	13.8	1.2	0.05	0.56	1.41	3.06	4.78	0.07			96.9
de Vries	Moroni	Moroni (cliff)	MC-3A	72.62	0.21	13.57	1.24	0.06	0.38	1.32	3.2	5.07	0.05			97.72
de Vries	Moroni	Moroni (cliff)	MC-2C	72.14	0.21	13.4	1.19	0.07	0.4	1.32	3.22	4.99	0.04			96.98
de Vries	Moroni	Moroni (cliff)	MC-2B	72.34	0.21	13.44	1.2	0.07	0.38	1.32	3.2	5.1	0.03			97.29
de Vries	Moroni	Moroni (cliff)	MC-2A	72.4	0.21	13.47	1.14	0.06	0.35	1.33	3.32	4.86	0.03			97.18
de Vries	Moroni	Moroni (cliff)	MC-1A	71.6	0.09	12	1.09	0.05	0.37	1.28	2.75	5.33	0.04			94.6
de Vries	Moroni	Moroni (cliff)	MC-1	73.47	0.2	13.48	1.16	0.07	0.38	1.22	3.27	5.31	0.03			98.59
de Vries	F. Green North	Salt Creek dike	SCD	62.2	0.74	15.5	3.76	0.06	0.74	2.08	3.57	5.83	0.25			94.73
Delclos	Furner Ridge	Fernow	Fs3	70.87	0.24	14.09	1.70	0.05	1.02	2.92	2.91	4.21	0.07			98.09
Delclos	Furner Ridge	Fernow	Fs6	68.93	0.28	14.28	1.93	0.05	0.70	2.14	3.65	4.57	0.09			96.61
Delclos	Furner Ridge	Fernow	Fs7	69.44	0.28	14.74	1.85	0.07	0.62	2.22	3.73	5.08	0.08			98.10
Delclos	Furner Ridge	Fernow	Fs9	67.03	0.25	13.94	1.83	0.05	0.89	2.2	3.34	4.13	0.07			93.74
Delclos	Tintic Mtn.	Fernow	Fs10	72.31	0.27	13.62	1.35	0.03	0.55	1.77	3.35	4.71	0.08			98.04
Delclos	Tintic Mtn.	Fernow	Fs11	70.98	0.29	13.20	2.02	0.05	0.53	1.75	3.32	4.47	0.08			96.69
Delclos	Furner Ridge	Fernow	Fs12	68.43	0.30	15.87	2.05	0.07	1.17	2.51	3.44	4.33	0.08			98.25
Delclos	Furner Ridge	Fernow	Fs13	70.62	0.30	14.89	2.15	0.06	0.80	2.29	3.75	4.65	0.09			99.60
Delclos	Furner Ridge	Fernow	Fs14	67.60	0.29	15.26	1.95	0.07	1.12	2.50	3.22	4.46	0.08			96.54
Delclos	Furner Ridge	Fernow	Fs15	74.29	0.27	14.58	1.89	0.05	1.06	2.34	3.12	4.38	0.08			102.06
Delclos	Sage Valley	Tuff of LSV	Fs17	61.20	0.74	15.41	5.63	0.07	1.98	5.15	3.12	3.31	0.24			96.84
Delclos	Sage Valley	Tuff of LSV	Fs18	62.23	0.77	15.61	5.8	0.09	1.94	5.79	3.16	3.51	0.25			99.15
Delclos	Sage Valley	Fernow?	Fs19	68.00	0.25	14.20	1.81	0.07	0.65	3.31	3.46	5.18	0.09			97.01
Delclos	Sage Valley	Fernow?	Fs20	66.66	0.24	14.68	1.74	0.06	0.61	2.24	3.54	5.51	0.08			95.36
Delclos	Sage Valley	Fernow?	Fs21	67.67	0.26	15.17	1.88	0.07	0.6	2.12	3.57	5.66	0.08			97.07
Delclos	Sage Valley	Fernow	Fs22	69.18	0.30	15.57	2.11	0.08	0.97	2.46	3.59	4.80	0.09			99.15
Delclos	Sabie Mtn.	QL of W. Tintics	Wts4	77.39	0.21	11.06	1.24	0.04	0.53	1.45	2.08	4.92	0.10			99.02
Moore	Tintic Mtn.	Fernow	TD45	75.96	0.24	11.98	1.24	0.02	0.29	1.23	2.59	4.27	0.05		0.90	98.80

Table 7. *Whole rock geochemical data (trace elements) for volcanic rocks in the vicinity of Sage Valley.*
Data include samples from the present study and from deVries (1990), Delclos (1993), and Moore (1993).
Analyses for UGS by Chemex Labs in Sparks, Nevada.
Results in parts per million (ppm).
HKCSW is Hells Kitchen Canyon SW

Source	Quadrangle	Rock Unit	Sample No.	Ba	Ce	Cs	Co	Cu	Dy	Er	Eu	Gd	Ga	Hf	Ho	La	Pb	Lu	Nd	Ni
Clark	Skinner Peaks	Tgc	S-3	732	124.5	3.1	8	5	4.4	2.3	1.6	6.4	22	8	0.8	66.5	20	0.3	47.0	5
Clark	Sage Valley	Tvaf	S-16	1010	124.5	4.8	13.5	35	4.9	2.6	1.5	6.6	21	6	0.9	65.5	30	0.4	47.0	10
Clark	Sage Valley	Tgc	S-19	1250	118	7.4	5.5	5	3.9	2.2	1.5	5.7	21	8	0.8	62.5	30	0.3	42.5	5
Clark	Sage Valley	Tvf	S-24	713	73.5	6.8	3	<5	2.8	1.9	1	3.5	17	4	0.6	38	30	0.3	26.5	<5
Clark	Sage Valley	Tvs	S-26	1865	97.5	1.1	38	40	4.1	2.2	1.6	5.8	21	6	0.7	50.5	15	0.3	39.0	15
Clark	Sage Valley	Tvaf	S-29	862	132.5	2.1	10.5	<5	6.9	3.3	3.4	11.6	24	10	1.3	58	15	0.4	69.5	<5
Clark	Sage Valley	Tvat	S-33	1250	47	1.3	3.5	470	3.4	2.2	0.9	3.9	13	6	0.7	30.5	25	0.3	24.0	30
Clark	Sugarloaf	Meibos Fernow	S-34	574	57.5	6.4	3	<5	2.1	1.2	0.8	3	15	3	0.5	30	25	0.2	20.5	<5
Clark	Sage Valley	Tgc	S-36	1100	121	10.6	5	<5	4.4	2.2	1.8	6.2	23	8	0.8	63.5	25	0.3	45.0	5
Clark	Sage Valley	Tgc	SV-1	1240	111.0	7.1	6.0	<5	3.7	2.2	1.5	5.4	17	6	0.7	49.0	15	0.2	38.5	5
Clark	Sage Valley	Tvs	SV-2	786	102.5	1.0	13.0	15	4.3	2.6	1.6	6.5	18	6	0.9	44.5	15	0.2	41.0	5
Clark	Sage Valley	Tvf	SV-3	600	67.0	14.6	2.5	<5	2.7	1.9	0.9	3.5	13	2	0.5	29.5	15	0.2	24.0	<5
Clark	Sage Valley	Tvf	SV-4	573	61.0	6.4	3.0	<5	2.4	1.7	0.7	3.1	14	2	0.5	26.5	20	0.1	21.5	<5
Clark	Sage Valley	Tvaf	S-38	868	125.0	2.5	8.5	5	6.6	3.2	2.8	10.7	22	9	1.2	53.5	10	0.5	66.0	<5
Clark	Sage Valley	Tcw clast	S-40	1365	124.0	2.5	15.5	20	5.1	2.5	1.8	6.9	20	6	0.9	65.0	20	0.4	50.0	15
Clark	Sage Valley	Tvaf (top)	S-41A	1050	122.0	5.3	8.5	15	5.1	2.3	1.4	6.9	20	7	1.0	62.5	20	0.3	47.5	5
Clark	Sage Valley	Tvaf (middle)	S-41B	1020	120.5	5.0	12.5	15	5.4	2.5	1.6	7.1	21	7	1.0	63.0	20	0.3	45.0	40
Clark	Sage Valley	Tvaf (bottom)	S-41C	994	129.5	5.7	6.0	10	5.5	2.9	1.6	6.8	21	7	1.0	66.0	20	0.3	50.5	5
deVries	Juab	Tuff of LSV	CCT-DC	936			44	12												
deVries	Furner Ridge	Tuff of LSV?	F-1	850			37	12												
deVries	Furner Ridge	Welded Fernow	F-2	777			54	7												
deVries	Furner Ridge	Fernow glass	F-2-G	1326			126	3												
deVries	Furner Ridge	Fernow glass	F-3-Ga	1291			0	4												
deVries	Furner Ridge	Air Fall Fernow	F-5	726			55	5												
deVries	Sugarloaf	Meibos Fernow	SVC	568			78	5												
deVries	Skinner Peaks	CCT-Res	CCT-1a	1199			54	9												
deVries	Skinner Peaks	CCT Res Pumice	CCT-1P	7353			50	11												
deVries	Skinner Peaks	CCT-Res	CCT-1c	1277			40	10												
deVries	Juab	CCT-SV	CCT-3a	1039			39	10												
deVries	HKCSW	PR-Unit II	PR-2	660																
deVries	HKCSW	PR-Unit II	PR-2A	544																
deVries	HKCSW	PR-Unit IV	PR-4A	860																
deVries	HKCSW	PR-Unit IV	PR-4B	730																
deVries	HKCSW	PR-Unit IV	PR-4AP	765																
deVries	HKCSW	PR-Unit IV	PR-4BN	770																
deVries	HKCSW	PR-Unit IV	PR-5A	958																
deVries	HKCSW	PR-Unit IV	PR-5AE	901																
deVries	HKCSW	PR-Unit IV	PR-5BE	998																

Table 7. (continued)

Source	Quadrangle	Rock Unit	Sample No.	Ba	Ce	Cs	Co	Cu	Dy	Er	Eu	Gd	Ga	Hf	Ho	La	Pb	Lu	Nd	Ni
deVries	HKCSW	PR-Unit IV	PR-5BNP	823																
deVries	HKCSW	PR-Unit IV	PR-5C	1066																
deVries	HKCSW	PR-Unit IV	PR-5CE	922																
deVries	Skinner Peaks	Unknown Tuff	CCT-4A	685			25	7												
deVries	Skinner Peaks	Unknown Tuff	CCT-4B	838			24	8												
de Vries	Moroni	Moroni (hill)	MH-1	823			22	7												
de Vries	Moroni	Moroni (hill)	MH-1B	662			0	0												
de Vries	Moroni	Moroni (hill)	MH-1C	1141			0	0												
de Vries	Moroni	Moroni (hill)	MH-2	874			26	8												
de Vries	Moroni	Moroni (hill)	MH-3	882			28	9												
de Vries	Moroni	Moroni (hill)	MH-3A	938			27	7												
de Vries	Moroni	Moroni (hill)	MH-4	866			16	6												
de Vries	Moroni	Moroni (hill)	MH-4A	894			0	0												
de Vries	Moroni	Moroni (hill)	MH-5A	801			24	8												
de Vries	Moroni	Moroni (hill)	MH-5B	802			35	7												
de Vries	Moroni	Moroni (hill)	MH-6	878			0	0												
de Vries	Moroni	Moroni (cliff)	MC-4	1021			25	11												
de Vries	Moroni	Moroni (cliff)	MC-3C	1022			36	5												
de Vries	Moroni	Moroni (cliff)	MC-3B	1031			27	6												
de Vries	Moroni	Moroni (cliff)	MC-3A	934			38	5												
de Vries	Moroni	Moroni (cliff)	MC-2C	953			37	4												
de Vries	Moroni	Moroni (cliff)	MC-2B	901			34	5												
de Vries	Moroni	Moroni (cliff)	MC-2A	926			35	8												
de Vries	Moroni	Moroni (cliff)	MC-1A	988			0	0												
de Vries	Moroni	Moroni (cliff)	MC-1	935			22	5												
de Vries	F. Green North	Salt Creek dike	SCD	1387			0	0												
Delclos	Furner Ridge	Fernow	Fs3	683.3																
Delclos	Furner Ridge	Fernow	Fs6	701.3																
Delclos	Furner Ridge	Fernow	Fs7	679.2																
Delclos	Furner Ridge	Fernow	Fs9	635.2																
Delclos	Tintic Mtn.	Fernow	Fs10	587.3																
Delclos	Tintic Mtn.	Fernow	Fs11	478.2																
Delclos	Furner Ridge	Fernow	Fs12	823.8																
Delclos	Furner Ridge	Fernow	Fs13	627.9																
Delclos	Furner Ridge	Fernow	Fs14	720.9																
Delclos	Furner Ridge	Fernow	Fs15	657.5																
Delclos	Sage Valley	Tuff of LSV	Fs17	872.4																
Delclos	Sage Valley	Tuff of LSV	Fs18	935.3																
Delclos	Sage Valley	Fernow?	Fs19	787																
Delclos	Sage Valley	Fernow?	Fs20	766.2																
Delclos	Sage Valley	Fernow?	Fs21	808.4																
Delclos	Sage Valley	Fernow	Fs22	739																
Delclos	Sabie Mtn.	QL of W. Tintics	Wts4	824.1																
Moore	Tintic Mtn.	Fernow	TD45	577	46			3					12			23	30		20.0	9

Table 7. (continued)

Sample No.	Nb	Pr	Rb	Sm	Ag	Sr	Ta	Tb	Tl	Th	Tm	Sn	W	U	V	Yb	Y	Zn	Zr	Sc	Cr
S-3	18	13.4	104.5	7.5	<1	570	0.5	0.9	<0.5	23	0.3	<1	1	3.5	70	2.3	21.0	50	271		
S-16	15	13.1	134.0	7.6	<1	536	1.5	1.0	<0.5	13	0.3	2	1	4.5	115	2.4	28.0	90	243		
S-19	18	12.6	133.5	6.4	<1	512	0.5	0.8	<0.5	23	0.3	<1	1	5	65	2.1	21.0	50	272		
S-24	16	7.8	151.0	4.1	1	265	1	0.6	0.5	23	0.3	<1	2	6.5	25	1.8	17.0	30	119.5		
S-26	11	11.1	95.4	6.2	<1	579	<0.5	0.8	3	19	0.3	<1	3	4.5	130	2	19.5	65	203		
S-29	17	17.4	103.0	13.8	<1	1090	0.5	1.5	<0.5	8	0.5	<1	2	2	65	3.2	34.0	115	329		
S-33	11	6.6	131.0	4.3	<1	121.5	<0.5	0.6	0.5	9	0.3	<1	1	3.5	80	2	21.0	80	191		
S-34	14	6.2	164.0	3.3	<1	206	0.5	0.5	<0.5	21	0.2	<1	1	3.5	25	1.2	13.0	25	105		
S-36	18	12.9	150.0	6.7	<1	582	0.5	0.9	<0.5	21	0.3	<1	1	5	65	2.2	21.5	50	275		
SV-1	16	11.4	130.0	6.2	<1	494	<0.5	0.7	<0.5	17	0.2	<1	<1	4	55	2.1	20.0	55	281		
SV-2	12	11.5	106.0	7.3	<1	603	<0.5	0.9	<0.5	18	0.3	1	<1	3.5	100	2.4	24.0	65	260		
SV-3	14	7.1	197.5	3.8	<1	260	<0.5	0.5	<0.5	18	0.1	<1	1	7.5	15	2.1	18.0	20	120.5		
SV-4	15	6.5	155.0	3.7	<1	248	<0.5	0.4	0.5	18	0.1	<1	1	6.5	5	1.7	15.5	25	114.0		
S-38	17	16.5	91.4	12.2	<1	1010	0.5	1.5	<0.5	7	0.5	2	1	1.0	60	3.2	32.5	235	336		
S-40	15	13.2	119.0	8.6	<1	605	0.5	1.0	0.5	16	0.4	3	1	2.0	125	2.5	26.0	155	238		
S-41A	14	13.4	129.5	7.2	<1	494	1.0	1.0	<0.5	18	0.4	3	2	3.5	100	2.3	23.5	135	257		
S-41B	15	13.5	130.0	8.5	3	491	1.0	0.9	0.5	18	0.4	3	2	3.5	95	2.4	25.0	130	253		
S-41C	15	14.2	129.0	8.6	<1	498	1.0	1.0	<0.5	19	0.4	3	2	4.0	110	2.2	25.5	140	275		
CCT-DC	16		92			639									120		22	70	182	13	
F-1	16		111			548									100		25	60	193	13	
F-2	21		172			261									23		18	35	125	4	
F-2-G	20		139			430									11		24	65	323	6	
F-3-Ga	14		140			424									11		23	64	345	4	
F-5	20		150			247									30		16	33	99	3	
SVC	19		153			180									25		13	19	93	2	
CCT-1a	22		102			537									64		23	49	267	10	
CCT-1P	17		82			391									49		9	32	191	8	
CCT-1c	20		117			565									71		22	55	257	9	
CCT-3a	23		137			469									67		23	54	265	12	
PR-2						222									27				99	4	
PR-2A						184									23				78	2	
PR-4A						157									12				98	3	
PR-4B						237									24				130	3	
PR-4AP						160									27				125	3	
PR-4BN						155									15				130	4	
PR-5A						201									8				140	2	
PR-5AE						231									26				140	3	
PR-5BE						184									1				132	1	
PR-5BNP						136									14				117	3	
PR-5C						201									18				152	3	
PR-5CE						188									17				131	2	
CCT-4A	20		159			344									54		21	47	249	12	
CCT-4B	20		125			384									47		15	34	218	10	

Table 7. (continued)

Sample No.	Nb	Pr	Rb	Sm	Ag	Sr	Ta	Tb	Tl	Th	Tm	Sn	W	U	V	Yb	Y	Zn	Zr	Sc	Cr
MH-1	17		175			183									20		16	33	131	5	
MH-1B	0		0			269									27		0	0	140	5	
MH-1C	0		0			261									42		0	0	147	5	
MH-2	18		189			176									17		18	32	133	3	
MH-3	18		185			183									15		17	33	137	5	
MH-3A	18		169			189									22		16	33	133	2	
MH-4	19		162			183									21		17	36	137	3	
MH-4A	0		0			213									24		0	0	114	3	
MH-5A	16		165			183									21		13	29	118	6	
MH-5B	17		170			197									21		15	28	125	2	
MH-6	0		0			163									14		0	0	131	2	
MC-4	19		173			204									22		19	34	143	0	
MC-3C	17		170			187									19		18	34	129	2	
MC-3B	17		171			199									22		17	33	134	4	
MC-3A	18		186			189									22		16	30	135	3	
MC-2C	20		186			186									20		14	34	130	3	
MC-2B	18		179			176									18		15	32	127	5	
MC-2A	17		183			179									20		16	34	138	3	
MC-1A	0		0			224									8		0	0	111	3	
MC-1	17		180			175									27		15	31	127	5	
SCD	0		0			439									44		0	0	431	8	
Fs3						274.4									25		14		104.7	4	8
Fs6						269.6									28		20		148.2	4.6	11
Fs7						252.8									26		18		101.2	4.3	6
Fs9						248.1									24		17		100.2	4	8
Fs10						208.2									20		16		119.2	3.9	3
Fs11						196.2									25		19		104.6	4.3	6
Fs12						313.9									25		18		142.3	5	14
Fs13						257									28		19		131.7	4.8	8
Fs14						296.2									25		20		129.5	5	10
Fs15						260.5									25		17		109.3	4.1	16
Fs17						608.9									118		21		216.1	13.2	35
Fs18						612.5									125		22		174.1	13.8	41
Fs19						282.9									25		18		106.4	4.4	12
Fs20						269.2									22		16		100.5	3.8	8
Fs21						269.3									24		19		114.8	4.1	8
Fs22						296.6									27		23		137	5.1	11
Wts4						145.2									18		12		87.02	2.7	68
TD45	16		152.0			200				24				8	17		13.0	18	115		2

Table 8. Summary of selected geologic resources of the Sage Valley quadrangle. Data from UGS Energy and Minerals Program files and present study.

Deposit Name	Location	Commodity
Little Sage Valley SW Quarry	S32-T14S-R2W S5-T15S-R2W	Limestone
Unknown Prospects	S4-T15S-R2W	Limestone
Little Sage Valley NW Quarry (Little Gem 66 #1&2)	S19-T14S-R2W	Limestone
Morning Star Claims	S7-T14S-R2W	Limestone
Unknown Prospects	S24-T14S-R2W	Green mineral
Unknown Prospect	S18-T14S-R2W	Green mineral
Unknown Prospect	S23-T14S-R2W	Limestone
West Fork Quarries	S10-T14S-R2W	Road fill
Unknown Quarry	S35-T14S-R2W	Gravel

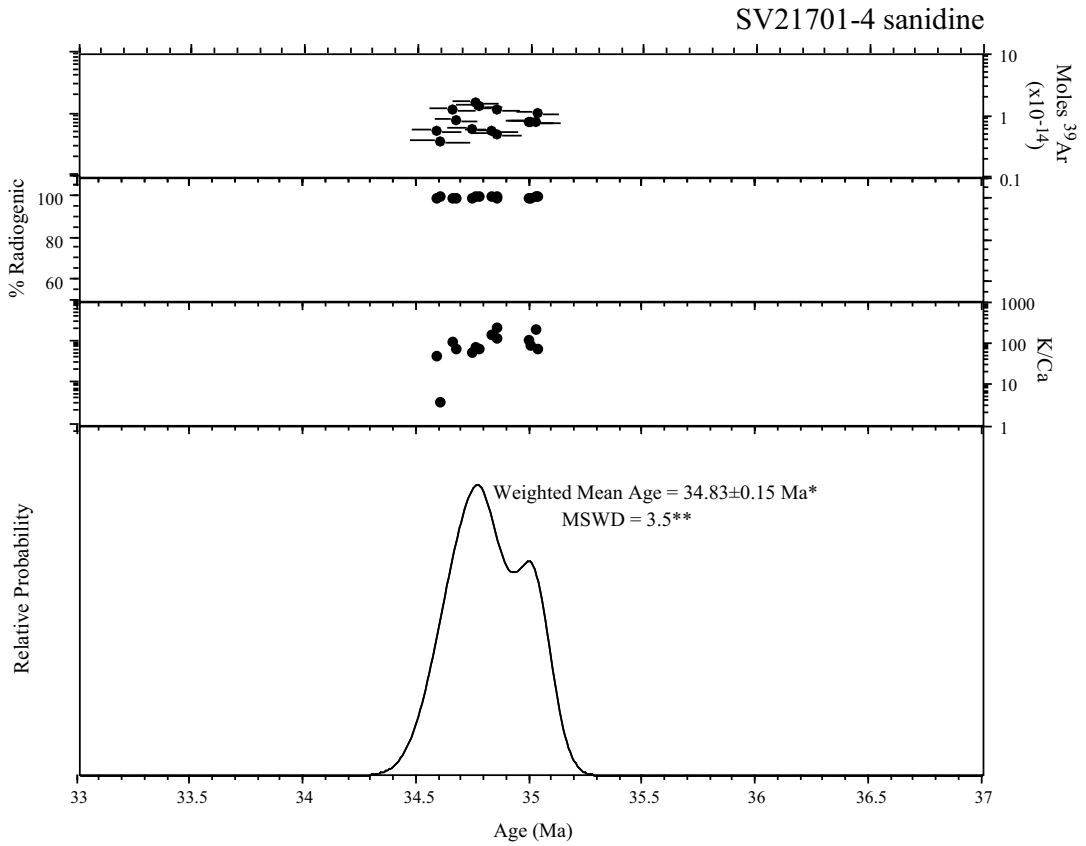
Table 9. Geochemical analysis of mineralized rock.
Refer to table 1 and plate 1 for sample location.
Analysis by Chemex Labs in Sparks, Nevada.
Results in parts per million (ppm), parts per billion (ppb) and weight percent (%).

Rock Unit	Sample No.	Au (ppb)	Ag (ppm)	Al (%)	As (ppm)	B (ppm)	Ba (ppm)	Be (ppm)	Bi (ppm)	Ca (%)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Ga (ppm)	Hg (ppm)	K (%)	La (ppm)
Prospect	S-21	<5	<0.2	0.17	4	10	40	<0.5	<2	0.16	<0.5	3	309	6	1.72	<10	<1	0.12	<10

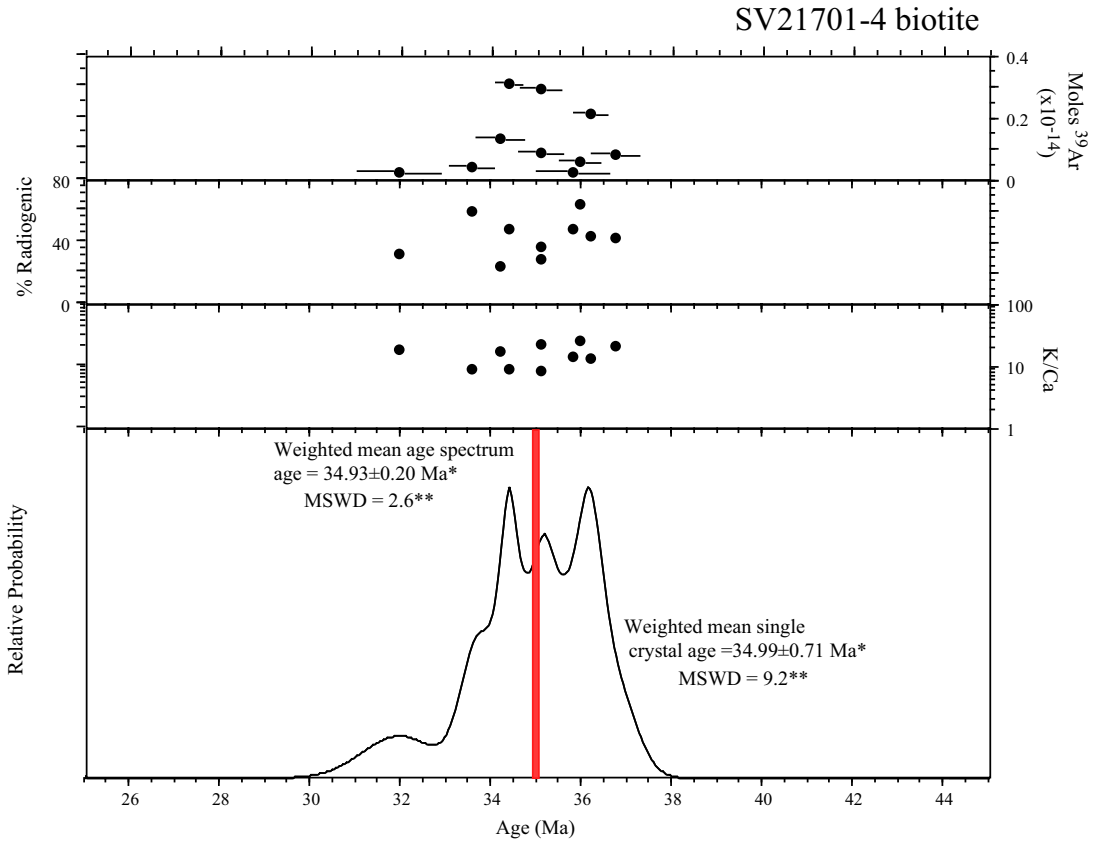
Mg (%)	Mn (ppm)	Mo (ppm)	Na (%)	Ni (ppm)	P (ppm)	Pb (ppm)	S (%)	Sb (ppm)	Sc (ppm)	Sr (ppm)	Ti (%)	Tl (ppm)	U (ppm)	V (ppm)	W (ppm)	Zn (ppm)
0.12	35.0	<1	0.01	10	40	<2	<0.01	<2	1	8	<0.01	<10	<10	20	<10	16.0

APPENDIX B

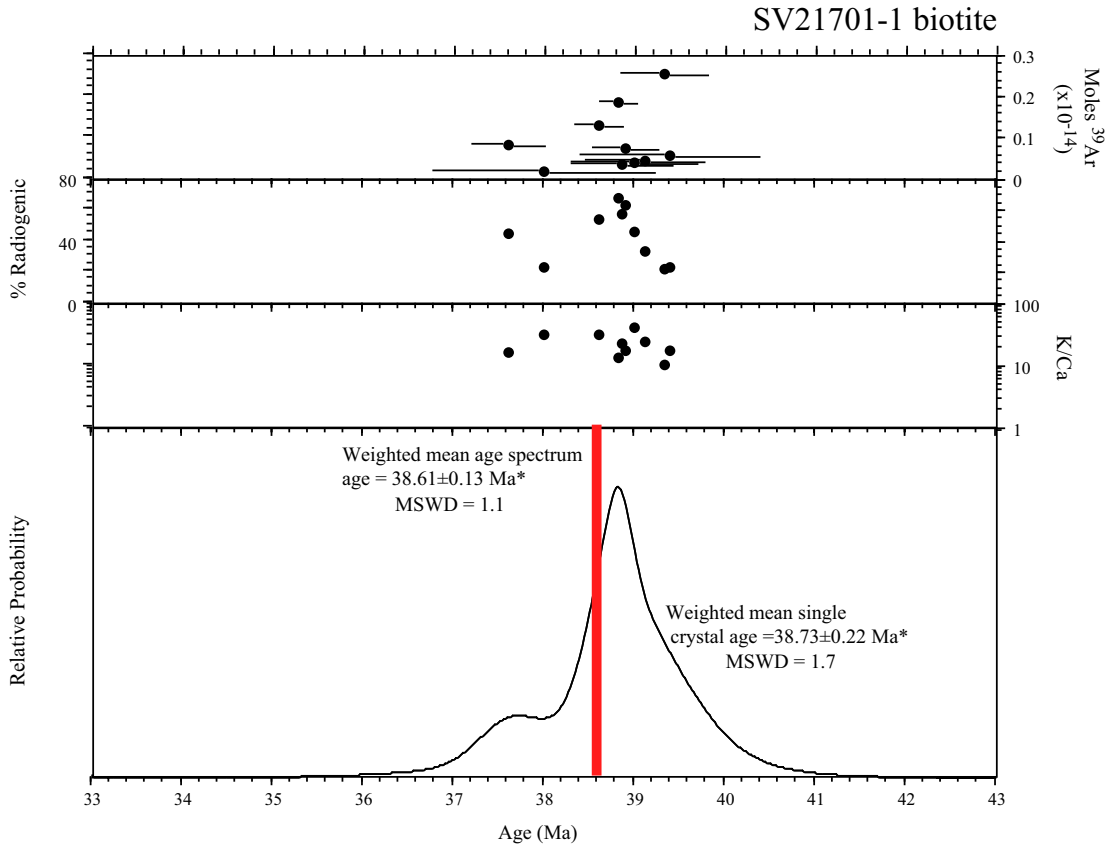
$^{40}Ar/^{39}Ar$ Geochronologic Data



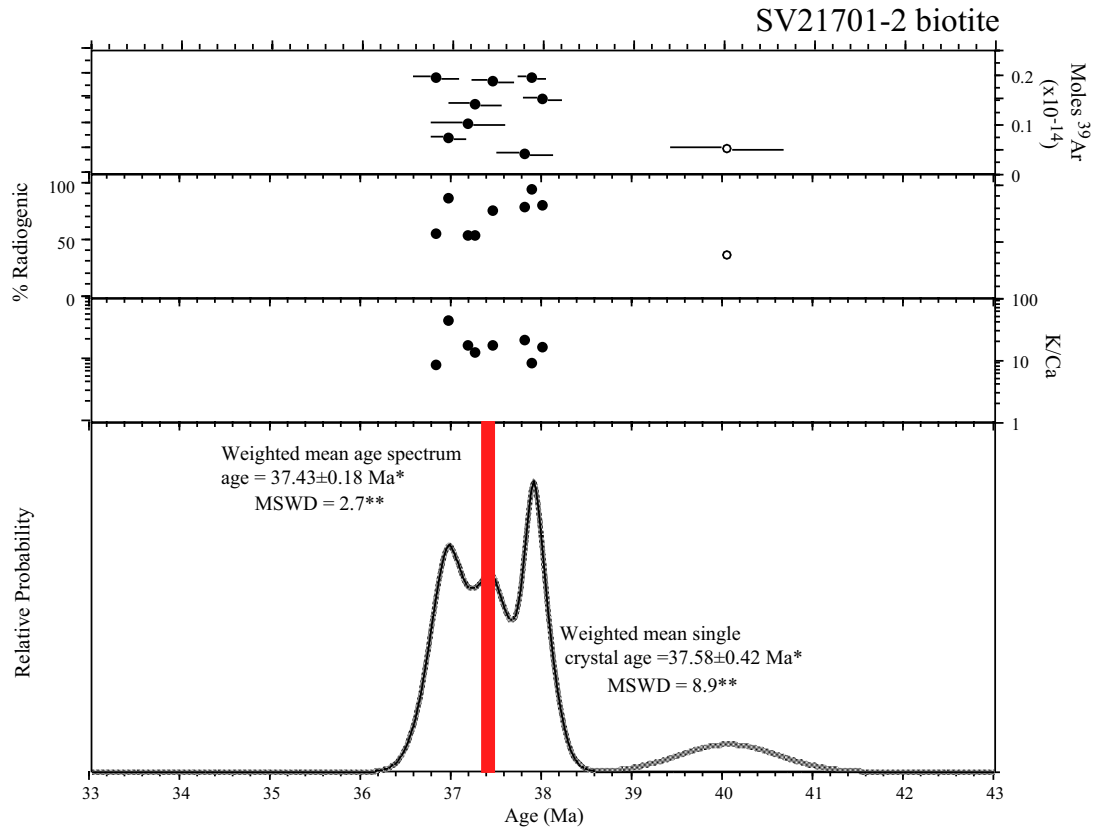
*Age probability distribution diagram of SV21701-4 single sanidine. *2σ error **MSWD outside 95% confidence interval*



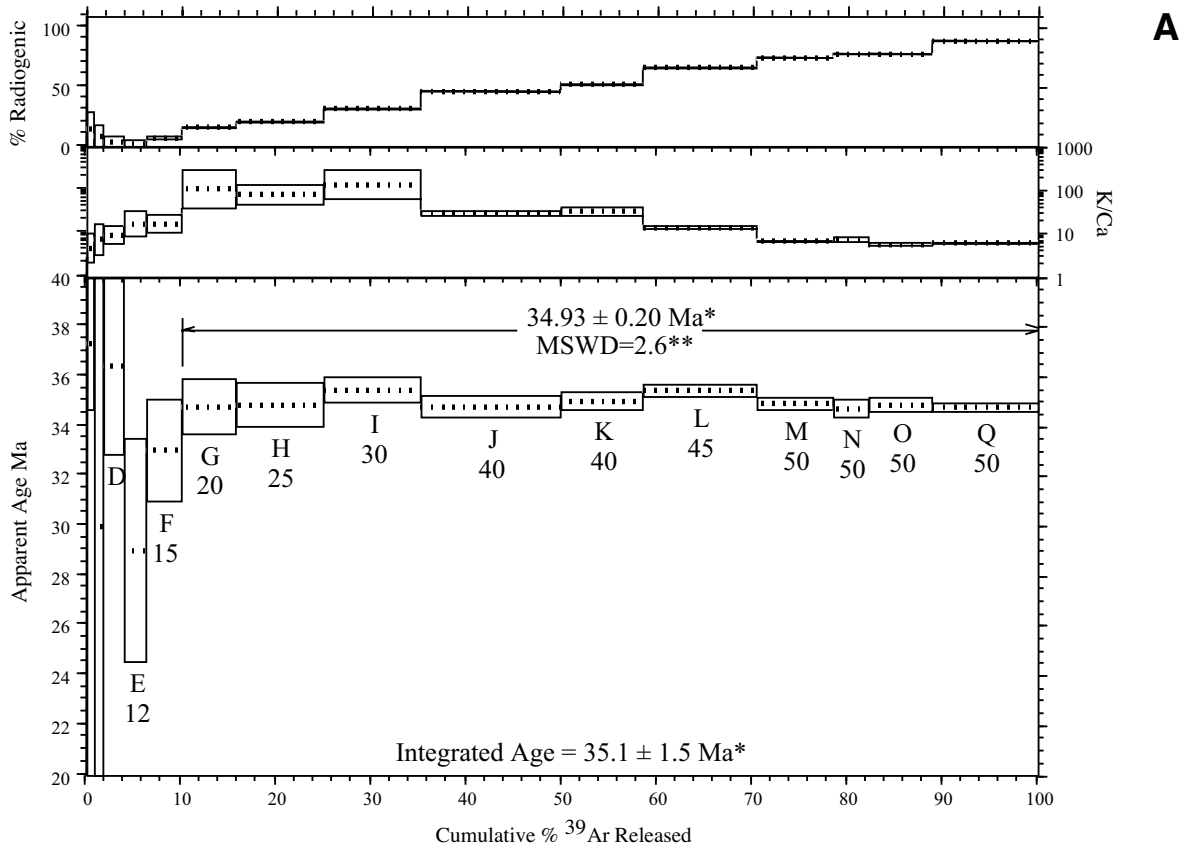
*Age probability distribution diagram of b steps for sample SV21701-4 single crystal biotite. Bar indicates weighted mean age calculated from bulk step-heating analysis. *2σ error **MSWD outside 95% confidence interval*

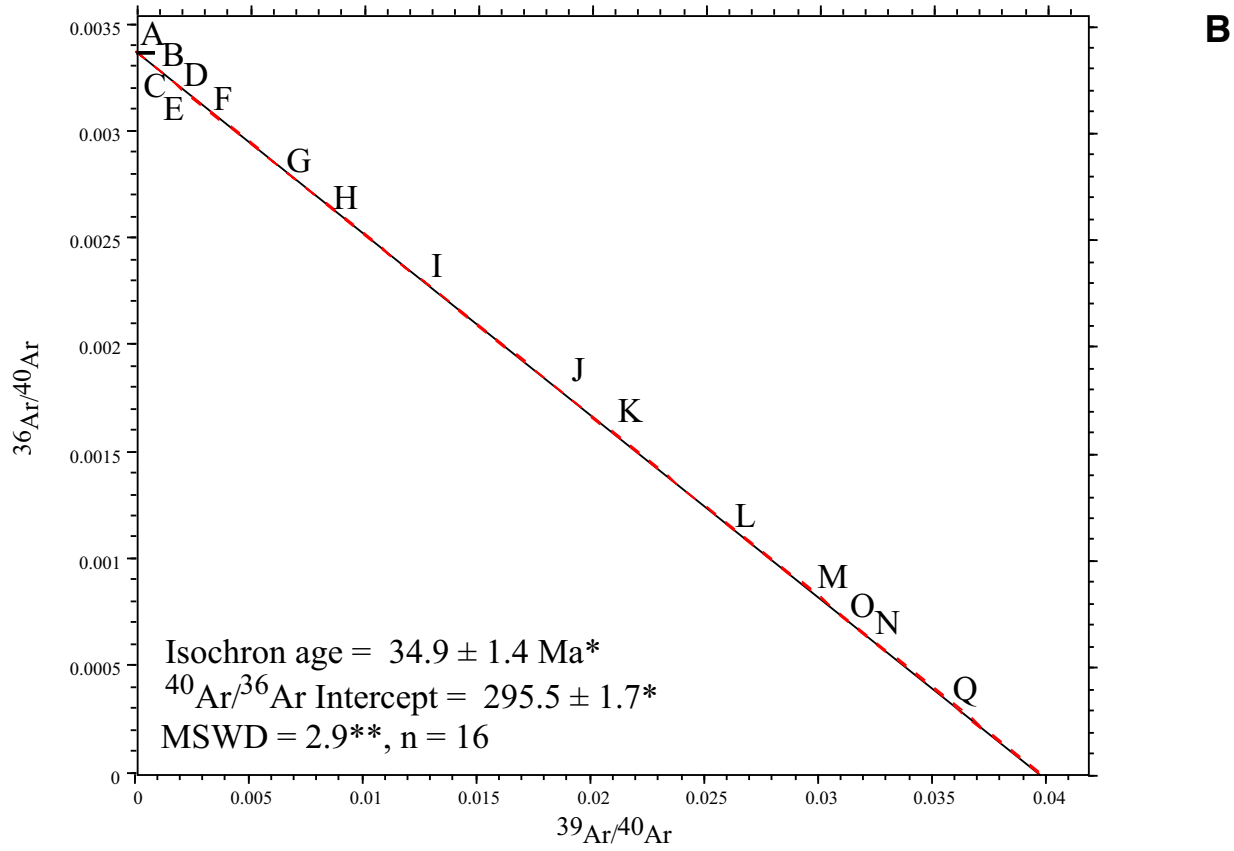


*Age probability distribution diagram of b steps for sample SV21701-1 single crystal biotite. Bar indicates weighted mean age calculated from bulk step-heating analysis. *2σ error*

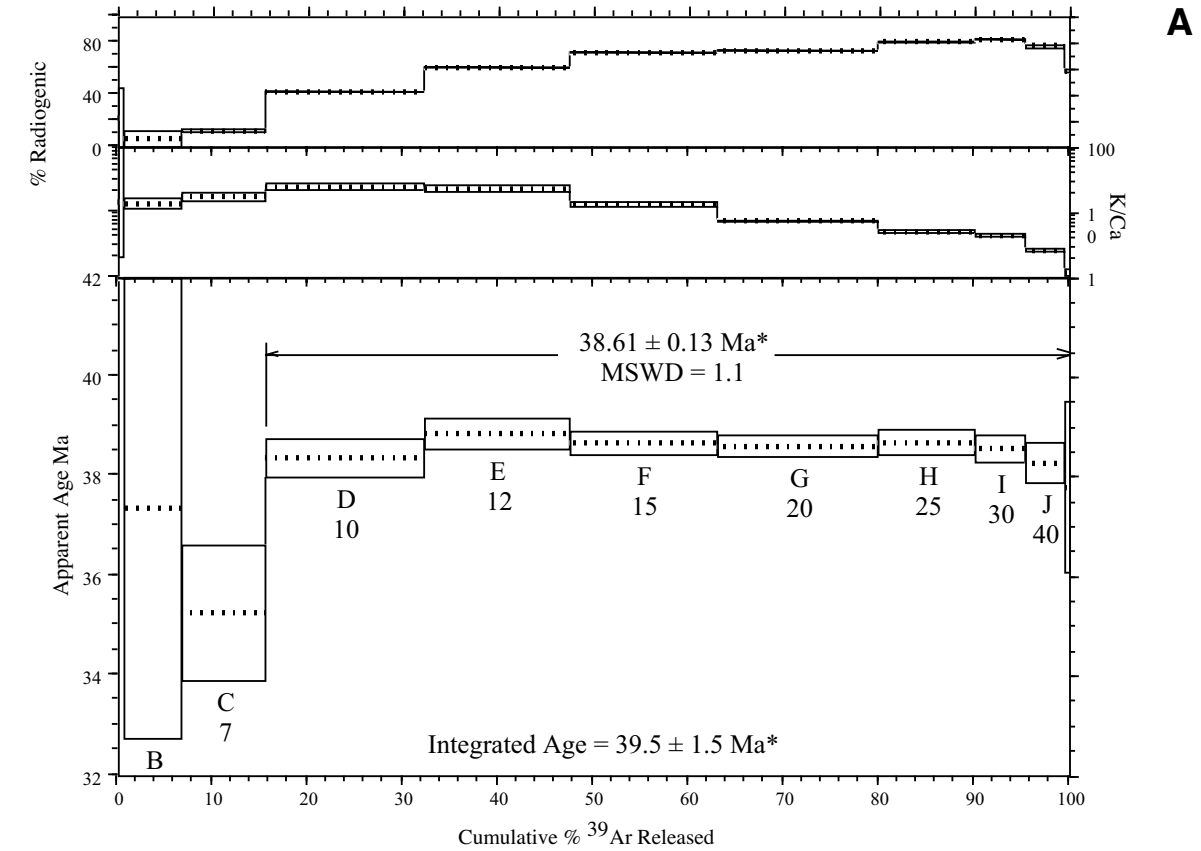


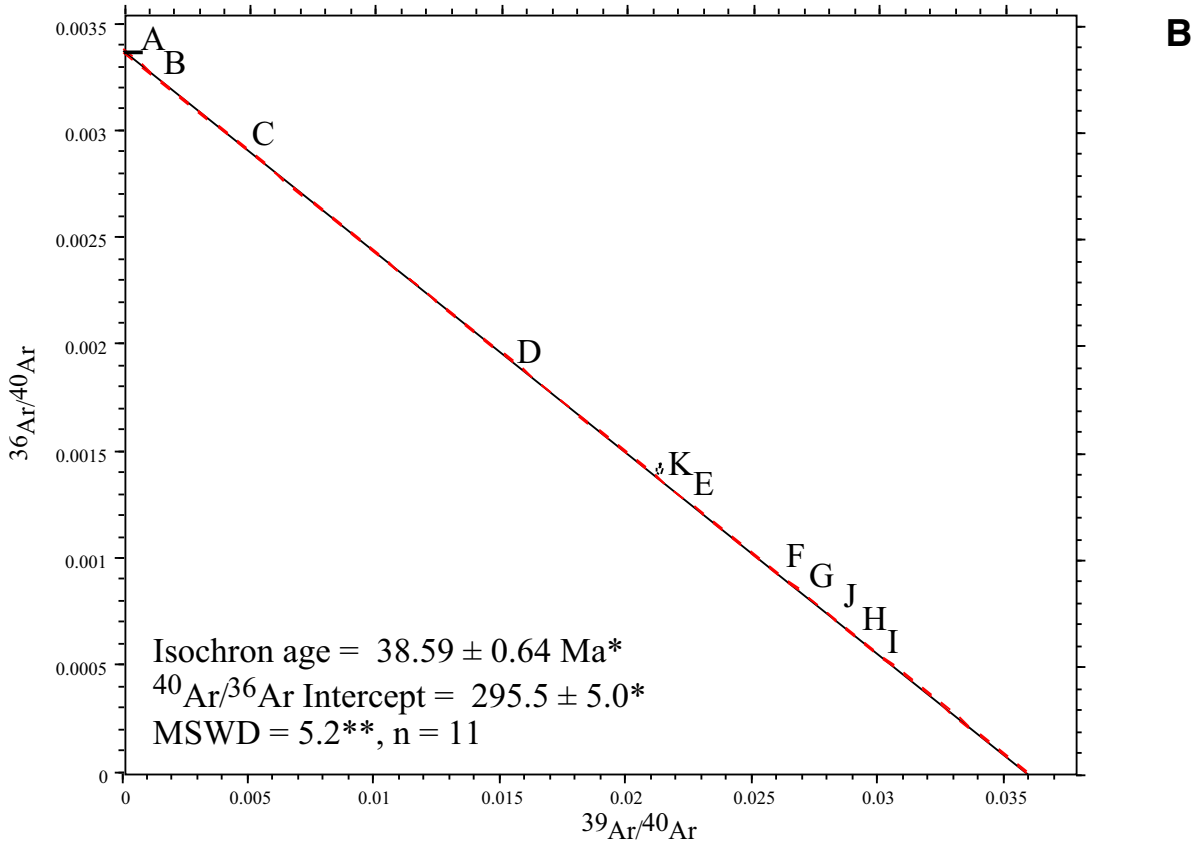
*Age probability distribution diagram of b steps for sample SV21701-2 single crystal biotite. Bar indicates weighted mean age calculated from bulk step-heating analysis. *2σ error **MSWD outside 95% confidence interval*



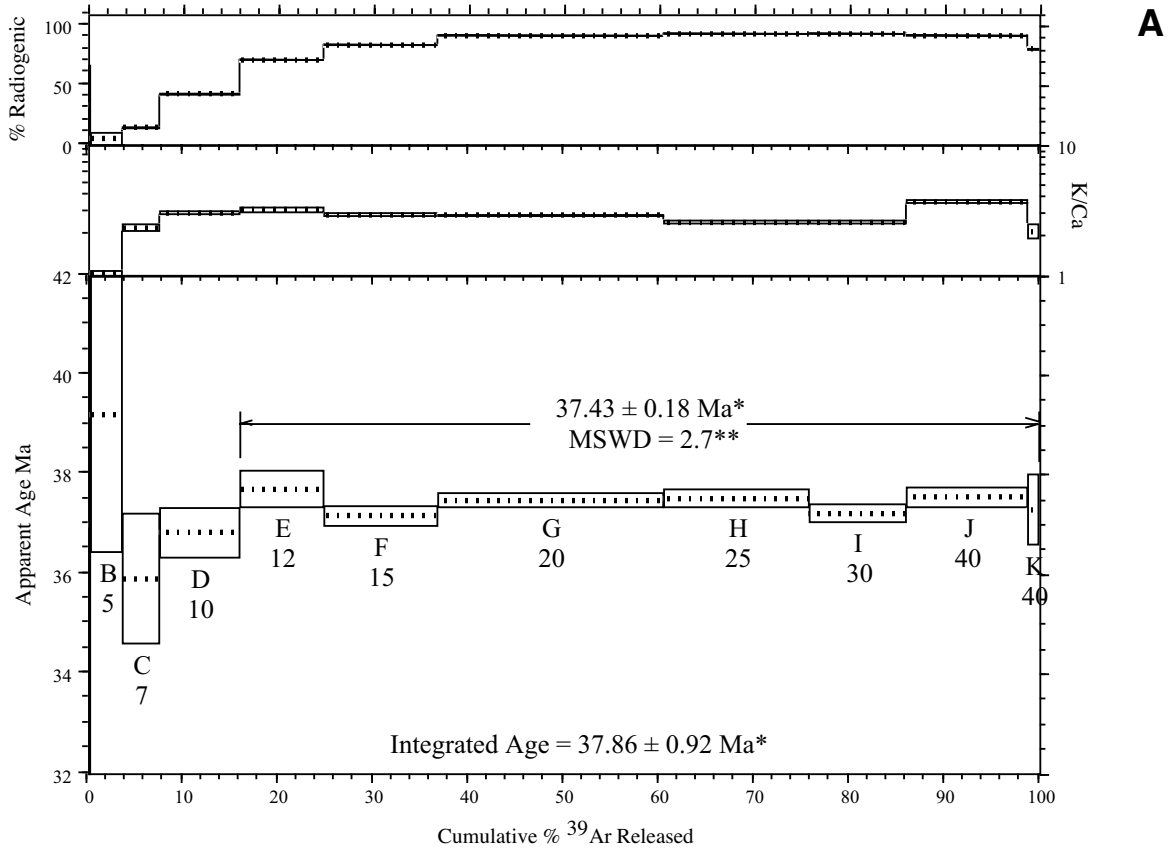


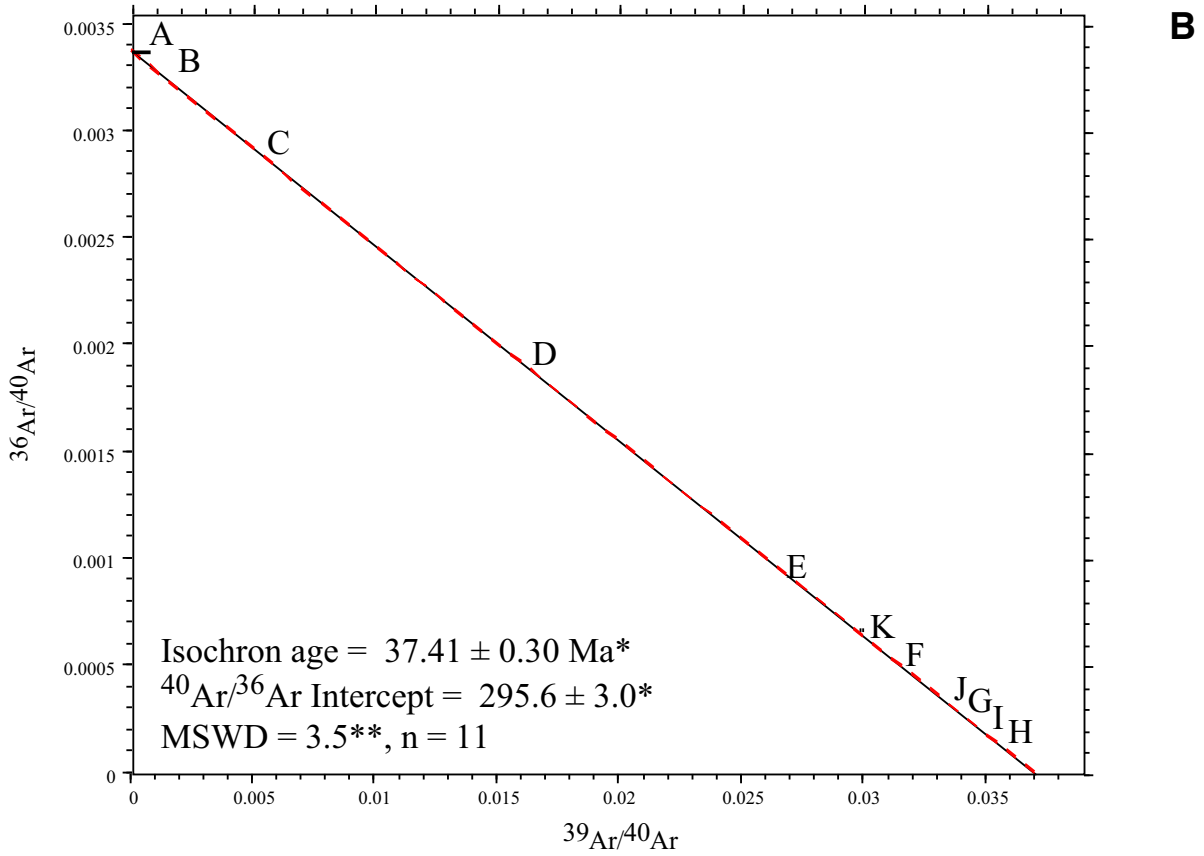
Age spectrum (A) and isochron (B) for sample SV21701-4 biotite. *2σ error **MSWD outside 95% confidence interval





Age spectrum (A) and isochron (B) for sample SV21701-1 biotite. *2σ error **MSWD outside 95% confidence interval





Age spectrum (A) and isochron (B) for sample SV21701-2 biotite. *2σ error **MSWD outside 95% confidence interval

Summary of $^{40}Ar/^{39}Ar$ results and analytical methods

Sample	Lab #	Irradiation	Mineral	Age	±2σ	Comments
SV21701-1	52309	NM-138	biotite	38.73	0.22	single crystal
SV21701-2	52325	NM-138	biotite	37.58	0.42	single crystal
SV21701-4	52324	NM-138	sanidine	34.83	0.15	single crystal

Sample preparation and irradiation:

Mineral separates were prepared using standard crushing, heavy liquid and hand-picking techniques.
The samples were loaded into a machined Al disc and irradiated for 7 hour in D-3 position, Nuclear Science Center, College Station, TX.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990) relative to Mmhb-1 at 520.4 Ma (Samson and Alexander, 1987).

Instrumentation:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Biotite separates were step-heated by a 50 watt Synrad CO_2 laser equipped with an integrator lens.
Heating duration: 30 seconds, 2 step analysis; 40 seconds, 11 step analysis
Reactive gases removed by a 6 or 13.3 minute reaction with 2 SAES GP-50 getters, 1 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filament operated at ~2000°C and a cold finger operated at -140°C.
Single sanidine crystals were fused by a 50 watt Synrad CO_2 laser.
Reactive gases removed during a 2 minute reaction with 2 SAES GP-50 getters, 1 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filament operated at ~2000°C and a cold finger operated at -140°C.

Analytical parameters:

Electron multiplier sensitivity averaged 7.84 x 10^{-17} moles/pA.
Total system blank and background for the single crystal biotite analyses averaged 898, 2.1, 0.7, 0.7, 3.8 x 10^{-18} moles, for the bulk biotite analyses averaged 1550, 8.3, 1.7, 1.4, 5.7, x 10^{-18} and for the single crystal sanidine analyses averaged 244, 1.9, 0.4, 1.5, 1.3 x 10^{-18} at masses 40, 39, 38, 37, and 36, respectively.
J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from each of 4 radial positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
$(^{40}Ar/^{39}Ar)_K = 0.00020 \pm 0.0003$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.00028 \pm 0.000005$; and $(^{39}Ar/^{37}Ar)_{Ca} = 0.0007 \pm 0.00002$.

Age calculations:

Total gas age and error calculated by weighting individual steps by the fraction of ^{39}Ar released.
Plateau age or preferred age calculated for the indicated steps by weighting each step by the inverse of the variance.
Plateau age error calculated using the method of (Taylor, 1982).
MSWD values are calculated for n-1 degrees of freedom for plateau age.
Isochron ages, $^{40}Ar/^{36}Ar_i$ and MSWD values calculated from regression results obtained by the methods of York (1969).
Decay constants and isotopic abundances after Steiger and Jäger (1977).
All final errors reported at ±2σ, unless otherwise noted.

Argon isotopic results for single crystal sanidine results.

ID	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$\%^{40}Ar^*$	Age (Ma)	$\pm1\sigma$ (Ma)
SV21701-4, single crystal sanidine, J=0.0007748, NM-138, Lab#=52307								
30	25.10	0.0111	0.3946	4.12	46.0	99.5	34.59	0.09
25	24.88	0.1551	-0.3441	2.82	3.3	100.5	34.60	0.11
22	25.11	0.0050	0.2769	8.82	102.6	99.7	34.65	0.08
31	25.12	0.0074	0.2601	5.93	69.3	99.7	34.67	0.07
32	25.24	0.0095	0.4767	4.38	53.6	99.4	34.75	0.08
20	25.17	0.0072	0.2188	11.7	70.4	99.7	34.76	0.08
29	25.14	0.0078	0.0592	10.2	65.6	99.9	34.78	0.07
33	25.03	0.0036	-0.4341	4.04	143.3	100.5	34.83	0.09
23	25.42	0.0024	0.8052	3.46	212.5	99.1	34.85	0.08
28	25.23	0.0042	0.1668	8.74	120.4	99.8	34.85	0.08
24	25.41	0.0047	0.4530	5.69	108.5	99.5	34.99	0.08
27	25.37	0.0060	0.2579	5.82	84.3	99.7	35.01	0.08
21	25.31	0.0026	0.0391	5.57	196.8	100.0	35.03	0.09
26	25.33	0.0076	0.0810	7.97	66.9	99.9	35.04	0.07
35	*25.20*	*3.764*	*0.6622*	*0.307*	*0.14*	*100.5*	*35.13*	*0.52*
34	*25.20*	*1.797*	*-0.7069*	*0.287*	*0.28*	*101.4*	*35.42*	*0.56*
weighted mean		MSWD = 3.5**	n=14		96.0 ±57.5		34.83	0.15*

Notes:
Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interferring reactions.
Individual analyses show analytical error only; plateau and total gas age errors include error in J and irradiation parameters.
n= number of heating steps
K/Ca = molar ratio calculated from reactor produced $^{39}Ar_K$ and $^{37}Ar_{Ca}$.

* 2σ error

** MSWD outside 95% confidence interval

Argon isotopic results for single-crystal step-heating results.

ID	Power (watts)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-01										
A	1	2617.5	0.0160	8774.7	0.822	31.8	0.9	1.4	34	12
B	10	90.24	0.0641	219.9	58.9	8.0	28.0	100.0	35.11	0.32
total gas age			n=2		59.7	8.3			35.10	0.49
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-02										
A	1	2544.7	-0.0132	8477.1	0.912	-	1.6	3.3	55	13
B	10	102.7	0.0307	264.2	26.4	16.6	24.0	100.0	34.18	0.43
total gas age			n=2		27.3	16.6			34.88	0.84
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-03										
A	1	1410.7	0.0051	4763.5	0.810	99.5	0.2	6.9	4.4	9.2
B	10	40.63	0.0207	49.92	10.9	24.7	63.7	100.0	35.95	0.36
total gas age			n=2		11.7	29.9			33.76	0.97
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-04										
A	1	884.6	0.0424	2926.8	0.679	12.0	2.2	13.7	27.4	8.0
B	10	54.22	0.0391	96.29	4.28	13.0	47.5	100.0	35.79	0.71
total gas age			n=2		4.96	12.9			34.6	1.7
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-05										
A	1	1657.5	0.0212	5537.0	2.86	24.0	1.3	14.7	29.7	6.6
B	10	69.80	0.0243	150.7	16.7	21.0	36.2	100.0	35.09	0.41
total gas age			n=2		19.5	21.4			34.3	1.3
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-06										
A	1	2356.6	0.0418	7936.7	4.84	12.2	0.5	10.2	15.8	7.7
B	10	61.39	0.0402	119.6	42.7	12.7	42.4	100.0	36.19	0.28
total gas age			n=2		47.5	12.7			34.1	1.0
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-07										
A	1	1921.8	0.0290	6504.7	1.52	17.6	0.0	8.9	-0.5	9.0
B	10	63.14	0.0251	124.2	15.6	20.4	41.9	100.0	36.74	0.45
total gas age			n=2		17.1	20.1			33.4	1.2
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-08										
A	1	1344.0	-0.0001	4459.5	0.967	-	2.0	17.6	36.4	8.6
B	10	73.95	0.0297	172.5	4.52	17.2	31.1	100.0	31.95	0.84
total gas age			n=2		5.48	17.2			32.7	2.2
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-09										
A	1	1056.7	-0.0193	3516.2	1.24	-	1.7	13.5	24.6	7.2
B	10	41.44	0.0595	58.49	7.90	8.6	58.3	100.0	33.59	0.36
total gas age			n=2		9.14	8.6			32.4	1.3
SV21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308-10										
A	1	3058.4	0.0101	10344.4	2.37	50.8	0.1	3.6	2	13
B	10	52.73	0.0605	94.74	63.0	8.4	46.9	100.0	34.37	0.21
total gas age			n=2		65.4	10.0			33.21	0.68

(continued on next page

ID	Power (watts)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-01										
A	1	7981.1	-0.0330	26682.2	2.49	-	1.2	4.6	131	21
B	10	134.4	0.0542	358.8	51.4	9.4	21.1	100.0	39.33	0.45
total gas age			n=2		53.9	9.4			43.5	1.4
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-02										
A	1	3574.9	0.0084	12031.2	1.27	60.9	0.6	10.6	27	13
B	10	128.4	0.0302	338.6	10.8	16.9	22.1	100.0	39.40	0.94
total gas age			n=2		12.0	21.6			38.1	2.2
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-03										
A	1	2047.3	0.0874	6815.3	0.746	5.8	1.6	5.0	46	11
B	10	44.63	0.0305	56.19	14.1	16.7	62.8	100.0	38.92	0.31
total gas age			n=2		14.8	16.2			39.29	0.86
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-04										
A	1	452.5	0.1196	1500.4	0.375	4.3	2.0	5.6	12.8	8.1
B	10	49.11	0.0239	71.44	6.36	21.4	57.0	100.0	38.88	0.50
total gas age			n=2		6.74	20.4			37.43	0.92
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-05										
A	1	916.4	0.0317	3053.1	1.90	16.1	1.6	4.9	19.9	5.8
B	10	42.02	0.0401	47.56	37.3	12.7	66.6	100.0	38.83	0.16
total gas age			n=2		39.2	12.9			37.92	0.43
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-06										
A	1	1360.2	0.0371	4528.3	0.994	13.8	1.6	5.8	30.8	9.6
B	10	60.89	0.0331	114.4	16.1	15.4	44.5	100.0	37.62	0.35
total gas age			n=2		17.1	15.3			37.22	0.88
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-07										
A	1	919.0	0.0950	3054.0	0.321	5.4	1.8	9.0	23	13
B	10	120.0	0.0168	313.4	3.23	30.3	22.8	100.0	38.0	1.2
total gas age			n=2		3.55	28.1			36.7	2.3
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-08										
A	1	4272.5	0.0842	14502.2	1.09	6.1	-0.3	11.1	-18	20
B	10	85.44	0.0220	193.8	8.69	23.2	33.0	100.0	39.12	0.62
total gas age			n=2		9.78	21.3			32.8	2.7
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-09										
A	1	966.9	-0.0011	3167.5	0.400	-	3.2	4.9	43	11
B	10	62.94	0.0131	117.9	7.79	39.0	44.6	100.0	39.01	0.64
total gas age			n=2		8.19	39.0			39.2	1.1
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309-10										
A	1	1166.9	0.0379	3898.4	0.850	13.5	1.3	3.1	20.8	8.9
B	10	52.16	0.0174	82.41	26.3	29.3	53.3	100.0	38.61	0.21
total gas age			n=2		27.1	28.8			38.05	0.49

(continued on next page

ID	Power (watts)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-01										
A	1	6054.9	-0.0894	20500.4	0.192	-	0.0	0.7	-4	44
B	10	50.00	0.0403	78.31	27.9	12.7	53.7	100.0	37.27	0.22
total gas age			n=2		28.1	12.7			36.99	0.52
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-02										
A	1	4722.0	0.6563	15551.6	0.051	0.78	2.7	0.5	169	88
B	10	77.06	2.514	163.9	9.92	0.20	37.4	100.0	40.06	0.56
total gas age			n=2		9.97	0.21			40.7	1.0
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-03										
A	2	2027.7	0.4355	6858.8	1.44	1.2	0.0	3.5	1.4	9.6
B	10	47.83	0.0624	72.07	39.3	8.2	55.5	100.0	36.82	0.20
total gas age			n=2		40.7	7.9			35.57	0.53
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-04										
A	2	3475.9	0.0537	11818.5	1.38	9.5	-0.5	4.3	-23	15
B	10	34.04	0.0330	22.46	30.5	15.5	80.5	100.0	38.01	0.16
total gas age			n=2		31.9	15.2			35.36	0.80
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-05										
A	2	1508.8	0.1730	5034.5	1.15	2.9	1.4	5.5	29.3	8.0
B	10	49.86	0.0302	78.04	19.9	16.9	53.8	100.0	37.18	0.36
total gas age			n=2		21.0	16.1			36.75	0.77
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-06										
A	2	4158.0	0.0948	13903.8	1.24	5.4	1.2	3.2	68	16
B	10	35.37	0.0317	28.30	37.8	16.1	76.4	100.0	37	0
total gas age			n=2		39.0	15.8			38.44	0.67
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-07										
A	2	353.3	0.2389	1112.0	0.422	2.1	7.0	1.1	34.4	6.4
B	10	28.96	0.0616	5.560	39.6	8.3	94.3	100.0	37.89	0.11
total gas age			n=2		40.0	8.2			37.85	0.17
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-08										
A	2	458.4	0.5554	1612.9	0.151	0.92	-4.0	1.9	-26	12
B	10	34.11	0.0255	23.18	7.91	20.0	79.9	100.0	37.81	0.25
total gas age			n=2		8.07	19.6			36.62	0.47
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310-09										
A	2	2737.1	0.0594	9194.7	1.24	8.6	0.7	8.0	28	11
B	10	30.67	0.0126	13.62	14.3	40.4	86.9	100.0	36.96	0.15
total gas age			n=2		15.5	37.9			36.2	1.0

Notes:
Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interferring reactions.
Individual analyses show analytical error only; plateau and total gas age errors include error in J and irradiation parameters.
n= number of heating steps
K/Ca = molar ratio calculated from reactor produced $^{39}Ar_K$ and $^{37}Ar_{Ca}$.

Argon isotopic data for B steps of single-crystal step-heating results.

ID	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	%$^{40}Ar^*$	Age (Ma)	±1σ (Ma)
SV21701-1, single crystal biotite, J=0.0007779, NM-138, Lab#=52309								
06B	60.89	0.0331	114.4	1.61	15.4	44.5	37.62	0.35
07B	120.0	0.0168	313.4	0.323	30.3	22.8	38.0	1.2
10B	52.16	0.0174	82.41	2.63	29.3	53.3	38.61	0.21
05B	42.02	0.0401	47.56	3.73	12.7	66.6	38.83	0.16
04B	49.11	0.0239	71.44	0.636	21.4	57.0	38.88	0.50
03B	44.63	0.0305	56.19	1.41	16.7	62.8	38.92	0.31
09B	62.94	0.0131	117.9	0.779	39.0	44.6	39.01	0.64
08B	85.44	0.0220	193.8	0.869	23.2	33.0	39.12	0.62
01B	134.4	0.0542	358.8	5.14	9.4	21.1	39.33	0.45
02B	128.4	0.0302	338.6	1.08	16.9	22.1	39.40	0.94
weighted mean		MSWD = 1.7	n=10		21.4 ±9.2		38.73	0.22*
V21701-4, single crystal biotite, J=0.0007776, NM-138, Lab#=52308								
08B	73.95	0.0297	172.5	0.452	17.2	31.1	31.95	0.84
09B	41.44	0.0595	58.49	0.790	8.6	58.3	33.59	0.36
02B	102.7	0.0307	264.2	2.64	16.6	24.0	34.18	0.43
10B	52.73	0.0605	94.74	6.30	8.4	46.9	34.37	0.21
05B	69.80	0.0243	150.7	1.67	21.0	36.2	35.09	0.41
01B	90.24	0.0641	219.9	5.89	8.0	28.0	35.11	0.32
04B	54.22	0.0391	96.29	0.428	13.0	47.5	35.79	0.71
03B	40.63	0.0207	49.92	1.09	24.7	63.7	35.95	0.36
06B	61.39	0.0402	119.6	4.27	12.7	42.4	36.19	0.28
07B	63.14	0.0251	124.2	1.56	20.4	41.9	36.74	0.45
weighted mean		MSWD = 9.2**	n=10		15.0 ±5.9		34.99	0.71*
SV21701-2, single crystal biotite, J=0.0007769, NM-138, Lab#=52310								
03B	47.83	0.0624	72.07	3.93	8.2	55.5	36.82	0.20
09B	30.67	0.0126	13.62	1.43	40.4	86.9	36.96	0.15
05B	49.86	0.0302	78.04	1.99	16.9	53.8	37.18	0.36
01B	50.00	0.0403	78.31	2.79	12.7	53.7	37.27	0.22
06B	35.37	0.0317	28.30	3.78	16.1	76.4	37.47	0.17
08B	34.11	0.0255	23.18	0.791	20.0	79.9	37.81	0.25
07B	28.96	0.0616	5.560	3.96	8.3	94.3	37.89	0.11
04B	34.04	0.0330	22.46	3.05	15.5	80.5	38.01	0.16
02B	77.06	2.514	163.9	0.992	0.20	37.4	40.06	0.56
weighted mean		MSWD = 8.9**	n=9		15.4 ±11.1		37.58	0.42*

Notes:
Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interferring reactions.
Individual analyses show analytical error only: plateau and total gas age errors include error in J and irradiation parameters.
n = number of heating steps
K/Ca = molar ratio calculated from reactor produced ^{39}Ark and $^{37}Ar_{Ca}$-
* 2σ error
** MSWD outside 95% confidence interval

Argon isotopic results for bulk step-heating analyses.

ID	Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
SV21701-1, 5.19 mg biotite, J=0.0007779, NM-138, Lab#=52309-25										
A	*2*	*8685.4*	*0.0073*	*29017.5*	*4.64*	*69.7*	*1.3*	*0.7*	*149.04*	*28.68*
B	*5*	*1352.7*	*0.0378*	*4465.7*	*41.3*	*13.5*	*2.4*	*6.7*	*45.86*	*6.56*
C	*7*	*210.4*	*0.0301*	*626.1*	*60.9*	*16.9*	*12.1*	*15.6*	*35.27*	*0.68*
D	10	65.44	0.0211	127.9	114.0	24.2	42.2	32.2	38.38	0.20
E	12	45.77	0.0229	60.23	105.0	22.3	61.1	47.6	38.84	0.16
F	15	38.64	0.0393	36.56	106.0	13.0	72.1	63.0	38.66	0.13
G	20	37.60	0.0705	33.12	116.2	7.2	74.0	80.0	38.62	0.11
H	25	34.78	0.1034	23.44	68.9	4.9	80.1	90.0	38.69	0.13
I	30	33.81	0.1173	20.45	36.8	4.4	82.2	95.4	38.57	0.14
J	40	35.37	0.1938	26.49	27.7	2.6	77.9	99.4	38.28	0.20
K	40	46.97	0.4360	66.98	3.84	1.2	57.9	100.0	37.80	0.86
total gas age			n=11		685.5	14.3			39.5	1.5*
plateau		MSWD = 1.1	n=8	steps D-K	578.5	13.7		84.4	38.61	0.13*
SV21701-2, 5.15 mg biotite, J=0.0007769, NM-138, Lab#=52310-25										
A	*2*	*13886.2*	*0.6969*	*46757.1*	*1.67*	*0.73*	*0.5*	*0.3*	*95.00*	*43.68*
B	*5*	*1664.0*	*0.4936*	*5514.5*	*17.6*	*1.0*	*2.1*	*3.6*	*47.76*	*5.66*
C	*7*	*190.5*	*0.2209*	*557.0*	*20.7*	*2.3*	*13.6*	*7.5*	*35.93*	*0.66*
D	*10*	*62.25*	*0.1687*	*120.9*	*45.2*	*3.0*	*42.6*	*16.0*	*36.83*	*0.25*
E	12	37.77	0.1620	35.85	47.1	3.1	72.0	24.8	37.71	0.18
F	15	31.88	0.1760	17.25	63.5	2.9	84.1	36.7	37.17	0.10
G	20	29.27	0.1775	7.630	126.9	2.9	92.3	60.6	37.49	0.08
H	25	28.83	0.1996	6.080	81.2	2.6	93.8	75.8	37.53	0.09
I	30	28.88	0.2019	6.984	54.0	2.5	92.9	85.9	37.23	0.10
J	40	29.59	0.1385	8.588	68.5	3.7	91.5	98.8	37.54	0.09
K	40	33.45	0.2371	22.29	6.59	2.2	80.4	100.0	37.30	0.36
total gas age			n=11		532.9	2.8			37.86	0.92*
plateau		MSWD = 2.7**	n=7	steps E-K	447.8	2.9		84.0	37.43	0.18*
SV21701-4, 4.20 mg, J=0.0007776, NM-138, Lab#=52308-50										
A	*2*	*27756.0*	*0.5397*	*93878.3*	*0.392*	*0.95*	*0.1*	*0.1*	*21.02*	*112.82*
B	*5*	*6248.8*	*0.1108*	*20970.4*	*4.40*	*4.6*	*0.8*	*0.8*	*71.66*	*18.51*
C	*7*	*3230.1*	*0.0679*	*10868.9*	*5.99*	*7.5*	*0.6*	*1.9*	*25.57*	*12.41*
D	*10*	*1494.0*	*0.0555*	*4952.9*	*12.0*	*9.2*	*2.0*	*4.0*	*42.15*	*4.66*
E	*12*	*706.1*	*0.0316*	*2319.0*	*13.7*	*16.1*	*3.0*	*6.4*	*29.02*	*2.24*
F	*15*	*326.9*	*0.0304*	*1025.9*	*20.5*	*16.8*	*7.3*	*10.0*	*33.05*	*1.02*
G	20	158.6	0.0051	452.0	33.4	99.9	15.8	15.9	34.77	0.57
H	25	119.9	0.0067	320.8	52.1	75.9	20.9	25.0	34.87	0.46
I	30	81.32	0.0039		57.8	129.2	31.4	35.2	35.48	0.26
J	40	54.29	0.0176	99.01	83.9	29.0	46.1	49.9	34.79	0.23
K	40	48.70	0.0158	79.54	49.0	32.2	51.7	58.5	35.00	0.19
L	45	38.67	0.0379	44.55	68.3	13.4	66.0	70.5	35.44	0.14
M	50	33.51	0.0786	28.35	45.3	6.5	75.0	78.5	34.92	0.13
N	50	31.92	0.0715	23.53	22.0	7.1	78.2	82.3	34.70	0.18
O	50	32.22	0.0899	24.21	37.2	5.7	77.8	88.9	34.84	0.15
Q	50	28.16	0.0862	10.64	63.4	5.9	88.9	100.0	34.76	0.09
total gas age			n=16		569.5	37.7			35.1	1.5*
plateau		MSWD 2.6**	n=10	steps G-Q	512.5	40.5		90.0	34.93	0.20*

Notes:

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interferring reactions.

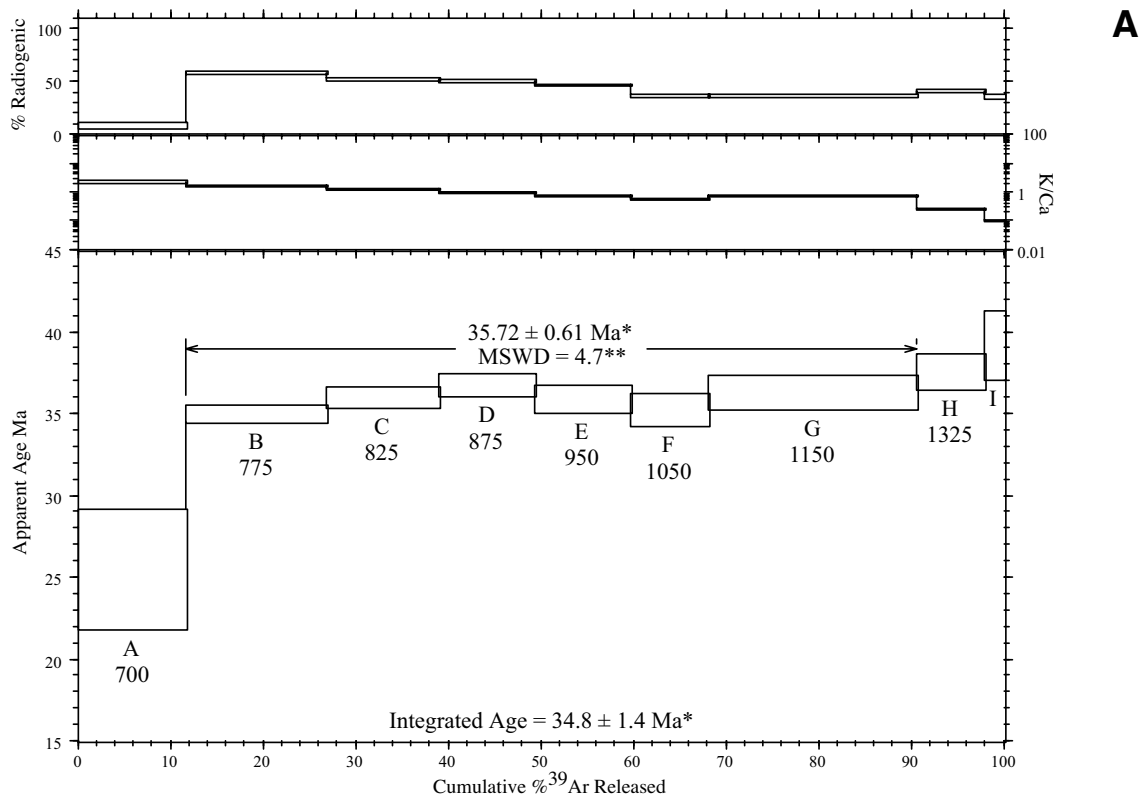
Individual analyses show analytical error only; plateau and total gas age errors include error in J and irradiation parameters.

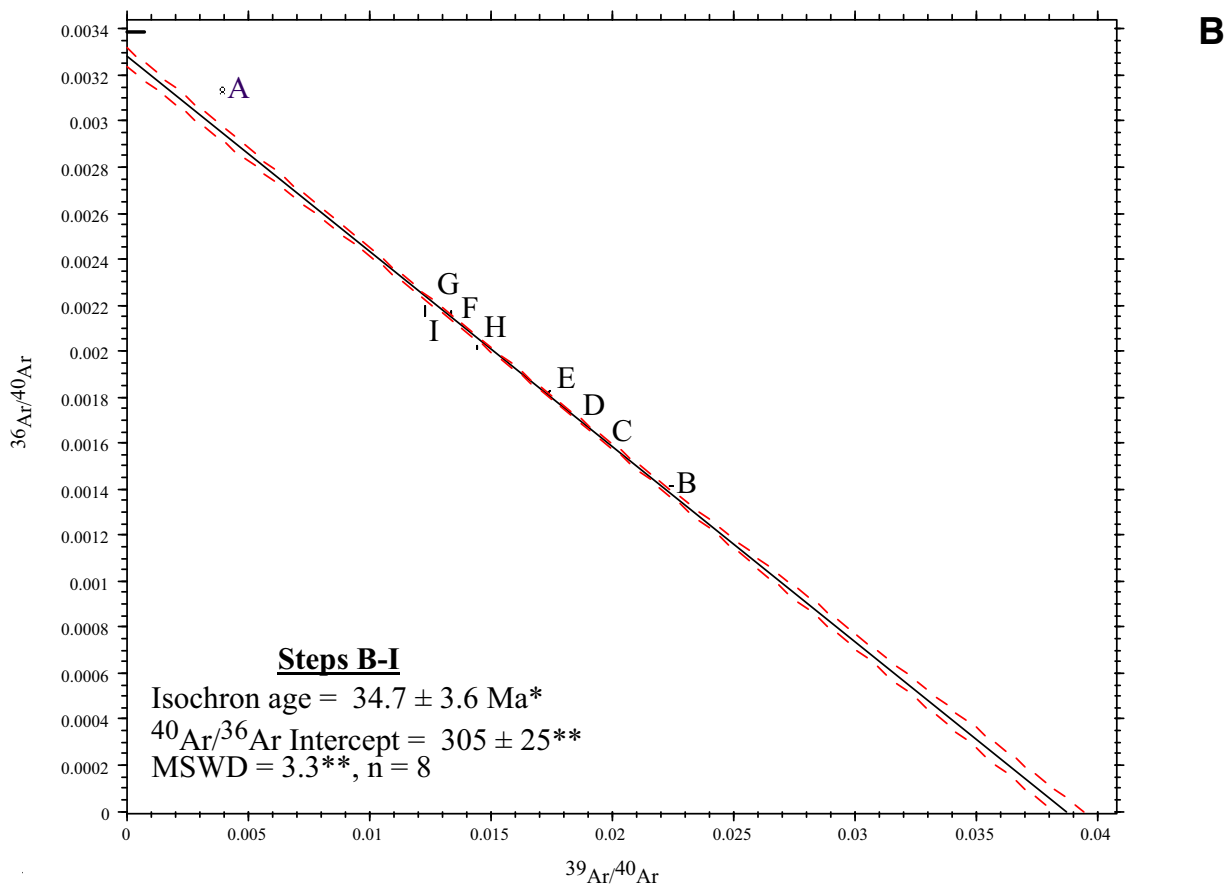
n= number of heating steps

K/Ca = molar ratio calculated from reactor produced $^{39}Ar_K$ and $^{37}Ar_{Ca}$.

* 2σ error

** MSWD outside 95% confidence interval





Age spectrum (A) and isochron (B) for sample S-40 groundmass concentrate. *2σ error **MSWD outside 95% confidence interval

Argon isotopic results for furnace step-heating analyses.

ID	Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
S-40, 11.97 mg groundmass concentrate, J=0.0007535, NM-144, Lab#=52697-01										
A	*700*	*251.3*	*0.2351*	*786.8*	*61.2*	*2.2*	*7.5*	*11.7*	*25.44*	*1.83*
B	775	44.53	0.3056	62.89	79.2	1.7	58.3	26.8	34.97	0.24
C	825	51.31	0.4147	83.29	63.7	1.2	52.1	39.0	35.99	0.30
D	875	54.09	0.5368	90.76	54.4	0.95	50.5	49.4	36.76	0.33
E	950	57.58	0.7424	105.0	54.2	0.69	46.2	59.7	35.82	0.40
F	1050	73.34	0.9610	160.0	43.6	0.53	35.6	68.1	35.21	0.47
G	1150	74.67	0.6838	161.7	118.3	0.75	36.1	90.6	36.26	0.49
H	*1325*	*68.97*	*2.033*	*139.7*	*38.4*	*0.25*	*40.4*	*98.0*	*37.53*	*0.55*
I	*1725*	*81.04*	*5.277*	*177.5*	*10.6*	*0.097*	*35.8*	*100.0*	*39.17*	*1.04*
total gas age			n=9		523.7	1.1			34.84	1.4*
plateau		MSWD = 4.7**	n=6	steps B-G	413.4	1.0		78.9	35.72	0.61*

Summary of $^{40}Ar/^{39}Ar$ data and analytical methods.

Sample	Unit/Location	Irradiation	mineral	analysis	# of steps/crystals	MSWD	K/Ca	Age	±2σ	Comments
S-40	Conglomerate of Sevier Canyon	NM-144	groundmass concentrate	furnace step-heat	6	4.7***		35.72	0.61	somewhat disturbed age spectrum

*** MSWD outside 95% confidence interval

Notes:

Sample preparation and irradiation:

Mineral separates were prepared using standard crushing, dilute acid treatment and hand-picking techniques.
Mineral separates were loaded into a machined Al disc and irradiated for 7 hours in NM-144 or 1 hour for NM-150 in the D-3 position, Nuclear Science Center, College Station, TX.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990)
relative to Mmhb-1 at 520.4 Ma (Samson and Alexander, 1987).

Instrumentation:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Groundmass concentrate, hornblende and biotite separates were step-heated using a Mo double-vacuum resistance furnace. Heating duration in the furnace was 9 minutes.
Reactive gases removed during furnace analysis by reaction with 3 SAES GP-50 getters, 2 operated at ~450°C and
1 at 20°C. Gas also exposed to a W filiment operated at ~2000°C.
Single crystal sanidine and hornblende were fused by a 50 watt Synrad CO_2 laser. Single crystal biotite step-heated with same laser.
Reactive gases removed during a reaction with 2 SAES GP-50 getters, 1 operated at ~450°C and
1 at 20°C (2 minutes for sanidine, 5 minutes for hornblende and biotite). Gas also exposed to a W filament operated at ~2000°C and a cold finger operated at -140°C.

Analytical parameters:

Electron multiplier sensitivities: 1.75 x 10^{-16} moles /pA for furnace analyses, 9.42 x 10^{-17} moles /pA for laser analyses.
Total system blank and background for furnace analyses averaged 709, 1.3 , 0.5 , 1.5, 3.1 x 10^{-18} moles at masses 40, 39, 38, 37, and 36, respectively.
and 44, 0.4, 0.3, 1.3, 0.4 x 10^{-18} moles at masses 40, 39, 38, 37, and 36, respectively for laser analyses.
J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from each of 6 or 4 radial positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
$(^{40}Ar/^{39}Ar)_K$ = 0.0002±0.0003; $(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028±0.000005; and $(^{39}Ar/^{37}Ar)_{Ca}$ = 0.0007±0.00002.

Age calculations:

Total gas age and error calculated by weighting individual steps by the fraction of ^{39}Ar released.
MSWD values are evaluated for n-1 degrees of freedom for weighted mean age.
$^{40}Ar/^{36}Ar_i$ and MSWD values calculated from regression results obtained by the methods of York (1969).
If the MSWD is outside the 95% confidence window (cf. Mahon, 1996; Table 1), the error is multiplied by the square root of the MSWD.
Decay constants and isotopic abundances after Steiger and Jäger (1977).
All final errors reported at ±2σ, unless otherwise noted.