U.S. DEPARTMENT OF THE INTERIOR
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PRELIMINARY GEOLOGIC MAP OF THE PAHROC 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 in part on the volume percent of phenocrysts as determined by thin section modal analyses and in part by thin section and handspecimen estimates of phenocryst modes. Isotopic ages are reported with 2 sigma errors. Previous mapping in the area has been published at a scale of 1:250,000 (Tschanz and Pampeyan, 1970; Ekren and others, 1977). Volcanic unit rock names are based on the chemical classification of Le Maitre (1989).]

Qal **Alluvium (late Holocene)**--Grayish-orange to pale-yellowish-brown sand, gravelly sand, and minor amounts of gravel; unconsolidated, poorly bedded. Sand is fine to coarse, poorly sorted, locally silty. Gravelly sand includes angular to subrounded pebbles, cobbles, and sparse boulders of ash-flow tuff, lava, limestone, quartzite, and dolomite. Unit forms channel deposits of active washes throughout the quadrangle and fan deposits near the southwest corner of the quadrangle. Channel deposits consist of poorly sorted sand interbedded with poorly to moderately well sorted gravelly sand that locally contains beds and lenses of gravel. Fan deposits are chiefly sand with a few interbeds of gravelly sand. Most exposures show no soil development; locally a thin sandy vesicular A horizon is developed. Maximum exposed thickness is about 2 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 rock 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 undetermined

Qae **Alluvium (early Holocene and late Pleistocene)**--Pale-grayish-brown to brownish-gray sand, gravelly sand, and gravel; unconsolidated to weakly consolidated, poorly to moderately well sorted, poorly bedded. Clasts in gravel and gravelly sand consist of angular rounded pebbles, cobbles and sparse boulders of ash-flow tuff, lava, limestone, quartzite, and dolomite. Sand is fine to coarse, mostly angular, commonly silty. Unit forms terrace deposits along the large washes in the area and fan remnants that overlie or are inset into fan remnants of unit Qaw. Terrace and fan deposits consist of interbedded sand and gravelly sand; interbeds and lenses of gravel occur locally and are more abundant near bedrock outcrops. Deposits of unit stand 1-2 m above channel deposits of active washes. Surface of deposit is typically smooth and undissected. Soil development consists of a thin sandy vesicular A horizon, a 0.6- to 0.8-m-thick B horizon that is the same color as the parent material, and a Cca horizon as thick as 0.3 m that has stage I carbonate development. The Cca horizon is weakly developed or absent where it is formed in sand. Maximum exposed thickness about 3 m

QTls **Landslide debris and gravity-slide block complex (Quaternary to Pliocene?)**--Complex mixture of unconsolidated debris and coherent blocks of volcanic rocks. Crude stratigraphic order exists within slide debris. Debris is locally cemented by secondary carbonate. Unit is locally at least 60 m thick. (Areas underlain by slide blocks and debris of a single bedrock unit are designated by that bedrock symbol; areas underlain by a mixture of lithologies are designated by QTls; in either case, unit is shown by coarse stipple pattern and, where appropriate, by fault trace with open teeth on the slide body)

Qaj **Alluvium of Jumbo Wash (late? and middle Pleistocene)**--Unit named for deposits along and near Jumbo Wash in the Gregerson Basin quadrangle (Scott and others, 1990) about 30 km southeast of the quadrangle. Brownish-gray to very pale orange sand and gravelly sand; weakly consolidated, poorly sorted, poorly bedded. Sand is fine to very coarse, mostly angular, locally silty. Clasts in gravelly sand consist of angular to subrounded pebbles, cobbles, and small boulders of ash-flow tuff, lava, limestone, quartzite, and dolomite. Unit forms a few small poorly exposed fan remnants and inset fans along the east flank of the North Pahroc Range. Unit stands about 3 m above channels of active washes; surface is slightly dissected. A loosely packed stone pavement is locally developed. Soil development typically consists of 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 Delamer 3 SE quadrangle (Swadley and others, 1990) 35 km south-southeast of the quadrangle. Pale-yellowish-brown to brownish-gray gravelly sand, sand, and gravel; weakly to moderately well consolidated, poorly sorted, poorly to moderately well bedded. Gravel and clasts in gravelly sand consist of angular to rounded pebbles, cobbles, and boulders, commonly less than 1 m across, of ash-flow tuff, lava, limestone, quartzite, and dolomite in a poorly sorted sand matrix. Locally unit includes abundant well rounded clasts derived from conglomerate beds in unit Tl. Sand is fine to coarse, locally silty. Unit forms numerous poorly exposed, moderately dissected fan remnants of interbedded sand and gravelly sand; lenses and interbeds of gravel occur locally, commonly near bedrock exposures. Surface of unit is moderately dissected by V-shaped washes and the areas between dissecting washes are commonly eroded down to the pedogenic carbonate horizon. Unit stands 2-6 m above the channels of through-flowing washes; the surface is commonly littered with chips and plates of pedogenic carbonate. Soil development consists of a silty sand vesicular A horizon, a 0.3-m-thick dark-yellowish-orange cambic B horizon that is rarely preserved, and a 1- to 2-m-thick K horizon that has stage III carbonate development in the upper part. Thickness 0 to more than 8 m

QTa **Alluvium (early Pleistocene and Pliocene?)**--Brownish-gray to grayish-brown gravel and gravelly sand; moderately well consolidated, poorly sorted, and poorly bedded. Consists of angular to rounded pebbles, cobbles and boulders, as large as 3 m across, of ash-flow tuff, lava, limestone, quartzite, and dolomite in a poorly sorted sand matrix. Unit forms poorly exposed, eroded fan remnants that crop out as rounded ridges that are littered with a lag of bouldery gravel and common to abundant chips and plates of pedogenic carbonate. Unit occurs chiefly near the south-central border of the quadrangle. No soil exposure observed in the quadrangle. Typically, where a soil is exposed on QTa elsewhere in the region, it consists of a 3- to 5-cm-thick clayey, silty sand vesicular A horizon underlain by a 1- to 2-m-thick K horizon that has 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 more than 10 m

Ta **Alluvium (Pliocene)**--Pale-yellowish-brown gravel; moderately well consolidated, poorly sorted, and poorly bedded. Consists of angular to rounded pebbles, cobbles, and small boulders of ash-flow tuff and lava; boulders as much as 2 m in diameter occur sparsely. Forms a poorly exposed, deeply dissected fan remnant near the northwest corner of the quadrangle; typically exposed as rounded ridges littered with a bouldery gravel lag that contains common to abundant chips of pedogenic carbonate on ridge crests and upper slopes. Soil development consists of a poorly exposed, partly eroded K horizon of unknown thickness that probably has stage III carbonate development. The soil seems to conform to the rounded surface of the deposit suggesting the soil formed on an eroded surface and may be significantly younger than the alluvium. Exposures limited to northwest and western parts of quadrangle. Maximum thickness exposed within the map area is about 30 m

Tb **Basalt flows (Miocene)**--Dark-gray to grayish-black olivine-plagioclase-clinopyroxene-bearing basalt flows. Basalt is locally vesicular near top of flows. Unit contains about 15 % phenocrysts. Unit forms a resistant cap above an angular unconformity and above older units also deposited on the unconformity (young nonwelded tuff [Tyn], alluvium of Hiko Tuff and Condor Canyon Formation boulders [Tahcb], and alluvium of Hiko Tuff boulders [Tahb]). Age undetermined. As much as 12 m thick south of the Pahroc Valley fault in the southern part of the quadrangle

Tyn **Young nonwelded tuff (Miocene)**--Nonwelded, pinkish-gray, lithic-rich, rhyolitic tuff. Tuff contains about 15 % light-gray volcanic lithic fragments 0.25-1 cm across. Also contains about 10 % phenocrysts that consist largely of quartz, a smaller portion of biotite, and traces of feldspars. Exposures are limited to a narrow zone south of the Pahroc Valley fault below basalt flows (Tb). Only a few meters of tuff are exposed

Tahcb **Alluvium of Hiko Tuff and Condor Canyon Formation boulders (Miocene)**--Light-brownish-gray to brownish-gray alluvium consisting of boulders in a matrix of finer debris. Boulders and matrix consist largely of detritus derived from primarily the Hiko Tuff (Th) and secondarily the Bauers Tuff Member (Tcb) of the Condor Canyon Formation. Degree and nature of cementation and consolidation unkown. The unit forms the upper part of remnants of the fan; alluvium of Hiko Tuff clasts (exclusively) (unit Tahb) forms the lower part of remnants of the fan. Most of the boulders range between 0.5 and 2 m across. Although the finer matrix is not exposed, debris on hillsides suggest that clasts grade continuously to sand size. The distribution of the fan remnants suggests that the unit was deposited in response to uplift north of the east-west striking Pahroc Valley fault. Exposures form low rounded hills. Thickness of unit may be as great as 25 m

Tahb **Alluvium of Hiko Tuff boulders (Miocene)**--Light-brownish-gray to brownish-gray alluvium consisting of monolithologic boulders in a matrix of finer debris. Unit is identical to unit Tahcb except for the lack of clasts derived from the Bauers Tuff Member (Tcb). Although most of the remnants of the fan form a belt south of the Pahroc Valley fault, smaller exposures lie within a narrow zone north of the fault where erosion has exposed deeper stratigraphic levels on the upthrown side of the fault. One exposure located 2 km north of the fault and 5.9 km east of the west boundary of the quadrangle may be a remnant of a separate fan related to the north-striking fault on the west side of the valley containing the exposure; the largest clast formed a column-like monolith at least 10 m on each side. The alluvium of Hiko Tuff boulders is probably at least 25 m thick

Th **Hiko Tuff (Miocene)**--Rhyolitic ash-flow tuff having a eutaxitic texture and consisting of one compound cooling unit. Light-brownish-gray, thick, densely welded and devitrified upper zone grades downward through a moderately welded, local vitrophyric tuff characterized by eutaxitic black fiamme to a pinkish-gray, relatively thin, nonwelded, partly vitric basal zone. Lenticular pumice fragments are a lighter color than the matrix, range from 0.3 to 8 cm in diameter along the plane of foliation, and form as much as 20 % of the rock. Rock is mottled very light gray to light brown and light brownish gray. Tuff contains about 30-40 % phenocrysts that consist of about 10-35 % quartz, 10-35 % sanidine, 30-65 % plagioclase, 5-15 % biotite, less than 5 % hornblende, a trace of pyroxene, and accessory sphene, zircon, apatite, allanite, and Fe-Ti oxides. Quartz phenocrysts are a distinct very pale purple. A relative increase in ferromagnesian and plagioclase higher in the unit at the expense of other phases has been noted (Scott and others, 1988; R.E. Anderson, unpublished data). Tuff contains trace to 4 % lithic fragments consisting largely of argillite. In some zones lithophysae are 4 cm in diameter and form between 2 and 10 % of the rock. A $^{40}Ar/^{39}Ar$ biotite date by Taylor and others (1989) of the Hiko Tuff is 18.5 ± 0.4 Ma, but they suggest that the best age estimate may be 18.6 Ma based on additional data. Unit forms bold cliffs and on dip slopes forms distinct knobby weathering surfaces several meters in diameter. Unit probably is greater than 100 m thick; its top is not preserved

Tbm **Middle basalt flows (Miocene)**--Basalt flows including those having aphyric, olivine-plagioclase, and pyroxene-plagioclase phenocryst assemblages. Flows are medium gray to dark gray and commonly have vesicular tops. Unit is exposed in the northwest and east central parts of the quadrangle but absent inbetween. Flows cap dip slopes or ledges and are locally as much as 20 m thick

Tbt **Bedded tuff (Miocene)**--Bedded tuff consisting of an upper ash-fall part and a lower water-lain part. Upper part is a pinkish gray lapilli tuff that consists largely of 2-7 mm diameter pumice fragments. Beds generally range between 20 and 50 cm thick. Beds are distinguished by differences in abundances of lava flow lithic fragments, ranging up to 20 % of the tuff and to 2.5 cm in diameter. Sparse quartz phenocrysts are present. Lower part has crossbedding and graded bedding, typically 5 to 20 cm thick, and light gray tuff in the lower part consists of gravel- to sand-sized clasts. Coarsest clasts are fragments of silicic lava flows, intermediate-sized clasts are altered reworked phenocrysts of plagioclase and biotite, and the finest clasts are largely glass shards. Unit is exposed in the east central part of the quadrangle and is as much as 50 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 to densely welded central zone, and a nonwelded basal zone. Unit is devitrified, phenocryst-rich, and massive with an indistinct foliation. The central zone of the unit ranges between pale red where more weathered and light olive gray to light gray where fresher. Pumice fragments are sparse. The rock contains about 40-55 % phenocrysts that consist of 2-10 % quartz, <3 % sanidine, 55-70 % plagioclase, 10-20 % biotite, <15 % hornblende, and <7 % pyroxene, and accessory Fe-Ti oxides, zircon, apatite, sphene, allanite, and perrierite and/or chevkinite. Biotite books are as much as 4 mm across. Lithic fragments form less than 5 % of the rock. Unit forms cliffs, the lower parts of which are commonly covered with colluvial debris. 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 Harmony Hills Tuff is about 30 m thick

Tpl **Pahranagat Lakes Tuff**--Rhyolitic ash-flow tuff consisting of one simple cooling unit. Although Best and others (1989) first published a report on the Pahranagat Lakes Tuff, they adopted the term from Williams (1967) who recognized these rocks in his dissertation. 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 % of tuff. Rock contains 15-35 % phenocrysts that consist of 20-45 % quartz, 30-50 % sanidine, 25-40 % plagioclase, 1-6 % biotite, 1-2 % hornblende and accessory Fe-Ti oxides, zircon, apatite, sphene, and allanite. About 1 % lithic fragments occur in the upper part of the tuff, but the lowest nonwelded part contains about 10 % lava-flow lithic fragments. The $^{40}Ar/^{39}Ar$ date of sanidine from the tuff is 22.65±0.02 Ma (Deino and Best, 1988). The relatively nonresistant unit forms thin benches between steeper cliffs of bounding units. Pahranagat Lakes Tuff is about 5-15 m thick in the quadrangle

Condor Canyon Formation (Miocene)--Rhyolitic ash-flow tuff that consists of two simple cooling units, in descending order, the Bauers Tuff and the Swett Tuff Members. Cook (1965) named the formation and Mackin (1960) named the two tuffs. 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, Deino, and others, 1989). This is about 1 my younger than the average K-Ar age of the Swett Tuff Member (23.7 Ma, Armstrong, 1970). The thin but persistent Isom compositional type tuffs of Pahroc Valley (Tip) separates the two members of the Condor Canyon Formation.

Tcb **Bauers Tuff Member**--Rhyolitic ash-flow tuff containing sanidine phenocrysts in addition to plagioclase and biotite. The tuff is pinkish gray, devitrified, moderately welded, and relatively crystal-poor near the top (about 10 % phenocrysts), is light brownish gray, devitrified, densely welded, and more crystal rich in the middle part (about 20 % phenocrysts), and forms a grayish-black to brownish-gray, moderately to densely welded, relatively crystal-rich vitropyhyre near the base (about 20 % 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 are similar 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 % sanidine, 35-70 % plagioclase, 0-5 % pyroxene, and accessory Fe-Ti oxides, zircon, and apatite; the absence of quartz is distinctive. The tuff contains less than a few percent lithic fragments and as much as 10 % highly flattened lithopysal cavities above the vitrophyre. The Bauers Tuff Member forms steep slopes and minor cliffs and ranges from 25 to nearly 60 m thick

Tcs **Swett Tuff Member**--Rhyolitic ash-flow tuff, containing plagioclase and biotite phenocrysts. The upper part of the tuff is light red to pale red, devitrified, moderately to densely welded. The transition from devitrified tuff to underlying vitrophyre is marked commonly by pronounced light-red to grayish-orange-pink mottling and 10-30 % lithophysal cavities. The thick vitrophyre near the base forms as much as 1/3 of the unit, is dark gray, and contains prominent white phenocrysts. The rock contains 10-20 % phenocrysts that consist of 65-85 % plagioclase, 7-20 % biotite, as much as 2 % pyroxene, and accessory Fe-Ti oxides and apatite; the absence of quartz and sanidine is distinctive. Lithic fragments are sparse. Unit forms steep slopes and narrow cliffs. Swett Tuff Member is uniformly about 10 m thick in the western part of the quadrangle, but elsewhere its thickness is more variable; locally the unit has the appearance of being as much as 85 m thick, but where these greater thicknesses occur, duplication of the unit by normal faults is suspected

Tip **Isom-type tuffs of Pahroc Valley (Miocene)**--Trachytic densely welded ash-flow tuffs forming thin dark layers between the members of the Condor Canyon Formation and having lithologic similarities to units of the Isom Formation. Two cooling units occur in the western part of the quadrangle but only one occurs elsewhere. The upper cooling unit is distinguishrd by a dark-gray vitrophyre above and below a dusky-red to light-red devitrified interior. The lower does not have the upper vitrophyre. Both units consist mostly of vitrophyre and both show evidence of post-emplacement flow, similar to the lithology of the Isom Formation described below. The rock contains about 15 % phenocrysts that consist of plagioclase and lesser amounts of clinopyroxene and Fe-Ti oxides, a mineralogy also similar to the Isom Formation. The absence of biotite is diagnostic. In devitrified rock pyroxene is altered to moderate greenish yellow to moderate yellow clay-like phases and feldspar is white. Lithic fragments form about 5 % of the rock. Unit forms steep slopes and small cliffs similar to bounding members of the Condor Canyon Formation. Age of unit undetermined. The Isom compositional type ash-flow tuffs of Pahroc Valley range from about 5 to 10 m thick

Trd **Rhyolite dike (Miocene?)**--Quartz- and sanidine-bearing rhyolitic dike. Unit commonly 1-2 m wide having vitrophyric margins. Age uncertain

Tlc **Leach Canyon Formation (Oligocene)**--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. Abundant flattened pumice fragments that form 10-20 % of the rock are commonly light brownish gray and 0.2-2 cm long in the plane of foliation. The rock contains 15-25 % phenocrysts that consist of 20-60 % quartz, 10-40 % sanidine, 20-55 % plagioclase, 2-14 % biotite, traces of hornblende and pyroxene, and accessory Fe-Ti oxides, sphene, zircon, and apatite. Lithic fragments are sparse except toward 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 may be the average of age of a coexisting sanidine and biotite pair dated by Armstong at about 23.8 Ma. Unit ranges from about 70 to 120 m thick

Tivs **Volcanic sedimentary rock of Isom clasts (Oligocene)**--Volcanic breccia containing of clasts derived from the underlying Hole-in-the-Wall Member of the Isom Formation. Light-brownish-gray breccia contains about 50 % pebble-size subangular to angular clasts in a matrix of sand and slit; each bed appears to be unsorted. Beds are 0.4-2.5 m thick. Unit probably was emplaced as a lahar or a mudflow. Unit forms gentle slopes, is exposed only in the southeast part of the quadrangle, and is as great as 25 m thick

Isom Formation (Oligocene)--Trachytic ash-flow tuffs consisting of two, and possibly three, members in this quadrangle: 1) the upper, Hole-in-the-Wall Tuff Member, 2) a newly proposed tuff member of Hamlight Canyon (C. S. Grommé, written commun., 1992; Scott and others, in press; its presence in this quadrangle is uncertain), 3) and the lower, Baldhills Tuff Member. Each member includes one or more separate simple cooling units. In this quadrangle, the upper and lower members of the Isom Formation are separated by six map units, which from youngest to oldest include a series of older basalt flows (Tob) and volcanic sandstone (Ts), a Blawn-like tuff (Tbl), the upper member of the Shingle Pass Tuff (Tspu), the rhyolitic tuff of Hancock Summit (Ths), and the lower member of the Shingle Pass Tuff (Tspl). If present, the middle tuff member consists of one or more of the ash-flow cooling units mapped as the Baldhills Tuff Member. The 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 unpublished plagioclase date of 25.9±0.8 Ma was determined by H.H. Mehnert (written commun., 1990) reported in Scott and others (in press). The younger Hole-in-the-Wall Tuff Member has not been dated; however, stratigraphic constraints suggest that its age is between the age 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 underlying upper member of the Shingle Pass Tuff (Tspu)

Tih **Hole-in-the-Wall Tuff Member**--Trachytic ash-flow tuff consisting of as many as four separate cooling units; four cooling units are present in the central and eastern parts of the quadrangle, but only two are present in the western and southern part of the quadrangle. Preliminary paleomagnetic data suggest that at least the reversely magnetized upper cooling unit is the Hole-in-the-Wall Tuff Member, and that the lowest normally polarized lower cooling unit may belong to the newly proposed tuff member of Hamlight Canyon. The individual cooling units are indistinguishible from one another, and therefore both members 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 are moderately to densely welded. The cooling units contain 5-15 % phenocrysts that consist of 70-80 % plagioclase and minor amounts of pyroxene and Fe-Ti oxide. Lithic fragments form 5-10 % of the rock. The cooling units form a series of small cliffs separated by narrow benches. Hole-in-the-Wall Tuff Member ranges from about 8 to 24 m thick

Tib **Baldhills Tuff Member of the Isom Formation (Oligocene)**--Trachytic ash-flow tuff consisting of as many as three cooling units; the middle cooling unit is present throughout the quadrangle, the upper cooling unit is present in the southwestern part of the quadrangle, and the lower cooling unit is present only in the eastern part of the quadrangle. The upper cooling unit is a medium-dark-gray vesicular vitrophyre containing about 15 % phenocrysts of plagioclase and lesser amounts of pyroxene and Fe-Ti oxide and containing about 20 % highly flattened vesicles (or lithophysal cavities) 2-5 mm long. Light-gray flattened pumice fragments(?) are less than 1 cm long. Devitrified upper part of the middle cooling unit is generally grayish red and densely welded. The vitrophyric lower part of the middle cooling unit is dark gray to grayish black and densely welded. The middle cooling unit contains as much as 15 % phenocrysts that consist of about 80 % plagioclase and minor abundances of pyroxene and Fe-Ti oxide. Lithic fragments form about 10 % of the rock. The cooling units form narrow benches below small cliffs. The lower cooling unit is a medium-gray, partly vitric, nearly aphyric tuff with partings in the plane of foliation parallel to unit boundaries. Baldhills Tuff Member ranges from about 25 to 40 m thick except in the western part of the quadrangle where the addition of the upper cooling unit makes the map unit about 65 m thick

Tob **Older basalt flows (Oligocene)**--Basalt flows ranging from olivine-phyric to pyroxene-plagioclase-phyric to aphyric. Olivine-phyric flows are most common and are generally massive, grayish black, and crystal-poor (< 5 percent). Pyroxene-plagioclase-phyric flows are massive, grayish-black, and relatively crystal-rich (containing 20 % phenocrysts, two-thirds of which are clinopyroxene); these flows commonly contain 15 % vesicles. Aphyric flows have light-bluish-gray coatings on walls of partings and small (1 mm diameter) vesicles. At several localities minor sandstone intervals containing basalt clasts occur between flows. These sandstone intervals are commonly grayish orange and contain crossbeds and channel structures that indicate they were deposited by fluvial processes. Where these sandstone intervals are locally thick enough to be mapped separately, they are assigned to the volcanic sandstone map unit (Ts), described below. The older basalt flows form steep to moderate talus-covered slopes at most localities and are sparsely exposed. Unit ranges from 50 to 80 m thick where undeformed by attenuating normal faults

Ts **Volcanic sandstone (Oligocene)**--Sandstone including beds interbedded with older basalt flows (Tob) and beds underlying older basalt flows. Interbedded sandstone contains basalt clasts but underlying sandstone contains rhyolitic volcanic clasts. Sandstone is commonly grayish orange between basalts flows and yellowish gray below the basalt. Crossbeds and channel fill structures are common. Sandstone is moderately sorted and beds are 0.2-4 m thick. Unit is generally poorly exposed in washes cut into talus slopes under the older basalt flows (Tob). Unit mapped in two localites in quadrangle, one 2.8 km west of the east boundary and 4.5 km south of the north boundary, the other 3.8 km east of the west boundary and 2.9 km north of the south boundary. Unit is at least 12 m thick

Tbl **Blawn-like tuff (Oligocene)**--Rhyolitic ash-flow tuff consisting of a nonwelded to partially welded, devitrified, yellowish-gray to very light gray rock. Although tuff resembles the high-silica rhyolitic tuff of the Blawn Formation (Best and others, 1987; Best, Lemmon, and Morris, 1989), its assignment to this formation is uncertain. The stratigraphic level of the Blawn Formation is not precise because rocks included in the definition of the unit range in age from 24 to 18 Ma (Best and others, 1987; Best, Lemmon, and Morris, 1989). Definitive chemical, petrographic, and paleomagnetic data, with which to make definitive correlations, are not available. Pumice fragments are sparse and less than 0.5 cm in diameter. The rock contains about 15 % phenocrysts that consist primarily of resorbed quartz, small amounts of feldspars, intermediate amounts 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. About 5 % of the rock consists of inconspicuous volcanic lithic fragments. Unit forms gentle to steep light-colored slopes and a prominent bench at its base. Blawn-like tuff ranges from 35 to 60 m thick where undeformed by attenuating normal faults

Tsp **Shingle Pass Tuff, undifferentiated (Oligocene)**--Rhyolitic ash-flow tuff consisting of two members in the Pahroc Spring quadrangle. 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 definitive estimate of the age of the members; the date for the upper member is 26.00 ± 0.03 Ma and the date for the lower member is 26.68 ± 0.03 Ma (Best, Christiansen, and others, 1989). Between the members of the Shingle Pass Tuff, an ash-flow tuff tentatively correlated with the tuff of Hancock Summit can be distinguished from the feldspar-rich Shingle Pass Tuff members by its greater quartz phenocryst abundance. In one area in the northeastern part of the quadrangle, poor exposures (and possibly structural omission of the intervening tuff of Hancock Summit) do not permit clear field distinction of the upper Shingle Pass member, Hancock Summit, or lower Shingle Pass member; in this case, they are included as one map unit (Tsp). This map unit is about 10-15 m thick

Tspu **Upper member**--Rhyolitic ash-flow tuff consisting of a pale-red, densely welded, devitrified upper part having hackly, crumbly, weathered surfaces and a thinner, moderate-reddish-orange to brownish-gray, densely welded, vitrophyric lower part having conchoidal fractures. Rock contains 5-10 % phenocrysts consisting of 1-2 % quartz, 30-40 % sanidine, 50-60 % plagioclase, 5-15 % biotite, lesser amounts of hornblende and pyroxene, and accessory Fe-Ti oxides, zircon, and apatite. The vitrophyre has a characteristic eutaxitic texture visible with a hand lens and grayish-orange-pink mottled areas around devitrification centers. The upper member is distinguished in the field from the lower by a higher biotite content in the upper. Unit forms steep slopes. Unit is nearly 50 m thick where it is unaffected by attenuation near the western boundary of the quadrangle. Most of the units at or below the stratigraphic level of the upper member of the Shingle Pass Tuff in the arched part of the range in the central and eastern parts of the quadrangle probably have been thinned structurally or duplicated by normal faults; in these areas the maximum apparent thickness of the unit is 35 m

Tspl **Lower member**--Rhyolitic ash-flow tuff consisting of a very light gray to pale-red, moderately welded to densely welded, devitrified upper part having hackly, crumbly, weathered surfaces and a brownish-gray to brownish-black, densely welded vitrophyric thinner lower part having conchoidal fractures. Rock contains 15-20 % phenocrysts consisting of 8-15 % quartz, 50-60 % sanidine, 25-35 % plagioclase, <2 % biotite and hornblende, as much as 5 % clinopyroxene, traces of fayalite, and accessory Fe-Ti oxides, zircon, and apatite. The vitrophyre has a characteristic eutaxitic texture visible with a hand lens and grayish-pink devitrification centers. The lower member is distinguished in the field from the upper by a lower biotite content. The sanidine and plagioclase phenocryst ratios are about 2 in the lower member and about 0.5 in the upper member, but require thin section study. Unit forms steep slopes and is commonly highly brecciated and covered by talus. Where unaffected by attenuating normal faulting in the western part of the quadrangle, the unit is about 25 m thick. Most of the units at or below the stratigraphic level of the upper member of the Shingle Pass Tuff in the arched part of the range in the central and eastern parts of the quadrangle probably have been thinned structurally or duplicated on unrecongized normal faults; in these areas thickness are uncertain

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 densely welded, tuff; vitrophyre is not present. Rock contains about 25 % phenocrysts consisting of about 40 % quartz, 30 % sanidine, 20 % plagioclase(?), nearly 10 % biotite, and accessory Fe-Ti oxides, zircon, and apatite. Lithic fragments are sparse. Unit forms rounded slopes and has an apparent thickness of about 50 m in the central part of the quadrangle; however, its thickness is difficult to determine in all areas of exposure in the central and eastern parts of the quadrangle because of intense normal faulting that both thins and duplicates the unit in plan view

Tl **Limestone (Oligocene)**--Lacustrine limestone containing subordinate interbedded conglomerate; seven sequences of limestone and interbedded limestone and conglomerate are present, separated by six volcanic intervals. In descending order, the volcanic intervals are 1) the Monotony Tuff (Tm), 2) an unnamed old Isom compositional type ash-flow tuff (Tio), 3) an upper member of the Petroglyph Cliff Ignimbrite (Tpcu) overlying a lower member of the Petroglyph Cliff Ignimbrite (Tpcl), 4) the Lund Formation (Tnl) and the andesite(?) of Mustang Spring (Tms), 5) the Wah Wah Springs Formation (Tnw), and 6) the Cottonwood Wash Tuff (Tnc), all of which are described below. The limestone and conglomerate occur between the Lund, the Wah Wah Springs, and the Cottonwood Wash at all exposures of these intervals, but only locally present between other volcanic intervals. The abundance of conglomerate relative to limestone increases downward from only a trace of conglomerate above the Petrogylph Cliff Ignimbrite to about 50 % conglomerate below the Wah Wah Springs and Cottonwood Wash. The limestone ranges from very light gray and medium dark gray, to pinkish gray, and to light brownish gray and forms 0.2-3 m-thick beds in most areas. Thin (1-2 cm) channel-like lenses of reworked volcanic clast occur in thicker limestone beds at several localities. Much of the limestone has been coarsely recrystallized but locally it commonly contains wavy, thinly layered algal(?) structures. In a few localities sparse gastropods and ostracods are present in darker-colored limestone; reed-like fossils are also locally present in lighter-colored limestone. Where hydrothermally altered, the limestone resembles that of the Devonian Guilmette Formation, exposed outside of this quadrangle. Tschanz and Pampeyan (1970) showed the Guilmette Formation on their Lincoln County map at one exposure of altered limestone in the map area (3.2 km north of the south boundary and 3.5 km west of the east boundary of the quadrangle). Yet that exposure of partly silicified, veined, and discolored limestone contains well-preserved Tertiary reed- and wood-like fossils; silicification has enhanced plant fossil preservation over that of other localities. Conglomerate strata are rarely exposed, but well-rounded boulders of Paleozoic limestone, dolomite, and quartzite as large as 2 m in diameter litter the surface between intervals of limestone exposure. A calcite-cemented matrix of sand- to pebble-sized clasts fill intertices of the boulders. Lack of exposures prohibits mapping conglomerate separately. The limestone and conglomerate intervals form bench- (conglomerate) and-riser (limestone) topography between the more resistant volcanic map units. The cumulative thickness of intervals of limestone and conglomerate in the map area is estimated to be about 150 m; structural complexity and discontinuous exposures make measurement of thickness at one locality impossible. Because the base of the map unit is not exposed, the maxium thickness is unknown

Tm **Monotony Tuff (Oligocene)**--Dacitic crystal-rich ash-flow tuff consisting of a simple cooling unit. The unit is a grayish-orange-pink to pinkish-gray, devitrified, partially welded, tuff that contains 20-50 % phenocyrsts consisting of 5-30 % quartz, 2-14 % sanidine, 45-65 % plagioclase, 5-20 % biotite, 0-10 % hornblende, 0-10 % clinopyroxene, and accessory magnetite, zircon, apatite, and allanite. As much as 5 % volcanic lithic fragments are present. The nonresistant unit forms benches. 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 ± 0.6 and 26.7 ± 0.3 Ma, respectively (Taylor and others, 1989), but perhaps the best estimate of the age of the Monotony Tuff is the $^{40}Ar/^{39}Ar$ sanidine date of 27.31 ± 0.03 determined by Best, Christiansen, and others (1989). Unit is locally as much as 40 m thick but is commonly thinner or absent; some of the thinner parts of the unit may be attributed to faulting

Tio **Old Isom-type ash-flow tuff (Oligocene)**--Trachytic ash-flow tuff consisting of one simple cooling unit. Rock contains phenocrysts of plagioclase and subordinate pyroxene. Most of the unit consists of medium-dark-gray, moderately welded, eutaxitic vitrophyre. Larger glass shards (< 1 mm long) and small pumice fragments (1-3 mm long) are black glass. Pale-greenish-yellow altered pockets (0.5-1 cm in diameter) containing clays are characteristic in some localities. Devitrified upper part of the unit ranges from 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. The stratigraphic proximity of the map unit to the Petrogylph Cliff Ignimbrite suggests it may be a third member of that unit but there is an absence of definitive evidence to make a genetic correlation. Lithic fragments are sparse. Unit forms slightly steeper slopes than surrounding units. Unit is part of the stratigraphic section that has been extensively attenuated and duplicated by normal faulting and the best estimate of its thickness in areas unaffected by faulting is between 6 and 10 m

Petroglyph Cliff Ignimbrite (Oligocene)--Trachytic ash-flow tuff consisting of an upper and a lower member. Only the lower member has been reported elsewhere, for example at its type locality at White Rock Spring (Martin, 1957; Cook, 1965). Each member is a simple cooling unit. Mineralogically, these two members form the oldest Isom compositional type ash-flow tuffs; they are phenocryst-poor containing of plagioclase and subordinate pyroxene phenocrysts. 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**--Nonwelded to partially welded, vitric, light-gray ash-flow tuff containing of as much as 30 % pumice fragments and less than 10 % phenocrysts. There is no evidence of appreciable flattening of shards or pumice fragments. The density of the rock is higher (about 2.4 g/cm^3) than that of unaltered nonwelded ash-flow tuff; calcite has filled the pores of most of the shardy matrix and pumice fragments. At one locality the 1 m-thick base of the unit consists of 1-5 mm-diameter fragments of black glass in a matrix of calcite. A thin ash bed separates the members. The unit forms rounded slopes and has a maximum thickness of about 30 m

Tpcl **Lower member**--Partially welded to densely welded trachytic ash-flow tuff containing conspicuous fiamme in a thick vitrophyric base. Light-red to light-brown devitrified upper part of tuff contains abundant and large (1-4 cm diameter) pumice fragments. Pumice fragments are flattened into black fiamme in the most highly welded zone. Very pale orange altered spots are typically 0.5 cm in diameter. In the vitrophyric lower part of the unit the matrix of the tuff is grayish orange pink grading downward into brownish gray and lastly into medium dark gray; conspicuous grayish-black fiamme contrast strikingly with the matrix and form about 20-25 % of the rock. The relative thicknesses of basal vitrophyre and devitrified tuff higher in the unit differ greatly at different localities; these differences probably are in part related to structural attenuation that has affected different parts of the unit to different degrees. The tuff contains 5 % phenocrysts plagioclase and subordinate pyroxene, typical of Isom compositional type ash-flow tuffs. Volcanic lithic fragments are common, forming about 15 % of the rock. Fiamme deformed about lithic fragments and phenocrysts form a distinctive eutaxitic texture. The unit forms steep slopes at the vitrophyre and gentle slopes in the devitrified upper part. The thickness of the unit ranges from 30 to 60 m where it seems to have the least effect from structural attenuation

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 based on the 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). As described above, a series of intervals of lacustrine limestone and conglomerate (unit Tl) separate the ash-flow tuff formations within the Needles Range Group. Also an andesitic lava flow, the andesite of Mustang Spring (Tms), occurs below the Lund Formation in the northern part of the quadrangle

Tnl **Lund Formation**--Ash-flow cooling unit, consisting of an upper moderately welded, devitrified part and a poorly developed vitrophyric, moderately to densely welded lower part. The upper part is pinkish gray to yellow gray and the lower part is light gray. Pumice fragments are indistinct and sparse. The rock contains about 30-50 % phenocrysts that consist of about 10-25 % quartz, less than 5 % sanidine, 45-60 % plagioclase, about 10 % biotite, 10-15 % hornblende, less than 5 % clinopyroxene, and accessory Fe-Ti oxides, sphene, apatite, and zircon. Typical biotite books range from 1 to 2 mm in diameter and, although most are subparallel to the weak plane of flattening, enough have nonparallel attitudes to give the rock a slightly random texture when viewed perpendicular to the plane of flattening. Lithic fragments are sparse. Generally the unit forms steep slopes and small cliffs. The Lund Formation is at least 105 m thick in this quadrangle, but it commonly is structurally attenuated or missing from the sequence; structural complications leave its original thickness uncertain

Tnw **Wah Wah Springs Formation**--Ash-flow cooling unit, consisting of an upper moderately welded, devitrified part and a well developed vitrophyric, densely welded lower part. The upper part is light gray to yellow gray and the lower part is medium gray. Pumice fragments are indistinct and sparse; distinctive 0.5-1 cm-diameter, very pale orange, clay-rich, altered ovoids may have been pumice fragments or filled lithophysae. The rock contains about 20-45 % phenocrysts that consist of less than 10 % quartz, 45-70 % plagioclase, about 5-15 % biotite, 10-25 % hornblende, less than 5 % clinopyroxene, and accessory Fe-Ti oxides, apatite, and zircon. Typical biotite books are 2 mm in diameter, and they are more nearly aligned parallel to the plane of flattening than are books in the Lund Formation (Tnl). Lithic fragments are sparse. Generally the unit forms steep slopes and small cliffs. The Wah Wah Springs Formation is at least 110 m thick in the quadrangle, but it commonly is structurally attenuated or its base in unexposed

Tnc **Cottonwood Wash Tuff**--Moderately welded ash-flow cooling unit, distinguished by the absence of a vitrophyre. The unit is light gray to yellowish gray and weathers yellowish gray to pale greenish yellow. In one area in the north-central part of the quadrangle, the unit has been pervasively affected by celadonite alteration, resulting in a distinctive greenish-gray to grayish-blue-green matrix with moderate-blue-green veinlets (area indicated on map by fine stipple pattern). Pumice fragments are indistinct and sparse, but 1 cm-diameter very pale orange, clay-rich, altered ovoids, which may have been either pumice or lithophysae, are common in some zones. The rock contains about 30-45 % phenocrysts that consist of 5-15 % quartz, 55-60 % plagioclase, about 10-15 % biotite, 10-15 % hornblende, less than 5 % clinopyroxene, and accessory Fe-Ti oxides, apatite, and zircon. Typical biotite books are 1-5 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. The Cottonwood Wash Tuff appears to be between 35 and 100 m thick, but its assumed base is exposed only in two areas and structural attenuation and duplication occur to undetermined degrees

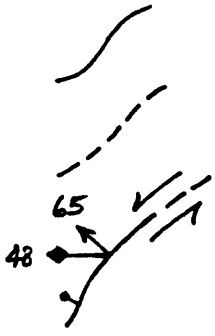
Tms **Andesitic lava flow of Mustang Spring (Oligocene)**--Andesitic, grayish-red to brownish-gray, massive lava flow containing about 20 % phenocrysts of subequal amounts of plagioclase and clinopyroxene. Partings in the flow are generally subparallel to the margins of the unit. Unit occurs only in the north-central part of the quadrangle, northeast of Mustang Spring, where it forms steep to moderate slopes and reaches a maximum of about 70 m thick

Dse **Sevy Dolomite (Devonian)**--Dolomite consisting of one stratigraphic interval. Light-gray to yellowish-gray, aphanitic, massive to thick-bedded unit. Rock is sparsely fossiliferous. Unit locally forms cap on dip slope of Laketown Dolomite (Sl). Only remnants of unit are exposed below the angular unconformity at the top of the Paleozoic rocks in southwest part of quadrangle. At least 100-120 m of the Sevy Dolomite are exposed, but its total thickness is unknown because the top of the unit is unexposed or eroded

Sl **Laketown Dolomite (Silurian)**--Dolomite consisting of upper and lower gray intervals separated by a rusty-weathering middle interval. Upper interval is a light- to medium-dark-gray, medium crystalline, thin- to thick-bedded dolomite, which contains irregular masses of brownish-black chert and fossils including solitary corals, long tubular corals, *Syringopora*, and brachiopods. The upper interval forms gentle slopes and is about 45 m thick. The middle interval is a light-gray to grayish-orange to dark-yellowish-brown, finely to coarsely crystalline dolomite including one 2-3m-thick dark-yellowish-orange dolomitic quartzite layer. The middle interval forms a more ledgy slope than the upper interval and is about 85 m thick. The lower interval is very light gray to medium-light-gray, somewhat cherty, dolomite that is characterized locally by networks of moderate-yellowish-brown veinlets of silica giving the rock a brecciated appearance. The upper part of the lower interval is vuggy, less cherty, and mottled. Thin beds containing 1 mm-diameter oncolites are present in the middle part of the lower interval. Fossils are particularly abundant near the base of the lower interval and include abundant thick-shelled pentamerid brachiopods and solitary corals. Stippled alteration pattern indicates area of secondary silicification formed below angular unconformity. The lower interval forms a series of small ledges and intervening slopes and is about 120 m thick. The Laketown dolomite is exposed only in the southwest part of the quadrangle where it has a total thickness of about 250 m

Oes **Ely Springs Dolomite (Ordovician)**--Dolomite consisting of two distinct intervals. The upper interval is a light-olive-gray to yellowish-gray weathering, aphanitic, argillaceous dolomite. The upper interval has light- to medium-gray mottling, forms gentle slopes, is about 20 m thick, and is less fossiliferous than the lower interval. Lower interval is a dark-gray to light-brownish-gray, finely crystalline dolomite The lower interval is thin- to thick-bedded, contains some grayish-brown irregular masses of chert, and forms narrow ledges and cliffs; relatively abundant fossils including pelmatozoan stems, brachipods, *Favosites*, and solitary horn corals are present. Because the base of the Ely Springs Dolomite is not exposed, only about 60 m of the unit are present

MAP SYMBOLS



Contact

Cooling break between ash-flow tuffs

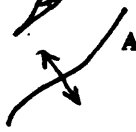
High-angle fault, showing dip (barbed arrow) and trend and plunge of lineation (diamond-shaped arrow)--Dashed where approximately located; dotted where concealed; and queried where uncertain. Bar and ball on downthrown side. Arrows indicate the relative direction of movement

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

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

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

Fault breccia or shear zone



Axis of arch--Arrows point in direction of dip of Tertiary strata. For clarity, axis is also drawn as a solid line where arched Tertiary rocks are concealed by nonarched alluvial deposits

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

Inclined

Horizontal

Vertical

Stike and dip of contact

Inclined

Strike and dip of flow foliation

Inclined

Hydrothermal alteration

Prospect

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Correlation of Map Unit Chart - Pahroc Spring Quadrangle