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Geologic Map of the Vigo NE Quadrangle, Lincoln County, Nevada

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Pamphlet to accompany
Scientific Investigations Map 2892

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Introduction

This map of the Vigo NE quadrangle, Lincoln County, Nevada records the distribution, stratigraphy, and structural relationships of Tertiary intracaldera lavas and tuffs in the southeastern part of the Kane Springs Wash caldera, extracaldera Tertiary and upper Paleozoic rocks, and late Cenozoic surficial deposits both within and outside the caldera. The alkaline to peralkaline Kane Springs Wash caldera is the youngest (14 Ma) of three chemically related metaluminous to peralkaline calderas (Boulder Canyon caldera, 15 Ma; Narrow Canyon caldera, 16 Ma) of the nested Kane Springs Wash caldera complex. The chemistry of this caldera complex became progressively more alkalic with time, in contrast to the older calc-alkalic calderas and caldera complexes to the north that migrated progressively southward in eastern Nevada. The increasingly peralkaline eruptions from the Kane Springs Wash caldera complex reached a climax that was simultaneous with the end of both rapid extension and magmatism in this part of the Basin and Range (Scott, Unruh, and others, 1995; Scott, Grommé, and others, 1995; Scott and others,1996). Using the assumption that degree of tilting is related to the degree of extension, the rate of extension increased until the abrupt halt at about 14 Ma. Silicic volcanism terminated at the Kane Springs Wash caldera followed only by local sporadic basaltic eruptions that ended by about 8 Ma. The northern boundary of an east-west-trending amagmatic corridor appears in the Vigo NE quadrangle south of the Kane Springs Wash caldera (Scott, Unruh, and others, 1995).

Kane Springs Wash caldera complex covers parts of eight 7.5' quadrangles. Of these eight, three are published: the Gregerson Basin (Scott, Swadley, and others, 1990), the Delamar 3 NE quadrangle (Scott, Novak, and Swadley, 1990), and the Vigo NW (Scott and others, 1991, Scott and others, in press) quadrangles. The remaining four quadrangles, the Elgin, Elgin SW, Delamar, and Slidy Mountain are mapped and are scheduled for publication. This map covers the eighth quadrangle.

Steve Novak, who mapped the Kane Springs Wash caldera in the Delamar Mountains west of the Meadow Valley Mountains as part of his dissertation research (Novak, 1984), suggested to Anne Harding that she map suspected young volcanic rocks in the Meadow Valley Mountains east of his map area for her Master's thesis. Subsequently, the preliminary map of the Vigo NW quadrangle (Scott and others, 1991) and reports by Harding (1991) and Harding and others (1991, 1995) first established the presence of the Kane Spring Wash caldera in the Meadow Valley Mountains and attributed the young volcanic rocks in the Meadow Valley Mountains to caldera fill of the Kane Springs Wash caldera in the Meadow Valley Mountains.

DESCRIPTION OF MAP UNITS

Age assignments for surficial deposits are based chiefly on the degree of modification of original landforms or surface morphology, height above stream level, and degree of soil development. Sand, gravel, and other surficial deposits shown on the map are estimated to be at least 1 m thick. Where surficial deposits are less than 1 m thick or discontinuous, they were not mapped. Soil-horizon designations are those of the Soil Survey Staff (1975) and Guthrie and Witty (1982). Most surficial deposits are calcareous and contain variable amounts of primary and secondary calcium carbonate; stages of secondary calcium carbonate morphology (referred to as stages I through IV horizons in this report) are those of Gile and others (1966) and Birkeland (1999). Grain sizes given for surficial deposits and bedrock units are based on field estimates and follow the modified Wentworth (1922) scale (American Geological Institute, 1982) (table 1). In descriptions of surficial map units, the term "clast" refers to the fraction greater than 2 mm in diameter, whereas the term "matrix" refers to the particles less than 2 mm in size. Dry matrix colors of the surficial deposits were determined by comparison with Munsell Soil Color Charts (Munsell Color, 1973). Colors of the surficial deposits generally correspond to those of the sediments and (or) bedrock from which they were derived.

Table 1. Grain sizes in metric and English units (American Geological Institute, 1982).

Clay	less than 0.004 mm	less than 0.00016 inches
Sand	0.062 to 2 mm	0.0025 to 0.08 inches
Granule	2 to 4 mm	0.08 to 0.16 inches
Pebble	4 to 64 mm	0.16 to 2.5 inches
Cobble	64 to 256 mm	2.5 to 10 inches
Boulder	greater than 256 mm	greater than 10 inches

Bedrock colors were determined by comparison with the Geological Society of America Rock-Color Chart (Rock-Color Chart Committee, 1951). Igneous rock terms follow that of the IUGS classification (LeMaitre, 1989). Identification of volcanic units is based mostly on megascopic identification and estimates of phenocryst abundances except where noted. Radiometric ages of units are reported with 2 standard-deviation errors and older K–Ar dates have been corrected to modern standards.

Metric units are used in this report; a conversion table is provided for those more familiar with English units (table 2). A list of the divisions of geologic time used in this report is also provided (table 3).

Table 2. Factors for conversion of metric units to English units to two significant figures.

Multiply	**By**	**To obtain**
centimeters (cm)	0.39	inches
meters (m)	3.3	feet
kilometers (km)	0.62	miles

Table 3. Definitions of divisions of geologic time used in this report.

ERA	Period	Epoch	Years ago
CENOZOIC	Quaternary	Holocene	0 to 10 thousand
		[1]Pleistocene	10 thousand to 1.65 million
	Tertiary	Pliocene	1.65 to 5.3 million
		Miocene	5.3 to 23.7 million
		Oligocene	23.7 to 36.6 million
PALEOZOIC	Permian		245 to 286 million

After Hansen (1991) except for the Pleistocene.

[1]Subdivisions of Pleistocene time are informal and are as follows: late Pleistocene is 10–132 thousand years ago, middle Pleistocene is 132–788 thousand years ago, and early Pleistocene is 788–1,650 thousand years ago (Richmond and Fullerton, 1986). Subdivisions of the Paleozoic follow those of the Geological Society of America (1999).

SURFICIAL UNITS

Alluvial and colluvial deposits

Alluvial and colluvial deposits consist mostly of silt, sand, gravel, and boulders. Both predominant stream alluvium and less abundant debris-flow and sheet-wash deposits are combined in units because alluvium and colluvium are interbedded on a scale that precludes mapping separate alluvial and colluvial units

Qal **Alluvium and colluvium (late Holocene)**—Consists of light-yellowish-brown to very pale brown sand, gravelly sand, and gravel that are generally unconsolidated, poorly bedded, and generally poorly sorted. Intervals of sand range from fine to very coarse and are chiefly coarse; the sand intervals are massive to moderately well bedded and locally crossbedded. Clasts in gravel and gravelly sand are angular to rounded pebbles, cobbles, and boulders as much as 1.5 m across. Clasts of rhyolitic ash-flow tuff and lava are most abundant; clasts of basaltic lava flows and shallow silicic intrusions are locally abundant. The map unit forms channels along modern washes. In channels, bar-and-swale topography is common. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil on the map unit is limited to a thin, sandy, vesicular A horizon developed locally. The thickness of the map unit is 0 to more than 2.5 m

Qae **Alluvium and colluvium (early Holocene and latest Pleistocene)**—Consists of pinkish-gray to light-yellowish-brown gravel and gravelly sand that are unconsolidated to weakly consolidated, poorly to moderately well bedded, and generally poorly sorted. Clasts are angular to subrounded pebbles, cobbles, and boulders generally less than 1 m across. Clasts consist of rhyolitic ash-flow tuff, lava flows, and shallow intrusive rocks except in the west-central part of the map unit; basaltic clasts are also common where derived from local basaltic flows. Sand is fine to coarse and poorly sorted. The map unit forms small fan remnants in south- to southwest-flowing washes on the western side of the Meadow Valley Mountains and along the upper reaches of southeast-flowing washes along the east side of the Meadow Valley Mountains. Deposits of the map unit stand 1–2 m above active washes; surfaces are smooth and generally undissected. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil developed on the map unit consists of a thin, sandy, vesicular A horizon, a B horizon that shows no color difference from that of the parent material, and a 0.4-m-thick C horizon that has stage I carbonate development in the upper part. The thickness of the map unit ranges from 0 to more than 3 m

Qt3 **Alluvial and colluvial terrace deposits (early Holocene and latest Pleistocene)**—Consists of pinkish-gray to light-yellowish-brown gravel and gravelly sand that are unconsolidated to weakly consolidated, poorly to moderately well bedded, and generally poorly sorted. Clasts are angular to subrounded pebbles, cobbles, and boulders generally less than 1 m across. Clasts consist of rhyolitic ash-flow tuff, lava flows, and shallow intrusive rocks. Sand is fine to coarse and poorly sorted. The map unit forms terraces on the eastern side of the Meadow Valley Mountains along southeast-flowing washes that drain the Meadow Valley Mountains. The terraces are equivalent in age to alluvium and colluvium (Qae) because deposits of the map unit stand 1–2 m above active washes, the same as unit Qae. Surfaces are smooth and generally undissected. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil developed on map unit consists of a thin, sandy, vesicular A horizon, a B horizon that shows no color difference from that of the parent material, and a 0.4-m-thick C horizon that has stage I carbonate development in the upper part. The thickness of the map unit ranges from 0 to more than 3 m

Qaj **Alluvium and colluvium of Jumbo Wash (late Pleistocene)**—Consists of light-yellowish-brown to pinkish-gray gravel and gravelly sand that are weakly consolidated, moderately well to poorly bedded, and generally poorly sorted. The map unit is named for deposits along and near Jumbo Wash (Scott, Swadley, and others, 1990) in the Gregerson Basin quadrangle, which is northwest of the adjacent Vigo NW quadrangle (Scott and others, 1991). Clasts consist of angular to rounded pebbles, cobbles, and boulders generally less than 1 m in diameter of local basaltic lava flows, ash-flow tuff, and rhyolitic lava flows. The map unit forms small, poorly exposed, fan remnants mostly in the southwestern part of the quadrangle. Surfaces of the deposits are smooth to slightly dissected and commonly stand 2–4 m above active washes. A loosely to moderately packed stone pavement is locally developed; some surface clasts have a dull-brown rock varnish. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil typically consists of a 2–5-cm-thick, vesicular A horizon of silty sand, a 25–40-cm-thick, yellowish-red, cambic B horizon, and a 0.4-m-thick C horizon that has stage II carbonate development in the upper part. The thickness of the map unit ranges from 0 to more than 6 m

Qt 2.5 **Alluvial and colluvial terrace deposits (late Pleistocene)**—Consists of light-yellowish-brown to reddish-brown gravel and gravelly sand that are weakly consolidated, moderately well to poorly bedded, and generally poorly sorted. Clasts consist of angular to rounded pebbles, cobbles, and sparse boulders generally less than 1 m in diameter of ash-flow tuff and rhyolitic lava flows. The map unit forms small, poorly exposed terraces along south-draining Vigo Canyon wash in the southeastern part of the map area and along the wash to the west of Vigo Canyon. Surfaces of the deposits are smooth and commonly stand 2–3 m above active washes. A loosely to moderately packed stone pavement is locally developed; some surface clasts have a dull-brown rock varnish. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil typically consists of a 2–4-cm-thick, vesicular A horizon of silty sand, a 20–30-cm-thick, yellowish-red, cambic B horizon, and a 0.3-m-thick C horizon that has stage II carbonate development in the upper part. The thickness of the map unit ranges from 0 to more than 3 m

Qt2 **Alluvial and colluvial terrace deposits (late Pleistocene)**—Consists of light-brown to pinkish-gray gravel and gravelly sand that are weakly consolidated, moderately well to poorly bedded, and generally poorly sorted. Clasts consist of angular to rounded pebbles, cobbles, and sparse boulders generally less than 1 m in diameter of rhyolitic ash-flow tuff, lava flows, and shallow intrusive rocks. The map unit forms poorly exposed terraces mostly near the east-central border of the quadrangle. Deposit surfaces are generally slightly dissected and commonly stand 3–4 m above active washes. A loosely to moderately packed stone pavement is locally developed; some surface clasts have a dull-brown rock varnish. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil typically consists of a 2–5-cm-thick, vesicular A horizon of silty sand, a 25–35-cm-thick, yellowish-red, cambic B horizon, and a 0.5-m-thick C horizon that has stage II carbonate development in the upper part. The thickness of the map unit ranges from 0 to more than 3 m

Qaw **Alluvium and colluvium of Willow Spring (middle Pleistocene)**—Consists of pale-brown and pink to reddish-yellow gravel, gravelly sand, and sand that are weakly to moderately well consolidated, poorly bedded, moderately well to poorly sorted, and weakly cemented with secondary calcium carbonate along some bedding planes. The map unit is named for deposits about 3 km south of Willow Spring in the Delamar 3 SE quadrangle (Swadley and others, 1994), which is located two quadrangles to the west and one to the south. Clasts in gravel and gravelly sand consist of angular to rounded pebbles, cobbles, and boulders as much as 1.5 m in diameter of ash-flow tuff and rhyolitic lava flow. Sand is fine to coarse and poorly sorted. The map unit forms small remnants of steep fans of gravel and gravelly sand exposed only along the northwest flank of the Meadow Valley Mountains near the northwest corner of the quadrangle. Depositional surfaces of fans are mostly intact but are moderately dissected by sharp v-shaped washes. A tightly packed stone pavement is locally developed; some surface clasts have a dark-brown, dull to shiny rock varnish. Surfaces of the map unit generally stand 3–5 m above active washes. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil developed on the map unit typically has a 4–6-cm-thick, clayey, silty, and sandy vesicular A horizon, a cambic to slightly argillic B horizon that is sparsely preserved, and a 1–1.5-m-thick carbonate horizon that commonly has stage III carbonate development in the upper part. The thickness of the map unit ranges from 0 to more than 5 m

Qt1 **Alluvial and colluvial terrace deposits (middle Pleistocene)**—Consists of light-brown to light-reddish-brown interbedded gravel, gravelly sand, and sand that are weakly to moderately well consolidated, poorly bedded and moderately well to poorly sorted. The map unit is weakly cemented with secondary calcium carbonate along some bedding planes. Clasts in gravel and gravelly sand consist of angular to rounded pebbles, cobbles, and boulders as much as 1.2 m in diameter of ash-flow tuff, rhyolitic lava flow, and basaltic lava flow. Sand is fine to coarse and poorly sorted. Map unit forms two small terraces exposed only along a wash about 2.4 km east of the western border and 3.6 km north of the southern border of the quadrangle. Depositional surfaces of fans are moderately dissected by sharp v-shaped washes. A tightly packed stone pavement is locally developed; some surface clasts have a dark-brown, dull to shiny rock varnish. Surfaces of the map unit stand 3–6 m above active washes. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil developed on the map unit typically has a 4–6-cm-thick, clayey, silty, and sandy vesicular A horizon, a cambic to slightly argillic reddish-brown B horizon that is only locally preserved, and a 1–1.5-m-thick carbonate horizon that commonly has stage III carbonate development in the upper part. The thickness of the map unit ranges from 0 to more than 6 m

QTa **Alluvium and colluvium (early Pleistocene and Pliocene?)**—Consists of grayish-brown to light-reddish-brown gravel and gravelly sand that are moderately well consolidated, poorly bedded, poorly sorted, and weakly to moderately cemented with secondary calcium carbonate. Clasts consist of angular to subrounded pebbles, cobbles, and boulders of ash-flow tuff and rhyolitic lava flow and shallow intrusive rock. Most boulders are 0.6–1 m in diameter, but some reach 2 m. The map unit forms remnants of a fan near the center of the quadrangle and small fan remnants adjacent to bedrock hills near the northwest and southwest corners of the quadrangle. Depositional surfaces of fans are completely eroded to form rounded interfluves. Based on this more advanced stage of erosion of unit QTa, the map unit is significantly older than the alluvium and colluvium of Willow Spring (Qaw). The map unit is well exposed only in a few cutbanks; typical exposures have rubble-covered slopes littered with 0.6–2-m boulders and abundant chips of pedogenic carbonate. A tightly packed stone pavement is locally present on gently sloping surfaces. Surface clasts commonly have a dark-brown to black rock varnish. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. The soil developed on the map unit typically has a 4–6-cm-thick, vesicular A horizon of clay, silt, and sand overlying a 1–2-m-thick K horizon that has stage III carbonate development in the upper part. The soil commonly conforms to the rounded interfluve surfaces. The map unit is locally as much as 30 m thick

Tas **Aggradational side-stream fan deposits (Pliocene)**—Consists of light-brown to yellowish-red gravel, gravelly sand, and sand that are moderately well consolidated, poorly bedded, poorly sorted, and highly cemented with secondary calcium carbonate. The map unit forms broad fans deposited by side tributaries of Meadow Valley Wash, which is 2–3 km east of the quadrangle. Clasts consist of angular to subrounded pebbles, cobbles, and boulders of rhyolitic ash-flow tuff, lava flows, and shallow intrusive rocks; includes abundant boulders 0.5–1.5 m across and a few as much as 2.5 m across. Four major fans slope gently southeastward at 1.6°: the top of the northernmost fan stands about 18 m above modern washes; the next fan to the south stands somewhat higher at about 30.5 m above modern washes; farther to the south the next fan stands only 10.5 m above modern washes; and the southernmost fan stands 36.5 m above modern washes. A smaller fan remnant on the east side of older ash-flow tuff bedrock (mostly pre-Kane Springs Wash caldera tuffs) is the highest standing fan, at about 42.5 m above modern washes. Map unit Tas is well exposed in numerous cutbanks; typical exposures of fan surfaces are rubble-covered slopes littered with 1–2.5-m boulders and abundant chips of pedogenic carbonate. A tightly packed stone pavement is locally present on gently sloping surfaces. Surface clasts commonly have a dark-brown to black rock varnish. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil horizons have been mostly removed by erosion. A 1–2-m-thick K horizon has stage IV dense plugged carbonate development (Birkland, 1984) in the upper part. Soil commonly conforms to eroded surfaces of the deposits. The map unit is 0 to more than 40 m thick

Tam **Aggradational main-stream fan deposits (Pliocene)**—Consists of pale-brown to yellowish-brown gravel, gravelly sand, and sand that are moderately well consolidated, poorly bedded, poorly sorted, and moderately to highly cemented with secondary calcium carbonate. Clasts consist of subangular to rounded pebbles and cobbles with only sparse small boulders of rhyolitic ash-flow tuff, lava flow, shallow intrusive rock, and basaltic lava flow. The fan deposits form a single 1–1.5-km-wide fan remnant that slopes gently at 0.5° slightly west of south, parallel to Meadow Valley Wash, which is 2–3 km east of the eastern quadrangle border. The upper part of this gently dipping slope has been eroded down to its K-horizon and forms an undissected, remarkably smooth surface (the margins of this surface are shown by a dotted line). Map unit Tam is poorly exposed; typical exposures have rubble-covered slopes littered with abundant chips of pedogenic carbonate and an unmapped colluvial veneer. A tightly packed stone pavement is locally present on gently sloping surfaces. Surface clasts commonly have a dark-brown to black rock varnish. Locally, the map unit includes sheet-wash deposits and debris-flow deposits that were not mapped separately. Soil horizons have been mostly removed by erosion. A 1–2-m-thick K horizon has stage IV dense plugged carbonate development in the upper part (Birkland, 1984). The map unit is 0 to about 25 m thick

Qaw/Tas **Alluvium and colluvium of Willow Spring (middle Pleistocene) over aggradational side-stream fan deposits (Pliocene)**—Unit probably includes some early Pleistocene and Pliocene(?) alluvial and colluvial deposits (QTa) that have not been mapped separately beneath unit Qaw

Eolian deposit

Consists of massive, well sorted, silty, very fine to fine-grained sand

QTes **Eolian silt (early Pleistocene? and Pliocene?)**—Consists of light-brownish-gray to light-gray and light-reddish-gray carbonate-rich silt and minor sand, which are moderately well consolidated, massive, well sorted, and moderately cemented with secondary calcium carbonate. Abundant pedogenic carbonate chips that litter the surface may represent remnants of a soil. The map unit is 0 to more than 2 m thick

Colluvial deposits

Colluvial deposits include unsorted, angular pebbles to boulders deposited by mass wasting of steep bedrock slopes. Although landslides exist in the quadrangle, they are not mapped as a surficial unit; instead, the bedrock units within the landslide bodies are identified, and the contacts of landslides are decorated by an open-tooth symbol on the landslide body

Qc **Colluvium (Quaternary)**—Consists of unconsolidated to well-consolidated talus composed of angular pebble- to boulder-size volcanic rock clasts. Colors are inherited from the source rock. The map unit is generally nonbedded and locally is cemented by secondary calcium carbonate; the map unit exists along base of steep slopes developed on Tertiary volcanic rocks. The map unit includes minor clay, silt, and sand-size material of eolian origin. The thickness of the map unit is undetermined

Tc **Colluvium (Pliocene)**—Consists of well-consolidated talus composed of angular pebble- to boulder-size clasts. Colors are inherited from the volcanic source rock. The map unit is generally nonbedded and is well cemented by secondary calcium carbonate; the map unit exists along base of steep slopes developed on Miocene volcanic rocks. A matrix of fine eolian material is between the larger clasts and is highly cemented with secondary calcium carbonate. The thickness of the map unit is undetermined

BEDROCK UNITS

Post-collapse extracaldera units

Tmh **Muddy Creek and Horse Spring Formations, undivided (late? and middle Miocene)**—Moderate-orange-pink to pale-grayish-orange, sandy siltstone, sandstone, conglomeratic sandstone, and conglomerate. The map unit is poorly exposed and is mostly covered by unmapped colluvial material from aggradational side-stream (Tas) and main-stream (Tam) fan deposits. The upper part of the map unit is more sandstone- and siltstone-rich, whereas the lower part is more conglomerate-rich. Sandstone clasts consist mostly of material derived from silicic ash-flow tuffs and lava flows and to a lesser degree from andesitic and basaltic rocks. Sandstone is fine to coarse grained and commonly contains a high silt content; map unit is poorly sorted, weakly to moderately cemented, and calcareous. Probable soil horizons are locally developed within the sequence. Sandstone beds range from about 0.5 to 2 m thick. Light-brown to pale-yellowish-brown conglomerate and conglomeratic sandstone beds are generally concentrated in scour-and-fill channel structures. Clasts in the conglomerate range from pebbles to small boulders, generally less than 0.4 m in diameter and are composed of volcanic rocks derived from the Meadow Valley Mountains. Conglomerate beds range from 0.05 to 0.15 m thick.

No marker beds are exposed to help distinguish between the Muddy Creek (5 to 11–12 Ma) and Horse Spring (11–12 to 20 Ma) Formations, and poor exposures makes mapping of a contact between the finer upper material and coarser lower material infeasible; therefore, these two formations are undivided. Four km northeast of the northeast corner of the Vigo NE quadrangle in the adjacent Leith quadrangle, a series of basalts are interbedded in rocks that appear to be laterally equivalent to unit Tmh. These basaltic rocks were sampled by R.E. Anderson and dated by H.H. Mehnert (written commun., 1992) by whole-rock K-Ar methods; the lowest basaltic rock was dated at 13.24±0.6 and 13.33±0.6 Ma, and the uppermost basaltic rock was dated at 8.12±0.5 Ma. Armstrong (1970) also dated this younger basaltic rock at 8.5±0.6 Ma. Although the map unit at this locality is lithologically similar to the Horse Spring Formation (Longwell, 1928; Longwell and others, 1965; Bohannon, 1984; Schmidt, 1994), the young basalt age prohibits correlation of the upper part of the map unit with the Horse Spring Formation. Because the upper part of these rocks overlies the youngest basaltic rocks, the upper part must have been deposited during deposition of the lacustrine Muddy Creek Formation (Longwell and others, 1965; Bohannon, 1984). These upper sedimentary rocks probably represent a coarse proximal facies of the Muddy Creek Formation, similar to the coarser basal facies recognized by Bohannon (1984). The map unit in the Vigo NE quadrangle probably represents a transition from coarser proximal facies near the Meadow Valley Mountains and Clover Mountains sources to the more distal and finer facies described by Schmidt (1994) three quadrangles to the south. The map unit in the eastern part of the quadrangle is at least 60 m thick

Tby **Basaltic flows (Miocene)**—Medium-dark-gray and dark-gray basaltic flows have scoriaceous tops and bottoms and are massive in the middle. The map unit is exposed at two localities about 3.5 km north of the southern border and 2.5 km east of the western border of the quadrangle. The flows probably erupted from the basaltic dike (Tbd) that intruded a major fault about 100 m northwest. Because the extracaldera basaltic flows overlie a significant angular unconformity on the Harmony Hills Tuff and because the last major period of extensional deformation occurred close to the time of eruption of the Kane Springs Wash caldera (14 Ma) (Scott, Unruh, and others, 1995), the basaltic rocks probably are considerably younger, perhaps younger than about 11 Ma, which is the age of basaltic flows that erupted from the caldera. The remnants of the map unit are at least 15 m thick

Tbd **Basaltic dike (Miocene)**—The dark-gray massive basaltic dike probably acted as the feeder for the basaltic flow (Tby). The dike is located at only one site about 3.4 km north of the southern border and 2.4 km east of the west border of the quadrangle. The dike is about 25 m wide and 400 m long

Tbt **Bedded tuff (Miocene)**—Pumice-rich, pinkish-gray, rhyolitic, ash-fall(?) tuff was probably erupted from the Kane Springs Wash caldera during the caldera-filling phase of activity. The only mapped exposures are located outside the caldera about 2.2 km east of the west border and 3.5 km north of the south border of the quadrangle. The map unit thickness is as great as 3 m

Post-Collapse Caldera-Filling Units

These map units are located in the eastern part of the Kane Springs Wash caldera in the Meadow Valley Mountains. Some of the uppermost map units are also found outside the caldera because they either overfilled the collapse structure or were deposited by eruptive mechanisms outside the caldera

Tbiu **Upper basaltic intracaldera flows (Miocene)**—Dark-gray and medium-dark-gray basaltic flows contain 10% phenocrysts that consist of about 50% clinopyroxene, 50% slightly altered olivine phenocrysts, and a trace of plagioclase; the map unit includes minor basaltic andesitic flows. The map unit is exposed in the southwestern part of the map area where it caps both caldera-filling rocks to the north and also caldera outflow facies consisting of the Kane Wash Tuff. K-Ar whole-rock ages of the basaltic flows are 11.4±0.4 and 11.6±0.4 Ma (Novak, 1984). The map unit generally forms gentle hillsides on dip slopes and cliffs where flows have been deeply eroded; at least 60 m thick

Tard **Aphyric rhyolitic dikes (Miocene)**—Very light gray to light-brownish-gray, massive or flow-banded, aphyric rhyolitic dikes, locally having glassy margins. Some dikes contain minor (<10%) phenocrysts of sanidine and quartz. The distribution of dikes is restricted to northeastern part of quadrangle in Meadow Valley Mountains. Dikes dip steeply and generally trend northward, suggesting that the direction of extension was essentially east-west during magmatic dilation of the caldera during post-collapse filling (Scott, Unruh, and others, 1995). An unusual feature of these dikes is the 1.0 by 0.7 km oval body just west of Avertt Reservoir. At several localities along the vitrophyric dike margin, the rock displays a strongly eutaxitic foliation that dips at moderate attitudes into the body (33–44°). It has sparse quartz and sanidine phenocrysts, 15–20 % pumice fragments, and 15% lithic fragments. This marginal rock facies was emplaced as an ash flow. Farther from the margin, the foliations increase significantly and the rock is a typical aphyric dike. This suggests that the magma that was injected along the margins was sufficiently gas rich to erupt as a pumice- and lithic-rich froth on the edges of a funnel-shaped orifice, the core of which was subsequently filled with less gas-rich, hotter, and aphyric magma. Dikes range from 1 to 800 m wide; the largest is about 800 m wide and 1,800 m long

Trd **Rhyolitic dikes (Miocene)**—Grayish-pink, pale-red-purple, medium-light-gray, light-brownish-gray, and very light gray phenocryst-bearing rhyolitic dikes include quartz-sanidine-mafic, quartz, quartz-sanidine, and sanidine phenocryst assemblages. Rhyolitic dikes range from massive to flow-banded; vitrophyres are sparse. Phenocryst contents range from <1 to 25%. Rhyolitic dikes are commonly exposed within the caldera but are less abundant in the southern and eastern parts near the caldera boundaries. Rhyolitic dikes generally dip steeply to the west, have moderate or no topographic expression, and are commonly <1 m to 10 m wide, but are locally as much as 180 m wide

Trds **Rhyolitic dike swarm (Miocene)**—The swarm of very light gray to light-gray, massive or flow-banded, aphyric rhyolitic dikes locally has glassy margins too numerous and thin to map separately. These dikes dip steeply and generally trend northward roughly parallel to dikes described above. The map unit is in the northwestern part of the map area near the west border of the quadrangle. The swarm is about 800 m wide and 1,300 m long

Tar **Aphyric rhyolitic flows (Miocene)**—Medium-light-gray to pale-red-purple, massive or flow-banded, aphyric rhyolitic flows, locally have vitrophyric margins. The vitrophyres are blackish red, dark gray, and black; grayish-red spherulites mark devitrification centers. A minor, partially welded, grayish-orange aphyric ash-flow tuff is locally present and contains about 10% lithic fragments. The map unit is restricted to the caldera in the northeastern part of the quadrangle. The thickness of the flows is as great as 200 m

Trf **Rhyolitic flows (Miocene)**—Light-gray, medium-light-gray, grayish-orange-pink, yellowish-gray, and grayish-red, mostly devitrified, massive to autobrecciated rhyolitic lava flows commonly contain vitric basal zones. The rock generally contains phenocrysts of quartz and sanidine. Phenocryst abundances are generally less than 5 % but can range to as much as 20 %; however, some of the rock is nearly to totally aphyric. The vitric basal zones are generally black to dark gray; spherulitic devitrification centers and opalized patches are particularly abundant near opal prospects close to Avertt Reservoir. Although most of the opal is white to light bluish gray, some is iridescent, and opal either fills spherulitic voids or cracks in devitrified glass. Map unit Trf is present in the southeastern part of the caldera and is as great as 40–50 m thick

Tyt **Yellow ash-flow tuff (Miocene)**—Very pale orange, grayish-orange-pink, and grayish-yellow, devitrified, nonwelded to partially welded, rhyolitic ash-flow tuff includes minor ash-fall tuff and bedded tuff. Very dusky red and medium-gray lithic fragments form 5–15% of the tuff, very pale orange to white and pale-greenish-yellow pumice fragments form 15–75% of the tuff, and the tuff contains no recognized indigenous phenocrysts. In some parts of the caldera, the tuff is separated into an upper and lower part by the distinctive marker bed of red ash-flow tuff (Traf). The map unit forms gentle, rounded slopes and ranges from 0 to 230 m thick

Traf **Red ash-flow tuff (Miocene)**—Pale-red, pale-reddish–brown, and grayish-red, moderately to densely welded ash-flow tuff that locally separates the yellow bedded tuff (Tyt) into an upper and a lower interval. The upper, less welded part of map unit Traf is crystal poor, containing < 5% subequal quartz and sanidine phenocrysts and 25% non-flattened, white pumice fragments that are 0.1–2 cm in diameter. The lower, densely welded part contains 20% phenocrysts with subequal quartz and sanidine and 10% highly flattened, grayish-red pumice fragments. The lower part has sanidine crystals 5 mm long, whereas the upper part has sanidine only 1 mm long. As unit Traf is generally less than a few meters thick, it is also shown as a single line within unit Tyt on the map

Tgr **Gray rhyolite flows (Miocene)**—Light- to medium-gray devitrified rhyolitic lava flows commonly have thick brownish-gray to grayish-black chilled vitric basal zones. In several areas, the glass has been altered to pale-red, vug-like, 1–2-cm-diameter hollow spherulites in a yellowish-gray matrix. The rock contains 0–15% phenocrysts that commonly consist of about 30–70% sanidine, 20–60% quartz, and minor mafic phases. The thickness of the map unit is estimated to be as much as 150 m

Tbrf **Biotite-rhyolitic flows (Miocene)**—Very light gray, light-brownish-gray, and pale-red, devitrified, aphyric, thinly flow-banded (1–2 mm), rhyolitic flows consist of two similar flows. Both flows locally have 5-m-thick glassy bases but the upper has distinctive marekanites (Apache tears) that erode from its glassy base. The map unit is exposed near the west border of the quadrangle, forms steep slopes, and is as thick as 110 m

Tbrd **Biotite-rhyolitic dikes (Miocene)**—Very light gray to pale-red-purple, devitrified, massive, biotite-rhyolitic dikes locally include vitrophyres at the margins. Rock typically contains 15% phenocrysts of 50% quartz (<2 mm across), 40% sanidine (<4 mm long), and 10% biotite (<2.5 mm long), and altered mafic phases. The K-Ar biotite date of 13.1±0.5 Ma and sanidine date of 12.8±0.5 Ma are conformable (Harald Mehnert, written commun., U.S. Geological Survey, 1990). The dikes are located in the northwestern part of the map area. Dikes form small ridges and are typically 2–20 m wide but locally are 60 m wide

Trlr **Red-lithic rhyolitic ash-flow tuff (Miocene)**—Pale-red to dusky-red, flow-banded to massive and autobrecciated rhyolitic ash-flow tuff contains grayish-red basaltic xenoliths. The presence of lithic fragments and weakly formed eutaxitic textures suggest that the map unit was emplaced by ash flow rather than lava flow, and the autobreccia is probably related to post-emplacement flow. Locally the rock contains as great as 15% phenocrysts that consist of 75% quartz and 25% sanidine. A local vitrophyre is near the base, and spherulitic devitrification is common at the devitrification boundary. Size, abundance, and distribution of basaltic lithic fragments differ greatly with locality; some fragments are as great as 15 cm long. The groundmass of the lithic fragments contains plagioclase and pyroxene. The map unit is found on the far western side of the map area within the caldera; forms gentle slopes to steep cliffs; as thick as about 60 m

Tt **Trachytic stock (Miocene)**—Pale-red trachytic or trachyandesitic stock intruded caldera-filling units to the level of the comenditic zone of the columnar-jointed cooling unit of the lower part of the Gregerson Basin Member of the Kane Wash Tuff (Tkjc). The rock is massive, has no flow banding, and contains 50% phenocrysts that consist of about 50% potassium feldspar, 40% altered plagioclase(?), and 10% altered mafic phases. The stock is present near the northwest corner of the quadrangle and is 0.6 km wide where exposed

Tbil **Lower basaltic intracaldera flows (Miocene)**—Medium-dark-gray to grayish-black, generally massive, basaltic flows contain sparse clinopyroxene, plagioclase, and partially altered olivine phenocrysts less than 1 mm long. The map unit is restricted to the caldera near the west border of the quadrangle. In the northwestern part of the map area, an exposure of basaltic flows with a scoriaceous base rests on the comenditic zone of the flow-lineated upper part of the Gregerson Basin Member of the Kane Wash Tuff (Tkfc). This relationship requires a local absence of the trachytic zone of the flow-lineated upper Gregerson Basin Member (Tkft). The map unit is locally as thick as 25 m

Twb **Caldera wall breccia (Miocene)**—Coarse, angular, boulder breccia was deposited as a wedge along the topographic wall or margin of the Kane Springs Wash caldera and consists mostly of clasts of precaldera trachytic flow (Tpt) and the Grapevine Spring Member (Tkg) of the Kane Wash Tuff. Clasts range from 2 mm to 2 m long and are light grayish brown. The clasts are set in a pale-reddish-brown, partially welded tuffaceous matrix. The matrix contains phenocrysts of quartz and sanidine. In some localities the clasts are in a matrix of moderate-reddish-brown, aphyric, welded volcanic ash. The breccia is exposed at two small localities along the southeast side of the caldera wall. Locally, exposures of the map unit are 60 m wide but the map unit has an unknown thickness

Kane Springs Wash caldera in-filling units

Kane Wash Tuff (Miocene)—The intracaldera part of the Kane Wash Tuff generally consists of two members: the Gregerson Basin Member and the underlying Grapevine Spring Member. The intracaldera part of the Grapevine Spring Member is not exposed in the Vigo NE quadrangle, but is exposed in the adjoining Vigo NW quadrangle (Scott and others, in press)

Gregerson Basin Member—The intracaldera part of the Gregerson Basin Member consists of two cooling units: an upper cooling unit informally called the flow-lineated cooling unit of the Gregerson Basin Member and a lower cooling unit informally called the columnar-jointed unit of the Gregerson Basin Member. Locally, two informal volcanic units are between the flow-lineated cooling unit and the columnar-jointed unit; these units are the quartz-rich rhyolitic ash-flow tuff (Tkqr) and the underlying welded lithic-rich rhyolitic tuff (Tkwl), both found near the western edge of the caldera near the northern quadrangle boundary

Flow-lineated cooling unit—The cooling unit displays conspicuous flow lineations in the densely welded part of the cooling unit. The cooling unit consists of two zones: a trachytic zone and a comenditic zone

Tkft **Trachytic zone**—Consists of pale-red to grayish-red, trachytic to comenditic tuff. At the top it is frothy, but it is a densely welded ash-flow tuff at the base. The map unit contains abundant grayish-red trachytic inclusions. The map unit is interpreted to be the inflow-facies equivalent of the trachytic zone of the upper cooling unit of the Gregerson Basin Member of the outflow facies of the Kane Wash Tuff. Although the outflow facies equivalent of this map unit is not exposed in this quadrangle, it is well exposed in the Gregerson Basin quadrangle, two quadrangles to the west and one to the north (Scott and others, 1991). The map unit contains 22–39% phenocrysts that consist of 27–29% quartz, 57–61% sanidine, <1–5% opaque phases, 9–11% mafic phases (clinopyroxene?) (two thin sections, 2069 and 2707 total counts). Trachytic inclusions form <1% to 25% of the rock, contain alkali-feldspar phenocrysts, range from 1 cm to 2.5 m long, and are generally elongate parallel to the foliation of the ash-flow tuff matrix. The trachytic zone forms gentle slopes and ranges from 0 to about 80 m thick

Tkfc **Comenditic zone**—The map unit consists of a densely welded, devitrified, light-gray to pale-red tuff that contains stringers of highly flattened, very light gray pumice fragments aligned parallel to foliation. The map unit is interpreted to be the inflow-facies equivalent of the comenditic zone of the upper cooling unit of the Gregerson Basin Member of the outflow facies of the Kane Wash Tuff. Although the outflow-facies of this unit of the Kane Wash tuff is not exposed in this quadrangle, it is well exposed in the Gregerson Basin quadrangle (Scott and others, 1991). Locally prominent flow lineations form 1–2-mm-high ridges and are on the foliation planes. The map unit contains about 20–35% phenocrysts that consist of 30% quartz (most <2 mm in diameter), 60% sanidine (<5 mm long, some adularescent), 10% mafic phases (altered grayish red, possibly pyroxene). The densely welded, well-layered, 3-m-thick basal part of the comenditic zone has highly distinctive stratigraphic sequences. At one locality from top to bottom, it contains a pale-red, hackly fractured layer containing 20% phenocrysts; a pale-red and light-greenish-gray to dark-yellowish-brown layer containing 10% phenocrysts including some white, altered sanidine; a grayish-red layer containing <5% phenocrysts; a pale-red layer containing 50% phenocrysts of quartz and sanidine; and a black vitrophyre. These layers probably represent a sequence of welded ash-fall tuffs or possibly surge deposits. Locally, close to the bottom of the basal part, a relatively crystal-poor, light-gray, devitrified tuff (< 5% quartz and sanidine) contains 3–5-cm ovoids of crystal-rich, pale-red, devitrified tuff (15–20% quartz and sanidine). In the eastern part of the caldera near the northern border of the quadrangle, the basal part of the map unit consists of grayish-pink, pumice-rich tuff. The K-Ar sanidine dates of the map unit are 14.6±0.4 and 14.9±0.5 Ma (Harald Mehnert, written commun., U.S. Geological Survey, 1990), and the $^{40}Ar/^{39}Ar$ sanidine date is 14.43±0.14 Ma (Scott, Unruh, and others, 1995). The comenditic zone forms steep slopes and cliffs. The map unit is as much as 180 m thick

Tkqr **Quartz-rich rhyolitic ash-flow tuff**—White to pale-red, somewhat mottled, rhyolitic ash-flow tuff contains 25% phenocrysts that consist of 80% quartz and 20% sanidine. The map unit is isolated to a few exposures in the northeastern part of the quadrangle within the eastern wall of the caldera. The map unit is less than 50 m thick

Tkwl **Welded lithic-rich rhyolitic tuff**—Yellowish-gray to pale-olive, lithic-rich rhyolitic tuff contains <5% quartz and sanidine phenocrysts within its moderately welded ash matrix. The rock typically includes 20–30% lithic fragments of dark-gray glassy and yellowish-gray, sanidine- and quartz-bearing, rhyolitic lava flow that are 2–4-cm in diameter. The map unit is present in a few exposures in the northeastern part of the quadrangle within the eastern wall of the caldera, and it is less than about 60 m thick

Columnar-jointed cooling unit—The cooling unit displays conspicuous columnar joints in the densely welded part of the cooling unit. The cooling unit consists of two zones, a trachytic zone and a comenditic zone

Tkjt **Trachytic zone**—The partially welded, grayish-pink to pale-red-purple, comenditic to trachytic ash-flow tuff consists of a comenditic matrix that contains a range of abundances of trachytic inclusions. The map unit is interpreted to be the inflow facies equivalent of the trachytic zone (unit Tkblt) of the lower cooling unit of the Gregerson Basin Member of the outflow facies of the Kane Wash Tuff. The inflow map unit contains 7% phenocrysts that consist of 27% quartz, 62% sanidine, 2% opaque phases, and 8% mafic phases (clinopyroxene?) (1 thin section, 3,483 total counts). The map unit is exposed near the northern border of the quadrangle and is about 35 m thick

Tkjc **Comenditic zone**—Consists mostly of a densely welded, devitrified, light-gray to medium-light-gray, ash-flow tuff. The map unit is interpreted to be the inflow facies equivalent of the comenditic zone of the lower cooling unit (Tkblc) of the Gregerson Basin Member of the outflow facies of the Kane Wash Tuff. Rock has a weak foliation, but columnar jointing is locally distinctive. The upper part of the map unit contains 15% phenocrysts consisting of 30% quartz, 60% sanidine (some adularescent), and 10% mafic phases (pyroxene?). The upper part is about 90 m thick. The basal part is densely welded, layered, and generally < 5 m thick, but locally it is < 30 cm thick. From top to bottom, the basal part consists of a light-bluish-gray layer containing 20% phenocrysts, a pale-red layer containing 20% phenocrysts, a black vitrophyric layer, and a greenish-gray altered vitrophyre at the basal contact. The K-Ar sanidine date of the columnar-jointed ash-flow tuff is 14.6±0.5 Ma (Harald Mehnert, written commun., U.S. Geological Survey, 1990). The upper part forms gentle slopes, and the basal and middle parts form steep slopes and cliffs. The map unit is about 130 m thick

Tlt **Lower tuffs (Miocene)**—Shown in cross section only. Probably inflow facies equivalent to the Grapevine Spring Member of the Kane Wash Tuff and older units that were mapped in the Vigo NW quadrangle are present at depth here

Kane Springs Wash caldera outflow units

The older stratigraphic nomenclature of Cook (1965), Noble (1968), and Novak (1984) have been replaced by the nomenclature of Scott and others (1993) and Scott, Unruh, and others (1995). The stratigraphic relationships of the Kane Springs Wash caldera complex and vicinity have been summarized by Scott, Unruh, and others (1995) and Scott, Grommé, and others (1995)

Kane Wash Tuff (Miocene)—Consists of two ash-flow tuff members: the Gregerson Basin Member and the underlying Grapevine Spring Member

Gregerson Basin Member—Consists of an upper and a lower cooling unit. Only the lower cooling unit is present in the Vigo NE quadrangle

Lower cooling unit—The cooling unit consists of trachytic zone that overlies a comenditic zone

Tkblt **Trachytic zone**—Caps the lower cooling unit of the Gregerson Basin Member and is mostly devitrified, partially welded to moderately welded, and brownish-gray to light-brownish-gray, comenditic to trachytic ash-flow tuff. The map unit contains as much as 20% cognate trachytic inclusions that are typically 1–4 cm long but as great as 10 cm long, pale brown to grayish brown, contain about 25–30% phenocrysts of alkali feldspar, and are slightly to highly scoriaceous. Only the basal 5 m of the map unit are present at the one isolated exposure in the central part of the quadrangle

Tkblc **Comenditic zone**—Consists of comenditic ash-flow tuff that contains upper, middle, and basal parts. The upper part is devitrified, moderately to densely welded, and grayish pink to yellowish gray. The upper part contains about 20% highly flattened pumice fragments that enhance parting parallel to the plane of compaction, has 0–5% lithophysal cavities that contain vapor-phase crystals of amethyst and blocky mafic minerals (riebeckite and unidentified phases). The ash-flow tuff contains about 35–40% phenocrysts that consist of 25% quartz, 60% sanidine, and 15% hedenbergite, fayalite, and ilmenite; iron-rich phases are commonly altered. Sanidine crystals are commonly 2–5 mm in diameter. Upper part is as thick as about 200 m near the caldera wall. The middle part is devitrified, moderately to densely welded, commonly mottled light bluish gray and light brownish gray, and has phenocryst abundance and ratios similar to the upper part. The middle part ranges from 1 to 5 m thick. The basal part is commonly nonwelded to partially welded, moderate orange pink to pale yellowish orange, contains slightly fewer phenocrysts than the middle part, and is 1–2 m thick. Compaction foliation partings follow boundaries between 1– to 10-cm-thick layers of tuff that differ greatly in phenocryst abundances (2–15%); these layers probably represent welded ash-fall and(or) base surge tuff. Phenocryst-poor layers display sanidine crystals 1–2 mm in diameter. The map unit is characterized by locally conspicuous, adularescent sanidine phenocrysts. The K-Ar sanidine date for the lower cooling unit is 14.1±0.4 Ma (Novak, 1984), and the $^{40}Ar/^{39}Ar$ sanidine date is 14.55±0.14 Ma (Scott, Unruh, and others, 1995). The map unit forms cliffs to moderate slopes. The comenditic zone is locally as thick as 220 m at the caldera boundary but thins significantly to the south

Tkg **Grapevine Spring Member**—Rhyolitic to trachytic ash-flow tuff consists of one compound cooling unit. Whereas the map unit grades downward through four zones that locally include a poorly developed trachytic cap above upper, middle, and lower rhyolitic zones in the adjoining Vigo NW quadrangle (Scott and others, in press), only middle and lower zones are present in this quadrangle. The middle zone is devitrified, densely welded, and light brownish gray to brownish gray. The middle zone weathers to form a rough-textured, hackly surface; this hackly texture may be related in part to a relatively high abundance of phenocrysts (20–30%). The middle zone contains few recognizable pumice fragments and less than 10% lithophysal cavities, which have minor vapor-phase crystals of quartz and sparse garnet. Phenocrysts in the middle zone include 25% quartz, 60% sanidine, and 15% hedenbergite, fayalite, and ilmenite. The middle zone contains less than 2% lithic fragments and ranges from about 20 m thick close to the caldera wall but is thinner farther from the caldera. The lower zone grades downward from moderate-brown, partly devitrified, partly vitric, densely welded, locally lithophysal tuff to pale-brown and dark-yellowish-brown nonwelded tuff. Where the vitrophyre is preserved, it is dark gray and contains grayish-red, spherulitic, devitrification centers. Lower zone is about 2 m thick. Map unit forms moderate to rugged slopes where dips are moderate or gentle. Only a small bench marks the cooling break at the upper contact with the overlying Gregerson Basin Member. The map unit is characterized by a moderate abundance of adularescent sanidine phenocrysts. The K-Ar sanidine dates for the map unit are 14.0±0.4 and 14.2±0.4 Ma (Novak, 1984), and the $^{40}Ar/^{39}Ar$ sanidine date is 14.67±0.22 Ma (Scott, Unruh, and others, 1995). The Grapevine Spring Member is only 35–40 m thick near the caldera margin in the Meadow Valley Mountains and thins to 25 m in the south part of the quadrangle

Pre-Kane Springs Wash caldera units

Tpt **Precaldera trachyte (Miocene)**—Pale-red to grayish-red, devitrified, trachytic lava flow contains conspicuous alkali feldspar phenocrysts. The map unit was named by Novak (1984). Alkali feldspar phenocrysts form about 35% of the rock, range from 0.25 to 1 cm long, have a sieved texture and are zoned. Sparse, altered, mafic phenocrysts are probably clinopyroxene. The trachytic flow is massive and has no flow banding, but about 5% of the rock consists of pores 1 mm in diameter that are coated with secondary silica and altered feldspar and mafic phases. The K-Ar sanidine dates from the map unit are 14.1±0.4 and 14.7±0.4 Ma (corrected to new standards) (Novak, 1984). The map unit forms moderate slopes and is adjacent to the southeastern caldera wall near the center of the quadrangle. At least 140 m of the unit are exposed, but the upper part has been removed by caldera collapse.

Tpr **Pumice-rich ash-flow tuff of Narrow Canyon caldera (Miocene)**—Pale-purple, moderately to densely welded, devitrified, rhyolitic ash-flow tuff was erupted from the Narrow Canyon caldera, the oldest recognized caldera in the Kane Springs Wash caldera complex (Scott, Unruh, and others, 1995). The rock contains about 20% phenocrysts that consist of 60% sanidine, 35% quartz, and about 5% altered mafic phases. Highly flattened, light-gray pumice fragments are conspicuous and form about 25% of the tuff; lithic fragments are sparse. The $^{40}Ar/^{39}Ar$ date for the sanidine in this unit is 15.77±0.16 Ma (Scott, Unruh, and others, 1995). Map unit is present just outside the southeastern wall of the caldera in the central part of the map and is about 60 m thick

Sunflower Mountain Tuff, undivided (Miocene)—Consists of a more highly welded upper zone and a less welded lower zone that may represent different cooling units. The K-Ar date for the tuff is 15.1 Ma (Novak, 1984; Scott, Unruh, and others, 1995). The Sunflower Mountain Tuff appears to be chemically related to the magmas of the Kane Springs Wash caldera complex although no caldera source had been recognized (Scott, Unruh, and others, 1995)

Tsmu **Upper zone**—Consists of pinkish-gray to pale-red, devitrified, partially welded to moderately welded rhyolitic ash-flow tuff. Pumice fragments form about 10% of the rock and are 1–2 cm long in the plane of foliation. The rock contains 20% phenocrysts that consist of subequal amounts of quartz and sanidine and sparse hedenbergite and fayalite, and volcanic lithic fragments form about 2% of the rock. The map unit is present in the hills in the southwestern part of the quadrangle, forms moderate slopes, and has a thickness of 50 m

Tsml **Lower zone**—Consists of grayish-orange-pink to grayish-pink, devitrified, nonwelded to partially welded, mottled, rhyolitic ash-flow tuff. White pumice fragments form about 20% of the rock and are 0.5–2 cm long. The rock contains about 10% phenocrysts that consist of subequal amounts of quartz and sanidine and sparse altered mafic minerals. Volcanic lithic fragments form about 10–20% of the rock. The map unit forms gentle to moderate slopes, is present in the hills in the southwestern part of the quadrangle and at one locality just outside the southeastern caldera wall, and has a thickness of about 130 m

Ts **Tuffaceous sandstone (Miocene)**—Moderate-orange-pink, medium-grained, poorly exposed, bedded tuffaceous sandstone is exposed locally only on the western side of the hills in the southwestern part of the quadrangle. The map unit is about 0–5 m thick

Tdl **Delamar Lake Tuff (Miocene)**—Pale-red, devitrified, moderately to densely welded rhyolitic ash-flow tuff consists of one cooling unit. No caldera source has been recognized for this tuff although it is found in the vicinity of the Kane Springs Wash caldera. Pinkish-gray to grayish-red, flattened, eutaxitic pumice fragments as large as 3.5 cm across in the plane of foliation form about 10% of the tuff. The rock contains about 20% phenocrysts that consist of 25% quartz, 70% sanidine, and 5% fayalite and other mafic minerals. Less than 7% of the rock consists of lithic fragments. The K-Ar sanidine dates for the unit are 15.5±0.4 and 15.8±0.4 Ma (Novak, 1984), and the $^{40}Ar/^{39}Ar$ sanidine date of the unit is 16.06±0.08 Ma (Scott, Unruh, and others, 1995). Delamar Lake Tuff is exposed in the hills in the southwest part of the quadrangle where it is as great as 190 m thick

Th **Hiko Tuff (Miocene)**—Rhyolitic to dacitic ash-flow tuff consists of one cooling unit. The rock is devitrified, moderately welded, and light brownish gray. Pumice fragments form 10–25% of the rock, are pale pink to white, and as long as 3 cm in the plane of foliation; locally, pumice fragments have been welded to form medium-gray fiamme. The rock contains about 35% phenocrysts that consist of 25% very pale purple quartz, 25% sanidine, 35% plagioclase, 10% biotite, and <5% hornblende and pyroxene. Locally, some zones in the tuff contain as much as 25% lithic fragments, but most of the tuff contains about 10%. The Hiko Tuff is the youngest calcalkaline tuff to erupt prior to the metaluminous to peralkaline tuffs related to the Kane Springs Wash caldera complex. The Hiko was erupted from the Caliente caldera complex to the north (Rowley and others, 1995). An $^{40}Ar/^{39}Ar$ biotite date for the Hiko Tuff is reported as 18.5±0.4 Ma, another estimate is 18.6 Ma based on other data (see Taylor and others, 1989). However, the best age estimate probably is the $^{40}Ar/^{39}Ar$ sanidine date of 18.19±0.14 Ma (Scott, Unruh, and others, 1995). The Hiko Tuff is exposed in the hills in the southwest part of the quadrangle and locally has been slightly hydrothermally altered. The unit thickness is about 80 m

Thh **Harmony Hills Tuff (Miocene)**—Andesitic ash-flow tuff consists of one cooling unit grading downward from a nonwelded and partially welded upper zone to a moderately to densely welded central zone to a nonwelded base. The tuff is devitrified, phenocryst-rich, and massive, displaying crudely developed foliation, and it is pale red where less welded and grayish purple to pale red purple where more highly welded. Pumice fragments are sparse. The rock contains 45-55% phenocrysts that consist of 5% quartz, 65% plagioclase, 15% biotite, 10% hornblende, and less than 5% clinopyroxene. Lithic fragments are generally sparse, but one sample contains a rounded (partially resorbed?) 5-cm-diameter fragment of hornblendite, possible evidence of lower crustal magmatic involvement, indicated by the Nd, Sr, and Pb isotopic signature of the tuff (Scott, Unruh, and others, 1995). Five K-Ar dates of the Harmony Hills Tuff by Armstrong (1970) and one by Noble and McKee (1972) average 21.6 Ma for the map unit; however, isotopic dates of 22–22.5 Ma for plutons and an ash-flow tuff that postdate the Harmony Hills Tuff in the Iron Springs District of southwestern Utah may provide a better minimum age constraint (Rowley and others, 1989). Although the Harmony Hills Tuff, the Bauers Tuff Member of the Condor Canyon Formation (Tcb), and the Leach Canyon Formation (Tlc) were included in the Quichapa Group (Cook, 1957; Williams, 1967; Anderson and Rowley, 1975), the group name is not used here because the source(s) of two of the ash-flow tuffs within the group have not been recognized and they may not be genetically related. The unit forms gentle to steep slopes. The Harmony Hills Tuff is exposed in the hills in the southwest part of the quadrangle and locally has been slightly hydrothermally altered. The thickness of map unit is about 200 m

Tcb **Bauers Tuff Member of the Condor Canyon Formation (Miocene)**—Rhyolitic ash-flow tuff consists of one simple cooling unit, which is moderately to densely welded, devitrified, pale red purple, pale purple, and moderate yellowish brown. Highly flattened pumice fragments are elongate (1–25 cm long) lenticules that form about 25% of the rock. The rock contains about 10% phenocrysts that consist of 30% sanidine, 65% plagioclase, 5% biotite, and a trace of hornblende. About 5% of the rock consists of volcanic lithic fragments that are <1 cm in diameter. The unit forms indistinct ledges. The $^{40}Ar/^{39}Ar$ date for the Bauers Tuff Member is 22.8±0.03 Ma (Best and others, 1989), but Best and others (1993) suggest that 22.7 Ma based on several analyses is a better estimate. The map unit is exposed on the eastern side and the northern end of the hills in the southwestern part of the quadrangle, locally has been slightly hydrothermally altered, and is about 45 m thick

Tlc **Leach Canyon Formation (Oligocene)**—Rhyolitic ash-flow tuff consists of one compound cooling unit and grades downward from grayish-orange-pink moderately welded devitrified tuff to pinkish-gray nonwelded to partially welded devitrified tuff at the base. Pumice fragments are less than 0.5 cm in diameter and form less than 5% of the rock. The rock contains about 15% phenocrysts that consist of 35% quartz, 25% sanidine, 35% plagioclase, 5% biotite, and a trace of hornblende sphene. Lithic fragments are sparse. The unit forms gentle, undulating slopes. The average K-Ar age of Leach Canyon Formation is about 24.7 Ma (Armstrong, 1970), and Best and others (1993) report an $^{40}Ar/^{39}Ar$ sanidine date of 23.8 Ma. The map unit is exposed on the eastern side of the hills in the southwest part of the quadrangle; locally the tuff has been slightly hydrothermally altered. The unit is thicker than the 270-m thickness of the tuff exposures because the upper part of the unit has been removed by faulting

Tt1 **Unnamed rhyolitic ash-flow tuff (Oligocene)**—Consists of pale-red to grayish-red, crystal-poor ash-flow tuff that displays a pronounced eutaxitic texture and contains about 10% phenocrysts that consist of 50% sanidine, 20% quartz, 10% plagioclase, and 10% biotite and hornblende. About 20 percent of the rock contains highly flattened, eutaxitic pumice fragments; about 10% of the rock consists of lithic fragments. The map unit is exposed in one uplifted fault block on the eastern side of the hills in the southwestern part of the quadrangle. The map unit is only about 4 m thick

Trls **Unnamed red limestone (Oligocene)**—Pale-red to light-gray, wavy-bedded algal limestone is exposed in one uplifted fault block on the eastern side of the hills in the southwestern part of the quadrangle. This limestone and the four underlying limestone and conglomeratic units described below (Tgls, Tlpc, Tl, and Tcg) may be partly correlative with the Claron Formation of southwestern Utah. The map unit has a thickness of about 3.5 m

Tgls **Unnamed gray limestone and pebble conglomerate (Oligocene)**—Light-gray algal limestone interbedded with a pebble conglomerate composed of Paleozoic sedimentary clasts is exposed in one uplifted fault block on the eastern side of the hills in the southwestern part of the quadrangle. The unit is about 8 m thick

Tt2 **Unnamed rhyolitic ash-flow tuff (Oligocene)**—Pale-red, devitrified, moderately welded, sanidine- and quartz-phyric ash-flow tuff contains about 15–20% phenocrysts that consist of 55% sanidine, 40% quartz, minor plagioclase, and <5% biotite. Toward the base of the unit, a brownish-gray vitrophyre is present. Moderately flattened pumice fragments form about 10 % of the rock and are as much as 3 cm long. No lithic fragments are present. The map unit is exposed in one uplifted fault block on the eastern side of the hills in the southwestern part of the quadrangle. The thickness of the map unit is about 12 m thick

Tlpc **Unnamed gray limestone and red pebble conglomerate (Oligocene)**—Light-gray to medium-gray limestone is interbedded with grayish-orange-pink to pale-red pebble and cobble conglomerate containing both volcanic and Paleozoic sedimentary clasts. The map unit is exposed in one uplifted fault block on the eastern side of the hills in the southwestern part of the quadrangle. The limestone has wavy bedding characteristic of algal growth laminations. The unit thickness is about 10 m

Tt3 **Unnamed rhyolitic ash-flow tuff (Oligocene)**—Rhyolitic ash-flow tuff grades downward from a pale-red, densely welded devitrified zone to a dusky-red to blackish-red vitrophyre. The tuff contains about 20–30% phenocrysts that consist of 40% quartz, 30% plagioclase, 20% sanidine, and 10% biotite; minor small pumice fragments (<1 cm diameter) make up < 5% of the rock. No lithic fragments are present. The map unit is exposed at two small uplifted fault blocks on the eastern side of the hills in the southwestern part of the quadrangle; the exposed thickness of the unit is < 80 m but some of the map unit has been removed by faulting

Tl **Unnamed limestone (Oligocene)**—The map unit is a poorly exposed, grayish-pink to pale-red limestone and silty limestone. The bedding is thin, typically 2–6 cm, and displays wavy (algal?) bedding. The unit is exposed at one locality about 2.7 km east of the western border and 1.3 km north of the southern border of the quadrangle. The exposed thickness of the map unit is < 40 m, but the lower part of the unit has been faulted out

Tcg **Unnamed cobble conglomerate (Oligocene)**—Consists of light-gray, massive, poorly bedded, well consolidated cobble conglomerate cemented by calcium carbonate. Clasts consist of Paleozoic limestone, dolomite, and quartzite. The poorly exposed unit is at least 30 m thick, and its base is not exposed

Pkt **Kaibab Limestone and Toroweap Formation, undivided (Lower Permian)**—Cherty limestone, silty limestone, and hackly limestone overlie a basal cherty limestone breccia. The cherty limestone has pale-red to pale-reddish-brown fresh exposures, light-brown weathered surfaces, and irregular dark-yellowish-brown cherty masses; sparse fusulinids are present. The silty limestone has pale-reddish-brown partings and pale-red limy layers that are 0.5–2 cm thick. The hackly limestone is light brownish gray, massive, and contains coarsely crystalline sparry calcite. The contact of the map unit with the Permian red beds (Prb) is marked by a distinctive moderate-orange-pink chert and limestone breccia as noted by Pampeyan (1993); the largest clasts are 3 cm across, angular, and consist of chert. In some clasts within the breccia, fragments of silicified solitary horn corals and brachiopods are present. Probably this breccia resulted from dissolution of gypsum in the underlying Permian red beds (Prb), similar to breccia found above evaporite deposits in west-central Colorado related to dissolution of Pennsylvanian evaporite (Scott and others, 1999; Kirkham and Scott, 2002). The top of the map unit has been removed by faulting, and close to the fault, evidence of weak hydrothermal alteration exists (shown by the stipple pattern on map). About 160 m of the map unit are exposed

Prb **Red beds (Lower Permian)**—Light-brown, thinly bedded silty limestone, pale-reddish-brown calcareously cemented siltstone, and pale-red to grayish-red calcareously cemented fine-grained sandstone. Faults repeat parts of the Permian red beds and parts of the undivided Kaibab Limestone and Toroweap Formation (Pkt) and cut out the lower part of the Permian red beds mapped to the south by Pampeyan (1993). Local changes of bedding attitudes suggest either complex unobserved faulting or folding, some of which may be due to collapse related to dissolution of gypsum beds (Kirkham and Scott, 2002). Note that a southeast-directed thrust with about 100 m of displacement probably exists where attitudes within the map unit change drastically from northwest dipping to southeast dipping. It is likely that a hanging wall anticline and a footwall syncline are associated with this thrust although these details are not shown on the map. Exposures of the map unit may be as great as 220 m thick

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