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PRELIMINARY GEOLOGIC MAP OF THE FARRIER QUADRANGLE, CLARK AND LINCOLN COUNTIES, NEVADA

By

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EXPLANATION

DESCRIPTION OF MAP UNITS

[(1) Altitude, height (h), and thickness (t) of alluvial units on the map are given in feet and inches in order for reader to directly correlate such figures with the topographic contours reading in feet; in text all measurements are in metric units as is standard except references to topographic contours are listed in feet and meters.

(2) Localities described in text are indexed to the borders of the quadrangle and to the railroad site of Farrier, except that an unofficial place name, Farrier narrows, is used in reference to the conspicuous canyon of Meadow Valley Wash from 2.5 to 4.0 km north of Farrier. The structural and sedimentary basin of Meadow Valley Wash is herein informally called the Glendale basin for the small town of Glendale at the southern end of the basin in the adjacent Moapa East quadrangle.

(3) Stacked units: any two units combined by a slash indicates that a thin younger unit covers or nearly covers an older unit. For example, Qe/Qym where thin eolian sand covers young mainstream alluvium; in another example, Qrs/Qrm, Qys/Qym, and Qis/Qim, stacked units show combined Quaternary alluvial deposits along the valley sides of Meadow Valley Wash where sidestream deposits of slightly to considerably younger age prograde as fans on the last deposited mainstream alluvium, and where the sidestream fan deposit is thin either by deposition or by erosion. Stacked units are self explanatory and are not listed in description of map units; for most stacked units pertaining to alluvial terrace deposits, the map color used is that of the underlying unit because the altitude and physiographic form is approximately that of the underlying unit.

(4) Thick carbonate soils developed on terrace deposits, especially on Tertiary deposits, are mapped because they constitute genuine mappable units contrary to convention of not mapping soils. In the Correlation of Map Units, the soil units are set apart from their host terrace deposits in order to show their long developmental history, that is, the soils developed both constructionally and erosionally at various times since their inception. However, in the text (Description of Map Units), each soil is described with its respective host terrace deposit on which its soil development began and where the age of the soil relates directly to the age of the terrace alluvium]

wm **Works of man**—Ground disturbed and reworked by man for railroad and road construction, agriculture, and mine sites

Qc **Channel alluvium (late Holocene)**—Active flow channel of Meadow Valley Wash and of some sidestream fans on the valley floor of Meadow Valley Wash. For Meadow Valley Wash (mainstream), channel alluvium consists mostly of sand and muddy, sandy silt and, in a few places, of dark-gray, well-sorted, rounded, polymictic gravel; elsewhere as between Farrier and 3 km south, the channel alluvium consists largely of slightly reddish-tan, fluvially reworked eolian sand. Meadow Valley Wash has some perennial flow especially at and downstream from a valley-floor spring, 3.7 km north of Farrier, at north end of Farrier narrows and within the narrows bedrock canyon; elsewhere it has nearly perennial flow and an abundance of channel vegetation; it is mostly entrenched 1.5-3 m below its Holocene terrace (Qrm); and the wash attempts to meander where its channel is laterally cutting in mud- and clay-bank deposits. For sidestreams, channel alluvium consists of tan and pale-gray silt, sand, and gravel mapped mostly in entrenched, dry, braided channels on sidestream fans at the mainstream valley margins

Qf **Flood-plain alluvium (late Holocene)**—Tan silty sand and brown-to-gray sandy silt and mud of Meadow Valley Wash; in a few places dark-gray gravel where ancestral channel gravel bars project above the fine-grained fill of the flood plain. Flood plain is everywhere narrow, commonly 150 m wide, rarely as wide as 300 m. Microrelief, such as, former meander channels and channel bars and swales are well preserved; locally bush-stabilized sand dunes (coppice) are abundant. Thickness considerably greater than the 1 or 2 m of section commonly exposed along the modern channels

Qz **Paludal deposit (late Holocene)**—Black mud and dark-gray muddy silt, in places tan sandy mud where mixed with eolian sand; covers most of the narrow canyon floor of Meadow Valley Wash at and below the valley-floor spring at about 1,810 feet (552 m) altitude at north end of Farrier narrows (3.7 km north of Farrier). The lush vegetated, marshy environment is enhanced by beaver dams

Qw **Slopewash, nondivided (Quaternary)**—Slope debris including talus; slopewash unit mapped mostly where location of contacts of underlying Quaternary or Tertiary units are uncertain; unit is much more extensive than shown on map. Age of the nondivided unit is mostly late Pleistocene, but in places where it is reasonably assumed to be of intermediate age (late middle Pleistocene), a subdivided unit, Qiw, is mapped. In upper reaches of some high-altitude sidestreams, where Holocene channel dissection is minimal or absent, the broad slopewash deposit is not dissected, is currently active, and commonly nearly coincides with a broad, ancient (late Tertiary?) constructional slopeform

Ql (Taf) **Landslide deposit (Quaternary)**—Parent rock unit shown in parentheses. The only conspicuous slide area is along the south side of Farrier Wash in the central part of the quadrangle where the sharp southward, lateral cutting of Farrier Wash undercut red clay of the Muddy Creek Formation (Tmr); age of sliding is probably intermediate terrace time (late middle Pleistocene; Qif) during wetter-than-present climatic conditions. One small landslide is located at the north end of Farrier canyon

Qe **Eolian silt and sand, nondivided (Quaternary)**—Extensive, but mostly a thin, surficial deposit; results from widespread exposure of fine-grained sediments of Quaternary and Tertiary age in the area. Mostly mapped where one foot thick or thicker, but difficult to evaluate because eolian sand is readily reworked into Quaternary surface materials, commonly as slopewash. Well-formed sand dunes are rare, whereas several, large, vegetation-stabilized, hummocky sand flats are mapped on the east side of Meadow Valley Wash from northeast of Farrier to near the southeast quadrangle corner; coppice dunes of various sizes are abundant in many parts of the quadrangle; sand transport indicates predominantly westerly to southwesterly wind directions. The eolian unit is not subdivided; stacked map units are mapped where the eolian sand deposit is thin and where the underlying surface and deposit can be inferred; they include Qe/Qf, Qe/Qw, Qe/Qrm, Qe/Qrs, Qe/Qys, Qe/Qim, Qe/Qis, and Qe/Tam; (the stacked unit on the map is colored to emphasize the underlying unit)

Recent terrace alluvium (Holocene)—Mostly tan silt and sand, but some mainstream gray gravel exposed in low mainstream terraces; tan sandy gravel in low sidestream terraces. Unit is subdivided into mainstream (Meadow Valley Wash, Qrm) and sidestream (Farrier Wash and other sidestream) deposits. Exposed mainstream alluvium is mostly a silt and fine sand, pluvial deposit; in many places covered by or mixed with much reworked eolian sand; dark-gray mainstream gravel is not well exposed, except in the southeastern corner where the gravel is exposed in a large, low terrace (Qrmg); elsewhere, gravel probably more widely underlies the silt and sand. The recent mainstream alluvium forms terraces about 3 m high, and is inset below the young alluvial terrace (Qym) of Meadow Valley Wash ; sidestream terraces are lower but likewise inset. Depositional surface of mainstream terrace is intact, meander channel and bar and swale features are well preserved; no obvious carbonate-enriched soil or associated pavement is recognized

Qrm **Recent mainstream alluvium**—Mainstream-terrace alluvium of Meadow Valley Wash. Predominantly silt, sand, and mud and locally some intertongued gravel lenses; the fine-grained sediments were deposited either as a normal overbank, flood-plain deposit of a perennial Meadow Valley Wash, or as a special, climatic-controlled, pluvial, paludal deposit; distinction between these two processes for Meadow Valley Wash has not been studied

Qrmg **Recent gravel-facies of mainstream alluvium**—Locally exposed deposit containing abundant, well-sorted, dark-gray, coarse, mainstream gravel; mapped in southeastern corner of quadrangle

Qrf **Recent alluvium of Farrier Wash**—Tan and light-gray terrace sand and gravel of Farrier Wash

Qrs **Recent sidestream alluvium**—Tan and light gray sidestream-terrace sand and gravel

Young terrace alluvium (late Pleistocene)—Tan to gray, silty to sandy gravel, and silt and sand, poorly bedded, moderately sorted; gravel mostly clast supported. Subdivided into mainstream (Meadow Valley Wash) and sidestream (Farrier Wash and other sidestream) deposits, of which the mainstream deposit commonly consists of dark-gray gravel overlain by overbank or pluvial silt, all inset in the erosional valley of Meadow Valley Wash; the sidestream deposit is mostly a thin gravel terrace inset in the erosional sidestream valley, but the deposit forms a thick alluvial fan on the mainstream valley floor and an upstream thinning alluvial wedge in the lower sidestream valley. Clast composition is polymictic for mainstream, Paleozoic carbonate rocks plus sparse Kane Wash Tuff clasts for Farrier Wash, and only Paleozoic clasts for other sidestreams from the west. Deposit is slightly cemented by calcite and in many places holds a vertical face where exposed by stream cutting. Forms terraces 6-9 m high in Meadow Valley Wash; sidestream terrace heights are less. Depositional top of terrace is widely preserved as are many depositional microrelief features, such as meander and braided-channel remnants and bar-and-swale relief. The flat terrace surface has a carbonate soil zone of disseminated, mostly white powdery carbonate; the soil pavement is firm, has lightly varnished cobbles overlying several centimeters of loose, cobbly silt (A horizon). Pavement surface is dark, surface of cherty limestone clasts show only slight or no solutional relief (that is, differential solution of limestone relative to chert on cobble surface), and carbonate undercoating on under side of surface cobbles is mostly a film, but to as thick as 1 mm. The carbonate soil development is stage II (Machette, 1985; Gile and Grossman, 1979). The young terrace alluvium was deposited during pluvial climatic cycles; deposit probably coincides with early and late Wisconsin glacial cycles

Qym **Young mainstream alluvium**—Mainstream-terrace alluvium of Meadow Valley Wash

Qymg **Young mainstream alluvium, gravel facies**—Dark-gray polymictic gravel of Meadow Valley Wash, mapped where conspicuously exposed

Qyms **Young mainstream alluvium, sand facies**—Tan fluvial sand of Meadow Valley Wash; mapped where conspicuously contrasted to gravel facies (Qymg)

Qyf **Young alluvium of Farrier Wash**—Terrace alluvium of Farrier Wash

Qys **Young sidestream alluvium**—Thin sidestream-terrace alluvium and thick sidestream-fan alluvium built out on the young mainstream alluvium

Qyw **Young slopewash (late Pleistocene)**—Mapped only where in contact with intermediate-age (late middle Pleistocene) slopewash (Qiw) in southwestern part of quadrangle

Intermediate terrace alluvium (late middle Pleistocene)—Tan to gray, silty to sandy gravel, poorly bedded, moderately sorted, mostly clast supported; and silt, fine sand, and clay, mostly well bedded. Subdivided into mainstream (Meadow Valley Wash) and sidestream (Farrier Wash and other sidestream) deposits. Mainstream deposit commonly consists of a thick gravel overlain by thick aggradational silt; deposit inset in the erosional valley of Meadow Valley Wash; base is rarely exposed, but thickness of deposit probably considerably exceeds the 15 m commonly exposed. The sidestream deposit is mostly a thin terrace gravel inset in the erosional sidestream valley, but forms a thick wedge of sidestream alluvium that intertongues with the thick mainstream deposit and overlies it as a fan deposit. Clast composition is polymictic for mainstream and Paleozoic carbonate rocks plus sparse Kane Wash Tuff clasts for Farrier Wash and several other sidestreams from the west. Deposit is not well cemented by calcite, but commonly stands well in exposed vertical faces that have been case hardened by shallow ground-water carbonate at the exposed face (Lattman and Simonberg, 1971).

Forms high terraces, about 40 m high in north part and about 32 m high in south part of quadrangle in Meadow Valley Wash; sidestream terrace heights are much less, depending on the size of wash; sidestream deposit thickens sharply as a wedge-shaped fan on approach to the mainstream valley. (Terrace height is the difference between the terrace altitude and the altitude of the adjacent modern channel; Meadow Valley terrace heights are laterally constant and slope uniformly and gently downstream. Sidestream terrace heights and thicknesses, however, are variable on and near the mainstream valley because the sidestream slope extrapolates to any laterally variable position of confluence across the broad flood plain of Meadow Valley depending on the position of the mainstream channel at the time the sidestream terrace was built).

The flattish terrace top of the unit is mostly preserved as the depositional surface with only moderately, erosionally, rounded edges, but initial depositional microrelief features are not preserved. In places, the initial flat terrace surface has been preserved by a carbonate soil zone, about 2 m thick, of which about 0.5 m is a resistant calcrete; the soil pavement is firm and is set in about 5 cm of silty A horizon; about 10 percent of the pavement surface as viewed from above consists of light-gray, soil-carbonate fragments, mostly as carbonate undercoating on rotated surface cobbles, but the albedo of the surface remains dark from the prevailing dark-brown varnish on resistant clasts; differential surface solutional relief on limestone-chert clasts is as much as 1 cm; and carbonate undercoating beneath cobbles is as thick as 3 mm. The carbonate soil development is stage III (Machette, 1985; Gile and Grossman, 1979). Deposition of the intermediate terrace alluvium was climatically controlled and possibly coincided with Illinoian glacial cycles

Qim **Intermediate mainstream alluvium**—Mainstream-terrace alluvium of Meadow Valley Wash

Qif **Intermediate alluvium of Farrier Wash**—Terrace alluvium of Farrier Wash

Qis **Intermediate sidestream alluvium**—Thin sidestream-terrace alluvium and thick sidestream-fan alluvium built out onto intermediate mainstream alluvium

Qiw **Intermediate slopewash (late middle Pleistocene)**— Talus and slopewash deposits accumulated on and upslope of the intermediate terrace either below older terraces or conspicuously below some highly cherty carbonate rock outcrops of the Bird Spring Formation (PCb); moderately well preserved in many more places than mapped, best preserved at higher altitudes remote from deep stream dissection. Above intermediate terrace, slope deposit characteristically erodes with a distinctive arch-and-pillar structure, where relatively noncemented slope debris erodes out from under the resistant carbonate soil (commonly about 0.5 m thick) developed on the slopewash--long, narrow, slope-parallel pillars of resistant carbonate soil-covered slopewash are connected by equally long, but slope-perpendicular arches of similar construction. Reconstruction of original slopewash surface suggests how thoroughly covered were the many excellent, present-day outcrops of older sediments and rocks above the intermediate-age terrace.

Below some highly cherty, carbonate-rock outcrops of the Bird Spring Formation are conspicuous remnant, intermediate-age, talus-slope deposits of a distinctive brown to dark-brown color caused by weather-accumulated surface varnish on individual resistant talus fragments (Whitney and Harrington, 1993)

Qit **Scarp-seep travertine (late middle Pleistocene)**—Medium- to dark-gray, porous, aphanic calcite having a coarse algal-mat(?) lamination, and containing abundant casts and molds of former plant debris; calcite is impure, contains slopewash and eolian debris. Travertine was precipitated from shallow ground water seeping from a stream-cut scarp or fault scarp shortly after the scarp formed; each scarp initially exposed clay overlain by pervious gravel from which the ground water seeped, and each scarp accumulated a scarp fill against its exposed face; travertine cemented the scarp fill and formed a massive, sloping sheet of travertine, about a meter or two thick on the scarp fill at near the angle of repose (45° - 25°); travertine forms a resistant, protective layer that preserves the scarp fill from erosion much longer than normal. Located in 0.5 km^2 area, 1.5 - 2.5 km north-northeast of Farrier; three principal scarps are 3-12 m high and are cut in red claystone of the Muddy Creek Formation, which is overlain by well-sorted, highly permeable, intermediate-mainstream gravel (Qim) a few meters thick, which in turn is overlain by much less permeable, intermediate-sidestream sandy gravel (Qis) several meters thick.

Field mapping did not resolve the origin of the travertine. Two possible hypotheses follow: (1) At the end of the intermediate deposition, the wide, stable, intermediate alluvial surface of Meadow Valley Wash began to be dissected; the first, shallow, lateral sweep of Meadow Valley Wash cut into the Muddy Creek clay, mainstream gravel, and sidestream alluvium sequence and at the same time inset a layer of mainstream gravel that was covered by a scarp fill and sidestream gravel; meanwhile, shallow ground water flowing from the sidestream drainage basin to the east, seeped from the highly permeable, intermediate mainstream gravel, evaporated, and precipitated travertine on the scarp fill. This sequence was repeated three times as Meadow Valley Wash each time cut down a little deeper and a little farther west. Or (2) Scarps cut by Meadow Valley Wash (as in hypothesis 1) are proximal and down gradient from several late Miocene faults slightly displacing the uppermost Muddy Creek Formation (the near coincidence of river-cut scarps and possible fault scarps makes distinction between the two scarps difficult); the faults discharged small amounts of deep ground water that flowed a short distance in the permeable mainstream gravels to seep out and evaporate at the stream-cut scarps. The first hypothesis is preferred because the lateral mainstream cuts are real, whereas Quaternary reactivated faulting seems much less likely. In addition, deep, regional ground water should contain significant amounts of gypsum in solution that on evaporation should precipitate conspicuous gypsum as well as calcite (however, the precipitation of gypsum and calcite from their mixed solution is a complex process that needs evaluation for this situation (Reheis, 1987, p. 11); and faulting of late middle Pleistocene age in the region is so uncommon that the coincident Quaternary faulting with mainstream lateral cutting is highly unlikely; one negative aspect of the first hypothesis is that we know of no other seep-travertine deposits at similar sites of lateral cutting by Meadow Valley Wash. One point in favor of the second hypothesis is that regionally, the few known, similar seep-travertine deposits seem to be associated with faults that discharge small amounts of regional bicarbonate ground water, and that shallow ground-water discharges commonly do not form travertine deposits

Old terrace alluvium (middle and early? Pleistocene)—Tan to gray, silty to sandy gravel, poorly bedded, moderately sorted gravel; mostly clast supported; and interbedded silt, sand, and clay, moderately well bedded. Subdivided into mainstream (Meadow Valley Wash) and sidestream (Farrier Wash and other sidestream) deposits. Mainstream deposit commonly consists of thick gravel overlain by a thick aggradational silt (exposed thickness of the gravel and silt at one locality is 14 m); deposit is inset in the erosional valley of Meadow Valley Wash. The sidestream deposit is mostly a thin terrace gravel, inset in the erosional sidestream valley, but it also forms a thick wedge of alluvium that intertongues with and overlies the thick mainstream deposit as a fan. Clast composition is polymictic for the mainstream unit, and Paleozoic carbonate rocks plus sparse Kane Wash Tuff clasts for Farrier Wash and for several other sidestreams from the west; all other sidestream deposits contain only Paleozoic clasts, except for a few clasts reworked from erosion of the Horse Spring Formation. Deposit is poorly to moderately well cemented by calcite, but everywhere stands well in exposed vertical faces with or without case hardening (Lattman and Simonberg, 1971).

Mainstream terrace is about 56 m high at about 1,840 feet (561 m) altitude in southeast corner of quadrangle in Meadow Valley Wash; sidestream terrace heights are much less except near the confluence of the sidestream and mainstream where the two approach each other in height and altitude (terrace heights are measured relative to adjacent active channels).

Terrace top is eroded into shallow, well-rounded, broad ridges whose accordant tops are but slightly lower than the depositional top of the original terrace. In some places, the initial flat terrace surface has been preserved by a thick carbonate soil zone, commonly 3 m thick, of which about 1 m is a massive, resistant calcrete that commonly forms a resistant, vertical rim along the terrace edge; the soil pavement is firm, has about 15 cm of silty A horizon, and the resistant, surface clasts are heavily varnished; exposed surface clasts are about 50 percent carbonate-soil fragments, thereby giving the surface a light color and moderately high albedo regardless of other dark, thickly varnished clasts; the soil carbonate undercoating of surface clasts may be several centimeters thick, this undercoating, where rotated or fragmented from the clast, contributes to the moderately high surface albedo; and differential solutional surface relief on cherty-limestone clasts can be deeper than 2 cm. The carbonate soil development is stage IV to IV+ (Machette, 1985; Gile and Grossman, 1979). Deposition of the old terrace alluvium was climatically controlled, and possibly coincided with pluvial cycles older than Illinoian

Qom **Old mainstream alluvium**—Mainstream-terrace alluvium of Meadow Valley Wash

Qof **Old alluvium of Farrier Wash**—Terrace alluvium of Farrier Wash

Qos **Old sidestream alluvium**—Sidestream-terrace alluvium

Qok **Carbonate soil developed on old alluvium (Holocene through middle Pleistocene)**—Not widely mapped because soil does not normally show well at scale of map; erosional soil-scarp line, representing as much as 1 m of calcrete, is more widely mapped by "C" line symbol described below

Tr **Regrade gravel of Moapa (late early Pliocene)**—Gray-weathering (mainstream) and tan-weathering (sidestream), thick-bedded, commonly coarse gravel, that is well sorted, clast supported, with moderate interstitial sand, and some internal lenses and thin beds of sand; the coarse gravel is nearly uniform from top to base and has a few coarse boulders about 25 cm across and many clasts about 10 cm across. In places the gravel is well cemented by calcite.

Clast composition and provenance are similar to that of the underlying Whitmore Mesa aggradational gravel (Ta). Both gravels have the same source areas except that the deeper incision at the time of the regrade gravel made more Paleozoic rocks available (also note, that some of the regrade gravel is derived from erosion and reworking of the Whitmore Mesa aggradational gravel); the composition is about one half Paleozoic limestone-dolomite-chert and one half Tertiary silicic volcanic rocks plus sparse basalt and rare Mesozoic clastic rock, Cambrian red quartzite, and Precambrian metamorphic and igneous rocks.

The regrade terrace lies above the old Quaternary terrace and is much less preserved than the old Quaternary terrace; in south-central part of quadrangle, the mainstream regrade terrace (Trm) height above Meadow Valley Wash is about 250 feet (84 m) at about 1,980 feet (604 m) altitude. At the north quadrangle edge, the mainstream regrade terrace lies about 450 feet (137 m) below the reconstructed top of the Whitmore Mesa aggradation terrace, whereas at the southeastern edge, the terrace is about 320 feet (98 m) below the aggradational terrace. The mainstream regrade gravel is as thick as 60 feet (18 m).

The regrade gravel of Moapa is named for Moapa, a small post office in the adjacent, to the south, Moapa West quadrangle (Schmidt and Page, in prep., 1994), where the gravel is well exposed in the highest terrace overlooking the Moapa Indian Reservation village from the north. The regrade gravel results from the natural attempt of the ancestral Meadow Valley Wash to carry its alluvial load across the flattish dry surface of the drained Muddy Creek Lake, all the way to the entrenched Colorado River. At the same time as the Whitmore Mesa aggradational gravel prograded southward, a very low-gradient degradational stream (ancestral Virgin River) was eroding headward toward the Muddy River and Meadow Valley Wash (Muddy River farther south). The very low gradient resulted from the fine-grained and small load the degradational stream acquired where cutting only in clays and other very fine grained sediments of the Muddy Creek Formation. Where the aggrading stream met the degrading stream, the aggrading stream momentarily faced a much lower base level, so that the now combined stream entrenched in the aggradational fan and deposited relatively coarse alluvium in the low-gradient, downstream, degradational channel. As a result, the degradational channel aggraded to carry the sudden increased stream load. This regrading proceeded until near equilibrium of grade, load, and discharge was attained, and the relatively stable alluvial surface of the regrade gravel of Moapa resulted. This surface remained relatively stable until the Quaternary and developed a thick carbonate soil similar to—but somewhat younger than—that developed on the Whitmore Mesa gravel.

The age of the regrade gravel of Moapa is late Tertiary on the basis of the stage of development of its carbonate soil; the age of the gravel is presumably somewhat younger than the regrading of the Colorado River itself, which may have been completed about 3.8 Ma (Lucchitta, 1979); we suggest an age between 4.0 and 3.5 Ma for the regrading of the ancestral Meadow Valley Wash in the Farrier quadrangle

Trm **Regrade gravel of Moapa, mainstream**—Regrade gravel of Meadow Valley Wash

Trf **Regrade gravel of Moapa, Farrier Wash**—Regrade gravel of Farrier Wash

Trs **Regrade gravel of Moapa, sidestream**—Regrade gravel of sidestream

QTrk **Carbonate soil developed on regrade gravel of Moapa (Holocene through late early Pliocene)**—Within the quadrangle, an old carbonate soil is partly to severely eroded in comparison to the still older Mormon Mesa soil (carbonate soil on the Muddy Creek Formation); terrace surface is everywhere erosional so that no complete Tertiary-age soil is preserved on the regrade gravel of Moapa in the Farrier quadrangle. In many places, 1-2 m of calcrete is preserved on well-rounded, broad, flattish ridges (ballena type); locally, high concentrations of soil carbonate fragments on surface indicate a resistant lag from a Tertiary soil now deeply eroded. Possible reasons for the poor preservation of a Tertiary soil on the regrade gravel are as follows: (1) the well-sorted gravel as substratum for the soil is more porous and less consolidated in comparison to the substratum of other Tertiary soils on the Muddy Creek Formation and Whitmore Mesa aggradation gravel, and (2) a decreased carbonate dust flux is inferred during and after regrade gravel deposition because thick carbonate soils covered much of the probable sources of carbonate dust, namely the formerly widely exposed, unconsolidated Muddy Creek clays and Whitmore Mesa aggradational gravels

Ta **Whitmore Mesa aggradational gravel, nondivided (early early Pliocene)**—Tan- to brown-weathering, interbedded gravelly sand and sandy gravel, thick- to thin-bedded, poorly-sorted, grades from more sandy lower part to more gravelly upper part. Cobbles and boulders mostly matrix supported in a matrix of abundant pebble, grit, and coarse to medium sand; dispersed boulders are as much as 30 cm in diameter. The gravel is moderately well cemented by calcite and commonly erodes to a high, steep slope.

Clast compositions consist of a western provenance from the southern Meadow Valley Mountains to the west consisting predominantly of late Paleozoic limestone, dolomite, and chert and sparse middle Miocene Kane Wash Tuff (Tk); and of a northern provenance from the northern Meadow Valley Mountains to the north and from farther north upstream on Meadow Valley Wash consisting predominantly of late Oligocene to middle Miocene volcanic clasts, including the Kane Wash Tuff; subordinately of Paleozoic limestone, dolomite, and chert and late Tertiary basalt; and of sparse Mesozoic sedimentary rocks including rare but conspicuous chert-pebble conglomerate from the Triassic Shinarump Conglomerate. Sparse, red-brown clasts of orthoquartzite and chert-pebble conglomerate (Cambrian Prospect Mountain Quartzite) and igneous and metamorphic clasts (Precambrian) are found in the eastern part of the mainstream gravels where an eastern provenance from the Mormon Mountains mixed with mainstream alluvium of northern provenance. A small contribution consists of mixed clasts reworked from local conglomeratic outcrops of Horse Spring Formation. Dicke (1990) measured and described this aggradational gravel, and her section D stacked on section J (or section D on G, plate 2) represents the Whitmore gravel overlying the green clay at the top of the Muddy Creek Formation.

The Whitmore Mesa gravel forms the highest terrace in the region; in and adjacent to the map area, two terrace highs are 2,525 feet (770 m) altitude, or about 650 feet (198 m) above Meadow Valley Wash, on Whitmore Mesa adjacent to the northeast corner of the quadrangle and about 2,600 feet (790 m) altitude, or about 280 feet (85 m) above Farrier Wash, near the apex of the Farrier aggradational fan. The mainstream aggradational gravel is about 390 feet (119 m) thick where it overlies the Muddy Creek Formation in the northeast corner; near the apex of the Farrier fan (Taf), the sidestream aggradational gravel is about 280 feet (85 m) thick overlying the Horse Springs Formation or about 200 feet (61 m) thick overlying the top of the Muddy Creek Formation 3 km east of the bedrock range front. The aggradational gravel in most places overlies the depositional, green clay at the top of the Muddy Creek Formation (Tmg), mostly with a slight, non-erosional disconformity marked by thin deposits of eolian sand and sheet-wash sand (commonly centimeters to somewhat more than a meter thick), or with slight erosion and a weak carbonate paleosoil developed on the top clay of the Muddy Creek before burial by the aggradational gravel. Locally, the aggradational gravel overlies the sediment of White Narrows (Tsw), which in turn overlies the Muddy Creek Formation with slight angular unconformity; this relationship is defined in the Moapa West quadrangle (Schmidt and Page, in prep., 1995), to the south and is not well exposed in the Farrier quadrangle where the sediment of White Narrows and its associated faults have long been eroded or covered in the axial area of the Glendale basin along Meadow Valley Wash.

The Whitmore Mesa aggradational gravel is named for Whitmore Mesa just off the northeast corner of the Farrier quadrangle where the type section is designated between the top of Whitmore Mesa from the 2,420-foot (738-m) contour (0.5 km east and 3.3 km south of northwest corner of Rox SE quadrangle) westward down section to the top of the Muddy Creek Formation 1.2 km west in the Farrier quadrangle. In this section, the thick (390 feet, 119 m) aggradational gravel was deposited on well-exposed, thick green clay at the top of the Muddy Creek Formation.

The Whitmore Mesa gravel is a normal response of streams feeding into the Glendale basin to aggrade and establish a gradient across the flattish lake-bed floor of the Muddy Creek lake after it was drained by the integration of the Colorado River through the central part of the Muddy Creek lake region (present-day Lake Mead area). On this strong premise, the age of the start of aggradation is the age of draining of the Muddy Creek lake at about 5 Ma. The end of aggradation, or youngest age of the Whitmore Mesa gravel, is the age of integration of the Glendale basin to the Colorado River system via the Muddy River and lower Virgin River, which is the earliest age of about 4 Ma for the inception of the regrade gravel of Moapa as discussed above

Tam **Mainstream aggradational alluvium**—Mainstream facies of the Whitmore Mesa gravel; alluvium of Meadow Valley Wash of northern provenance from the northern Meadow Valley Mountains and other upstream drainage areas of the ancestral Meadow Valley Wash

cg **Coarse gravel bed**—Coarse gravel bed, 0.3 to about 1 m thick, in finer grained, sandy aggradational alluvium, northeast corner of quadrangle; used as a horizon trend line

Tamg/Tams **Gravel facies overlying sand facies**—Stacked unit; in places, abrupt change from sandy to overlying gravelly facies of mainstream aggradational alluvium, mapped in northeast corner of quadrangle; probably signifies the natural progression of the aggradational process--although more gradational in most places--from finer grained deposition below and nearer the prograding front to coarser gravels above the finer-grained alluvium and upstream. Mapping of two facies incomplete, and such detailed mapping is probably not feasible except locally; facies designated only by symbol on map (color is that of Tam)

Tamp **Purple volcanic gravel subfacies**—Purplish-gray-weathering, well-sorted, rounded pebbly gravel, about 6 m thick, consists of 80 percent silicic volcanic clasts as much as 25 cm in diameter, and is overlain by about 7 m of tan siltstone; mapped in north bank at mouth of Farrier Wash. Origin and correlation of purple volcanic gravel is uncertain, but is a key deposit in that it is sparsely but widely distributed in quadrangle to the south; it always directly overlies red Muddy Creek Formation (Tmr). The purple gravel is interpreted here as the earliest prograding aggradational gravel derived from a mostly volcanic terrane before more mixed gravels of larger provenance became available. This early gravel was deposited on slightly eroded, down-faulted, uppermost Muddy Creek; this interpretation requires north-trending faults in the formation at the Farrier Wash site and elsewhere; such faults have not been seem or mapped at the Farrier Wash site

Taf **Aggradational alluvium of Farrier Wash**—Sidestream fan facies of the Whitmore Mesa gravel; alluvium of Farrier Wash of western provenance from the southern Meadow Valley Mountains

c/f **Coarse facies overlying fine facies**—Mapped as a locally distinct depositional horizon or zone that changes upward from finer- to coarser-grained aggradational alluvium along Farrier Wash; may indicate maturing of aggradation in upper part of Farrier alluvial fan wherein more coarse gravel is transported farther into the aggrading basin

wz3 **White zone 3**—White, carbonate concretion zone, 20 cm thick; probably a shallow ground-water precipitation horizon (rather than an ancient soil) 41 m above top of Muddy Creek Formation in middle part of aggradational gravel on the Farrier fan (Taf) north of Farrier Wash; a localized feature above white zone 2 (wz2) wz2 **White zone 2**—White, carbonate concretion zone, 75 cm thick; probably a shallow ground-water precipitation horizon (rather than an ancient soil) 32 m above top of Muddy Creek Formation in middle part of aggradational gravel on the Farrier fan (Taf) north of Farrier Wash; a localized feature, but considering the entire map area, it is the second white zone above the top of the Muddy Creek Formation

Tas **Sidestream aggradational alluvium**—Sidestream facies of all sidestreams other than Farrier Wash; alluvium mostly of western provenance from the southern Meadow Valley Mountains

Taf-Tam **Mainstream alluvium intertongued with Farrier Wash alluvium**—Mixed aggradational gravel unit; the intertonguing of Meadow Valley Wash mainstream alluvium and the Farrier Wash alluvium was incompletely determined in the field, but enough resolution was made to suggest a wide zone of intertonguing. During Whitmore Mesa gravel time, the mainstream deposition skirted west around low hills of Horse Spring Formation north of Farrier and spread widely, southwestward of Farrier, across the basin floor to at least half way to the Meadow Valley Mountains

——A—— **Ash-fall bed**—White pumice ash bed in middle of the Whitmore Mesa aggradational gravel in the mainstream-sidestream intertongued zone (Taf-Tam) of the Farrier Wash fan 2-2.5 km south of Farrier Wash in south-central part of Farrier quadrangle. Ash is white, fine grained, pumiceous, and variably contaminated with fine and coarse detritus; is in lenses and discontinuous beds, mostly less than 1.5 m thick, but in places, where it is reworked into alluvium, it is a few meters thick; a 1.5 to 3.5-m-thick channel of coarse, well-sorted, mainstream gravel (Tam) has a matrix of mostly reworked ash. The ash bed lies about 24 m above the top of the Muddy Creek Formation, where the aggradational gravel is about 46 m thick

Tak **Carbonate soil developed on Whitmore Mesa aggradational gravel (Holocene through late early Pliocene)**—Well-preserved carbonate soil extensively mapped in the uppermost part of the aggradational alluvium of Farrier Wash high on the Farrier Wash fan (Taf); also, just off the quadrangle to the northeast, east, and southeast, the same carbonate soil is well preserved overlying mainstream aggradational gravel (Tam) and forms the top surfaces of Whitmore and Wieser Mesas. The carbonate soil on Farrier Wash fan surface is weathered and eroded down to, and in places below, the soil laminar zone; the exposed thickness of soil calcrete is about 3.5 m; the soil pavement has a high albedo, because it consists of about 95 percent light-gray carbonate soil fragments and only several percent shiny black chert fragments as well as a few inconspicuous gray Paleozoic clasts; the chert fragments are highly varnished, polished, mostly of fine pebble size, and concentrated in large patches several meters across; these patches of chert are characteristic of this Tertiary soil developed on sandy gravel.

This oldest carbonate soil preserved in the Farrier quadrangle is nearly as old as the regionally widespread Mormon Mesa soil, whose reference section is northeast of Overton, Nevada, 6.5 km southeast of the Farrier quadrangle. The soil on the Farrier Wash fan was initially less well developed than the Mormon Mesa soil and subsequently was more deteriorated than the Mormon Mesa soil because (1) The Farrier fan altitude, 2,300-2,600 feet (701-793 m), is 400 to 700 feet (122 to 213 m) about 200 m higher than the Mormon Mesa soil, (2) the host Farrier fan slopes much more than the flattish Mormon Mesa surface (the Farrier fan even slopes 3.3 times more than the mainstream slope on Whitmore and Wieser Mesas) (3) The Ferrier fan oil is developed on more pervious gravels in contrast to the Mormon Mesa soil on the clay and fine sand of the Muddy Creek Formation, (4) the western side of the basin probably (if compared to the present day) received a lower air-borne, carbonate flux than the central basin position of Mormon Mesa; the carbonate flux is needed to nourish and maintain the soil during the several million years since its inception, and (5) the carbonate dust flux on the dried up Muddy Creek lake (initial Mormon Mesa soil-forming time) was probably much greater than the later dust flux when most of the top of the Muddy Creek Formation was covered by aggradational gravel

Tsw **Sediment of White Narrows (early early Pliocene)**—Mostly medium- to light-gray and greenish-gray to buff in fresh exposure that commonly weathers white; fine-grained sediments filling shallow graben structures displacing the top of the Muddy Creek Formation in the northeastern part of the quadrangle; mapped with some uncertainty because of isolated and incomplete exposure; sediments consist of marl, reworked Muddy Creek sediments, and reworked eolian sand; mostly fluvial, but may be in part lacustrine; upper part grades into the Whitmore Mesa aggradational gravel (Ta); lower contact is a slight unconformity on the top of the Muddy Creek Formation; age of unconformity (graben) is well established 2-5 km to the south in the Moapa West quadrangle where several well-exposed grabens cut the top of the Muddy Creek but do not displace the middle and upper parts of the Whitmore Mesa gravel; unit is 1-10 m thick; it may be much more widespread than mapped in the Farrier quadrangle, but where thin and sandy, it is difficult to distinguish from the basal, finer-grained parts of the Whitmore Mesa gravel. The well-exposed small grabens on the east side of Meadow Valley Wash, 2 km east and northeast of Farrier, are filled with Whitmore Mesa gravel (Ta), presumably because the prograding gravelly sand was available at the time of faulting, whereas, 15 km farther south in the Moapa West quadrangle, grabens of the same age were filled with the fine-grained sediment of White Narrows, presumably because the prograding Whitmore Mesa gravels had not yet reached the area to the south.

Unit named for exposures in the Muddy River valley in the Moapa West quadrangle. The abundant marl in the White Narrows sediments and in association with small extensional structures represents a presumed sudden influx of deep-circulating, regional ground water from the west and north

Tsc **Spring carbonate mound (early early Pliocene)**—Precipitation of calcite in travertine mound from discharge of regional, bicarbonate ground water precisely on the top of the Muddy Creek Formation; medium-gray, porous, aphanic calcite, having well-preserved algal-mat lamination, and containing abundant calcic casts and molds of former megaplant debris both in vertical (growth) and horizontal (fallen) positions; calcite is impure and contains minor eolian contaminants. Mound is as much as 7 m thick and thins to 2 m, 1.5 km south of its presumed center. The spring carbonate mound is slightly younger than the top of the Muddy Creek and slightly older than the prograding Whitmore Mesa gravel; its estimated age is slightly less than 5 Ma. Located 6.5 km southwest of Farrier

Tsg **Spring gypsum bed (early early Pliocene)**—White gypsum nodules, 5-10 cm in diameter, closely packed, and uniformly spaced in green clay filling a possible fluvial channel, 3 m deep, cut in green clay (Tmg) at the top of the Muddy Creek Formation; ratio of gypsum to clay about 1:1; nodular gypsum bed overlain by the Whitmore Mesa aggradational gravel containing little or no gypsum. Origin of gypsum uncertain in this unique occurrence in the Farrier quadrangle; small outcrop located 2.3 km east and 4.5 km north of west and south quadrangle borders, respectively. Gypsum bed is about 0.5 km west and upstream from the spring carbonate mound (Tsc) deposited on top of the Muddy Creek green clay--both deposits probably have similar age and perhaps a common ground-water discharge origin. The ground water was probably the same sulphate-bicarbonate type for both deposits, the difference being that at the gypsum deposit, the spring water was evaporative (small volume discharge?), and at the carbonate mound, the spring water was flowing away from the mound (large volume discharge). In detail, it appears that a degradational channel had been cut in the green clay at the top of the Muddy Creek, and the channel aggraded with reworked green clay and precipitated gypsum; both degradation and aggradation may have been by ground water discharging from a spring in limestone of the Bird Spring Formation, exposed today, only meters from parts of the gypsum bed. The nodular-gypsum, green-clay channel deposit actually may be a part of the sediment of White Narrows (Tsw) where sediment deposition coincided with gypsiferous ground-water discharge.

The impressive concentration of gypsum here need not suggest that the gypsum content in discharging ground water was large; it is probable that the sulphate-ion concentration was not greater than that discharging at the Muddy River Springs, today, that is, about 200 ppm. The age of the gypsum bed is inferred to be slightly less than 5 Ma, the same as the probably age of the spring carbonate mound (Tsc)

Top of Muddy Creek Formation (latest Miocene)—On the geologic map, the top—that is, upper contact—of the Muddy Creek Formation is represented by a bold line, dashed where approximately located and queried where uncertain; in most places the top (GC) is a green clay facies (unit Tmg). Elsewhere, as in south-central part of quadrangle, the top of the Muddy Creek is represented by a slight disconformity close to the base of, but within a white, calcic nodular to massive carbonate and marl zone (WZ), as thick as 3 m; within this zone calcium carbonate mostly filled pores in the aggradational silty sand and conglomerate of the Whitmore Mesa gravel above the unconformity and slightly infiltrated the underlying fine sand and clay of the uppermost Muddy Creek Formation. Altitude of upper contact and thickness of green clay and white zone are recorded at many localities on the map. In a few places where upper contact is uncertain, the inferred contact is labeled TT (for top of Tmc) and the recorded altitude is queried.

Green clay bed at top of Muddy Creek Formation probably represents characteristic, nonoxidized, clay deposition in ancient Muddy Creek Lake; the green clay was spared diagenetic oxidation and reddening by gypsiferous pore waters because, after the lake drained, the pore water in the uppermost clay was replaced by relatively fresh water at the then subaerially exposed former lake bottom. In contrast, the white zone (WZ) perhaps represents a part of the Muddy Creek top that was slightly eroded, several meters, to below the thin green clay, so that, only diagenetically oxidized red clay formed the top of the formation. In a few places, such as just north of Farrier Wash in the center of the quadrangle, both the white zone and the green clay occur together, wherein the white zone overlies most of the green clay layer; the calcareous precipitation in the white zone may include a slight amount of pedogenic carbonate, but is mostly, later, shallow ground-water carbonate precipitated at the contact between the permeable overlying aggradational gravel (Ta) and the impervious clays of the upper Muddy Creek. (Although shallow ground water obviously fed the carbonate precipitation in the white zone, the localization of the white zone about 5 Ma on the west side of the Glendale basin below Paleozoic carbonate rock outcrops strongly suggests that the ultimate source of the water was the regional bicarbonate-saturated ground water; see discussion under Tsc, Tsg)

GC
2190-11t **Green clay, upper contact, depositional top of Muddy Creek Formation**—Showing altitude of top contact and thickness (t) of green clay, both in feet

WZ
2190-8t **Calcareous white-zone, depositional top of Muddy Creek Formation**—Showing altitude of approximate basal contact and thickness (t) of white zone, both in feet

WZ(CB)
2320?-3t **Calcareous white zone with carbonate bed?, depositional top of Muddy Creek Formation**—White calcic to marly calcic layer (bed?) at or near depositional top of Muddy Creek Formation; showing altitude and thickness (t) in feet. Calcic zone is presumably the most calcite-rich end product of the mapped white zone (WZ), but alternatively, the carbonate bed could be a spring carbonate or travertine bed deposited subaerially from nearby spring waters just prior to deposition of the Whitmore Mesa gravel; not well exposed. Mapped in central north part of quadrangle, 1.5 km south of center of north quadrangle edge

TT-2200 (?) **Top contact of the Muddy Creek Formation**—Showing queried altitude (in feet) of inferred top contact as exposed; probably close to depositional top, but uncertain; some erosion of depositional top of Muddy Creek Formation probable

Muddy Creek Formation (late Miocene)—Fine-grained basin fill deposited in the Glendale basin after cessation of essentially all extensional deformation. Pale-brownish-red (salmon color), and rarely green, gypsiferous and calcareous, lacustrine deposit containing little or no fluvial alluvium; contains mostly claystone and some fine-grained sandstone and siltstone; well bedded and thin to laminar bedded where freshly exposed; exposures commonly have thick clay wash on exposed surfaces that makes observation of detailed stratigraphy and structure difficult. Sediments are moderately well consolidated, stand vertical in recent stream cuts, but with weathering and time the outcrops become well rounded and flatten. In upper part, formation contains as much as 10 percent medium-grained, calcic-cemented sandstone in lenses and discontinuous tabular beds, as thick as 10 cm, which weather to plate- and flag-form fragments. Mud cracks and gypsum beds are uncommon suggesting that complete drying of the lake was infrequent.

A thin, massive to thick-bedded, pale-greenish-gray claystone constitutes the uppermost part of the formation and is found throughout a large central basin area where covered by the Whitmore Mesa gravel and where not erosionally removed along the broad Meadow Valley. This unit or facies is as thick as 30 m in the northeast corner of the map area and thins to zero toward the margins of the Glendale basin. Rare, small (centimeters thick by meters wide) remnants of green clay also are found within thick red claystones of the main, red-bed mass of the Muddy Creek Formation. The green color reflects an inferred reduced state of the clay during deposition (abundant organic content in freshwater lake) in contrast to the oxidized state of the clay in the buried, diagenetic phase. In the Miocene clay beds the diagenetic, red-bed oxidation process (rubification) was rapid, presumably aided by a well-dispersed gypsum content in the sediments. The green clay facies or unit in the uppermost Muddy Creek presumably was spared rubification because, once the Muddy Creek lake was drained, the pore water in the uppermost few meters to few tens of meters of the green clay was displaced by fresh meteoric water containing little or no gypsum.

Thickness of the exposed part of the Muddy Creek in the central southern part of the Farrier quadrangle is estimated at 150 m; however, the full thickness of the formation is much thicker, especially in the deeper axial part of the Glendale basin beneath and east of Meadow Valley Wash. Northwest of Farrier, the base of the Muddy Creek laps onto a steep, high-relief unconformity of structural and erosional origin above the Horse Spring Formation; 12 km south in the Moapa West quadrangle, the Muddy Creek thickens to an estimated 400 m in a drill hole near the Nevada Power plant.

Fossil preservation is exceedingly rare in the Muddy Creek Formation, probably because of the high gypsum content. A rare find included 5 articulated short bones about 1.3 cm in diameter and a total length of 13 cm, in brownish-red claystone located 1.7 km N. 25° E. of Farrier in steep cliffs and canyons cut in the formation on the east side of Meadow Valley; fossil identification has not been possible because the "bone" is a cast of calcareous sediment, all organic bone material has been dissolved (C.A. Repenning, oral commun., 1993); nearby in the same outcrop area, several camel-foot imprints and casts (one about 8 cm in diameter and 12 cm deep) were found (by R.E. Reynolds, July 12, 1992) in pale-greenish-gray calcareous claystone about 30 m below the estimated top of the Muddy Creek. Several other similar soft-mud impressions of foot prints have been found in the quadrangle, especially near and at the top of the formation.

The formation is horizontally bedded except (1) for a gentle slope toward the basin axis east of Meadow Valley Wash; this slope is probably a combination of depositional slope, differential compaction of basin-fill sediment, and maximum structural down faulting along the basin axis; and (2) in the vicinity of faults cutting the Muddy Creek Formation where bedding is commonly deformed and tilted as much as 45 degrees for as much as 30 m or more on either side of a given fault; most known faults are slightly younger than the age of the depositional top of the formation.

The age of the depositional top of the Muddy Creek Formation is about 5 Ma as determined in the adjacent Moapa West quadrangle to the south (Schmidt and Page, in prep., 1995); the early, deep base of the Muddy Creek is nowhere exposed in the map vicinity, but the age of the base is about 12 Ma for the Lake Mead area, if the red sandstone unit of Bohannon (1984, p. 49) is included in the Muddy Creek, as we suggest.

The thin, conspicuous, and significant green-clay facies (Tmg) in the uppermost Muddy Creek is divided from the underlying thick pale-brownish-red claystone, red clay facies (Tmr) that constitutes most of the formation in the quadrangle; in addition, a variegated sandy facies and a chocolate-brown clay facies beneath the green clay are noted locally in the northeastern part of the map.

The Muddy Creek beds were named by Stock (1921), mapped and described as an informal formation in the Muddy Mountain area by Longwell (1928), and more widely mapped and described as a formal formation throughout Clark County, including most of the Farrier quadrangle, by Longwell and others (1965) and Bohannon (1984). Dicke (1990) measured and described 5 sections of the Muddy Creek Formation in the quadrangle but does not define the top of the Muddy Creek as done on the current map, however, the uppermost green clay (Tmg) of the formation was included in 3 of her sections and the white zone (WZ) in another section

Tmr **Red-clay facies**—Comprises most of the Muddy Creek Formation exposed in the Farrier quadrangle

Tmg **Green-clay facies**—Uppermost part of the Muddy Creek Formation; defines the upper contact of the formation; widely exposed in the quadrangle. See also description above (TT, GC)

W/B **Variegated facies and brown-clay facies**—Two distinctive local facies in upper Muddy Creek Formation locally identified by letter symbols on their mutual contact; incompletely mapped; the green clay facies (Tmg) overlies the variegated facies which consists of interbedded, variegated, red and white, clay and fine sand (W) about 30 m thick that in turn overlies the brown-clay facies, which consists of thick-bedded, dark-brown (chocolate color) clay (B) about 15 m thick; reference section located about 1 km east of south end of Farrier narrows

Horse Spring Formation (middle and early Miocene)—Silty conglomeratic basin-fill deposited during extensional deformation and opening of the Glendale basin. Pale-red-brown, very poorly sorted, immature, discontinuously thick-bedded, polymictic, silty, sandy conglomerate (coarse facies, Thc) and conglomeratic, sandy siltstone (fine facies, Thf); in map area the exposed formation is mostly silty, sandy conglomerate of which about one half is silt and sand and one half is gravel. Clast size is well graded from a few boulders and abundant cobbles (20 percent) and angular pebbles (30 percent) to a matrix (50 percent) of sand and silt, but content is variable both laterally and vertically in section; most large clasts float in fine-grained matrix; locally, gravel-rich layers are interbedded with silt-rich layers. Boulders are commonly 15-25 cm across, common maximum size is about 45 cm across, but rare, locally derived boulders of volcanic rock are as much as 2 m across (for example, boulders of Harmony Hills Tuff). The silty sandy conglomerate and conglomeratic sandy siltstone are well indurated and well cemented by calcite and clay; exposures are steep and high near stream cuts and especially in the east bank of Meadow Valley Wash from the north end of Farrier narrows to far beyond the north border of quadrangle.

Clasts consist mostly of Paleozoic limestone, dolomite, and chert; conspicuous jet-black Mississippian chert and white Ordovician quartzite; sparse volcanic (mostly ignimbritic) clasts except locally where volcanic clasts may predominate; and rare Mesozoic sedimentary rocks, Lower Cambrian clastic rocks, and Precambrian metamorphic and igneous rocks. Clasts are derived from the adjacent ranges, mostly from the southern Meadow Valley Mountains (Thcw, west source) and from the northern Meadow Valley Mountains (Thcn, north source). The basal contact is seen only where the basin fill marginally onlaps against the adjacent bedrock ranges; here, where exposed, the coarse facies (Thc) of immature conglomerate onlaps Paleozoic bedrock with little or no transitional facies.

The deposit is everywhere deeply eroded, forming well-rounded, semiaccordant ridges (no depositional accordance implied), covered by a lag concentration of boulders and cobbles; in most places the deposit has only a young Pleistocene-age carbonate soil, but locally on middle and lower ridge slopes, an intermediate carbonate soil (Qik, late middle Pleistocene), may be preserved (mostly on slopewash); rarely is an older carbonate soil preserved.

The Horse Spring debris was synextensionally shed from the actively rising ranges into the actively extending and subsiding basin by fluvial and mass-wasting processes as stream deposits, debris flows, mudflows, and gravity slides (huge, megabreccia, gravity slides are exposed just north of quadrangle near Rox); however, most of the debris in the formation exposed in the Farrier quadrangle was moderately fluvially washed into the axial part of the Glendale basin and was distal with respect to the source areas.

Extensional deformation within the Glendale basin caused minor angular unconformities within the exposed Horse Spring basin fill; these unconformities exhibit weathering and erosion of small horst structures and local sedimentary filling of discrete small grabens; much of the polymictic fill was derived from adjacent deformed conglomerate on walls of the local grabens; locally the fill is monolithic volcanic detritus (Thw) where derived from adjacent, upfaulted Kane Wash Tuff (west bank Meadow Valley Wash, 2.4 km north of Farrier). The most conspicuous internal unconformity in the exposed Horse Spring lies just below interlayered Kane Wash Tuff, where emplacement of two ash-flow tuffs was largely controlled by the topography of north-trending graben structures of an age comparable to that of the ash flows.

The thickness of the Horse Spring Formation as exposed in the quadrangle is roughly 150 m, wherein the stratigraphic base is not exposed (actually deeply buried) and the top of the formation is everywhere deeply eroded. Such erosion is not characteristic of closed-basin filling and is explained below (fault symbol text) to be caused by strong uplift of the basin in the northeast part of the map area In the axial part of the Glendale basin just east of Meadow Valley Wash, the formation may be 600 m thick (approximate estimate from gravity anomaly); this axial thickness probably increases greatly to the south of the map area.

The age of the Horse Spring Formation within the Farrier quadrangle is well fixed by the age of the two ash-flow tuffs of the Kane Wash Tuff that range from 14.4 to 14.6 Ma (Scott and others, 1993). Near the north edge of the quadrangle on the east bank of Meadow Valley Wash, 120 m of section of the Horse Spring Formation underlies the Kane Wash Tuff; at a reasonable, inferred depositional rate of between 20 and 40 cm/ka, about one half million years of basin filling is represented below the ash flows.

The Horse Spring Formation of the Farrier quadrangle, as herein assigned, is a synextensional basin-fill deposit underlying the postextensional Muddy Creek Formation. It is correlated with the Horse Spring Formation of the Virgin and Muddy Mountains (Longwell, 1928; Longwell and others, 1965; Bohannon, 1984; Beard and Ward, 1993) on the basis of (1) its deformation by normal faulting and tilting, (2) its unconformable position below the nondeformed to slightly deformed Muddy Creek Formation, (3) the age of the interlayered Kane Wash Tuff corresponds to about the time of maximum regional extension in this southeastern Nevada region, and (4) the age of the Tuff fits well within the age range of the currently acceptable age range of the Horse Spring Formation from somewhat older than 20 to about 12 Ma. The silty conglomerate in the map area is most similar to the Dead Horse Trail member of the upper Horse Spring Formation that ranges from about 15.5 to somewhat less than 12 Ma (R.G. Warren and D.A. Sawyer, oral commun., 1992) in the western Sheep Range (Schmidt, 1988, p. 242-244)

Thc **Coarse facies of Horse Spring Formation**—Silty, sandy conglomerate, constitutes most of the formation

Thcn **Coarse facies of northern provenance**—Provenance from the northern Meadow Valley Mountains; much of the exposed part of the formation consists of this facies, which suggests basin deposition controlled by continual, north-trending axial deformation

Thcw **Coarse facies of western provenance**—Provenance from the southern Meadow Valley Mountains

Thf **Fine facies of Horse Spring Formation**—Conglomeratic, sandy siltstone of more than 60 percent sand and silt; a distinctly fine-grained facies of the predominantly silty conglomerate formation; is mapped at both ends of Farrier narrows along Meadow Valley Wash where its distribution suggests restricted deposition in synchronously formed grabens along the axial part of the basin. A reference section of the fine-grained facies is along the county road on west bank of Meadow Valley Wash, west of the north end of Farrier narrows, where locally abundant plant impressions, including palm fronds, are preserved in the fine-grained sediments and especially in some marly beds; also, a thick ash-fall bed (Tha) and three or more thin ash-fall beds crop out within the overlying ten meters of section; the contact with the overlying coarse facies (Thc) consists of a basal layer of large conglomeratic blocks (to 4 m across) derived from the Horse Spring Formation, itself, the blocks probably collapsed from local, synextensional graben walls

Thfn **Fine facies of northern provenance**—Further suggests basin deposition in actively deforming axial part of basin

Thl **Spring carbonate bed**—White to pale-pinkish-gray, thin-bedded to laminated, coarsely porous, aphanic calcite, commonly having algal-mat lamination and in places abundant molds and casts of former plant fossils either as disoriented fragments or in growth position; impressions of palm fronds are well-preserved in the spring carbonate bed (Thl). The carbonate rock is similar to travertine and is probably proximal to a spring carbonate mound and spring source discharging warm regional, bicarbonate ground water. Mapped only on the flood plain in Farrier Wash where only about 5 m of section is exposed about 3 km east of the quadrangle west border; unit is probably much thicker and laterally much more extensive than exposed. Assigned to Horse Spring Formation by its moderate fold and fault structures and by its similarity to outcrops of similar range-front rock to the south in the Moapa West quadrangle. Age of the carbonate bed within the formation is likely younger than the Gregerson Basin Member of the Kane Wash Tuff (Tk) rather than older, because late-extensional upfaulting along the range front is not evident

Thw **Local slopewash facies**—Tan monolithic volcanic detritus, mostly gruss weathered from nearby paleo-outcrops of ash-flow tuff (Tkl, lower unit Gregerson Basin Member, Kane Wash Tuff); intraformationally deposited within coarse conglomeratic facies, northern provenance, of the Horse Spring Formation (Thcn). Slopewash unit helps to define an intraformational disconformity within the synextensional Horse Spring. Located 0.3 km southwest of south end of Farrier narrows

—WA— **White-ash bed**—Ash-fall bed in conglomerate of Horse Spring Formation; most ash beds mapped are 0.3 m to several meters thick; source and age of ash unknown

Tha **Ash-fall tuff, nondivided, Horse Spring Formation (middle Miocene)**—White-weathering, silver-shard, air-fall tuff; in places pumiceous, sparse crystals (including rare pyroxene), and rare biotite (contamination?) and interbedded, especially in upper part, with contaminating detritus; middle part contains silver-colored, nearly pure-shard, silicic concretions, 0.1-2 m in diameter. This silver tuff is located in west bank of Meadow Valley Wash at north end Farrier narrows, is about 20 m thick, and is overlain and underlain by fine-grained facies of Horse Spring Formation (Thf).

Both the stratigraphic and structural position of silver tuff is uncertain; stratigraphically the tuff probably lies about 60 m below the lower ash-flow tuff (Tkl) of the Gregerson Basin Member of the Kane Wash Tuff (Tk), even though, structurally, the two units are at the same level (altitude) on the flood plain of Meadow Valley Wash at the north end of Farrier narrows; the ash composition is peralkalic by chemical analysis and similar to the composition of the lower ash-flow tuff (Tkl). With seemingly rapid sediment deposition between the two volcanic units (Tha, Tkl), the silver ash might be correlative to the Grapevine Spring Tuff at 14.67 Ma (lowest member of the Kane Wash Tuff; Scott and others, in press, 1994)

Tk **Kane Wash Tuff, Gregerson Basin Member, nondivided (middle Miocene)**—The Gregerson Basin Member is a peralkalic rhyolite (comendite) ash-flow tuff sequence that at Farrier narrows in the Farrier quadrangle is represented by two units: an upper ash-flow tuff (Tku) and a lower ash-flow tuff (Tkl). Elsewhere in the quadrangle, these two ash-flow tuffs, apparently, each have an equivalent ash-fall tuff (Tkau, Tkal), which are described separately below under ash-fall units (Tka). The proximity of equivalent ash-flow and ash-fall units in the same quadrangle is unusual and is explained here by a difference in depositional altitude and by the fact that the ash flows were at about their lateral limit of welding. The two ash-flow units of the Gregerson Basin Member are similar to those described by Scott and others (1993; in press 1994) in that each unit may consist of two (or more?) cooling parts, but with the exception that the two units in the Farrier quadrangle are separated by 12 m of conglomerate of the Horse Spring Formation (Thf) (12 m thickness may represent about 40 ka of time between eruptions as calculated using a reasonable 30 cm/ka rate of sedimentation). Weathers reddish yellowish tan to brown in near vertical cliffs in Farrier narrows, elsewhere, away from canyon cut, weathers to a scree-covered, steep slope. Fresh rock is a glassy red and green vitrophyre where locally, thinly preserved (about 40 cm thick) at base of each unit, respectively; reddish brown in devitrified welded tuff of lower unit, and white to tan and greenish gray in devitrified welded tuff of upper unit; paler colors in upper, vapor-phase-altered parts of both units where many autoliths, commonly 1-3 cm across, weather out as conspicuous holes. Eutaxitic foliation well preserved in more highly welded tuff low in each unit. Thin sections of the welded tuffs indicate about 15 percent total crystal content consisting of about 65 percent sanidine (commonly showing adularescence), 30 percent quartz, and less than 5 percent altered mafic minerals and small iron-oxide globs (mostly inferred to be altered from sodic mafic minerals). In places, as much as 3 m of white, unconsolidated or carbonate-cemented, pumiceous ash abundantly contaminated with detritus may underlie the basal glass or welded tuff. In many places the basal welded tuff of both units is obviously contaminated, mostly with older volcanic rock and mineral fragments, to as high as 30 cm above the base; this and inconspicuous micro-contamination at still higher levels probably account for the consistently old ages determined for the welded tuff from Farrier narrows during the past few years.

Thicknesses at Farrier narrows are as follows: lower unit is 28 m thick and contains a diagnostic dark-gray zone about one meter thick, 13 m above its base; upper unit is 19 m thick, and consists of a pale-gray to white, in part vitric, readily weathered lower part (cooling unit) and greenish-gray- to tan- and brown-weathering, much more resistant upper part (upper cooling unit?).

The Gregerson Basin Member is divided into an upper unit (Tku) and a lower unit (Tkl) in the Farrier quadrangle; correlation of the member to the type section and to the Kane Spring Wash caldera is based on chemistry of the lower unit and physical characteristics of both units at Farrier narrows. The ash-flow tuffs in Farrier narrows are located 40 km south of the southern rim of its caldera source in Kane Spring Wash. K-Ar and fission-track age determinations on tuffs from Farrier narrows during the past 25 years, give 4 different unpublished ages, ranging from 19 to 21 Ma (R.G. Bohannon, U.S. Geol. Survey, oral commun., May, 1986), which match no known regional ash-flow tuff. The age of the upper unit of the Gregerson Basin Member of the Kane Wash Tuff is 14.39 ± 0.25 and the lower unit is 14.55 ± 0.14 Ma ($^{40}Ar/^{39}Ar$ by L.W. Snee, *in* Scott and others, 1993), if our correlation is correct.

In the Farrier quadrangle, the Gregerson Basin tuff is welded only in the narrow Meadow Valley from Farrier narrows to the north edge of the quadrangle, in the west reach of Farrier Wash, and in a small sidestream valley in the northwest corner of the quadrangle. In Meadow Valley, the two welded tuffs occupy a narrow, deep, north-trending, basin-axial graben synchronously formed during regional extension; in the western part of the quadrangle, the two tuffs occupy a few narrow, deep, ancient erosional channels that probably resulted from base-level changes directly related to formation of the axial graben. North of Farrier narrows, the ash-flow tuff is up faulted nearly 120 m on the east bank of Meadow Valley Wash, and it thins eastward against the side slope of the ancient axial graben. At small outcrops of ash-flow tuff in the present-day Farrier Wash drainage near the west border of the quadrangle and in the Small Valley in the northwest corner, the two tuffs are inset in paleochannels in Permian carbonate bedrock; this paleodrainage has to date back to about 14 Ma (the age of the ash flows) and, coincidentally, the modern drainages have been superposed on the old drainages at almost exactly the same altitude; the same superposition is apparent in Farrier narrows. The synextensional graben in Farrier narrows probably was located near the axis of the Glendale depositional basin during late Horse Spring time

Tku **Upper ash-flow unit, Gregerson Basin Member**

Tkl **Lower ash-flow unit, Gregerson Basin Member**

Tka **Ash-fall units, nondivided, Gregerson Basin Member, Kane Wash Tuff**—The Gregerson Basin Member is also divided into two, white, peralkalic, rhyolitic (comendite) ash-fall tuffs, an upper ash unit (Tkau) and a lower ash unit (Tkal) each of which probably correlates with the upper (Tku) and lower (Tkl) ash-flow tuffs, respectively, at Farrier narrows. The white ash contains about 20 percent pumice fragments commonly about 1 cm across, about 10 percent crystals of quartz and sanidine, plus sparse altered sodic(?) mafic minerals, and sparse contaminants of biotite and hornblende, as well as about 5 percent lithic inclusions; lithic and crystal contaminants increase toward the base and especially in the lower 6 m where lithic fragments are as much as 33 cm across and consist mostly of greater than 18-Ma-old silicic ash-flow tuffs characteristic of the southwestern Utah volcanic section and lesser amounts of Paleozoic carbonate rocks and Mesozoic clastic rocks. Both units are nonwelded and commonly only moderately consolidated, but it is likely that between the reference section (1.5 km west of Meadow Valley Wash and 1.2 km south of the north edge of quadrangle) and Farrier narrows, the lower unit was emplaced as a nonwelded ash-flow tuff as suggested by the systematic vertical distribution of amount and size of pumice and exotic inclusions. Three kilometers to the south and 2.7 km northwest of Farrier, the lower unit is a white ash and the upper unit is densely welded ash-flow tuff, about 16 m thick.

The thicknesses of the ash-fall units, well-exposed at the reference section, are as follows: lower ash about 24 m and upper ash about 6 m; about 1 km to north the lower ash thins to about 8 m and the upper ash was not found and is exceedingly thin or was not deposited.

The correlation of the lower ash-fall unit with the Gregerson Basin Member is on the basis of its chemistry and is convincing because of the unique and distinctive composition of the units of the Kane Wash peralkalic suite (Scott and others, in press-1994). The age of the ashes are the same as those of the ash-flow tuff units.

The ash-fall units were deposited on a structural upland only slightly modified by some intraformational (intra-Horse Spring Formation) erosion, in contrast to the highly welded ash-flow tuffs that were deposited in grabens in the axial zone of the basin as well as in deep erosional channels cut in bedrock at the basin margin

Tkau **Upper ash-fall unit, Gregerson Basin Member**

Tkal **Lower ash-fall unit, Gregerson Basin Member**

PCb **Bird Spring Formation, nondivided (Lower Permian, Pennsylvanian, and Upper Mississippian)**—Six informal members were mapped; in descending order, sandy limestone member (Pb6), red slope-forming member (Pb5), medium-dark-gray limestone member (Pb4), dolomitic member (PIPb3), Tungsten Gap member (IPb2), and lower limestone member (IPMb1). Formation not mapped in detail. For names, detailed descriptions, and thicknesses of the informal members, see Page (1992) who described the formation in the adjoining Arrow Canyon quadrangle. In Farrier quadrangle, as throughout the region, erosional outcrop of formation is characterized by a conspicuous step-and-riser (staircase) profile of a consistently thick-bedded sequence as seen from a distance. Base and top of formation not exposed in Farrier quadrangle, but base is exposed in normal sequence just to west of quadrangle (Pampeyan, 1993); thickness of formation from base to uppermost part exposed in quadrangle is estimated at 1,715 m. Earlier geologic maps at 1:250,000 scale by Longwell and others (1965) for Clark County and Tschanz and Pampeyan (1970) for Lincoln County and at 1:50,000 scale by Pampeyan (1993) for the Meadow Valley Mountains, all include the Farrier quadrangle. Some previous descriptions of the formation in adjacent Arrow Canyon Range were by Langenheim and others (1962), Langenheim and Langenheim (1965), and Webster (1969)

Pb6 **Sandy limestone member (Lower Permian)**—Medium- to light-gray-weathering limestone and some pale-reddish-gray-weathering silty to sandy limestone especially in lower part just above the red slope-forming member (Pb5); thick bedded; some beds are highly fossiliferous; colonial rugose coral biostrome having coral heads to 0.6 m across is characteristic of lower part and especially near contact with member five. Thickness in canyon of through-flowing wash in northwestern part of quadrangle, where member dips east about 65°, is about 575 m without an exposed top of the member and without consideration for any subtle structural complications. Identity of member six is uncertain near southwestern corner of quadrangle

Pb5 **Red slope-forming member (Lower Permian)**—Upper part is medium-dark-gray, cherty, laminated limestone, and lower part is reddish-brown calcareous silty mudstone and calcareous siltstone having thin interbeds of limestone; thickness is about 215 m, and is equivalent to unit d of Pampeyan (1993). Member is readily mappable in western one-third of quadrangle, except in southwestern area where deeper erosion, cover by younger rocks, and structural complexity cause minimal exposure

Pb4 **Medium dark-gray limestone member (Lower Permian)**—Thick bedded, erosionally well stepped in outcrop, weathers a conspicuously darker gray than most of formation below; includes a conspicuous, light-gray, white-weathering, thick limestone(?) bed near top. Lower contact is base of 7-m-thick cherty limestone bed commonly containing 40 or more percent dark-red-brown-weathering chert. Thickness is about 45 m

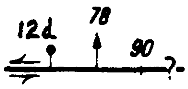
PIPb3 **Dolomitic member (Lower Permian and Upper and Middle? Pennsylvanian)**—Medium-gray, olive-gray to light-gray-weathering, interbedded limestone, dolomitic limestone, and dolomite; fossiliferous in part; thickness is about 210 m

IPb2 **Tungsten Gap member (Middle Pennsylvanian)**—Dusky-brown to medium-brown-weathering slightly argillaceous dolomitic limestone, finely crystalline and thin-bedded; makes conspicuous brown bed or pair of brown beds in outcrop; exposed in resistant cliff; thickness is about 15 m

IPMb1 **Lower limestone member (Middle Pennsylvanian to Upper Mississippian)**—Medium-gray, thin- to thick-bedded limestone and minor dolomitic limestone; in part arenaceous and bioclastic, fossiliferous in places. Member only partly exposed in quadrangle; thickness in Arrow Canyon quadrangle is 60 m, of which the lower 15 m is considered Mississippian age (Webster, 1969)

——— – –?- **Contact**—Dashed where gradational, queried where uncertain

Trace of bedding plane—Trace identified on aerial photographs; mostly in Bird Spring Formation, but locally in Whitmore Mesa aggradational gravel unit (Ta)



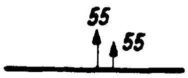
Normal fault (mostly late Tertiary)—Dashed where approximately located; dotted where concealed; queried where uncertain. Bar-and-ball on down thrown side of fault where known; displacement shown in feet (12d) where known. Arrow indicates direction and amount of dip of fault plane; cross bar marked 90 indicates vertical fault. Opposed arrows indicate relative direction of strike-slip movement.

Three generations of normal faults are mapped, but not distinguished on the map: (1) Young, end of Muddy Creek time; (2) middle, time of up-arching of Mormon Mountains; and (3) old, time of regional extensional deformation. No older faulting, especially that of Sevier thrusting age, is distinguished, and no Quaternary faulting is recognized.

(1) The young faulting event, which displaces the top of the Muddy Creek Formation (Tmr) and only the lowest part of the Whitmore Mesa aggradational gravel (Ta), consists of faults trending about north and about 5 Ma old; the faults spectacularly displace the green clay top of the Muddy Creek (Tmg), 1.5-2.5 km east of Farrier; individual displacements are as much as 24 m mostly down to the east toward the axis of the Glendale extensional basin, but some small graben structures exist; cumulative displacement not determined but may be 100 m down to east. This well-defined, short-lived faulting event is probably part of, and approximately in line with, a regional north-trending major zone of faulting that extended north from the Gulf of California along the alinement of the lower Colorado River and that somewhere between the present-day Davis and Parker Dams caused the breaching of a divide that had contained Muddy Creek lake for about six million years. Evidence of surface discharge of regional ground water during this period of faulting is not apparent in the Farrier quadrangle because the erosional base level of the surface drainage was not significantly lowered at this time along range-front zone of the Meadow Valley Mountains, in contrast to a significant lowering of the base level at the range front to the south in the adjacent Moapa West quadrangle (Schmidt and Page, in prep.-1995). No, or at least very little, ground water was discharged from the 5-Ma-old faults, 2 km north-northeast of Farrier, according to our analysis given below of the scarp-seep travertine unit (Qit).

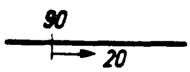
(2) The middle faulting event during late extensional deformation has an eastward trend along- and north- of the northern border of the Farrier quadrangle and a northeastward trend in the central to northeastern part of the quadrangle; that is, faulting was radial to the up-arching of the Mormon Mountains (to the northeast of the Farrier quadrangle); actual trend of faults has been somewhat compromised by the westward, regional-extension stress, which was active at the same time. The age of faulting is older than the young faulting event (1) and younger than the old faulting event (3); that is, at some time between more than 5 Ma and less than 14.5 Ma. Reasonably, the faulting event is probably older than most of the deposition of the Muddy Creek Formation, which suggests that most of the middle faulting was between about 11 Ma and less than 14.5 Ma. The east to northeast trend of spring carbonate veins in the northern third of the quadrangle represent ground-water bearing fractures coincident with the up-arching deformation. A large amount of regional ground water apparently was discharged through the Bird Spring carbonate rocks and through the consolidated Horse Spring conglomerate at this time in the northern part of the Farrier quadrangle (see discussion under spring carbonate vein unit, SCV).

(3) The old faulting event is associated with approximately east-west extension that caused the generally north-south, basin-and-range configuration of the Meadow Valley Mountains and Glendale basin. This faulting event was synchronous with, and also older than, that of the second faulting event described above; this north-trending faulting is best observed away from the influence of the uparching, that is, in the southern Meadow Valley Mountains in the western part of the Farrier quadrangle and farther south in the Arrow Canyon Range. The extension mostly deformed the Meadow Valley Mountains on many, multioriented normal faults and fractures, many of which have large amounts of associated fault breccia. Breakage of the Bird Spring carbonate bedrock along the range front in the southwestern part of the quadrangle is especially severe where the range was breaking down into the adjacent Glendale basin to the east, however, some of this breakage was coincident to the outcrop of the low-strength, thin-bedded siltstone and limestone of the red-slope-forming member (Pb5) of the Bird Spring Formation



Inclined with oblique slickensides—Short arrow shows direction and amount of dip; long arrow shows trend and plunge of oblique slickenside lineation

Inclined with dip-slip slickensides—Short arrow shows direction and amount of dip; long arrow shows trend and plunge of dip-slip slickenside lineation



Vertical with oblique slickensides—Arrow shows trend and plunge of oblique slickenside lineation

Vertical with horizontal slickensides—Double arrow shows trend of horizontal slickenside lineation

Low-angle normal fault (Late Tertiary)—Hachures on upper plate, arrow indicates direction and amount of dip of fault plane. Within the red slope-forming member (Pb5) of the Bird Spring Formation in southwestern corner of quadrangle; fault localized in silty carbonate rock, which is structurally much less competent than other parts of formation, and is localized along an especially broken range-front zone adjacent to the Glendale basin to east and south

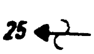
Landslide, surface trace of slip plane (Quaternary)—Hachures on slide mass (see description of landslide deposit, (Ql)

Major fold (early Tertiary to Late Cretaceous)—Broad anticline and syncline, folded during Sevier thrust deformation, has fold-limb asymmetry suggesting east-northeastward transport, but initially axes probably trended north-northeast, and were gently refolded about an east- to northeast-trending axis (not shown) associated with up arching of Mormon Mountains after emplacement of Kane Wash Tuff (Tk, about 14 Ma) and probably before Muddy Creek time (Tmr, about 12 Ma)

Anticline—Showing crestline; dashed where approximately located; queried where uncertain; dotted where concealed

Syncline—Showing crestline; dashed where approximately located; queried where uncertain; dotted where concealed

Minor folds at outcrop scale



Multiple folds—Showing trend and amount of plunge of parallel axes

Strike and dip of beds

16

Inclined

Vertical

Horizontal

Strike and dip of joints

60

Inclined

Vertical

Fault breccia (Late Tertiary)—In and parallel to fault zone; brecciation during extensional deformation

Brecciated bedrock (Late Tertiary)—Carbonate bedrock breccia in Bird Spring Formation where bedding was especially broken during extensional deformation

Carbonate soil scarp (Quaternary and Pliocene)—Conspicuous scarp along edge of alluvial terrace representing resistant upper part of carbonate soil zone and consisting of commonly 0.3-1 m of resistant calcrete depending on age and erosional degradation of soil; thickness commonly represents normal soil development on intermediate or old Quaternary terraces; for late Tertiary terraces, thickness represents either severe degradation of a former, thick Tertiary soil or total destruction of Tertiary soil and development of a Quaternary soil

Alluvial transport direction

tc

Direction measured—Determined from: tc, alluvial channel; tx, crossbedding; ts, sand streaks or flutes characteristic of aggradational deposition; ti, cobble imbrication

ts

Orientation measured—Specific transport direction not determined; symbols same as above

cd
2

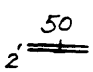
Clastic dike (Late Tertiary)—Downward filling of open fracture, mostly small and vertical; dike width in feet and inches; fill consists of wall-rock breccia; dikes formed mostly in well-cemented Horse Spring Formation during extensional fracturing of Horse Spring age

Spring carbonate veins (Late Tertiary)—White, finely to coarsely laminated, coarse- to fine-crystalline calcite veins ranging from microsize to large compound veins as wide as 16 m and more than 1 km long, veins a few centimeters wide by meters long are most common; laminations are microsize to centimeters wide; color mostly translucent white but varies from black and dark brown to honey-colored, red, and clear; coloring follows lamination and color in any given vein is variegated; crystal axes and growth are perpendicular to the vein walls; crystal size may vary from one lamina to the next, but generally does not vary; for some coarse crystallization, individual crystals are continuous from wall to vein center and the laminae seem independent of crystal growth. Vein growth is mostly symmetrical about a central plane and the two sides of the vein are mirror images; the central zone is commonly open space a few millimeter wide and may have relatively coarse crystal growth representing the termination of vein growth.

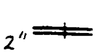
Carbonate veins are precipitated from regional, bicarbonate ground water that today is commonly about 90°C, which indicates deep circulating ground water. Wall-rock fragments and breccia are rarely associated with, or included in, the vein regardless of width of vein, and this suggests that most veins originated as narrow fractures with little or no movement parallel to the vein, which further suggests that the fractures widened as the vein grew in width. Lamination and crystallization variations along the vein width (crystal length) probably vary with trace-chemical changes of the ground water and crack-and-seal controls by the ground water; Winograd and others (1992) and Coplen and others (1994) have clearly demonstrated that cyclical isotopic variations across the veins match climatic glacial cycles. Carbonate veins are formed where ascending, deep-circulating ground water loses dissolved CO_2 presumably mostly by upward venting to the atmosphere via joints and fractures; the depth of veins probably rarely exceeds one kilometer (whence the name *spring carbonate vein* because nearby spring discharge is implied).

Carbonate veins are widely and mostly sparsely distributed in the Bird Spring Formation along the western part of the map and in the well-consolidated Horse Spring Formation in the central north part of the map. In the northern third of the quadrangle, the preferred orientation of the veins is east and northeast nearly radial to the Mormon Mountains uparching between 12(?) and 14 Ma as suggested in part by the more common internal vein breakage in these old veins (that is, vein growth was synchronous with some active extension) in contrast to younger veins, which are rarely internally broken. These old veins also are much more colored than younger veins, suggesting that ground water was scavenging more trace elements from the widely extending and broken bedrock of that time. Some old veins are honey brown to tan, which suggests that the ground water had a significant organic content acquired at recharge sites where active soils during late Tertiary time contained more soluble organic components than during the Quaternary when most veins were milky white.

The abundance of carbonate veins in the Bird Spring Formation, 3-4.5 km southeast of the northwest corner of the quadrangle, probably indicates a highly transmissive, ground-water zone (carbonate-rock aquifer) close to its spring discharge point in the upper part of the Horse Spring Formation during late Horse Spring time. The small exposures of spring-carbonate beds (unit Thl) in the flood plain of Farrier Wash, about 3 km east of the west quadrangle border, could represent carbonate precipitation from spring discharge of regional ground water of similar age and source as the abundant veins just described. A small vein zone, trending northeast on the east canyon wall of Meadow Valley Wash, 2.8 km south of the north quadrangle border, in Horse Spring conglomerate, consists of many nearly vertical, mostly black, small carbonate veins; the largest is 1 m wide; this vein zone was part of a large dispersed zone of ground-water flow through fractures in the ash-flow tuffs (Tku) in Farrier narrows; age of veins probably from 12 to 14 Ma



Single vein site, inclined dip—Showing strike and dip of vein; vein width in feet and inches



Single vein site, vertical dip—Showing strike and vertical attitude of vein; vein width in feet and inches

Multiple vein site—Schematic crossed attitude symbol represents several to many veins at one site, veins mostly narrow and short at outcrop scale, strike and dip variable

R **Red-water-course rock (late Tertiary)**—Red oxidation of fractured Paleozoic carbonate rocks by flow of large quantities of warm, oxidizing, ground water in the regional, carbonate-rock aquifer system, also, in places in fractured, well-consolidated, Horse Spring conglomerate, and in the ash-flow tuff of Gregerson Basin Member of Kane Wash Tuff (Tk). The typically intense, red coloration is probably caused by the oxidation of iron-bearing impurities within the carbonate rocks, most commonly within fine clastic grains disseminated in the carbonate rock. Fault gouge and breccia of impure carbonate rocks are especially subjected to oxidation and red coloration. The red color is caused by aphanitic iron-oxide minerals. (The red coloration is preserved only on recently exposed rocks, as in youthful canyon walls and stream cuts; with time red color alters to dark brown and then to dark gray and eventually weathering obliterates it.)

Red-water-course rock in surface exposures today is indicative of the past flow of large quantities of regional ground water, that is, indicative of a highly transmissive ground-water zone (part of an aquifer). Coarse-crystalline calcite filling individual fractures and breccia cavities (same calcite as in spring carbonate veins) in fracture zones of the red-water-course rock is generally younger than the red oxidation where determinable because the two products and processes are incompatible; the red oxidation zone is at any water-circulating depth below the level of first release of CO_2 to the near surface, whereas calcite precipitation in fractures and other tectonic voids begins at this first release depth and is most abundant above this level.

Red-water-coarse rock is abundant in sandy limestone member (Pb6) of the Bird Springs Formation in the canyon walls of the spring carbonate vein zone, about 4 km southeast of the northwest quadrangle corner. A type reference example is the "little red canyon" in the medium-dark-gray limestone member (Pb4) of the Bird Spring Formation, 4.3 km northeast of the southwest quadrangle corner, just upstream (north-northwest) from the CSV No. 2 exploration water well. The west canyon wall of Farrier narrows (along the railroad) in the lower ash-flow tuff unit (Tkl) (Gregerson Basin Member of the Kane Wash Tuff) shows dispersed water-coarse rock and generally slightly younger, black, spring carbonate veins

Erosional-solution pipe (Holocene)—Surface-water piping structure in gypsiferous claystone of the Muddy Creek Formation; pipe size variable, but as much as 1 m in diameter and as deep as 15 m; discharge end at wash level; erosional cone at top may be more than 30 m across; most are too small show on map. Pipes develop in desiccation cracks and enlarge by gypsum solution and clay washing. Best, but inconspicuous example, is in south bank Farrier Wash, 2.3 km southwest of Farrier

o-CSV No. 2 **Exploratory water well**—Drilled in 1986 by U.S. Geological Survey for the Carbonate-Rock Aquifer Project of southern Nevada; depth, 146 m (478 feet) entirely in Permian-Pennsylvanian limestone (members Pb4 and PIP3) of the Bird Spring Formation (Pb4, Pb3) (Berger, 1992; Berger and others, 1988); minimal testing of the well suggested a favorable yield, but the well was not adequately developed or tested. Well is significant because it was drilled adjacent to a well-exposed, red-water-course rock zone that is potentially an excellent, ground-water exploration target. Well is about 4.3 km northeast of the southwest corner of quadrangle

Gravel quarry—In late Pleistocene, mainstream gravel of Meadow Valley Wash (Qym), noteworthy because gravel size is favorable, gravel is nonconsolidated, and gravel contains little calcite cement or gypsum; operated by Clark County, on county road, 3 km south of Farrier

$\times_{v}$ **Calcite-vein prospect**—In brecciated, coarse-crystalline, spring carbonate vein about 10 m wide (maximum width, 15 m) by more than 1 km long (see description of spring carbonate vein); probably prospected in search of optical calcite crystals during World War II, however, from our current experience non-fractured, clear, optical calcite of centimeter size or larger from the spring carbonate veins of the region are exceedingly uncommon; located 4 km east-southeast of northwest quadrangle corner

$\times_{c}$ **Clay prospect**—Small surface sample site in red clay facies (Tmr) of Muddy Creek Formation. Various operations by at least four companies during middle through late 1980's to recover background content of gold from the lacustrine red clay

o-DH **Prospect drill hole**—Shallow drill hole to sample red clay from Muddy Creek Formation; part of prospecting described above under "clay prospect;" 0.9 km north of center of south edge of quadrangle

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EXPLANATION

CORRELATION OF MAP UNITS