U.S. DEPARTMENT OF THE INTERIOR
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PRELIMINARY GEOLOGIC MAP OF THE WHEATGRASS SPRING QUADRANGLE, LINCOLN COUNTY, NEVADA

By

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DESCRIPTION OF MAP UNITS

[Ages of surficial units have not been determined by absolute dating techniques; ages are estimates based upon field observations of degree of soil development and local surface dissection. The stage of carbonate morphology reported for soils is a visual estimate using standards defined by Gile and others (1966). Soil horizon terminology follows that of Birkeland (1974). Unit colors are from the Rock-Color Chart (Rock-Color Chart Committee, 1951). Where a veneer of a younger unit masks but does not completely conceal the underlying unit, fractional symbols are used (Qae/Qaw). Identification of ash-flow tuff units is based where available on ranges of phenocryst abundances based on thin section modal analyses from samples in and outside the quadrangle. Isotopic ages are reported with 2 sigma errors. Previous mapping in the area was published at a scale of 1:250,000 (Tschanz and Pampeyan, 1970; Ekren and others, 1977); the geology of the northern part of the quadrangle is based partly on the dissertation map at a scale of 1:24,000 by Taylor (1989). The chemical classification of volcanic units is based on Le Maitre (1989).]

Qal **Alluvium (late Holocene)**--Grayish-orange to pale-yellowish-brown, unconsolidated, poorly bedded sand, gravelly sand, and minor gravel. Sand is fine to very coarse, angular, poorly sorted, locally silty. Gravelly sand and gravel include angular to subrounded pebbles, cobbles, and boulders of ash-flow tuff, lava flow, and smaller amounts of limestone, quartzite, and dolomite. Unit forms channel deposits and low terrace deposits commonly less than a meter high along active washes throughout the quadrangle and small fans near the east quadrangle edge. Channel deposits consist of poorly sorted sand interbedded with poorly to moderately well sorted gravelly sand and local beds and lenses of gravel. Fan deposits are chiefly poorly sorted sand containing interbeds of gravelly sand. Most exposures show no soil development. Maximum exposed thickness is about 1 m

Qc **Colluvium (Holocene and Pleistocene?)**--Unconsolidated to consolidated talus; angular pebble- to boulder-sized clasts, and minor amounts of silt and sand. Colors are inherited from source rock except where coated with brownish-black desert varnish. Unit is generally nonbedded and locally cemented by secondary carbonate. Unit occurs along base of steep slopes developed on Tertiary volcanic rocks. Unit thickness is generally less than 5 m

Qgs **Gravity-slide blocks (Holocene?)**--Complex mixture of coherent blocks of volcanic rocks and lesser amounts of jumbled debris. Numerous small faults that cut the slides terminate at the base of the slides. Debris is generally uncemented. The only Holocene gravity-slide block occurs in the north-central part of the quadrangle; it consists largely of the upper member of the Petroglyph Cliff Ignimbrite (Tpcu) and is about 300 m long. Holocene age of unit is estimated by youthful geomorphology; in fact, the gravity slide appears to still be active. Parent rock making up the slide is indicated by map unit symbol enclosed by parentheses (Tpcu). Map unit is shown by coarse stipple pattern and is bounded by an open-tooth fault symbol. Unit is as great as about 20 m thick

Qae **Alluvium (early Holocene and late Pleistocene)**--Pale-grayish-brown to grayish-orange-pink, unconsolidated to weakly consolidated, poorly sorted, poorly bedded sand, gravelly sand, and gravel. Clasts in gravel and gravelly sand consist of angular to rounded pebbles, cobbles, and sparse boulders of ash-flow tuff, lava flow, limestone, quartzite, and dolomite. Sand is fine to very coarse, mostly angular, locally silty. Unit occurs as terrace deposits along larger washes and as fan deposits inset into or overlying fans deposits of alluvium of Willow Spring (Qaw). Terrace and fan deposits consist of interbedded sand and gravelly sand; local interbeds and lenses of gravel are more abundant near bedrock outcrops. Terrace deposits and inset fans commonly stand 1-2 m above active washes; fan deposits that overlie older fans are as much as 6 m above washes. Surface is commonly smooth and undissected. Typical soil development consists of a thin sandy vesicular A horizon, a 0.5-m-thick B horizon that is the same color as the parent material, and a Cca horizon as thick as 0.2 m that has stage I carbonate development. The Cca horizon is weakly developed or absent where the soil is formed in sand. Maximum exposed thickness about 5 m

Qaj **Alluvium of Jumbo Wash (middle Pleistocene)**--Named for deposits along and near Jumbo Wash in the Gregerson Basin quadrangle (Scott and others, 1990) about 45 km to the south. Brownish-gray to pale-yellowish-brown gravelly sand and gravel; weakly consolidated, poorly sorted, poorly bedded. Clasts consist of angular to subrounded pebbles, cobbles, and boulders of ash-flow tuff, lava flow, limestone, quartzite, and dolomite. Unit forms two small remnants of an inset fan along an unnamed wash near the northeast border of the quadrangle. A moderately packed stone pavement occurs on remnants, which stand about 4 m above floor of wash. Clasts at the surface have a dark-brown desert varnish. Soil development typically has a silty sand vesicular A horizon, a 30-cm-thick dark-yellowish-orange cambic B horizon, and a 40- to 50-cm-thick Cca horizon that has stage II carbonate development in the upper part. Thickness 0 to more than 4 m

Qaw **Alluvium of Willow Spring (middle Pleistocene)**--Named for deposits near Willow Spring in the Delamar 3 SE quadrangle (Swadley and others, 1990, Swadley and others, in press) 50 km to the south-southeast. Pale-yellowish-brown to brownish-gray and grayish-orange-pink, weakly to moderately consolidated, poorly sorted, poorly bedded gravelly sand, sand, and gravel. Clasts consist of angular to rounded pebbles, cobbles, and boulders as much as a meter across of ash-flow tuff, lava flow, limestone, quartzite, and dolomite. Sand is fine to very coarse, mostly angular. Unit forms numerous fan remnants that stand 2-6 m above through-flowing washes in the eastern part of the quadrangle and as much as 14 m in the western part. Depostional surfaces of fan remnants are generally intact but are moderately dissected by small washes that head within the fan. Areas of fan between dissecting washes commonly eroded down to the pedogenic carbonate horizon; these surfaces are commonly covered with a sandy gravel lag that includes common to abundant chips and plates of pedogenic carbonate. Soil development typically consists of a locally developed silty sand vesicular A horizon overlying a partly eroded K horizon; the K horizon is about a meter or less thick and has stage III carbonate development in the upper part. Thickness 0 to more than 15 m

QTgs **Gravity-slide blocks (Pleistocene? and late Pliocene?)**--Complex mixture of coherent blocks of volcanic rocks and lesser amounts of jumbled debris. Numerous small faults that cut the slides terminate at the base of the slides. Debris is generally moderately to highly cemented with secondary calcite. Two exposures of Pleistocene? and late Pliocene? gravity-slide blocka occur in the northwestern part of the quadrangle. The Pleistocene and Pliocene age of unit is estimated from geomorphologic features that are more mature than the Holcene gravity-slide (Qgs), but more youthful than the deeply eroded Pliocene to Miocene gravity slide (Tgs). Unit is designated by QTgs without any attempt to map individual parent rocks in the complex. Also, the map unit is shown by coarse stipple pattern and is bounded by an open tooth fault symbol. Unit is as great as about 30 m thick

QTa **Alluvium (early Pleistocene and Pliocene?)**--Grayish-brown to light-brownish-gray, moderately consolidated, unsorted, poorly bedded gravel and gravelly sand. Consists of angular to rounded pebbles, cobbles, and boulders as much as 1.5 m across of ash-flow tuff, lava flow, limestone, quartzite, and dolomite in a sandy matrix. Unit forms eroded fan remnants that commonly have little or none of the original fan surface preserved; remnants are typically deeply dissected with rounded interfluves. Surfaces commonly littered with a bouldery gravel lag that contains common to abundant fragments of pedogenic carbonate. No soil exposure observed in the quadrangle. Typical soil developed in the region includes a 1- to 2-m-thick K horizon that has a stage III carbonate development in the upper part. The soil commonly conforms to the rounded topography and appears to have developed on an eroded surface. Thickness 0 to at least as much as 5 m

Formation of White River Narrows of DiGuiseppi and Bartley (1991) (Pliocene or older)--Informal unit consisting of basin-fill sediments deposited in a closed sedimentary basin and now exposed along the White River in northwestern Lincoln County. Formation assigned a middle to early Pleistocene age by DiGuiseppi and Bartley (1991). We believe it to be Pliocene or older based on the degree of cementation and an interpretation of the geomorphologic hisotry and inferred ages of overlying and deeply inset surficial deposits exposed in the adjacent Deadman Spring quadrangle (Scott and others, 1994). Formation divided into conglomerate memeber and underlying sandstone member in the Deadman Spring quadrangle where formation is more extensively exposed

Twc **Conglomerate member**--Conglomerate, conglomeratic sandstone, and sandstone; grayish-yellow to yellowish-gray, poorly sorted, moderately cemented, poorly bedded. Conglomerate clasts are angular to subrounded pebbles, cobbles, and boulders as much as 3 m across and consist of ash-flow tuff, lava flow, limestone, lava, dolomite, and chert. Beds range from 0.3 to 2 m thick; scour-and-fill structures are common. Locally unit includes monolithologic boulder beds containing clasts as large as 3 m. Sandstone is angular, fine to very coarse grained, and silty. Unit is deeply dissected but poorly exposed; slopes are steep and typically covered with a thin bouldery colluvium (not mapped separately). Colluvium covers the contact between the map unit and volcanic bedrock units exposed on the western flank of the Pahroc Range. Conglomerate member dips gently westward at about 6°, close to an expected depositional slope, but underlying bedrock commonly dips 30°-7° westward and has been repeated on east-dipping normal faults that do not affect the overlying basin-fill sediments. Thickness greater than 120 m

Tgs **Gravity-slide blocks (Pliocene? and Miocene?)**--Complex mixture of coherent blocks of volcanic rocks and lesser amounts of jumbled debris. Numerous small faults that cut the slides terminate at the base of the slides. Debris is generally cemented by secondary carbonate. One slide is greater than 2 km across. Identification as gravity-slide blocks is based on geometric relation of blocks that overlie throughgoing structures and on stratigraphy and geographic location of slides relative to potential source areas. Age of map unit is poorly constrained and is based on depth of erosion of original slide mass as well as by ages of underlying and overlying units. Parts of slides that were derived from a single parent rock are indicated by map unit symbols enclosed by parentheses; parts of slides consisting of a mixture of lithologies are designated by Tgs; in either case, map unit is shown by coarse stipple pattern and is bounded by an open tooth fault symbol. Map unit is locally at least 75 m thick.

Th **Hiko Tuff (Miocene)**--Rhyolitic ash-flow tuff having a coarse megascopic eutaxitic texture and consisting of one compound cooling unit. Hiko Tuff was named by Dolgoff (1963) for the knobby, joint-controlled landforms of the unit in the Hiko Range about 45 km to the southeast. Light-brownish-gray, thick, moderately welded and devitrified upper zone grades downward through a moderately welded, locally vitrophyric tuff characterized by eutaxitic black fiamme to a pinkish-gray, relatively thin, nonwelded, partly vitric basal zone. In the northwestern part of the quadrangle, the tuff is less welded, typically moderately to partially welded. Lenticular pumice fragments are a lighter color than the matrix, range from 0.3 to 8 cm long in the plane of foliation, and form as much as 20 percent of the rock. Where more welded, rock is mottled from very light gray to light brown and light brownish gray; where less welded, rock is unmottled and is grayish orange pink to very pale orange. Tuff contains about 30-40 percent phenocrysts that consist of about 10-35 percent quartz, 10-35 percent sanidine, 30-65 percent plagioclase, 5-15 percent biotite, less than 5 percent hornblende, a trace of pyroxene, and accessory sphene, zircon, apatite, allanite, and Fe-Ti oxides (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press and Rowley and others, in press). Quartz phenocrysts are a distinct pale purple. An increase in ferromagnesian and plagioclase phenocrysts higher in the unit relative to other phenocysts has been noted (Scott and others, 1988; Scott and others, 1993; R.E. Anderson, unpublished data, 1992). Tuff contains trace to 4 percent lithic fragments consisting of fine-grained flow-banded volcanic rocks and minor argillite. In some zones rock contains lithophysae as large as 4 cm in diameter that form between 2 and 10 percent of the rock. $Ar^{40}Ar/^{39}Ar$ biotite date by Taylor and others (1989) of the Hiko Tuff is 18.5 $\pm$ 0.4 Ma, but they conclude that the best age estimate may be 18.6 Ma based on additional data. Based on new dating, Rowley and others (in press) suggest that a more likely age of the Hiko Tuff is 18.2 Ma. Unit forms bold cliffs and on dip slopes forms distinct knobby weathering surfaces several meters in diameter where densely welded. The Hiko Tuff is exposed only in the western half of the quadrangle. Source of map unit is the Delamar caldera about 30 km to the southeast (Rowley and Siders, 1988). Unit probably is greater than 80 m thick; its top is not preserved

Tbt **Bedded tuff (Miocene)**--Nonwelded, ash-fall tuff and possibly water-laid bedded tuff. Very pale orange to very light gray, poorly to moderately consolidated, moderately to well sorted, 0.1- to 2-m-thick, graded and crossbedded tuff consists of silt-, sand-, and pebble-sized clasts that consist of rhyolitic glass shards, pumice fragments, and sparse lava flow fragments; tuff is mineralogically similar to the Hiko Tuff and probably represents of precursor eruption. Unit forms gentle slopes between the steeper slopes of the Hiko Tuff (Th) and Harmony Hills Tuff (Thh). Bedded tuff is locally present in the western part of the quadrangle and is less than 20 m thick

Thh **Harmony Hills Tuff (Miocene)**--Andesitic to trachyandesitic ash-flow tuff consisting of one simple cooling unit, grading downward from a partially welded upper zone, a moderately welded central zone, and a nonwelded basal zone. Mackin (1960) defined the tuff as the youngest member of the Quichapa Formation, subsequently Cook (1965) raised the Harmony Hills Tuff to formation rank, and finally Anderson and Rowley (1975) included the tuff as the youngest formation in the Quichapa Group. The group name is not used here because the formations of the group, the Harmony Hills Tuff, the Condor Canyon Formation (Tc), and the Leach Canyon Formation (Tlc) probably were erupted from different sources and are unrelated petrologically (Scott and others, in press). Unit is devitrified, phenocryst-rich, and massive; the plane of compaction foliation is indistinct. The central zone of the unit ranges between pale red where weathered and light olive gray to light gray where fresh. Pumice fragments are sparse. The rock contains about 40-50 percent phenocrysts that consist of 2-10 percent quartz, <3 percent sanidine, 55-70 percent plagioclase, 10-20 percent biotite, <15 percent hornblende, <7 percent pyroxene, and accessory Fe-Ti oxides, zircon, apatite, sphene, allanite, and perrierite and/or chevkinite (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). Biotite books are as much as 4 mm across. Lithic fragments form less than 5 percent of the rock. Unit forms steep to moderate slopes. Five K-Ar dates provided by Armstrong (1970) and one by Noble and McKee (1972) average 21.6 Ma for the unit; but more recent dating of overlying rocks by Rowley and others (1989) and the age of the underlying Bauers Tuff Member (Tcb) constrain the age of the Harmony Hills Tuff to be between 21.7 and 22.8 Ma. The unit is is exposed only in the western half of the quadrangle. The Harmony Hills Tuff thins from about 130 m thick in the southwestern part of the quadrangle to a little as 10 m in the northwestern part

Tb **Basalt lava flows (Miocene)**--Medium-dark-gray basalt lava flows, massive in their interiors and more vesicular toward their margins. Basalt contains small phenocrysts (< 2 mm long) that consist of 5 percent blocky clinopyroxene and 10 percent lath-shaped plagioclase phenocrysts in a fine groundmass intergrowth of plagioclase, pyroxene, and opaque phases (hand specimen inspection of samples from this quadrangle only). Resistant unit forms distinct dip slopes where the younger volcanic units have been eroded; it occurs only along the west margin of the quadrangle and in the northwestern part of the quadrangle, where it has a maximum thickness of about 35 m

Tp **Pahranagat Formation (Miocene)**--Rhyolitic ash-flow tuff consisting of one simple cooling unit. Best, Christiansen, and others (1989) first published a report on the Pahranagat Lakes Tuff, which they adopted from Williams (1967) who described this unit in his dissertation. Scott and others (in press) renamed the unit the Pahranagat Formation to include related volcanic units found close to and within the Kawich caldera, the source of the formation. The tuff is devitrified, partially welded to moderately welded, and grayish pink to pinkish gray. White pumice fragments are 0.2-5 cm in diameter and form 15-30 percent of tuff. Rock contains 15-35 percent phenocrysts that consist of 20-45 percent quartz, 30-50 percent sanidine, 25-40 percent plagioclase, 1-6 percent biotite, 1-2 percent hornblende and accessory Fe-Ti oxides, zircon, apatite, sphene, and allanite (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). About 1 percent lithic fragments occur in the tuff. The $^{40}Ar/^{39}Ar$ date of sanidine from the tuff is 22.65 ± 0.02 Ma (Deino and Best, 1988). This relatively nonresistant unit forms thin benches between steeper cliffs of bounding units. Pahranagat Formation is about 20 m thick (locally as thick as about 45 m) in the southwestern and west-central part of the quadrangle but pinches out locally in the north part

Tc **Condor Canyon Formation (Miocene)**--Rhyolitic ash-flow tuff that consists of two simple cooling units, in descending order, the Bauers and Swett Tuff Members. Cook (1965) named the formation and Mackin (1960) named the two tuffs. Rowley and Siders (1988) named the Clover Creek caldera as the source of the Bauers Tuff Member in the Caliente caldera complex, but the source of the Swett Tuff Member, probably an earlier caldera in that caldera complex, has not been recognized. Anderson and Rowley (1975) included the formation in the Quichapa Group, but the group name is not used here because the formations of the group, the Harmony Hills Tuff, the Condor Canyon Formation (Tc), and the Leach Canyon Formation (Tlc) probably were erupted from different sources and are unrelated petrologically (Scott and others, in press). The average K-Ar age of the Bauers is 22.7 Ma (Armstong, 1970), close to the $^{40}Ar/^{39}Ar$ sanidine date of 22.78 ± 0.03 Ma (Best, Christiansen, and others, 1989). This is about 1 m.y. younger than the average K-Ar age of the Swett Tuff Member (23.7 Ma, Armstrong, 1970). Although the two members of the Condor Canyon Formation are mapped separately throughout most of the quadrangle, the formation is mapped as one unit in the northwestern part of the quadrangle where it is about 8-40 m thick, too thin to depict as members. Also in this area, the apparent thinness of the Condor Canyon Formation may be a function of structural attenuation

Tcb **Bauers Tuff Member**--Rhyolitic ash-flow tuff, consisting of an uppper part that is pinkish gray, devitrified, and moderately welded to densely welded, and relatively crystal-poor (10 percent phenocrysts); a middle part that is is light brownish gray, devitrified, densely welded, and relatively crystal rich (20 percent phenocrysts); and a lower part that is grayish black to brownish gray, densely welded, vitropyhyric, and relatively crystal rich (20 percent phenocrysts). Distinctive pinkish-gray flow partings common in the middle part are as long as 0.5 m but only a few millimeters thick; these partings have a similar appearance to highly flattened pumice fragments that are smaller in diameter (< 8 cm). The phenocrysts in the middle part of the Bauers consist of 15-35 percent sanidine, 35-70 percent plagioclase, 0-5 percent pyroxene, and accessory Fe-Ti oxides, zircon, and apatite; the absence of quartz is distinctive (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press; Rowley and others, in press);. The tuff contains less than a few percent lithic fragments and as much as 10 percent highly flattened lithophysal cavities above the vitrophyre. The Bauers Tuff Member forms steep slopes and minor cliffs and ranges from nearly 20 to about 40 m thick except where tectonic thinning is suspected

Tcs **Swett Tuff Member**--Rhyolitic ash-flow tuff, consisting of an upper part that is light red to pale red, devitrified, and moderately to densely welded and a lower part that is dark gray to brownish gray, densely welded, and vitrophyric. The transition from devitrified tuff to underlying vitrophyre is marked commonly by pronounced light-red to grayish-orange-pink mottling and 10-30 percent lithophysal cavities. The thick vitrophyre near the base forms as much as 1/3 of the unit. The rock contains 10-20 percent phenocrysts that consist of 65-85 percent plagioclase, 7-20 percent biotite, as much as 2 percent pyroxene, and accessory Fe-Ti oxides and apatite; the absence of quartz and sanidine is distinctive (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press and by Rowley and others, in press). Lithic fragments are sparse. Unit forms steep slopes or narrow cliffs. Swett Tuff Member ranges between 15 and 35 m thick in the western part of the quadrangle; at one locality in the eastern part an apparent thickness of 90 m thick may be due to repetion along small normal faults

Tlc **Leach Canyon Formation (Miocene)**--Rhyolitic ash-flow tuff consisting of a compound cooling unit. The tuff is partially to moderately welded, devitrified except for sparse local vitrophyre, and very light gray, pinkish gray, to yellowish gray. Mackin (1960) named the formation, and Anderson and Rowley (1975) adopted the name, following the nomenclature of Williams (1967). Anderson and Rowley (1975) included the formation in the Quichapa Group, but the group name is not used here because the formations of the group, the Harmony Hills Tuff, the Condor Canyon Formation (Tc), and the Leach Canyon Formation (Tlc) probably were erupted from different sources and are unrelated petrologically (Scott and others, in press). Abundant flattened pumice fragments that form 10-20 percent of the rock are commonly light brownish gray and 0.2-2 cm long. The rock contains 15-25 percent phenocrysts that consist of 20-60 percent quartz, 10-40 percent sanidine, 20-55 percent plagioclase, 2-14 percent biotite, traces of hornblende and pyroxene, and accessory Fe-Ti oxides, sphene, zircon, and apatite (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press and by Rowley and others, in press). Lithic fragments are sparse except near the base of the unit. The Leach Canyon forms bold light-colored cliffs and steep slopes. The average of three K-Ar dates (Armstrong, 1970) and one fission track date (Kowallis and Best, 1990) provides an age of about 24.6 Ma but with large errors; a better estimate of the age of the unit is the average age of a coexisting sanidine and biotite pair dated by Armstong at about 23.8 Ma, identical to a new $^{40}Ar/^{39}Ar$ sanidine date for the Leach Canyon Formation of 23.8 Ma (Best and others, 1993). Unit ranges from estimates of 115 to 160 m thick in the southwest part of the quadrangle; its thickness elsewhere has not been determined because of faulting, including both local attenuation and local duplication of strata

Isom Formation (Oligocene)--Trachytic ash-flow tuffs, generally dominated by densely welded vitrophyres. The Isom Formation was originally defined by Mackin (1960), and subsequently redefined by Anderson and Rowley (1975), to consist of three members, in descending order, the Hole-in-the-Wall, Baldhills, and Blue Meadows Tuff Members. The Blue Meadows is absent here because that member is restricted to the Markagunt Plateau of Utah. Scott and others (in press) have proposed that an additional member of the Isom Formations exists; they informally named a sequence of normally magnetized Isom-like cooling units, which underlie the reversely magnetized Hole-in-the Wall Member, the tuff member of Hamlight Canyon based on paleomagnetic studies at Condor Canyon, 50 km to the east. Unpublished paleomagnetic data from samples collected in the Pahroc Spring quadrangle to the south correlate on the basis of magnetic data with the tuff member of Hamlight Canyon in Condor Canyon (Scott and others, 1992; C.S., Grommé, written commun., 1993). In this quadrangle, the Baldhills Tuff Member is separated from the Hole-in-the-Wall Tuff Member and underlying tuff member of Hamlight Canyon by six map units, the most widespread of which are the members of the Shingle Pass Tuff. Published dates for the Baldhills Tuff Member consist of a whole rock-date of 25.7±0.5 (Armstrong 1970) and a plagioclase date of 25.7±0.4 (Fleck and others, 1975); an additional plagioclase date of 25.9±0.8 Ma was determined by H.H. Mehnert (written commun., 1990) reported by Scott and others (in press). The younger Hole-in-the-Wall Tuff Member has not been dated; however, its age is between that of the Leach Canyon Formation (Tlc), about 23.8 Ma, and the sanidine date of 26.00±0.03-Ma determined by $^{40}Ar/^{39}Ar$ by Best, Christiansen, and others (1989) for the upper member of the Shingle Pass Tuff (Tspu)

Tih **Hole-in-the-Wall Tuff Member**--Trachytic ash-flow tuff consisting of one and, in some localities, two or more cooling units. Because the informal tuff member of Hamlight Canyon is indistinguishable from the overlying Hole-in-the-Wall Tuff Member without additional paleomagnetic data, and because these thin units are difficult to display at this scale, all Isom-like cooling units between the Leach Canyon Formation (Tlc) and the Shingle Pass Tuff (Tsp) are mapped as the Hole-in-the-Wall Tuff Member. Devitrified upper parts of the cooling units range from pale red to light brownish gray and are densely welded for the most part. The vitrophyric lower parts are brownish gray to dark gray and mostly densely welded but are moderately welded in part. The cooling units contain 5-15 percent phenocrysts that consist of 70-80 percent plagioclase and minor amounts of pyroxene and Fe-Ti oxide (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). Lithic fragments form 5-10 percent of the rock. At one locality in the southeastern part of the quadrangle, a partially to moderately welded uncorrelated rhyolitic tuff about 5 m thick separates the upper cooling unit of the Hole-in-the-Wall Tuff Member from a lower Isom-like cooling unit; this uncorrelated tuff is mapped as part of the Hole-in-the-Wall Tuff Member. The uncorrelated tuff is pale red to grayish orange pink, contains 10 percent pinkish-gray pumice 1 cm in diameter, and contains about 15 percent phenocrysts of quartz, sanidine, plagioclase, and biotite in order of decreasing abundance (based on hand specimen inspection only). The cooling units form a series of small cliffs and narrow benches. Hole-in-the-Wall Tuff Member ranges from about 0 to 15 m thick and is locally absent, particularly in the northern part of the quadrangle

Tib **Baldhills Tuff Member**--Trachytic ash-flow tuff consisting of as many as two cooling units. Devitrified upper parts of the cooling units are generally grayish red and densely welded; vitrophyric lower parts are dark gray to grayish black and densely welded. The unit contains as much as 15 percent phenocrysts that consist of about 80 percent plagioclase and minor abundances of pyroxene and Fe-Ti oxide (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). Lithic fragments form about 10 percent of the rock. The cooling units form narrow benches and small cliffs. The thickness of the Baldhills Tuff Member ranges from about 50 m in the southern part of the quadrangle to 15 m in the northern part

Tob **Older basalt lava flows (Oligocene)**--Basalt lava flows ranging from olivine-phyric to olivine-pyroxene-plagioclase-phyric to aphyric. Olivine-phyric flows are most common and are generally massive, grayish black, and crystal-poor (<5 percent phenocrysts). Flows of the unit are massive, grayish black, relatively crystal rich (containing 0-20 percent phenocrysts), and commonly contain 15 percent vesicles (based on hand specimen inspection from this quadrangle only). Aphyric flows have light-bluish-gray coatings on subhorizontal partings and small (1 mm diameter) vesicles. The lava flows form poorly exposed, steep to moderate talus-covered slopes. In the southwestern part of the quadrangle, a sequence of flows is over 230 m thick and is particularly scoriaceous; the sequence probably represents a vent. Elsewhere the unit is as much as 90 m thick where undeformed by attenuating normal faults; at some localities where lava flows are absent, basalt boulders are found

Tbl **Blawn(?) Formation (Oligocene)**--Rhyolitic ash-flow tuff consisting of a nonwelded to partially welded, devitrified, yellowish-gray to very light gray cooling unit. Unit is only tentatively correlated with the high-silica rhyolitic tuff of the Blawn Formation (Best and others, 1987; Best, Lemmon, and Morris, 1989) because definitive chemical, petrographic, isotopic age, and paleomagnetic data are not available for definitive correlation. Furthermore, the stratigraphic level of the Blawn Formation is not precise because the age of rocks included in the definition of the unit range from 24 to 18 Ma (Best and others, 1987; Best, Lemmon, and Morris, 1989). Pumice fragments are sparse and less than 0.5 cm in diameter. The rock contains about 15 percent phenocrysts that consist primarily of resorbed quartz, small amounts of feldspars, intermediate amounts of biotite, and trace amounts of accessory phases. The quartz phenocrysts are as large as 5 mm in diameter and commonly have a distinctive very pale purple color (based on hand specimen inspection of samples from this quadrangle and semiquantitative thin section study of samples from the Pahroc Spring quadrangle (Scott and others, 1992). About 5 percent of the rock consists of inconspicuous volcanic lithic fragments. Unit forms gentle to steep, light-colored slopes and a prominent bench at its base. Locally below the Blawn(?) Formation in the southeastern part of the quadrangle, a 10-m-thick pale-red tuff that cannot be correlated regionally is included in the map unit. The pale-red tuff is biotite- and pumice-rich, moderately to partially welded and contains 5 percent conspicuous moderate-red pumice fragments, some as much as 5 cm across, about 3 percent biotite, and about 5 percent felsic phenocrysts including quartz, plagioclase, and sanidine. This pale-red tuff has about 5 percent lithic fragments, one of which is biotite gneiss(?). Blawn(?) Formation ranges from 25 m thick in the central part of the quadrangle to 50 and 75 m thick in the southern and northern parts, respectively, where undeformed by attenuating normal faults

Shingle Pass Tuff (Oligocene)--Rhyolitic ash-flow tuff consisting of an upper and a lower member. Originally, Cook (1965) called a rhyolitic tuff at Shingle Spring the Shingle Pass Ignimbrite. Subsequently, Ekren and others (1971) recognized as many as three similar rhyolitic ash-flows that they called the Single Pass Tuff. Most recently, Best, Christiansen, and others (1989) assigned the name to two petrographically and paleomagnetically correlative rhyolitic tuffs and suggested the Quinn Canyon Range as a probable source. Although K-Ar dates for the Shingle Pass Tuff range over almost 4 million years (Marvin and others 1973), $^{40}Ar/^{39}Ar$ sanidine dates provide a more narrow estimate of the age of the two members; the date for the upper member (Tspu) is 26.00±0.03 Ma and the date for the lower member (Tspl) is 26.68±0.03 Ma (Best, Christiansen, and others, 1989) In this quadrangle, the two members of the Shingle Pass Tuff are separated by a rhyolitic ash-flow tuff, the tuff of Hancock Summit

Tspu **Upper member**--Rhyolitic ash-flow tuff consisting of a pale-red, densely welded, devitrified upper part, characterized by hackly, crumbly, weathered surfaces and a thinner, moderate-reddish-orange to brownish-gray, densely welded, vitrophyric lower part, characterized by distinct black fiamme, megascopic black eutaxitic glass shards, and conchoidal fractures. The vitrophyre has grayish-orange-pink mottled areas around devitrification centers. Rock contains 5-10 percent phenocrysts consisting of 1-2 percent quartz, 30-40 percent sanidine, 50-60 percent plagioclase, 5-15 percent biotite, lesser amounts of hornblende and pyroxene, and accessory Fe-Ti oxides, zircon, and apatite (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). Unit forms steep slopes. Unit is 50-65 m thick where it is unaffected by attenuation. Yet many of the units at or below the Shingle Pass Tuff in the central arched part of the North Pahroc Range probably were structurally thinned and (or) duplicated by normal faults

Tspl **Lower member**--Rhyolitic ash-flow tuff consisting of a very light gray to pale-red, moderately welded to densely welded, devitrified upper part characterized by hackly, crumbly, weathered surfaces and a brownish-gray to brownish-black, densely welded vitrophyric thinner lower part characterized by black fiamme or silky white pumice fragments, conspicuous megascopic, eutaxitic, black glass shards, and conchoidal fractures. The vitrophyre has grayish-pink devitrification centers. Rock contains 15-20 percent phenocrysts consisting of 8-15 percent quartz, 50-60 percent sanidine, 25-35 percent plagioclase, <2 percent biotite and hornblende, as much as 5 percent clinopyroxene, traces of fayalite, and accessory Fe-Ti oxides, zircon, and apatite (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). The lower member is distinguished in the field from the upper by a lower biotite content. The sanidine to plagioclase phenocryst ratio is about 2 in the lower member and about 0.5 in the upper member. Unit forms steep slopes and is commonly highly brecciated and covered by talus. Where unaffected by attenuating normal faults, the unit is about 50 m thick.

Ths **Tuff of Hancock Summit (Oligocene)**--Rhyolitic, devitrified ash-flow tuff ranging from light-brownish-gray to grayish-orange-pink moderately welded tuff to pale-red mostly densely welded tuff; no vitrophyre is present. Best, Christiansen, and others (1989) first used the informal name tuff of Hancock Summit for the moderately welded, relatively quartz-rich rhyolitic ash-flow tuff exposed between the overlying upper member of the Shingle Pass Tuff and the underlying "Isom-type sheet" (p. 127) at Petroglyph Cliff at White River Narrows. Rock contains about 25 percent phenocrysts consisting of about 40 percent quartz, 30 percent sanidine, 20 percent plagioclase, nearly 10 percent biotite, and accessory Fe-Ti oxides, zircon, and apatite (hand specimen inspection of samples from this quadrangle and semiquantitative thin section study of samples from the Pahroc Spring quadrangle, Scott and others, 1992). Lithic fragments are sparse. The tuff of Hancock Summit is distinguished from the adjacent members of the Shingle Pass Tuff by a greater quartz phenocryst content, lack of fiamme, absence of a vitrophyre, and massive, poorly foliated appearance. Unit forms rounded slopes. Where unaffected by tectonic attenuation, the tuff of Hancock Summit is about 20-35 m thick in the southern part of the quadrangle but about 75 m in the northern part

Tsph **Shingle Pass Tuff and tuff of Hancock Summit, undivided (Oligocene)**--Three rhyolitic ash-flow tuff units -- in descending stratigraphic order, the upper member of the Shingle Pass Tuff, the tuff of Hancock Summit, and the lower member of the Shingle Pass Tuff; these units are combined where they cannot be shown separately at map scale or exposures are insufficient. In one area in the southeastern part of the quadrangle, apparent structural attenuation of parts of all three of these units does not permit showing each cooling unit separately. In several localities of poor exposure in the southern part of the quadrangle, these three units are lumped, and in one slide complex where structural complications are too great to distinguish between units, they are also lumped. This map unit is only about 25-35 m thick, roughly one-quarter the total stratigraphic thickness of these three units

Tlf **Lacustrine and fluvial sedimentary rocks (Oligocene)**--Interbedded lacustrine limestone and fluvial siltstone, sandstone, and boulder conglomerate that occur at eleven stratigraphic intervals separated by ten intervals of volcanic rocks and minor bedded tuffs. In descending order, volcanic intervals consist of (1) the Baldhills Tuff Member of the Isom Formation (Tib), (2) Monotony Tuff (Tm), (3) tuff of Little Boulder Spring (Tlb), pumice-rich nonwelded tuff (Tpn), upper member of the Petroglyph Cliff Ignimbrite (Tpcu), andesitic lava flow of Hamilton Spring (Tah), bedded tuff (Tbt), lower member of the Petroglyph Cliff Ignimbrite (Tpcl), bedded tuff (Tbt), Lund Formation (Tnl), and orange tuff (Tot), (4) andesite of Mustang Spring (Tms) and muflow of Coal Spring (Tco), (5) tuff of Deadman Spring (Tds), and bedded tuff (Tbt) within tuff of Deadman Spring (Tds), (6) Wah Wah Springs Formation (Tnw), and (7) Cottonwood Wash Tuff (Tnc), (8) Windous Butte Formation (Twb), (9) andesite of Wheatgrass Spring (Twg) above interbedded lacustrine and fluvial sedimentary rocks, and (10) andesite of Wheatgrass Spring (Twg) below interbedded lacustrine and fluvial sedimentary rocks. The lowest stratigraphic level of lacustrine and fluvial sedimentary rocks occurs on the west side of the quadrangle below the andesite of Wheatgrass Spring (Twg) and above Paleozoic rocks.

Limestone is the most abundant rock type in the lacustrine and fluvial sedimentary rock intervals above the upper member of the Petroglyph Cliff Ignimbrite (Tpcu). From the lower member of the Petrogylph Cliff Ignimbrite (Tpcl) down to the Wah Wah Springs Formation (Tnw), poorly exposed tuffaceous siltstone and sandstone are the more abundant and more resistant limestone is the most conspicuous rock type in these sedimentary rock intervals. From the base of the Wah Wah Springs Formation (Tnw) down to Paleozoic strata, boulder conglomerate is most abundant but is also poorly exposed. The limestone ranges from very light gray and medium dark gray, to pinkish gray, and to light brownish gray and forms 0.2- to 3-m-thick beds in most areas. Thin (1-2 cm) channel-like lenses of reworked volcanic clasts occur in thick limestone beds at several localities. Much of the limestone has been coarsely recrystallized and locally it commonly contains wavy, thinly layered algal(?) structures. In a few localities, dark limestone beds contain sparse gastropods and ostracods; light limestone beds locally contain reed-like fossils. At other localities, silicification has enhanced preservation of Tertiary reed- and wood-like fossils in discolored limestone beds cut by abundant calcite veins. Boulder conglomerate is indicated by well-rounded boulders of Paleozoic limestone, dolomite, and quartzite as large as 2 m in diameter that litter the surface. A calcite-cemented matrix of sand- to pebble-sized clasts fills intertices between boulders. Poorly exposed intervals characterized by an absence of evidence of limestone or conglomerate generally consist of poorly to moderately consolidated, yellowish-gray to very light gray tuffaceous sandstone and siltstone composed of clasts of reworked volcanic phenocrysts, rounded pumice fragments, subrounded fragments of volcanic rocks, and clay minerals. Bedding in these tuffaceous rocks is generally indistinct but locally crossbedded and sorting is poor to moderate; exposures are limited to cut banks along washes. The lacustrine and fluvial sedimentary rocks form bench- (clastic) and-riser (limestone) topography between the more resistant volcanic map units.

Structural complexity and discontinuous exposures make an accurate measurement of the thickness of the lacustrine and fluvial sedimentary rocks in the quadrangle impossible. The maximum cumulative thickness of all the intervals of lacustrine and fluvial sedimentary rocks is estimated to be about 500 m. Drastic changes in thicknesses of the sedimentary beds below the lower member of the Petrogylph Cliff Ignimbrite (Tpcl) probably reflect tectonic attenuation although gradual changes in thickness may also be related to depositional or erosional variations

Tm **Monotony Tuff (Oligocene)**--Dacite crystal-rich ash-flow tuff consisting of a simple cooling unit. The Monotony Tuff was defined by Ekren and others (1971) and Ekren and others (1972, 1974), Best, Christiansen, and others (1989), and Best and others (1992) identified the source of the tuff as the Pancake Range caldera in central Nevada. The upper part of the unit is a devitrified, grayish-orange-pink to light-gray, partially welded to densely welded tuff; the basal part contains a medium-gray densely welded vitrophyre. Both parts contain 20-50 percent phenocrysts consisting of 5-30 percent quartz, 2-14 percent sanidine, 45-65 percent plagioclase, 5-20 percent biotite, 0-10 percent hornblende, 0-10 percent clinopyroxene, and accessory magnetite, zircon, apatite, and allanite (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). As many as 5 percent volcanic lithic fragments are present. The nonresistant partially welded part of the unit forms benches, and the more densely welded part forms steep slopes and small cliffs. K-Ar dates of biotites from the unit range between 26.8 and 29.1 Ma (Marvin and others, 1973). A biotite-hornblende pair gives concordant $^{40}Ar/^{39}Ar$ dates of 27.1 $\pm$0.6 and 26.7 $\pm$0.3 Ma, respectively (Taylor and others, 1989), but perhaps the best estimate of the age of the Monotony Tuff is based on the $^{40}Ar/^{39}Ar$ sanidine date of 27.31 $\pm$0.03 determined by Best, Christiansen, and others (1989). Unit ranges from 50 to 60 m thick in the southern part of the quadrangle, but ranges from 45 m to as much as 80 m thick in the central and northern part; attenuation faulting has thinned the unit in places

Tlb **Tuff of Little Boulder Spring (Oligocene)**--Trachytic ash-flow tuff consisting of one simple cooling unit. Unit consists mostly of a medium-dark-gray, moderately welded to densely welded vitrophyre that displays a conspicuous megascopic eutaxitic texture formed by glass shards greater than 1 mm long and pumice fragments 1-10 cm long. The thin, locally absent, upper part of the unit is mostly devitrified, moderately welded, pale reddish brown to moderate reddish brown and contains black glass fiamme similar to, but smaller than, those fiamme characteristic of the lower member of the Petroglyph Cliff Ignimbrite (Tpcl). Rock contains about 10 percent phenocrysts of plagioclase and subordinate pyroxene. Lithic fragments are sparse. Locally, pale-greenish-yellow altered devitrification centers are 0.5-1 cm in diameter and are filled with clay. The tuff of Little Boulder has mineralogical, physical, and compositional similarities to the Isom Formation and may belong to the Isom compositional-type (Scott and others, in press). The map unit may be a member of the stratigraphically adjacent Petroglyph Cliff Ignimbrite. Unit forms slightly steeper slopes than surrounding units. The unit is present only in the southern and central parts of the quadrangle. Unit is part of the stratigraphic section that has been extensively attenuated and duplicated by normal faulting; the best estimate of its thickness in areas unaffected by faulting is between 2 and 10 m

Tpn **Pumice-rich nonwelded tuff (Oligocene)**--Nonwelded, pumice-rich ash-flow tuff distinguished by a high density related to secondary calcite in the interstices. The upper part of the tuff is moderate orange pink to very pale orange, contains about 50 percent unflattened unoriented pumice fragments about 2-4 cm in diameter in a matrix of finer tuff, and includes about 10 percent lithic fragments. The lower part of the tuff is generally light gray and contains about 30-40 percent pumice fragments 0.5-2 cm in diameter; the original tabular shapes of unflattened pumices are subparallel to the unit contact, reflecting a preferred orientation during deposition. In the lower part less than 2 percent biotite and blocky pyroxene are present; less than 5 percent felsic phenocrysts of quartz, sanidine(?), and plagioclase(?) are present (based on hand specimen study only). Lithic fragments are sparse in the lower part. The unit forms rounded slopes and is present only locally in the southern part of the quadrangle where it reaches a maximum thickness of about 20 m; its local absence in the southern part may be attributed to attenuation faulting; it appears to be stratigraphically absent in the northern part

Petroglyph Cliff Ignimbrite (Oligocene)--Trachytic ash-flow tuff consisting of two, densely welded, dark members. Martin (1957) named this unit the White Rock Spring ignimbrite unit, but Cook (1965) first defined the Petroglyph Cliff Ignimbrite and its type section at White Rock Spring, a few kilometers north of White River Narrows, 2 km northwest of this quadrangle; only the lower member is present at the type section. Both members of the unit are simple cooling units, phenocryst-poor, and contain plagioclase and subordinate pyroxene phenocrysts. Except for abundant cognate lapilli and blocks that distinguish the Petroglyph Cliff Ignimbrite, the mineralogical, chemical, and physical charactertistics of the map unit are similar to those characteristics of the ash-flow tuffs of the Isom compositional-type magmatic association (Scott and others, in press). The Petroglyph Cliff Ignimbrite has not been dated, but its age is stratigraphically restricted between about 27.3 Ma, the age of the Monotony Tuff (Tm), and about 27.9 Ma, the age of the Lund Formation (Tnl) (Scott and others, in press).

Tpcu **Upper member**--Trachytic ash-flow tuff containing 30 percent conspicuous cognate dark flattened pumice lapilli (fiamme) and 25 percent blocky cognate(?) inclusions. The unit is mostly densely welded but partially welded locally at its upper margin, is light red to moderate red to light brown, and is largely devitrified. Fiamme are 1-4 cm in diameter and commonly vitric, and 25 percent cognate(?) inclusions are 0.5-1.5 cm in diameter. The inclusions are commonly grayish red whereas the fiamme are moderate red. Very pale orange altered devitrification centers are typically 0.5 cm in diameter. The tuff contains about 10 percent phenocrysts of plagioclase and subordinate pyroxene (based on hand specimen study only). The upper member is found only in the north-central part of the quadrangle where it is always separated from the lower member by the andesite of Hamilton Spring (Tah). Close to the northern edge of the quadrangle, the upper member of the Petroglyph Cliff Ignimbrite is densely welded where it is fused(?) to the contact with the underlying andesite lava flow; this apparent close genetic relationship between Isom-type ash-flow tuffs and andesitic lava flows has been noted elsewhere (Anderson and Rowley, 1975; R.B. Scott, unpublished mapping). Unit has a maximum thickness of about 15 m

Tpcl **Lower member**--Trachytic ash-flow tuff displaying conspicuous fiamme and a thick basal vitrophyre. The upper part of tuff is largely devitrified, mostly densely welded but partially welded near its upper margin, and light red to moderate red to light brown except for 1-5-cm-diameter black vitric fiamme in most of the densely welded tuff. Very pale orange altered devitrification centers(?) are typically 0.5 cm in diameter. The matrix of the densely welded basal vitrophyre grades downward from grayish orange pink to brownish gray and then to medium dark gray; conspicuous grayish-black fiamme contrast strikingly with the matrix and form about 20-30 percent of the rock, and 2- to 10-cm-diameter, grayish-purple to medium-gray cognate blocks form about 25 percent of the rock. The tuff contains 10 percent phenocrysts of plagioclase and subordinate pyroxene, typical of Isom compositional-type ash-flow tuffs (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). The unit forms steep slopes at the vitrophyre and more gentle slopes in the devitrified upper part. The lower member of the Petroglyph Cliff Ignimbrite is widespread throughout the quadrangle and is correlative with the unit exposed at the type section based on unpublished paleomagnetic data (C.S. Grommé, written commun., 1994). The relative thicknesses of the overlying devitrified tuff and basal vitrophyric tuff differ greatly at different localities; these differences are in part related to structural attenuation that has variously effected different parts of the unit. The thickness of the unit ranges from 35 to 85 m

Tah **Andesitic lava flows of Hamilton Spring (Oligocene)**--Knobby textured, medium-dark-gray to dark-greenish-gray andesitic lava flows displaying a massive interior and vesicular margins. Taylor (1989) incorrectly applied this name to the Baldhills Tuff Member of the Isom Formation. The knobby texture is created by the nearly 30 percent plagioclase phenocrysts as large as 1 cm in diameter. The rock also contains about 5 percent clinopyroxene (based on hand specimen study only). Vesicles are elongate parallel to flow direction and are typically 1-2 cm long. Unit is exposed only in the north-central part of the quadrangle, where it forms steep cliffs and is as much as 60 m thick, but pinches out toward the south

Tbt **Bedded tuff (Oligocene)**--Two types of bedded tuff occur at this stratigraphic interval. At some localities bedded tuff consists of grayish-green, ash-fall or water-laid(?) nonwelded tuff dislaying massive bedding and minor subtle crossbedding. At other localities, the unit is light-gray to yellowish-gray, ash-fall and water-laid tuff, poorly consolidated, displaying 0.2- to 10-cm-thick beds. Unit occurs between the lower member of the Petroglyph Cliff Ignimbrite and the Lund Formation (Tnl) of the Needles Range Group. Unit is poorly exposed, weakly consolidated, and relatively unsorted. Where grayish green, the tuff includes euhedral pyroxene and plagioclase crystals that were probably derived by deposition and minor fluvial reworking of nonwelded eruptive products similar to the overlying lower member of the Petroglyph Cliff Ignimbrite. In contrast, where light-gray to yellowish-gray, the tuff contains biotite crystals that were probably derived from reworking of the underlying Lund Formation (Tnl). Unit forms gentle slopes below the more resistant lower member of the Petroglyph Cliff Ignimbrite. Unit is about 15-30 m thick

Needles Range Group (Oligocene)--Crystal-rich dacitic ash-flow tuff consisting of three formations in this quadrangle, in descending order, the Lund Formation, the Wah Wah Springs Formation, and the Cottonwood Wash Tuff (Best, Christiansen, and Blank, 1989). The age of the Lund Formation is about 27.9 Ma (average of 4 K-Ar dates), the Wah Wah Springs Formation is about 29.5 Ma (average of 16 K-Ar dates), and the Cottonwood Wash Tuff is about 30.6 Ma (average of 4 dates; Best and Grant, 1987). The Needles Range Formation was originally defined by Mackin (1960), but was elevated to group status by Best and Grant (1987)

Tnl **Lund Formation**--Crystal-rich, dacitic ash-flow tuff consisting of a pinkish-gray to yellow-gray, partially welded to moderately welded, devitrifed upper part and a light-gray, moderately welded, poorly developed, basal vitrophyre. Pumice fragments are indistinct and sparse. The rock contains about 30-50 percent phenocrysts that consist of about 10-25 percent quartz, less than 5 percent sanidine, 45-60 percent plagioclase, about 10-15 percent biotite, 15-20 percent hornblende, less than 5 percent clinopyroxene, and accessory Fe-Ti oxides, sphene, apatite, and zircon (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). Typical biotite books range from 1 to 2 mm in diameter and, although most are subparallel to the weak plane of flattening, enough books have nonparallel attitudes to give the rock a slightly random texture when viewed perpendicular to the plane of flattening. Lithic fragments are sparse. In the eastern part of the quadrangle, a sedimentary tuff that contains clasts of the andesitic lava flow of Mustang Spring (Tms) is included at the base of the map unit. Generally the unit forms steep slopes and small cliffs. The Lund Formation is estimated to be 60-90 m thick in this quadrangle, but it commonly is structurally attenuated or missing from the sequence in addition to original variations in thickness; such structural complications leave its original thickness uncertain

Tnw **Wah Wah Springs Formation**--Crystal-rich, dacitic ash-flow tuff, consisting of a moderately to densely welded simple cooling unit. Upper devitrified part of unit is light gray to yellow gray to light brownish gray and lower vitrophyric part is medium gray to dark gray. Pumice fragments are indistinct and sparse; distinctive 0.5-1 cm diameter, very pale orange to yellowish-gray, clay-rich, altered devitrification centers in the vitrophyre may originally have been pumice fragments or lithophysal cavities. The rock contains about 20-45 percent phenocrysts that consist of less than 10 percent quartz, 45-70 percent plagioclase, about 5-15 percent biotite, 10-25 percent hornblende, less than 5 percent clinopyroxene, and accessory Fe-Ti oxides, apatite, and zircon (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). Typical biotite books are 2 mm in diameter and the foliation planes are better developed than those in the Lund Formation (Tnl). Lithic fragments are sparse. Generally the unit forms moderate slopes. The Wah Wah Springs Formation is at least 80 m thick throughout much of the quadrangle, but it commonly is structurally attenuated. At many localities the unit has been so deformed by faulting that hand specimens contain abundant sheared surfaces at several attitudes, such deformation makes estimations of the thickness imprecise. On the western side of the quadrangle, the unit occurs as isolated, sheared, slices along attenuation faults. In other areas, the unit pinches out against Paleozoic rock exposures but it is unclear how much of the thinning is depositional and how much is deformational

Tnc **Cottonwood Wash Tuff**--Crystal-rich, dacitic ash-flow tuff that is light gray to yellowish gray and weathers yellowish gray to pale greenish yellow. Unit is devitiried and partially welded to moderately welded. Pumice fragments are indistinct and sparse; 1 cm-diameter, very pale orange, clay-rich, altered devitrification centers(?) are common in some zones. The rock contains about 30-45 percent phenocrysts that consist of 5-15 percent quartz, 55-60 percent plagioclase, about 10-15 percent biotite, 10-15 percent hornblende, less than 5 percent clinopyroxene, and accessory Fe-Ti oxides, apatite, and zircon (hand specimen inspection of samples from this quadrangle and thin section study from other localities reported by Scott and others, in press). Typical biotite books are 1-7 mm in diameter, distinctly larger than most books in the Lund Formation (Tnl) and the Wah Wah Springs Formation (Tnw). Lithic fragments are sparse. Generally the unit forms gentle to moderate slopes. Locally in the northeastern part of the quadrangle, the Cottonwood Wash Tuff appears to be at least 75 m thick, but its base is faulted; in the western part only a few slices of the unit occur along the major east-dipping attenuation fault. Elsewhere, structural attenuation and normal fault duplication occur to undetermined degrees and the thickness of the Cottonwood Wash Tuff cannot be determined

Tot **Orange tuff (Oligocene)**--Moderate-orange-pink, massive, nonwelded ash-flow tuff consisting of two layers separated by thin ash-fall tuff. Unit contains less than 5 percent phenocrysts of plagioclase and pyroxene. Red volcanic lithic fragments and pumice fragments are abundant. Unit is exposed only at one locality in the northern part of the quadrangle between the bedded tuff below the lower member of the Petroglyph Cliff Ignimbrite and the andesite of Mustang Spring where it forms moderate slopes and is about 15 m thick

Tbt **Bedded tuff (Oligocene)**--Greenish-gray, water-laid, poorly exposed, weakly consolidated, poorly bedded, nonwelded tuff containing abundant clasts of reworked andesite lava flow mixed in a tuffaceous matrix. Unit occurs between the Lund Formation (Tnl) and the underlying andesite of Mustang Spring (Tms). Unit forms gentle slopes and is generally less than 35 m thick

Tms **Andesitic lava flow of Mustang Spring (Oligocene)**--Grayish-red to brownish-gray to greenish-black, massive andesitic lava flow containing minor vesicular zones. Rock has about 20 percent phenocrysts of subequal amounts of plagioclase and clinopyroxene (based on hand specimen study only). Partings in the flow are generally subparallel to the upper and lower contacts. Unit occurs throughout the quadrangle except in the west-central and northwestern part where the unit has been largely eliminated by attenuation faults. Unit generally forms steep to moderate slopes. The unit is involved with an undetermined degree of attenuation faulting and duplicating faulting; where it is less faulted, the andesite is a great as 160 m thick

Tco **Mudflow of Coal Spring** (Oligocene)--Medium-dark-gray to grayish-green (celadonite alteration) andesitic clasts in a light-gray matrix of andesitic mudflows. The stratigraphic position of the map unit below the Lund Formation (Tnl) and the andesite of Mustang Spring (Tms) indicates that this mudflow is stratigraphically below the mudflow called the conglomerate of Black Rock Spring by Taylor (1990), Taylor and others (1989), Taylor (1989), and Bartley and others (1988) that overlies the Lund Formation in the Deadman Spring quadrangle. Clasts as small as a few centimeters in diameter are angular to subangular but larger clasts typically 0.5-2 m in diameter are subrounded to rounded. Larger clasts are monolithologic, nearly holocrystalline coarse-grained andesitic rock containing highly contorted flow bands. Unit is a maximum of about 150 m thick in the northeast part of the quadrangle but pinches out about 1 km to the south

Tds **Tuff of Deadman Spring (Oligocene)**--Moderate-orange-pink to pale-red, devitrified, partially to moderately welded, rhyolitic ash-flow tuff, consisting of at least two indistinct cooling units locally separated by bedded tuff (Tbt). Taylor (1989, 1990) informally defined the tuff of Deadman Spring. Rock contains about 25 percent small pumice fragments that are less than 0.5 cm in diameter, about 15-20 percent phenocrysts that consist of about 60 percent quartz, less than 20 percent feldspars, and 20 percent small biotite crystals that are typically less than 1 mm in diameter. Lithic fragments are sparse. Unit forms low hills and gentle slopes. Unit is exposed only in the northeastern part of the quadrangle. The unit is as thick as 120 m and pinches out southward near the center of the quadrangle

Tbt **Bedded Tuff (Oligocene)**--Pinkish-gray to grayish-pink ash-fall and crossbedded water-laid tuff occurring between cooling units within the tuff of Deadman Spring (Tds). The mineralogy of the bedded tuff is similar to the tuff of Deadman Spring. Bedded tuff forms a small bench in the tuff and is less than 2 m thick

Tbt **Bedded Tuff (Oligocene)**--Light-gray to grayish-pink, partially welded, ash-fall tuff occurring between the tuff of Deadman Spring (Tds) and the Wah Wah Springs Formation (Tnw). The mineralogy of the bedded tuff is similar to the tuff of Deadman Spring and contains conspicuous smoky quartz. Unit probably was deposited by a precursor eruption of the tuff of Deadman Spring, and its presence suggests a proximal source. Unit forms small ledges and is less than 5 m thick

Twb **Windous Butte Formation (Oligocene)**--Yellowish-gray to pinkish-gray, partially welded to moderately welded, devitrified rhyolitic ash-flow tuff. Cook (1965) first defined the Windous Butte Formation, but the unit was first discussed by Faust and Callaghan (1948). Its age is about 31.3 Ma (Best and others, 1993). Unpublished paleomagnetic data (C.S. Grommé, written commun., 1994) confirm the correlation. Pumice fragments are common. Unit contains about 25 percent phenocrysts that consist of about 30 percent quartz, 20 percent sanidine, 30 percent plagioclase, 15 percent biotite, and less than 5 percent hornblende (based on hand specimen study only). Biotite flakes are as much as 5 mm in diameter. About 3 percent lithic fragments are present. This locality is the southermost reported occurrence of the Windous Butte Formation, forming a lobe roughly coincident with the North Pahroc Range. Unit forms low hills and gentle slopes on the west side of the quadrangle. Unit is less than 115 m thick but the upper part of the unit has been removed by faulting

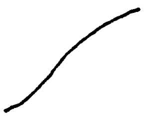
Twg **Andesite of Wheatgrass Spring (Oligocene)**--Andesitic, grayish-red to brownish-gray to greenish-black, massive lava flow containing minor vesicular zones. Rock contains about 15 percent phenocrysts of subequal amounts of plagioclase and clinopyroxene (based on hand specimen study only). Partings in the flow are generally subparallel to the upper and lower contacts of the unit. Unit occurs only on the western side of the quadrangle. At several localites lacustrine and fluvial sedimentary rocks (Tlf) were deposited between unit flows. Unit covers large topographic lows where it is commonly the oldest unit exposed. Unit locally forms steep to moderate slopes. Over much of its exposures, the unit forms an arched structure and its thickness is difficult to determine; however, using conservative estimates, it ranges from only a few tens of meters to at least 75 m thick

PPb **Bird Spring Formation (Permian and Pennsylvanian)**--Light-gray to pale-yellowish-brown, commonly alternating massive to thin-bedded limestone, commonly cherty in the massive beds and silty in the thin beds. Where better exposures of the map unit occur in the Deadman Spring qudrangle to the north, no unconformity was found at the Permian-Pennsylvanian boundary (R.B.Scott, unpublished mapping), as predicted by C.H. Stevens (written commun., 1994; Stevens, 1979) at the stratigraphic break between the Pennsylvanian Ely Limestone and the Permian Reipe Spring Limestone recongized north of the North Pahroc Range. We import Bird Spring Formation nomenclature because it spans the Pennsylvanian-Permian boundary with no apparent break, similar to the Bird Spring Formation sequence 90 km to the south in the southern Delamar Mountains (Swadley and others, in press). Locally abundant brachiopods, pelecypods, and solitary corals are present. Deformed areas have commonly been recrystallized to sparry calcite, destroying bedding. Upper contact of the Bird Spring Formation Limestone with Tertiary volcanic rocks is either an angular unconformity or an attenuation fault; lower contact is unexposed. Thickness of map unit is estimated to be about 400 m at the southern exposure and 250 m at the northern exposure, but structural complications make these estimates questionable

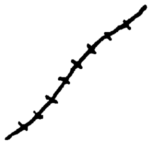
Mj **Joana Limestone (Mississippian)**--Thickly bedded to massive, medium-dark-gray, nonfossiliferous, cherty limestone. Chert is abundant, massive, irregular, somewhat stratiform, and grayish black to dusky red. Three small exposures are present in the eastern part of the quadrangle near Rattlesnake Spring. Only a thickness about 20 m of the Joana Limestone is exposed; and neither the top nor the bottom of the unit is exposed

Dg **Guilmette Formation (Devonian)**--Limestone, dolomite, and interbedded quartzite. The top and base of unit are not exposed, but exposed strata probably correlate with the upper part of the Guilmette Formation, because they resemble those strata in the southern Delamar Mountains and Meadow Valley Mountains (Swadley and others, 1990; Swadley and others, in press). Light-olive-gray, aphanic to finely crystalline, thin-bedded limestone is predominant; medium-dark-gray, aphanic to finely crystalline, arenaceous, thin to moderate bedded dolomite and light-brown to moderate-brown, fine- to medium-grained quartzite are subordinate. Quartzite grains are moderately to well sorted and subrounded; trough crossbedding is common and beds range from 0.2 to 1.5 m thick. Most of the unit is unfossiliferous but limestones at the highest stratigraphic position contain sparse brachipods, corals, and gastropods. The Guilmette Formation is about 190 m thick and is exposed north of Rattlesnake Spring and in the northeastern part of the quadrangle

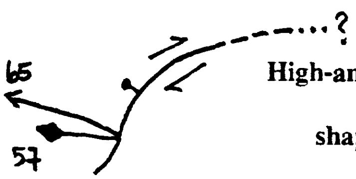
MAP SYMBOLS



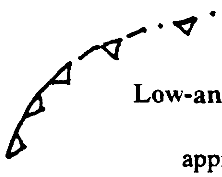
Contact



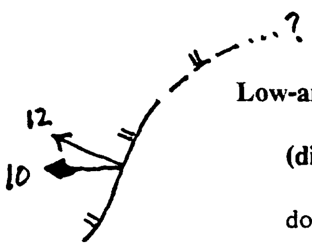
Contact of uncertain nature between units where tectonic thinning is suspect--May be either depositional or tectonic; limited exposures do not allow distinction between two interpretations. Thicknesses of units separated by this contact are significantly less than thicknesses of unit in undisturbed parts of the stratigraphic section. Generally stratigraphic order of units delineated by contact is preserved. Commonly units adjacent to contact display abundant slickensided surfaces. Attenuating faults may occur within unit and (or) at the contact between units



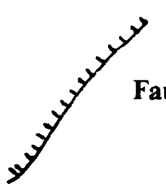
High-angle fault, showing dip (barbed arrow) and trend and plunge of fault-plane lineation (diamond-shaped arrow)--Dashed where approximately located; dotted where concealed; queried where location uncertain. Bar and ball on downthrown side. Opposed arrows indicate the relative direction of strike-slip movement



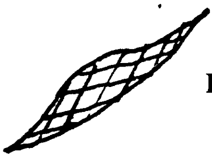
Low-angle fault below gravity-slide block--Sawteeth on upper plate of slide block. Dashed where approximately located; dotted where concealed.



Low-angle normal fault, showing dip (barbed arrow) and trend and plunge of fault-surface lineation (diamond-shaped arrow)--Double hachures on upper plate. Dashed where approximately located; dotted where concealed; queried where location uncertain

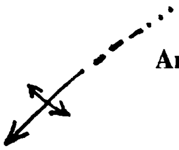


Fault scarp along which younger unit has been deposited--Hachures on side of postfault deposit



Fault breccia--Massive or sheared

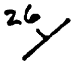
Breccia--Zones of breccia of undetermined origin; parent map units present are identified by map unit symbols in parentheses. Commonly a crude stratigraphic order of units is preserved in the breccia



Anticlinal axis--Dashed where approximately located; dotted where concealed. Showing direction of plunge

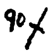
Synclinal axis--Showing direction of plunge

Strike and dip of sedimentary beds and compaction foliation of ash-flow tuffs



Inclined

Horizontal



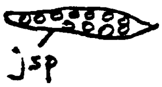
Vertical

Dip of contact

Inclined

Strike and dip of flow foliation

Inclined



Jasperoid alteration

Shaft

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Wheatgrass Springs quadrangle

Scott, Swadley
and Taylor

Correlation of Map Units