UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY GEOLOGIC MAP OF THE MEADOW VALLEY MOUNTAINS, LINCOLN AND CLARK COUNTIES, NEVADA

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DESCRIPTION OF MAP UNITS

All K-Ar dates cited have been recalculated using 1977 constants (Steiger and Jager, 1977), resulting in ages about 2.7 percent older than the original published data.

Phenocryst content is from modal analyses of rock, in percent. Phenocryst minerals are listed as percent of total phenocrysts: Q = quartz; K = alkali feldspar; P = plagioclase feldspar; B = biotite; H = hornblende; Py = pyroxene; M = undivided mafic minerals. For details on the chemistry of the Kane Wash Tuff the reader is referred to Novak (1984, 1985).

Color terminology used in the following descriptions is from the National Research Council Rock Color Chart (Goddard, 1948).

Qa **Alluvium (Holocene)**--Unconsolidated stream channel and fan deposits of clay- to cobble-size, poorly sorted, crudely stratified and generally undissected detrital materials in active drainage channels. Locally includes some basin and talus deposits. Finer-grained deposits concentrated in Meadow Valley, Kane Springs, and Pahranagat Washes. Commonly less than a few meters thick but probably exceeds 10 m in the major washes

Ql **Landslide deposits (Holocene)**--Irregular bodies of rock and sediment that have moved downward and outward from an adjacent source area. Predominant composition of the deposit, where known, indicated by letter symbol in parentheses. More small landlides exist than are shown

QTa **Alluvium (Pleistocene and Pliocene)**--Largely unconsolidated to mildly consolidated stream channel and coarse basin deposits of sand- to cobble-size, crudely stratified, lightly to moderately dissected detrital material. Locally well cemented by secondary calcium carbonate and forms erosion-resistant ledges in otherwise subdued exposures. Commonly present on former drainage terrace surfaces or perched on older alluvial or lacustrine deposits. In places may include alluvial fan deposits (QTg). Typical thickness less than 3 m; maximum thickness unknown

QTg **Alluvial fan deposits (Pleistocene, Pliocene, and Miocene(?))**--Largely unconsolidated to moderately consolidated, sand- to small boulder-size, angular to sub-angular, poorly sorted alluvial deposits forming large coalescing fans bordering upland areas. In places the deposits are strongly cemented with secondary calcium carbonate forming erosion-resistant layers 1-2 m thick in the fan deposits and in some thick sections of interlayered conglomerate and sandstone. Deposits are crudely stratified parallel to the fan surface, and commonly are deeply dissected. Where cemented these deposits stand in near-vertical slopes. Exposures of coarse fan deposits interfingering with upper parts of fine-grained Muddy Creek beds (Tmc) are present along Meadow Valley Wash. Thickness ranges from a few meters at the distal edges of the fans to perhaps as much as 100 m adjacent to the southwestern edge of the upland area. Between Farrier and Rox, and near Galt, includes outcrops of moderately well-cemented, well-rounded, boulder-to cobble-conglomerate and interlayered sandstone, the Rox Conglomerate of Olmore (1971, p. 59); the Rox Conglomerate is reported to underlie an ash-flow tuff at the base of the Muddy Creek Formation and overlie Horse Spring Formation beds about 1.6 km south of Rox (Olmore, 1971, p. 62)

Tmc **Muddy Creek Formation (Pliocene(?) and Miocene)**--White, grayish-green, light-brown, and pale reddish-brown lacustrine clay and silt and fluvial silt, sand, and gravel in moderately well-sorted, moderately well-stratified, weakly to moderately consolidated deposits exposed in the southern half of the map area. In general underlies but locally interfingers with alluvial fan deposits (QTg). Between Rox and Farrier Muddy Creek beds contain interlayered nonwelded (Tk) and welded (Tkv) tuffs believed to be from the upper part of the Kane Wash Formation but the tuffs may represent an underlying formation, for example the Horse Spring Formation (Olmore, 1971). The grayish-green deposits are silty clays and clayey silts containing abundant selenite gypsum and appear as isolated lenses in predominantly reddish-brown deposits. Northwest of Galt a white marker bed, visible on aerial photographs at two localities, may represent a volcanic ash. Total thickness unknown, but at least 120 m of section is exposed in cliffs along the east side of Meadow Valley Wash 1.2 km southeast of Rox

Tb_{1-3} **Basalt (Miocene)**--Dark-gray to grayish-black, brownish-black-weathering olivine basalt in compact to amygdaloidal flows. Subscripts designate basalt flows whose stratigraphic position is known, 1 being the oldest. Basalt Tb_3 is fine-grained and contains small phenocrysts of olivine and plagioclase in a subophitic matrix, and the structure grades upward from a basal vesicular interval 1-2 m thick into non-vesicular rock. Individual flows are less than 20 m thick but have an aggregate thickness apparently exceeding 150 m locally. Tb_3 rests unconformably on Kane Wash Tuff Members V_2 and V_3 (Tkv_{2-3}) and on an interlayered sequence of rhyolite flows (Tr) and zeolitized lithic tuffs (Tk). Basalt Tb_2, the northernmost basalt, consists of two or more thin flows interlayered with Kane Wash Tuff (Tkv and Tk) and rhyolite (Tr). This basalt is aphanitic with vesicular structure and zeolite minerals fill the vesicules. Basalt Tb_1, a single (?) aphanitic flow as much as 4 m thick exposed in the vicinity of Hackberry Canyon, lies between Hiko (Th) and Kane Wash (Tkv) Tuffs. This basalt locally is coarsely amygdaloidal with quartz-lined amygdules, many of which are 6 cm or more in long dimension. Basalt flows in the map area are as young as 11.4 m.y. (Tb_3; Novak, 1984). The presumed oldest basalt in the map area, thought not shown on the geologic map, is exposed at one locality near the mouth of Hackberry Canyon where it rests on red beds and is overlain by lacustrine limestone and Leach Canyon tuffs

Tv **Volcanic rocks, undivided (Miocene)**--Includes welded ash-flow tuffs and flows not assigned to any formation because the area was not visited or diagnostic details were lacking in isolated exposures

Tk **Kane Wash Tuff, undivided (Miocene)**--Rhyolite to commendite ash-flow tuffs comprising all but the basal basalt of the Kane Wash Formation of Cook (1965) and later redefined by Noble (1968) to include only the tuffs erupted from the Kane Springs Wash volcanic center. In the Meadow Valley Mountains equivalent to Unit 4 (Tt_4) of Ekren and others (1977). Includes Members O, W, V_{1-3} of Novak (1984). In the Meadow Valley Mountains consists of at least 5 crystal and lithic, non- to densely welded ash-flow tuff units, all of which contain few or no megascopic mafic minerals and most of which contain adularescent sanidine crystals. Generally can be subdivided into an upper group of crystal tuffs (Tkv), a middle unit of lithic tuff (Tkw), and a lower unit of crystal-lithic tuff (Tko). Maximum thickness exposed in the west-facing scarp along Kane Springs Wash is on the order of 437 m (E.F. Cook, unpub. data). In the northern part of the map area unit Tk consists of partially welded, devitrified, and zeolitized lithic ash-flow tuffs interlayered with rhyolite lavas (Tr). In the southeast part of the map area unit Tk consists of white non-welded lithic tuff

Tkv **Upper Kane Wash Tuffs of Novak (1984), undivided (Miocene)**--Densely welded crystal ash flow tuffs of at least three separate but closely related cooling units (Tkv_{1-3}) shown separately in the central part of the volcanic terrane. Equivalent to members V_1, V_2, and V_3 of Novak (1984) and members Tvk_{3-5} of Cook (1965). The ash-flow tuffs range in composition from rhyolite to trachyte and comendite; Members V_3 and V_2 are mildy peralkaline and V_1 is metaluminous (Novak, 1984). Megascopic mafic minerals are sparse and commonly altered and adularescent sanidine crystals are present in most cases. Plagioclase and biotite are found in Kane Wash Tuff units only as xenocrysts (Novak, 1984; R.B. Scott, written commun., 1988). Basal contact drawn at top of prominant pale-orange lithic tuff cliff, Member W of Novak (1984) and units Tvk_{2-2x} of Cook (1965), and top of basalt flow Tb_1 in Hackberry Canyon. Tkv is at least 150 m thick in west-facing scarp along Kane Springs Wash near Grapevine Spring (E.F. Cook, unpub. data) and thins northeastward to less than 40 m thick. Near Vigo Tkv is 100 to 150 m thick, and scattered exposures of Tkv capping Paleozoic rocks in the southern half of the area are as thick as 70 m

Tkv_3 **Member V_3 of Novak (1984) (Miocene)**--Predominantly densely welded, devitrified, comendite ash flow tuff that grades upward from a poorly exposed, dense, light-blueish-green, crystal-poor tuff about 30 cm thick into a pale-yellowish-brown, vapor-phase-altered crystal tuff. Mafic minerals are sparse and adularescent sanidine is present; mineralogically identical with Member V_2 (Novak, 1984). Overlain unconformably by basalt (Tb_3). Where mapped separately ranges from 20 to 30 m thick; maximum thickness in adjacent areas unknown. K-Ar ages of over- and underlying units in the adjacent Kane Springs Wash volcanic center are 14.1 m.y. (Novak, 1984). Member V_3 correlates with the Willow Spring unit of Scott and others (1988)

Tkv_2 **Member V_2 of Novak (1984) (Miocene)**--Thin, basal, blue-gray to blue-green, crystal-poor predominantly devitrified tuff about 1 m thick overlain by light-gray, light- to dark-brownish-gray-weathering, devitrified, lithic-crystal, comendite ash-flow tuff. Crystal content of Members V_1 and V_2 is: phenocrysts, 7-15; Q, 7; K, 7; M, 2-5 (Novak, 1985). Sanidine is sodic and commonly adularescent; fayalite and hedenbergite are the common mafic minerals, and vapor phase amethyst and reibeckite crystals are present locally. Lithic component is mostly flattened pumice. Unconformably overlain by basalt (Tb_3) in central part of volcanic terrane, where uppermost part of tuff is a green, feldspar-rich crystal tuff, locally separated from the basalt by a zone of very pale orange pumice sand and lapilli as much as 8 m thick. Where the tuff was mapped separately, it ranges from a few meters to about 90 m thick. Dated by K-Ar methods as 14.1 m.y. (Novak, 1984). Member V_2 correlates with the Gregerson Basin unit of Scott and others (1988)

Tkv_1 **Member V_1 of Novak (1984) (Miocene)**--Cliff-forming, devitrified, crystal-rich rhyolitic to trachytic ash-flow tuff grading upwards from densely welded, reddish-brown to less welded, brownish-gray lithic-crystal tuff. Contains flattened pumice fragments as large as 2.5 by 15 cm. A pinkish-orange, fine-grained, non- to partially welded ash about 3 m thick at the base contains feldspar and quartz and locally includes small boulders and cobbles of an underlying trachyte flow. In places there is a thin vitrophyre at the base of the tuff. Sanidine crystals as long as 10 mm, many of them adularescent, decrease in size, but increase in abundance, upwards. Mafic minerals are scarce and altered and consist largely of hedenbergite and fayalite. Phenocryst content in Delamar Mountains 5-25: Q, tr.-1; K, 3-25; M, 3-5; (Novak, 1985). Overlain by weak, covered zone 6-10 m thick with pinkish-orange, non-welded lithic tuff float at the surface that may be equivalent to the trachyte air-fall lapilli tuff reported by Novak (1984) at this horizon on the northeast side of the Kane Springs Wash volcanic center. Age by K-Ar methods is 14.1 m.y. (Novak, 1984). May be as thick as 120 m in the scarp along Kane Springs Wash. Member V_1 correlates with the Grapevine Spring unit of Scott and others (1988)

Tt **Trachyte lavas (Miocene)**--Black to grayish-purple, coarsely porphyritic, blocky weathering trachyte lavas, equivalent to the precaldera trachyte lavas of Novak (1984), containing equant phenocrysts of sanidine averaging 5 mm on a side, but as great as 2 cm, in a microcrystalline to glassy matrix that locally shows flow banding. Margins of the flow are chilled and commonly moderate-brown in color, and locally the rock is yellowish-green in zones as wide as 2 m along fractures where the sanidine phenocrysts are set in a perlitic glass matrix. The trachyte exposed along Kane Springs Wash overlies Member W (Tkw) and is overlain by Member V_1. The flow is 0 to about 163 m thick, and textural variations suggest the thickest section may consist of two separate but closely related flows. The lower 69 m of section is a grayish-brown, slabby weathering porphyry, with sieved feldspar phenocrysts as long as 10 mm that are more rectangular than equant in section, and closely resembles a flow at the mouth of Boulder Canyon (Novak, 1984), about 9 km to the north. The easternmost exposure of trachyte is somewhat vesicular and has the coarsest texture and largest coarsely sieved feldspar phenocrysts, many of them more than 12 mm long. The coarse trachyte overlies a welded crystal tuff that resembles Member V_1 but may actually be the upper densely welded part of Member W. Two trachyte bodies at the north end of the map, one of which is in Harmony Hills Tuff (Thh), appear to be dikes. Pre-caldera trachyte lava from the Meadow Valley Mountains yielded a K-Ar age of 14.0 m.y. (Novak, 1984, Table 3)

Tkw **Member W of Novak (1984) (Miocene)**--Pinkish-gray, pale-yellowish-brown-weathering, non- to densely welded, devitrified lithic rhyolite ash-flow tuff. Lower 80 percent grades upwards from non-welded lithic tuff with non-compacted pumice fragments, as much as 15 cm across, and cavities and few crystals, to partially welded; upper 20 percent is pink to pale-violet, moderately to densely welded cliff-forming devitrified lithic tuff. Crystal content of Member W is: phenocrysts, 10-11; Q, 45-49; K, 45-51; P, 0-2; M, 0-4 (Cook, 1965). Fayalite and hedenbergite, the principal mafic minerals, are present throughout Member W (Novak, 1984). The upper part of this map unit is lithologically similar to the lower part and may represent a separate nearly identical cooling unit. Included as a basal member of the lithic tuff is a 0-12-m-thick section of brick-red, pink, and grayish-yellow, poorly cemented, cross-bedded feldspathic sandstone (s) that locally overlies a thin pinkish-orange non-welded lithic tuff no more than a few meters thick. In the vicinity of Grapevine Spring, Member W is 207 m thick, thinning northward in well-defined exposures to about 137 m and eastward to zero. Age by K-Ar method given as 14.7 m.y. by Novak (1984). In the normal stratigraphic sequence Member W is overlain by Member V_1 (Tkv_1), however locally it is overlain by a trachyte flow (Tt), rhyolite flows (Tr), basalt (Tb_3), or undivided tuffs and flows (Trk). Member W correlates with the Sunflower Mountain unit of Scott and others (1988)

Tko **Member O of Novak (1984) (Miocene)**--Largely moderate- to reddish-brown, densely welded, devitrified eutaxitic crystal-lithic rhyolite ash-flow tuff easily recognized as a thin dark cliff under a thick light-colored slope. Locally the lowermost 4 to 5 m is a white lithic-crystal ash grading up through eutaxitic crystal-lithic tuff, with well-developed black glass fiamme in an orange-gray matrix, to orange-brown eutaxitic crystal-lithic vitrophyre closely streaked with black fiamme, to a black crystal-rich vitrophyre. The eutaxitic structure is unique to most of Member O. Crystal composition of Member O is the same as that of Member W (Novak, 1984). Locally near the base is an altered zone where highly welded rock is pink, yellow, purple, and red color-banded, and the northern part of the outcrop, near the eastward projection of the Kane Springs Wash caldera boundary, grades laterally into a red and white mottled, weak, slope-forming, altered tuff. Maximum thickness is about 79 m in the Kane Springs Wash scarp decreasing to 0 along the southern edge of the volcanic terrane. Novak's (1984) K-Ar analysis yielded an age of 15.6 m.y. for Member O. The upper contact commonly is a barren dip slope locally overlain by a thin lightly welded lithic tuff or cross-bedded sandstone (s) of Member W. Member O correlates with the Delamar Lake unit of Scott and others (1988)

Tr **Rhyolite lavas (Miocene)**--Includes grayish-red to brownish-gray, flow-banded rhyolite, white sugary rhyolite, and perlitic rhyolite glass. In the northern part of the map area consists of at least two flows interlayered with zeolitized lithic ash-flow tuffs assigned to the undivided Kane Wash Tuff (Tk) and crystal tuff thought to be Member V_1, all unconformably capped by basalt flows (Tb_3). Basal 0-15 m of rhyolite flows commonly are black to medium-gray perlite, grading up into a vapor-phase alteration zone of chalcedonic lithophysae, however some lithophysal rhyolites contain topaz crystals as long as 12 mm and specular hematite. Flow-banding is contorted. Some flows are at least 60 m thick and possibly as much as 120 m. Map unit locally includes some densely welded rhyolitic ash-flow tuffs that apparently flowed at the time of welding

Trk **Rhyolite lavas and Kane Wash Tuff, undivided (Miocene)**--Perakaline rhyolite lavas interlayered with lithic rhyolitic ash-flow tuffs, all cut by numerous rhyolite dikes. A significant amount of the rhyolite is perlitic and much of the lithic tuff is zeolitized (Pampeyan and others, 1988). Some of the lithic tuff may correlate with Member W but confirming data are not available. This map unit rests on Harmony Hills Tuff (Thh) and includes some tuffs with Hiko Tuff (Th) lithology in the area adjacent to Harmony Hills exposures

Tvo **Older volcanic rocks, undivided (Miocene)**--Includes volcanic rocks of the Hiko Tuff, Harmony Hills Tuff, Bauers Tuff Member of the Condor Canyon Formation, Leach Canyon Formation, and any other pre-Kane Wash Tuff volcanic rocks. In the map area equivalent to Unit 3 (Tt_3) of Ekren and others (1977)

Th **Hiko Tuff (Miocene)**--Pinkish- to brownish-gray brown-weathering moderately welded vitric-crystal to crystal ash-flow tuff, becoming slightly less welded upwards. Basal 10 to 15 m, where exposed, is white to pale greenish-yellow and light-gray, partially welded, punky lithic-crystal tuff. Overall composition is dacitic to quartz latitic (Dolgoff, 1963; Williams, 1967); phenocrysts 30-50: Q, 15-23; K, 10-25; P 40-57; B, 10-15; H, 2-5 (Ekren and others, 1977). Sphene is a diagnostic mineral and many of the quartz crystals are doubly terminated and amethystine; adularescent sanidine is not uncommon. Lithic fragments include yellow-gray tabular siltstone(?) fragments and light-colored flattened pumice lapilli. In the upper half of the section there are local lenses of coarse impure sandstone or wacke as much as 3 m thick. Maximum thickness in the Kane Springs Wash scarp is

107 m decreasing to 0-43 m towards Vigo. The Hiko Tuff has yielded K-Ar ages of 18-20 m.y. (Armstrong, 1970; Noble and McKee, 1972; Marvin and others, 1973) which average 18.7 m.y. and closely agree with the 18.8 m.y. ages of Taylor and Bartley (1988)

Thh **Harmony Hills Tuff (Miocene)**--Brownish-gray to reddish-brown, crystal-rich, biotite ash-flow tuff with a basal, partially welded, slope-forming zone grading up into a moderately welded, cliff-forming tuff that is more resistant to erosion than the over- and underlying ash-flow tuffs. Abundance and size of biotite crystals are diagnostic charcteristics as the Harmony Hills contains more euhedral biotite than any other ash-flow tuff in this region, usually in books as much as 3 mm in diameter and 1-2 mm thick. Rounded, cobble-size clasts of hornblende-biotite quartz monzonite and silicified lacustrine(?) limestone are common in the basal part of the section decreasing in size and abundance upwards, while dark, biotite-rich, vitric-crystal tuff fragments and gas cavities appear to increase upwards. The matrix glass is devitrified but the matrix of the dark vitric-crystal fragments is glass. In and near Hackberry Canyon the Harmony Hills Tuff rests on a thick basalt flow-breccia (Tbb); in the Kane Springs Wash escarpment the Harmony Hills locally rests on the Bauers Tuff Member of the Condor Canyon Formation (Tcb), or--though too thin to show where present--on two thin lenses of lacustrine limestone separated by about 3 m of pale violet biotite tuff. In places as much as 6 m of Bauers Tuff is included with the Harmony Hills. Total thickness of the Harmony Hills Tuff is about 81 m in Hackberry Canyon and 53 to 67 m along Kane Springs Wash. Radiometric analyses of the Harmony Hills from the surrounding region yielded an average age of 21 m.y. (Armstrong, 1970; Noble and McKee, 1972; Marvin and others, 1973). The Harmony Hills Tuff is rhyodacitic to quartz latitic; phenocrysts, 50; Q, 7; K, tr.; P, 62; B, 16; H, 8; Py, 5 (Williams, 1967)

Tbb **Basalt breccia (Lower Miocene)**--Thick, dark-purple, red, and black, monolithologic basalt flow-breccias and flows with some interlayered lenses of coarse volcanic sediment and hornblende trachyte(?) lava, well exposed in Hackberry Canyon and along the south edge of the volcanic terrane. Maximum thickness reported by E.F. Cook (unpub. data) as 289 m in the area 3 km west of Vigo; average thickness is closer to 100 m thinning to zero away from Hackberry Canyon. The interlayered volcanic sediments and trachyte(?) lava are as much as 20 m thick, and some of the flow breccia probably represents lahars. The basalt breccia overlies about 20 m of pale purple, lightly welded crystal-vitric tuff which on the map is included with the underlying Leach Canyon Formation. Overlying the flow-breccia in sharp contact is reddish-brown-weathering biotite-rich Harmony Hills Tuff

Tcb **Bauers Member of the Condor Canyon Formation (Lower Miocene)**--Typically a purplish-gray to pale-red-purple, highly welded, ledge-forming, devitrified to vapor-phase altered lithic-crystal ash-flow tuff overlying a dark red devitrified crystal tuff which in turn rests on a black crystal-rich vitrophyre. The black vitrophyre and red tuff are thin and poorly exposed, and have a total thickness of less than 6 m; the purplish-gray ledge-forming upper part is 7 to 10 m thick in the Kane Springs Wash scarp but as much as 80 m thick 4 km south of Sunflower Mountain. In the area west of Vigo a pale purple, highly welded tuff 8 m thick, interlayered with lacustrine limestones, has Bauers mineralogy but is too thin to show separately and is included with the underlying Leach Canyon Formation (Tlc). The Bauers Tuff has the composition of a rhyodacite (Rowley and others, 1975) or alkalic rhyolite (Williams, 1967); phenocrysts 10-20; Q, 0-tr; K, 30-40; P, 50-70; B, 3-7; M, 1 (Ekren and others, 1977). The Bauers Tuff has yielded K-Ar ages that average 22.1 m.y. (Armstrong, 1970)

Tlc **Leach Canyon Formation (Lower Miocene)**--Pale lavender, non- to lightly welded lithic-crystal ash-flow tuff equivalent to the Narrows Member of the Leach Canyon Formation of Williams (1967). Consists of two crystal-rich cooling units locally separated by lenses of light-gray, orange-mottled lacustrine limestone up to 5 m thick, the lower unit being four to five times as thick as the upper unit in the Kane Springs Wash scarp. Total thickness about 113 m near Grapevine Spring and 74 m west of Vigo (E.F. Cook, unpub. data). Age of the Leach Canyon Formation, based on K-Ar analyses of samples from the surrounding region is about 24.6 m.y. (Armstrong, 1970; Rowley and others, 1975). The Narrows Member of Williams (1967) is rhyolitic to quartz latitic. Average crystal content is: phenocrysts, 15; Q, 32; K, 24;, P, 35; B, 5; H, 2 (Williams, 1967). Along the south edge of the volcanic terrane, west of Vigo, the Leach Canyon map unit includes three lacustrine limestones that total about 21 m separating three tuff units that total about 32 m: the uppermost unit is a pale purple lightly welded, vitric-crystal tuff 20 m thick and was designated Tv2A3 by E.F. Cook (unpub. data); the middle unit is a purple pumiceous tuff 4 m thick also designated Tv2A3; and the third unit is a pale purple, highly welded tuff 8 m thick with Bauers phenocryst mineralogy

Tl_{1-2} **Lacustrine limestone (Lower Miocene and Oligocene)**--Pinkish-gray to light-gray with orange mottling, freshwater limestone in beds 10-30 cm thick, commonly containing algal structures. Locally there are nodules of pinkish-gray chert in the limestone and in Hackberry Canyon some small nodules of manganese oxides are present near the top of the limestone. Lacustrine limestones commonly occur at the base of the volcanic section resting unconformably on pre-Tertiary sedimentary rocks, and on, or locally interlayered with, prevolcanic conglomerates (Tc), but lacustrine limestone also is present locally at several horizons in the volcanic section, for example, at the base of the Hiko, Harmony Hills, and Bauers tuffs, and between cooling units of the Leach Canyon Formation. About 2.5 km northeast of Sunflower Mountain the basal lacustrine limestone (Tl_1) and a second one (Tl_2) separating the Leach Canyon from overlying Bauers

Tuff are shown separately. The units range in thickness from about 5 to more than 30 m, the widespread basal unit typically being 20 m thick. The limestones in and above the Leach Canyon Formation are Miocene; the basal limestone is considered to be late Oligocene in age inasmuch as it underlies early Miocene tuffs (Ekren and others, 1977). A small isolated outcrop in Farrier Wash labeled as lacustrine limestone resembles porous limestones of the Horse Springs Formation

Tc **Conglomerate (Tertiary(?))**--Reddish-orange- to reddish-brown-weathering, poorly sorted, synorogenic(?) conglomerate occurring in isolated patches filling low areas on the pre-volcanic erosion surface. Appears to interfinger locally with lacustrine limestone (Tl_1) 2.5 km northeast of Sunflower Mountain. Largely well-rounded cobbles in a silty to coarse sandy matrix, but pebble- to small-boulder-size clasts are present, all consisting of Paleozoic carbonates, quartzites, and some cherts. Matrix is poorly sorted and locally cemented with calcium carbonate. Thickness ranges from 0 to about 50 m. This conglomerate is part of the Older Clastic Rocks of Tschanz and Pampeyan (1970) and may be as young as Oligocene and possibly as old as late Cretaceous, but most likely post-dates the main Sevier orogenic events in this area. Conglomerates with similar characteristics are present to the west across Kane Springs Wash and to the east across Meadow Valley Wash

$T_{R}c$ **Chinle Formation (Upper Triassic)**--The Chinle Formation is a moderate-red to dusky red, fine-grained, non-marine, silty sandstone and shaley sandstone present in scattered outcrops along the south edge of the volcanic terrane. The Chinle Formation was estimated to be about 760 m thick (Tschanz and Pampeyan, 1970) based on the size of the outcrop area and by better exposures near the Mormon Mountains, but much of the section here is concealed and may be repeated by faulting and folding. The upper part of the Chinle in this area is capped by overthrust Moenkopi beds; the lower contact with the Shinarump Member is not exposed

$T_{R}cs$ **Shinarump Member of the Chinle Formation (Upper Triassic)**--Grayish-red, dark-brown-weathering, ridge-forming, fine-grained sandstone and chert-pebble conglomerate. Some of the sandstone is cross-bedded and quartzitic. Fossil wood common elsewhere in the Shinarump was not seen here, and the overall texture of the member is finer than in exposures farther east. The basal Shinarump Member may be as much as 107 m thick. The contact between the Shinarump and underlying Moenkopi beds is not exposed in the map area but was assumed to be conformable (Tschanz and Pampeyan, 1970)

$T_{R}m$ **Moenkopi Formation (Middle(?) and Lower Triassic)**--Predominantly gray, pale-brown, and yellowish-brown, grayish-yellow- to grayish-orange-weathering, even-bedded, dense marine limestone, with interbedded red, orange, and brown silty and shaley limestones giving large outcrops a color-banded aspect. Lowermost part of formation is made up of dark-gray, thin-bedded limestone overlain by green shale grading up into black shale, a cyclical sequence that is repeated several times; the limestones are about 1 m thick and the green and black shales each about 3 m thick. The Moenkopi rests with angular discordance on lenses of grayish-brown-weathering chert-rich sedimentary breccia derived from the underlying Kaibab Limestone and Toroweap Formation (Pkt). The upper contact with the Chinle Formation ($T_{R}c$) is exposed in an isolated outcrop but at least 746 (Olmore, 1971) to 823 m of Moenkopi is present in a homoclinal section 5 km west of Vigo and a thicker section may be present in the folded sequence 5 km farther west

Pz **Paleozoic carbonate rocks, undivided**--Includes three isolated exposures of limestone surrounded by volcanic rocks in the north half of the map area, two of which are 3.5 km south-southwest of Sunflower Mountain and one 1.6 km south of the Toroweap Limestone-Permian red bed outlier north of Vigo. Limestone in the northern exposure is sheared and does not resemble the nearby Permian carbonate rocks; the southern exposures could be of Upper Devonian Guilmette Formation which crops out to the south

Pkt **Kaibab Limestone and Toroweap Formation, undivided (Lower Permian)**--Pinkish-gray, cliff-forming limestones containing abundant dark-brown-weathering chert in lenses and nodules parallel to bedding. In the strike ridge 4.5 km west of Vigo the Toroweap Formation is represented by lenses of dark-brown-weathering chert breccia up to 75 m thick unconformably between Moenkopi limestones ($T_{R}m$) and Permian red beds (Prb). Outcrops of cherty limestone in the north half of the map are assigned to the Toroweap Formation; the exposure of cherty limestone at Rox is considered to be Kaibab Limestone (Tschanz and Pampeyan, 1961, 1970; Wernicke and others, 1984). Isolated exposures of the Toroweap may be as much as 300 m and about 36 m thick in Hackberry Canyon and 12 km north of Vigo, respectively, where the Toroweap appears to conformably overlie red beds. The section of Kaibab Limestone at Rox is about 245 m thick. The Toroweap and overlying Kaibab formations occur together farther east in the vicinity of the Mormon Mountains

Prb **Red beds (Lower Permian)**--Upper part is slope-forming, even-bedded, yellow, coarse-grained sandstone and silty sandstone overlying moderate-red, slope-forming, coarse-grained sandstone containing some interlayered resistant beds of gray, fossiliferous limestone. Middle part is bad-land-weathering contorted beds of red and yellow shaley sandstone and siltstone with interlayered beds of gypsum. Lower part is even-bedded, pink, white, and gray sandstone, gray limestone and sandy limestone, cross-bedded buff sandstone, pinkish shale, sandstone, and sandy limestone, with calcareous beds increasing downwards. Basal contact drawn at a thin white-weathering carbonate bed separating yellow-gray to pink sandy limestone and limey sandstone above from about 30 m of gray limestone over about 30 to 45 m of red-brown-weathering, very-fine-grained calcareous sandstone. Upper contact drawn at discordant contact with overlying chert breccia of the Toroweap Formation and carbonate beds of Moenkopi Formation. Upper part of formation is about 213 m thick, middle gypsiferous part about 152 m thick, and lower part about 186 m thick, for a total thickness of about 552 m. A complete red beds section is exposed southwest of Vigo, with the basal contact visible in cliffs along Meadow Valley Wash between Vigo and Galt. Gypsiferous beds up to 6 m thick occur in an area about 1,100 m long by 305 m wide (Jones and Stone, 1920) and appear to represent deformed evaporite basin deposits. Two isolated outcrops of red beds are present, one in Hackberry Canyon and the other about 12 km north of Vigo, where red calcarous sandstone and sandy limestone is in normal sedimentary contact with gray to pinkish-gray cherty limestone of the Toroweap Formation (Pkt). The red beds unit correlates approximately with beds mapped as Coconino and Queantoweap Sandstones and Pakoon Formation in the Beaver Dam Mountain to the east (Reber, 1952; Langenheim and Larson, 1973)

PPb **Bird Spring Formation (Lower Permian, Upper, Middle, and Lower Pennsylvanian)**--Interlayered beds of light- to dark-gray limestone, pinkish-gray cherty limestone, reddish-brown sandy, calcareous, and dolomitic limestone, and white to reddish-brown, fine-grained sandstone. The limestones are fine- to medium-crystalline, thin- to medium-bedded, and fossiliferous. The sandy beds, some of which are quartzitic, form brownish- to reddish-weathering ledges in the even-bedded step-like outcrop. About 30 m below the upper contact is a reddish-brown-weathering, very-fine-grained calcareous sandstone unit 30 to 45 m thick, well exposed in Meadow Valley Wash near Galt, and about 975 m above the base is a pinkish- to yellowish-brown-weathering interval of dolomitic and silty limestone (unit d) 106 to 150 m thick. Unit d is underlain by probable Early Wolfcampian beds and overlain by Middle Wolfcampian beds (C.H. Stevens, oral commun., 1988). The basal limestones and cherty limestones are Morrowan in age and rest on red-weathering shaley beds of the Scotty Wash Quartzite and Chainman Shale (Msc). A complete continuous section is not exposed in the Meadow Valley Mountains but was estimated to be about 1,310 m thick (Tschanz and Pampeyan, 1970); however, as much as 1,650 m of section may be exposed in the Bunker Hills which does not appear to include part of the uppermost 305 m exposed between Galt and Vigo

Msc **Scotty Wash Quartzite and Chainman Shale, undivided (Upper Mississippian)**--Includes quartzite and quartzitic sandstone of the Scotty Wash Quartzite and underlying fissile shale and calcareous sandstone and siltstone of the Chainman Shale. The Scotty Wash Quartzite consists of reddish- to yellowish-brown-weathering, locally cross-bedded, fine-grained, well-sorted quartzite and quartzitic sandstone with several interbeds of crinoidal limestone. In the vicinity of Grapevine Spring it overlies the Chainman Shale which here consists of an upper shale member and a lower siltstone member (Duley, 1957). The shale member is largely black to olive-green, fossiliferous, carbonaceous shale, with some reddish-brown-weathering siltstone, sandstone, and shale interbeds; in the vicinity of Grapevine Spring there is a 4-m-thick lens of black phosphatic shale with thin interbeds of pelletal phosphorite (Pampeyan and others, 1988). The siltstone member is predominantly siltstone, with several interlayered thin, dark-gray limestone beds, and weathers to white, red, purple, yellow, and brown forming a color-banded rock locally known as "wonderstone" (Duley, 1957; Pampeyan and others, 1988). Scotty Wash quartzite is 35 m thick in exposures along Kane Springs Wash near Grapevine Spring and 9 m thick just south of the map area in Arrow Canyon (Duley, 1957). The shale and siltstone members of the Chainman Shale are 215 and 69 m thick, respectively, near Grapevine Spring and 74 and 0 to 2 m thick, respectively, at Arrow Canyon (Duley, 1957; Langenheim and others, 1962). In the Bunker Hills this map unit (Msc) is about 108 m thick and commonly forms a red- to reddish-brown-weathering swale between cliff-forming carbonate rocks of the overlying Bird Spring and underlying Mississippian limestones. Map unit includes the Indian Springs Formation of Webster and Lane (1967) and Webster (1969) near Grapevine Spring, and in the southern half of the map area and Arrow Canyon Range is equivalent to the Indian Springs Formation and unit BSb of Langenheim and others (1962) and Langenheim (1964)

Ml **Limestone (Lower and Upper Mississippian)**--Includes the Joana Limestone on the west side of the range and members of the Monte Cristo Limestone in the southern half of the range. About 40 m of Joana Limestone is present 4.5 km north of Sunflower Mountain where it consists of bluish-gray, thin- to medium-bedded, dense to coarsely crystalline, crinoidal, cliff-forming limestone conformably underlying the Chainman Shale and in fault contact with limestones of the underlying Guilmette Formation (Dg). The Monte Cristo Limestone, though not subdivided on this map, consists of alternating members of gray to dark-gray, thin- to thick-bedded crinoidal limestone and cherty limestone that resemble the Bullion, Anchor, and Dawn Members at Arrow Canyon. The limestones weather light- to dark-gray and the cherty intervals weather dark-brown. The Mississippian limestone section in the northern Arrow Canyon Range is 431 m (Langenheim and others, 1962) to 538 m thick (Duley, 1957), and estimated to be 308 to 457 m thick in the southern Meadow Valley Mountains

MDp **Pilot Shale (Lower Mississippian and Upper Devonian)**--In the Meadow Valley Mountains contains little shale and consists mainly of medium-gray, reddish- to orangish-weathering, platy silty limestone and interbedded dark- to blue-gray, thin-bedded crinoidal limestone. Some reddish-brown-weathering bedded chert and cherty limestone is present locally. This platy unit is present east and southeast of Sunflower Mountain separating medium-bedded limestones of Guilmette Formation from red-brown-weathering shales and carbonate beds of Chainman Shale, the cliff-forming Mississippian limestones (Ml) being faulted out here. Thickness estimated to be about 215 m. The Pilot Shale was not seen elsewhere in the map area

Dg **Guilmette Formation (Upper and Middle Devonian)**--Alternating light- and dark-gray, yellowish-gray-weathering, aphanitic, cliff-forming, fossiliferous limestone, with some light- and dark-gray, orange-weathering silty dolomite and orange- to brown-weathering sandstone beds, all overlying a basal slope-forming zone of medium-gray, yellowish-gray-weathering, thin-bedded dolomite interbedded with light- to dark-gray aphanitic limestone. The cliff-forming limestones include thick beds of sedimentary reefs and reef breccias. In the southern half of the map area the uppermost 46 to 61 m of section, here included with the Guilmette, is light-gray to white, unfossiliferous, microcrystalline limestone that contrasts markedly with the underlying medium-gray Devonian limestones and overlying dark-gray- to brown-weathering Mississippian limestones. This limestone was called the Crystal Pass Member of the Sultan Dolomite in the Goodsprings district by Hewett (1931) and the Crystal Pass Limestone in the Arrow Canyon Range by Langenheim and others (1962). North of the Bunker Hills the light-gray to white limestone is absent and the Guilmette is overlain by rocks assigned to the Pilot Shale (MDp). The yellowish-gray slope-forming dolomite, known as the "yellow bed" is 10 to 100 m thick and marks the base of the Guilmette throughout the map area as it does to the north and west. Total thickness of the Guilmette Formation was estimated to be 412 m (Tschanz and Pampeyan, 1970) but may exceed 480 m. An isolated block of limestone, dolomite, sandy limestone, and sandstone in Kane Springs Wash is assigned to the sandy limestone facies of Tschanz and Pampeyan (1970) of the Guilmette Formation

DSu **Devonian and Silurian carbonate rocks, undivided (Middle(?) Devonian to Middle Silurian)**--Includes light- to dark-gray dolomites and dolomitic limestones of the Simonson Dolomite(?) (Dsi), Sevy Dolomite (Dse), and Laketown Dolomite (Sl) in one area 9 km southwest of Sunflower Mountain

Dsi **Simonson Dolomite (Middle Devonian)**--Alternating dark-gray to black, light-gray, and grayish-brown, fossiliferous dolomite and dolomitic limestone, with some brown-weathering sandstone, gray limestone, and cherty limestone beds. Uppermost 15 m is a black-weathering, cliff-forming, thin-bedded dolomite that underlies the "yellow bed" of the Guilmette Formation and contains a *Stringocephalus* sp. fauna a few meters below the top. The cherty beds interlayered with light-brownish-gray dolomite are as much as 3 m thick, and light-gray dolomite units containing brown-weathering sandstone and sandy beds are as much as 15 m thick. Total thickness estimated to range from 100 m in the southern part of the range to about 170 m in the central part of the range. Much of the dolomite and dolomitic limestone is replete with stromatoporoids, corals, and bryozoans. Characteristic four-part subdivision of the Simonson recognizable in sections to the north and west (Osmond, 1954) is obscure here

Dse **Sevy Dolomite (Lower Devonian)**--Predominantly light-gray, fine-grained, unfossiliferous, homogenous dolomite, laminated near the base and becoming thicker-bedded upwards. Uppermost 3 to 4 m is brown-weathering dolomitic quartzite that is underlain by about 15 m of dark-gray dolomite. Total thickness of the Sevy Dolomite is 83 m in the southern part of the Range (Osmond, 1962) and about 150 m in the central part of the range. Overall color of the Sevy here is darker than in sections to the north and west reducing the contrast between the overlying Simonson and underlying Laketown dolomites

Sl **Laketown Dolomite (Upper and Middle Silurian)**--Commonly divisible into three parts, a lower dark-gray, fetid, cherty dolomite containing some limestone beds, a middle light-gray, coarse-grained, crystalline dolomite, and an upper dark-gray to black, gray-brown-weathering, cherty dolomite. The three-part character of the Laketown is not as evident in the Meadow Valley Mountains as it is to the north and west for the upper dolomite is thin and easily overlooked here. The dolomites are fossiliferous, corals being most abundant. Total thickness ranges from about 70 m to 150 m, probably due largely to pre-Devonian erosion. The lower contact, also thought to be disconformable, separates dark-gray Laketown dolomites from underlying black-weathering Ordovician dolomites

Oes **Ely Springs Dolomite (Upper Ordovician)**--Dark-gray, black-weathering, medium-bedded, cliff-forming, coarsely crystalline dolomite and dolomitic limestone, with an inconspicuous interval of light-gray dolomite beds about 3 m thick at the top. The lower half of the Ely Springs is cherty and the upper half is fossiliferous. Total thickness ranges from 122 m in the west-central part of the range to 140 m in the south part. Probably the most recognizable Paleozoic formation because of its color contrast with lighter-colored overlying Laketown Dolomite (Sl) and underlying Eureka Quartzite and Pogonip Group rocks (Oep)

Oep **Eureka Quartzite and Pogonip Group, undivided (Middle and Lower Ordovician)**--Dominantly limestones of the Pogonip Group but at the top includes the Eureka Quartzite which is too thin to show separately. The Eureka Quartzite is a white, reddish-orange-weathering, vitreous, medium-grained orthoquartzite, with some reddish-weathering dolomitic sandstone beds in the lower part. The Eureka is 3.5 to 4.5 m thick in the west side of the range and 0 to 1 m thick in exposures on the east side of the range. The Pogonip Group, though not subdivided here, consists of upper and lower thin-bedded, slope-forming members, each about 100 m thick, separated by a middle cliff-forming member, with a total thickness of about 460 m. The upper member consists of light- to medium-gray, generally medium- to brownish-gray-weathering, thin-bedded, fossiliferous limestone, and silty limestone with red, yellow, and brown mottling, conspicuous orange-weathering silty dolomite beds, yellow-gray-weathering shaley beds, and some nodular and lenticular cherty limestones. The middle cliff-forming member is medium- to brownish-gray-weathering, fine- to coarse-grained, medium-bedded to massive, fossiliferous, cherty limestone with many intraformational conglomerate beds. Receptaculites and cephalopod fossils are abundant in the upper part of this member. The lower member is dark-gray, light-brown- to brownish-gray-weathering, cherty, fine- to coarse-grained limestone, with some red-on-gray mottled beds and thin, red, silty and shaley partings, and is less fossiliferous than the upper and middle members. At the base of the lower member is 7-8 m of medium- to dark-gray, brownish- to orange-weathering, coarse-grained limestone with some 2.5-cm-thick gray chert beds and abundant shaley partings. For mapping purposes the lower contact of the Pogonip was drawn to separate the brownish- and orange-weathering limestones from dark-gray- to black-weathering limestones and dolomites of the underlying Cambrian Nopah Formation (Ꞓn)

Ꞓn **Nopah Formation (Upper Cambrian)**--Predominantely alternating yellowish-gray- and light-olive-gray-weathering, cliff-forming limestone and dolomite topped by an upper unit consisting of two black, olive-gray-weathering, coarse-grained, cliff-forming dolomites bisected by a prominant band of white- to light-olive-gray-weathering dolomite. The Nopah Formation is present in the west-central part of the range but an unbroken section is not exposed. The upper black-white-black dolomite unit is about 180 m thick and divided into three roughly equal parts; the lower, lighter, color-banded part is estimated to be at least 185 m thick. The lower contact of the Nopah Formation is sharp with the underlying Dunderberg Shale (Ꞓnd). The Nopah Formation is the same as the Cambrian limestone and dolomite formation of Tschanz and Pampeyan (1970) in southern Lincoln County

Ꞓnd **Dunderberg Shale Member of the Nopah Formation (Upper Cambrian)**--Olive- to gray-green, brown- to yellowish-weathering, micaceous shale, siltstone, and silty limestone. The limestones are bioclastic and oolitic and occur as thin beds alternating with the shaley and silty beds. Trilobite fragments and other fossils are common. The Dunderberg, which forms a swale between resistant medium-gray dolomites of the overlying Nopah Formation and dark- and light-gray-banded dolomites of the underlying Highland Peak Formation (Ꞓhp), may be as much as 60 m thick here but its true thickness is distorted owing to deformation in the west-central part of the range

Ꞓhp **Highland Peak Formation (Upper and Middle Cambrian)**--The Highland Peak Formation is present in the west-central part of the Meadow Valley Mountains in prominant color-banded exposures of alternating beds of dark- and light-gray-weathering beds of dolomite and limestone. Near the contact with the Dunderberg Shale there are some beds of orange-weathering dolomite, dark-gray limestone mottled with orange-weathering dolomite, and brown-weathering silty limestone and oolitic limestone. The limestones and dolomites range in color from white to black and in texture from aphanitic to coarse-grained. At least 590--and possibly as much as 700--m of section are displayed in the east-dipping limb of a faulted anticline but the basal part of the formation is not exposed. The Highland Peak Formation correlates with the Bonanza King Formation to the west

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