Prepared in cooperation with the National Park Service

Preliminary Geologic Map of the Lake Mead 30′ x 60′ Quadrangle, Clark County, Nevada, and Mohave County, Arizona

By L.S. Beard[1], R.E. Anderson[2], D.L. Block[1], R.G. Bohannon[2], R.J. Brady[4], S.B. Castor[5], E.M. Duebendorfer[6], J.E. Faulds[5], T.J. Felger, K.A. Howard[3], M.A. Kuntz[2], and V.S. Williams[2]

Digital database by Debra Block[1], Tracey Felger[1], Melissa Aldrich[1], Michelle Harr[1], Anita Kaye[1], and Sue Priest[1]

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U.S. Department of the Interior
U.S. Geological Survey

[1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001
[2]U.S. Geological Survey, MS 913, Box 25046, Federal Center, Denver, CO 80225
[3]U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025
[4]Department of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91225
[5]Nevada Bureau of Mines and Geology, MS 178, University of Nevada, Reno, NV 89557
[6]Department of Geology, Northern Arizona University, Flagstaff, AZ 86011

Contents

Tables

Figures

Plates

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Introduction

The geologic map of the Lake Mead 30’ × 60’ quadrangle was completed for the U.S. Geological Survey’s Las Vegas Urban Corridor Project and the National Parks Project, National Cooperative Geologic Mapping Program. Lake Mead, which occupies the northern part of the Lake Mead National Recreation Area (LAME), mostly lies within the Lake Mead quadrangle and provides recreation for about 9 million visitors annually (Figure 1). The lake was formed by damming of the Colorado River by Hoover Dam in 1939. The recreation area and surrounding Bureau of Land Management lands face increasing public pressure from rapid urban growth in the Las Vegas area to the west. This report provides baseline earth science information that can be used in future studies of hazards, groundwater resources, mineral and aggregate resources, and of soils and vegetation distribution.

The preliminary report presents a geologic map and GIS database of the Lake Mead quadrangle and a description and correlation of map units. The final report will include cross-sections and interpretive text. The geology was compiled from many sources (Figure 2), both published and unpublished, including significant new mapping that was conducted specifically for this compilation. Geochronologic data from published sources, as well as preliminary unpublished $^{40}Ar/^{39}Ar$ ages that were obtained for this report (M. Kunk, written communication, 2000), have been used to refine the ages of formal Tertiary stratigraphic units and define new informal Tertiary sedimentary and volcanic units (Tables 1 and 2).

Methods

Sources of published and unpublished mapping from which this map was compiled are shown on Figure 2; some of the published sources were reinterpreted or modified based on field checking. Map sources include 1:24,000-scale maps published by the Nevada Bureau of Mines (Anderson, 2003, Bell and Smith, 1980, Brady and others, 2002, Castor and others, 2000, Duebendorfer, 2003, Howard and others, 2003, Mills, 1994, Smith, 1984, Wallace and others, 2006) and the U.S. Geological Survey (Beard and Campagna, 1991, Beard, 1992). About one-third of the map was compiled and modified from the 1:62,500-scale map of the Muddy and Northern Black Mountains (Bohannon, 1983). The remainder of the map involved new mapping at scales from 1:24000 to 1:100,000; in addition, mapping published in Fryxell and others, 1992 was compiled and modified by new mapping. A few local thesis maps were also used to guide compilation in the southwestern part of the quadrangle (Cascadden, 1991, Eschner, 1989, Feuerbach, 1986, Naumann, 1987, Scott, 1988, and Thompson, 1985).

Digital preparation of this map began in ArcInfo version 6 and was completed with ArcGIS 9.1. Data originally compiled into ArcInfo coverages were later transported into ArcGIS geodatabase structure. Geologic information was digitized, with either a tablet digitizer or from a scanned image, from published maps or from geologists' field sheets at various scales. The data were originally compiled from the existing and new mapping into 7.5-minute quadrangle segments, and then appended together as a single 1:100,000-scale sheet. The map was then generalized in certain areas that had been compiled from more detailed 7.5-minute quadrangles. Because of this approach, some areas of the final map may show relatively more detail than others.

General Geology

The Lake Mead 1:100,000-scale quadrangle includes some of the most spectacular scenery in the Basin and Range Province, scenery that is the direct result of the complex geologic history of the region. Extending from near the mouth of the Grand Canyon westward almost to Las Vegas, Nevada, the quadrangle exposes 1.8 billion years of geologic history through a tremendous range of strata, including Proterozoic crystalline rocks, Paleozoic and Mesozoic sedimentary rocks, Tertiary sedimentary, volcanic and plutonic rocks, and Late Tertiary to Quaternary surficial deposits. This history begins with the suturing of continents to form the Proterozoic crystalline basement, followed by deposition of Paleozoic strata along a continental margin. Mesozoic sedimentation, responsible for many of the brilliant colors seen in the Lake Mead area, began first on the craton side of an island arc and later in the foreland of Late Mesozoic (Sevier) thrusting.

Sevier-age thrusting telescoped the miogeoclinal Paleozoic strata eastward over more cratonal facies. Although thrust relations and correlations within the thrust belt are fairly well understood, the fronts of these thrusts and their structural interaction with cratonal strata of the Colorado Plateau to the east are poorly constrained. The Lake Mead area lies at the eastern limit of thrusting, defined here by the Muddy Mountain thrust exposed in the Muddy and North Muddy Mountains (Figure 3). The Arrowhead fault, which strikes east and dips south, is interpreted by Bohannon (1983) as part of the Muddy Mountain thrust system and forms the northern exposure of the thrust. The Arrowhead may represent a lateral ramp or tear fault in the Muddy Mountain thrust system, located where the thrust overrode an inferred ramp in the older Summit-Willow Tank-North Buffington thrust. This older thrust system is probably a secondary splay off the Muddy Mountain thrust that forms the east margin of the thrust system north of the Muddy Mountains (Bohannon, 1983). The eastern and southern edges of the Muddy Mountain thrust are somewhat enigmatic because of later disruption by Tertiary faulting so that the southern limit of thrusting is not known.

The geologic history culminates with Tertiary extensional tectonism that formed the present basin-range topography. East-west extension was accomplished by large-magnitude normal faulting, strike-slip faulting, and north-south shortening (Anderson and Barnhard, 1993). This complex deformation tilted and rotated structural blocks and allowed differential uplift, exposing a broad range of rock ages and type. The northwest-striking, right-lateral Las Vegas Valley shear zone and northeast-striking, left-lateral Lake Mead fault system intersect in the western Lake Mead area (Figure 4), accompanied by south-directed structural shortening (Anderson and Barnhard, 1993). These large lateral fault systems interrupt the northerly basin-range structural fabric and separate a terrain to the north containing thick sequences of Paleozoic and Mesozoic strata, from terrain to the south of Tertiary volcanic rocks underlain by Proterozoic crystalline rocks. Large-scale low-angle normal faults, such as the Lakeside Mine-Salt Spring Wash system and the Saddle Island detachment, unroofed large expanses of Proterozoic basement rocks and may have as much as 5 to 15 km of throw (Fryxell and others, 1992, Brady and others, 2000).

Tertiary rocks in the Lake Mead quadrangle include clastic and precipitated sedimentary strata, volcanic flows, vent facies, and domes and sub-volcanic plutonic rocks. These rocks are mostly syn- and post-extension, except for the lowest Tertiary sedimentary rocks which have been interpreted as pre-extension (Beard, 1996). This early pre-extensional basin was disrupted by the onset of extension. Syn-extensional basins were mostly fault-controlled and their locations shifted through time, resulting in complex stratigraphic relations. Volcanism and magmatism migrated northward into the Lake Mead area from the south, concomitant with extension (Faulds and others, 1999, 2001a). It was mostly confined to areas south of the Lake Mead fault system and volcanic rocks were intercalated with sedimentary basins only on their southern margins. Peak extension, from about 16 to 12 Ma, was accompanied by calc-alkaline mafic, intermediate and felsic magmas (Smith and others, 1990). In the Lake Mead quadrangle, several stratovolcanoes and sub-volcanic intrusions were emplaced. As extension waned, volcanism shifted to mostly tholeiitic basalts and basaltic andesites.

The differing style of structural disruption of two stratovolcanoes typifies extension in the Lake Mead region. The River Mountain stratovolcano was separated from its subvolcanic intrusion, Wilson Ridge, and transported west-southwest by the low angle Saddle Island detachment fault (Weber and Smith, 1987). In contrast, the Hamblin-Cleopatra stratovolcano was cut by the nearly vertical Hamblin Bay left-lateral fault with the Hamblin portion transported laterally about 20 km southwest (Figure 4a).

During the waning stages of and following extension, large shallow basins formed and filled low areas in the topography. These basins persisted until dissected by the Colorado River system, which cuts through the quadrangle from east to southwest. This dissection provides exceptional geologic exposures in most places in the Lake Mead quadrangle. The courses of the Colorado and Virgin Rivers are now drowned by Lake Mead, but the lake shows the general river courseways because it fills valleys and canyons formed, beginning in early Pliocene, by integration of these river systems. The latest history following integration of the Colorado River system includes development of alluvial fans, extensive pediment surfaces, dissection, and young faulting. These geologically young processes are important in the time scale of human life, and can affect ecosystems, human resources, and basic land-use planning.

Stratigraphic Nomenclature

The Lake Mead quadrangle straddles the transition from cratonal to miogeoclinal Paleozoic deposition. In addition, the Sevier-age Muddy Mountain and Dry Lake thrusts telescope miogeoclinal rocks eastward over autochthonous cratonal rocks (Figure 3a). For these reasons, stratigraphic unit names used in previous studies apply both Grand Canyon (cratonal) and Basin and Range (miogeoclinal) nomenclature. In this report, we use Grand Canyon stratigraphic nomenclature for the autochthonous rocks and restrict the Basin and Range terms to allochthonous rocks above the thrusts. Figure 3b shows the terminology used for Paleozoic and Mesozoic units across the Lake Mead quadrangle.

Tertiary nomenclature in the quadrangle is a mixture of formal and informal designations and is undergoing revision as new detailed studies that include high precision geochronologic data are in progress (e.g., Lamb and others, 2005). The Tertiary nomenclature in this report reflects these revisions as much as possible and new units have been kept at the informal level in anticipation of broader changes from the ongoing studies. Published geochronologic data used in this report that have location coordinates are presented in Table 1. Table 2 includes preliminary unpublished $^{40}Ar/^{39}Ar$ ages by M. Kunk (U.S. Geological Survey, written communication, 2000), and tephra correlation ages by A. Sarna-Wojcicki (U.S. Geological Survey, written communication, 2002). The geochronologic data and facies relations are used to group the Tertiary sedimentary rocks into 'basin-fill' sequences. In this report, basin-fill refers to sedimentary deposits that fill structural basins and that can be grouped by depositional basin facies relations.

Quaternary map units were defined on the basis of degree of soil development, surface characteristics, and tributary relations to the Colorado and Virgin Rivers, and photogeologic interpretation. Some parts of the quadrangle include new surficial mapping but in most areas the surficial geology is interpreted from previously published mapping with limited field checking. Distribution of the surficial deposits portrayed on this map represents a reconnaissance level of accuracy and ages of Quaternary deposits are preliminary. Mainstream fluvial deposits of the Colorado or Virgin Rivers are mapped separately from sidestream alluvial tributaries or alluvial fan deposits; number designations, which increase with age, indicate inferred correlations between mainstream and sidestream deposits as well as regionally extensive calcic soils. Stages of soil-carbonate morphology correspond to those described by Gile and others (1966) and Gile and Grossman (1979).

Description of Map Units

The generalized geology and major faults discussed below are shown in Figure 4. Figure 5 shows place names. Geochronologic ages for which location coordinates are available are included in Tables 1 and 2, sorted by age. Ages that do not have coordinates or are outside the map area are not included in the Tables. Because of the sheer abundance of age information used in the Description of Map Units, the Tables are referred to only when age ranges are given, but not for each individual age mentioned.

Surficial Deposits

af **Artificial fill and other land disturbances (Holocene)**—Areas where major excavation or filling by people has disturbed the land surface to the extent that its pre-existing natural character can not be accurately determined

Qa **Young alluvium (Holocene)—**Active channel alluvium, consisting of silt, sand, and pebble to boulder gravel; unconsolidated and poorly sorted. Deposited in channels, floodplains, low terraces and alluvial fans. No calcic soil horizon or desert pavement development. Bar and swale topography common. Typically inset into topographically higher and older alluvial units, but locally overlies them. Maximum terrace height is 10 m, but typically much lower

Qct **Colluvium and talus (Holocene to Pleistocene)**—Angular, poorly sorted, locally derived blocks of rock and colluvial material, mantling slopes, and at base of cliffs or steep slopes. Widespread in quadrangle but mapped only locally. Thickness 0 to 10 m

Qe **Eolian deposits (Holocene to Pleistocene)**—Non-indurated to slightly indurated, inactive to intermittently active sand sheet and sand dune deposits. Derived from wind erosion of three source areas: (1) Jurassic Aztec Sandstone exposed in the Virgin Mountain area, (2) channel and floodplain deposits (now submerged beneath Lake Mead) of the Colorado and Virgin Rivers, and (3) Dry Lake and other fine-grained playa and wash deposits in Las Vegas area. Thickness 0 to as much as 5 m

Qp **Playa deposits (Holocene to Pleistocene)**—Mud, silt, and clay playa and marginal playa deposits deposited on floors of interior drained valleys, in Dry Lake Valley and along west side of the Arrow Canyon Range. Thickness unknown

Q1a **Intermediate-age sidestream alluvium (upper to middle Pleistocene)—**Alluvium of local derivation, consisting of sand and gravel in dissected alluvial fans and low to intermediate terraces in washes. In upland areas with gentle gradients, surfaces are typically smooth, commonly exhibiting well-developed desert pavement

Q1m **Intermediate-age mainstream alluvium (upper to middle Pleistocene)**—Gravel and sand deposits of the Muddy River. Gravels contain distinctive, very well rounded and polished cobbles of quartzite, other siliceous rocks, carbonate, and volcanic rocks. Forms terraces 15 to 40 m above present river grade. Typically gravel-rich in lower half and sandy in upper half. Sandy part not preserved in some places. Calcic soil horizon development about Stage II. Exposed on west shore of Lake Mead, in Muddy River segment north of Overton Beach (fig. 1)

Q1s **Spring deposits (upper to middle Pleistocene)**—Carbonate tufa and gypsum spring deposits, exposed in two areas: (1) Large expanses down slope from outflow of Rogers and Blue Point Springs, east side of Muddy Mountains where inset below **Q2s** deposits. (2) Outcrops near Saint Thomas Gap in Virgin Mountains, where deposited on Moenkopi Formation (**Ŧm**) and locally overlapping Lime Ridge fault

Qu **Undivided inactive alluvium (Pleistocene)**—Undivided alluvium of local derivation, consisting of sand and gravel in inactive dissected alluvial fans and terraces of differing elevations. Shown where Quaternary alluvial deposits were not differentiated during mapping

QTl **Landslide deposits (Pleistocene to Pliocene?)**—Rubble and massive brecciated blocks of rock that have collapsed down slope from cliffs. Includes (1) large landslide block of Callville Formation and Pakoon Limestone (**PMpc**), derived from Sunrise Mountain; (2) small landslide blocks of Callville Mesa basalts (**Tcm**) that rim Black Mesa in Boulder Basin area; and (3) many large landslides of basalt surrounding mesas capped by basalt flows of Grand Wash (**Tgb**), in far eastern part of quadrangle

QTs **Spring deposits (Pleistocene to Pliocene?)**—Unstudied and poorly exposed carbonate tufa, gypsum beds, and gypsum-cemented beds of fine sediment. Plant and animal fossils locally found. Occurs on east side of Overton Arm; faulted or fault-controlled on east side of exposure. May be as old as Tertiary

Q2k **Calcrete (middle to lower Pleistocene)**—Calcrete soil; mapped separately from **Q2a** where widespread. Maximum calcrete soil development is Stage III. A geochemical correlation obtained on a tuff in an outcrop tentatively mapped as **Q2k** on the east side of Overton Arm suggests either Bishop Tuff or Glass Mountain Tuff, ranging in age from .744 to 1.2 Ma (A. Sarna-Wojcicki, written communication, 2002). **Locally caps:**

Q2a **Older sidestream alluvium (middle to lower Pleistocene)**—Alluvium consisting of sand and poorly-sorted gravel preserved on terraces and dissected alluvial fans

Q2m **Older mainstream alluvium (middle to lower Pleistocene)**—Gravel and sand deposits of the Virgin River consisting of isolated and dissected outcrops of sub-rounded to rounded pebbles, cobbles, and boulders of quartzite, gray to black carbonate rocks, chert, sandstone, granite and metamorphic rocks. Sandstone and siltstone matrix is rarely exposed. Most deposits highly eroded and uncemented, so that coarse rounded material mantles deposit and obscures sedimentary features. Where exposed, locally exhibits pebble imbrication indicating deposition from east and north. Exposed in channel and terrace deposits on east side of Overton Arm where Virgin River joins the Muddy River. Distinguished from younger **Q1m** by higher elevation and greater degree of dissection, and from older **QTm** by lower elevation and inset relationships

Q2s **Spring deposits (middle to lower Pleistocene)**—Older carbonate tufa and gypsum spring deposits from outflow of Rogers and Blue Point Springs, east side of Muddy Mountains. Small isolated outcrops are topographically higher than **Q1s**

QTk **Calcrete (lower Pleistocene to upper Pliocene)**—Thick calcrete soil deposit, mapped separately from **QTa** where widespread. Calcrete soil exhibits laminar carbonate layers at top, breaks across imbedded clasts. Up to 2 m thick, classified as Stage IV or higher carbonate development . Commonly caps:

QTa **Sidestream alluvium (lower Pleistocene to upper Pliocene)**—Poorly-sorted sandy gravel deposited as alluvial fans and sidestream channels. Clasts are typically angular and locally derived. Forms terraces

QTm **Mainstream alluvium (lower Pleistocene to upper Pliocene)**—Sub-rounded to rounded pebbles, cobbles, and boulders of quartzite, gray to black carbonate rocks, chert, sandstone, granite and metamorphic rocks. Matrix of sandstone and siltstone, rarely exposed. Most deposits highly eroded and uncemented, so that coarse rounded material mantles deposit and obscures sedimentary features. Where exposed, locally exhibits pebble imbrication indicating deposition from east and north. Distinguished from **T2m** by lower elevations and inset relationships. Exposed at shoreline of Lake Mead, from Sandy Point in Gregg Basin to Detrital Wash area

T1a **Sidestream alluvium (upper Pliocene)**—Sidestream alluvium graded to level below top of Muddy Creek Formation but higher than **QTa** deposits. Mapped only in isolated outcrops in Grand Wash trough area where deposits inset below **T2a** and topographically above **QTa**

T2k **Calcrete deposits (lower Pliocene)**—Stage V or greater calcrete soil, 5 to 10 m thick. Exposed extensively in the NW part of quadrangle in California Wash and north end of the Gale Hills, and in the Overton Arm area where developed on **T2a** and **T2m** deposits. Also caps about 4 to 5 Ma basalt flows (**Tgb**) on the westernmost edge of the Grand Wash Trough

T2a **Sidestream alluvium (lower Pliocene)**—Sidestream alluvium deposited on pediment surface near depositional top of Muddy Creek Formation prior to deep dissection. Exposed widely throughout quadrangle; locally faulted on east side of Overton Arm. Probably equivalent to the 'regrade gravel', or degradational gravel, as mapped by Schmidt (1994), Schmidt and others (1996), and Swadley and others (1995), and the Overton pediment alluvium in Moapa Valley of Gardner (1972) (see Williams and others, 1997)

T2m **Mainstream alluvium (lower Pliocene)**—Rounded to very well rounded pebble, cobble and boulder gravel, composed of quartzite, chert, limestone, and lesser volcanic and crystalline rocks.

Mostly eroded, forming gravel mantle at surface; internal bedding rarely exposed but typically clast supported with sandy matrix. These are the oldest and typically highest post-Muddy Creek fluvial deposits related to Virgin and Colorado Rivers. Deposits found in three areas of quadrangle, discussed below, and at Sandy Point, where the outcrop is too small to show at map scale. At Sandy Point, gravel exposed at lake level below basalt (**Tgb**) dated at 4.41 ± 0.03 Ma ($^{40}Ar/^{39}Ar$; Wallace and others, 2006). (1) Outcrops in north central part of quadrangle are inset below top of Muddy Creek Formation and form extensive deposits of well-rounded, polished cobbles and boulders at junction of Muddy Creek and Virgin River (now drowned by Lake Mead) and downstream on east side of lake. Gravel deposits also extend up Virgin River to north of quadrangle. (2) Isolated deposits in southern part of quadrangle along reaches of Colorado River (now drowned by Lake Mead) east and west of Temple Bar. Deposits east of Temple Bar probably mark course of abandoned Colorado River channel across topographically high area between Temple Bar and Gregg basin. Gravels in Spring Canyon, south of Virgin Canyon, rest on rubble deposit of Hualapai Limestone blocks (outcrops too small to show at map scale, Howard and others, 2003). Outcrops west of Temple Bar, on east side of Wilson Ridge, are up to 60 m thick. Base of main outcrop cuts downward to east, suggesting remnant of old channel edge. Deposits also slightly tilted to east. (3) Deposits in west central part of quadrangle along north shore of Lake Mead in Boulder Basin area are cross-bedded, well sorted angular sand, underlain by fluvial conglomerate of resistant, well-rounded cobbles. Overlain by **T2a** deposit that is capped by a 2 m thick or greater calcrete soil. Locally folded up to 40 degree dips

Deposits of Jumbo Pass (Pliocene?)—Dominantly conglomerate with subordinate limestone and sandstone. Includes talus blocks or gneiss in reddish brown matrix adjacent to gneiss outcrops. Exposed in scattered outcrops across Jumbo Pass area in southeast part of map, described in detail by Howard and others (2003). Deposits inferred to be related to initial downcutting of Colorado River. Subdivided into two units described below; stratigraphic relationship between two units unknown:

Tje **Eolian sandstone**—Reddish-orange to tan, medium-grained sandstone. Bedding has planar to tangential cross beds up to 30 m wide with dips up to 30 degrees. Mostly eolian deposit but may include fluvial beds. Locally interbedded with angular-clast conglomerate, reddish brown, rounded-cobble conglomerate, and poorly sorted and structureless sandstone. Less than 10 m thick

Tj **Limestone, roundstone conglomerate and sandstone**—Light gray limestone, reddish orange sandstone and roundstone conglomerate. Limestone exhibits travertine flowstone structures, stromatolites and algal-laminated structures, as well as tubular plant casts. Encloses isolated rounded chert and limestone pebbles and cobbles, as well as isolated boulders of porphyritic Gold Butte granite (**Yg**). Rounded clasts interpreted as reworked from eroded deposits of ancestral Colorado River. Conglomerate dominantly angular gneiss and granite-derived pebbles; contains sparse to moderately abundant distinctive rounded pebbles, cobbles and rare small boulders of limestone, chert, and quartzite. Sandstone occurs in small lenticular beds. Laps unconformably around eroded hills of conglomerate facies of 'Rocks of Overton Arm' (**Toac**). Thickness about 10 m

Tg **Gravel (Pliocene to upper Miocene?)**—Highly dissected, locally derived alluvial fan deposits that occur on or near bedrock exposures in the vicinity of California Wash. Geomorphic position suggests fans aggraded above regional top of Muddy Creek Formation, which formed the floors of Dry Lake Valley, California Wash, Overton Arm and Boulder Basin, prior to dissection by the Colorado and Virgin Rivers. Probably equivalent to aggradational gravels as described by Schmidt (1994), Schmidt and others (1996), Swadley and others (1995) and Williams and others (1997)

Basin-fill Deposits

Muddy Creek Formation (upper Miocene)—Mostly sandstone and siltstone but also includes evaporite deposits, limestone, conglomerate, breccia and rarely, tuff. Probably deposited in three separate basins within the quadrangle. Dates from the top of the formation all suggest a minimum age of about 5-6 Ma (see discussion below). Base of section not directly dated, but typically inferred to be younger than the red sandstone unit, about 10 Ma (Bohannon, 1984). Muddy Creek is unconformable on the red sandstone in most exposures, but in unexposed centers of the basins the contact may be gradational.

The largest of the basins occurs in the northern part of Overton Arm and is the southern extension of the Muddy Creek basin originally defined in the Moapa-Mesquite area to the north of the Lake Mead quadrangle (Stock, 1921; Bohannon and others, 1993; Schmidt and others, 1996). A basalt flow interbedded near the top of the section at the southern end of this basin, near Overton Beach (fig. 1), is dated at about 6 Ma.

A second sedimentary basin centered in the Virgin basin area in the southern part of the quadrangle locally includes Hualapai Limestone (**Th**) at the top (about 6 Ma). The Hualapai extends eastward from this basin across a bedrock high at Virgin Canyon and is flexed into a hanging-wall anticline against the Wheeler fault. It is possible that this southern basin was physically connected to the main Muddy Creek basin to the north, but bedrock outcrops and lack of Muddy Creek deposits in the intervening area suggest that deposition occurred in a separate basin.

The third basin is in the western part of the quadrangle east of Frenchman Mountain where gypsum, limestone, and marl deposits interfinger with marginal sandstone and conglomerate. A tuff near the top of the section has a geochemical correlation age of 5.59 Ma (Tuff of Wolverine Creek; Castor and Faulds, 2001; reported as 6 Ma in Castor and others, 2000). This basin extended both south toward Boulder Basin and northward to Nellis basin (Castor and others, 2000).

Large masses of salt (halite) occur in the northern Overton Arm, between Echo Bay and Overton Beach (fig. 1). Salt was originally exposed along the Virgin River, now buried by Lake Mead except for two outcrops south of Overton Beach (Mannion, 1963). The salt body is faulted to the west against the Roger Springs fault; its eastern limit is unknown but probably corresponds to a northeast elongate gravity low in Overton Arm that has been described as a structural pull-apart basin along the Lake Mead fault system. The salt has been inferred to be part of the Muddy Creek Formation, but it is possible that it is part of an older sequence of basin-fill deposits, most likely the Rocks of Overton Arm (Bohannon, 1984). The source of the salt is unknown; Mannion (1963) suggested that the salt was derived from Upper Paleozoic and Mesozoic rocks on the Colorado Plateau, deposited by an ancestral Virgin River to the Lake Mead area and deposited in the Overton Arm area. Consists of the following units:

Tm **Muddy Creek Formation, undivided**—Sandstone, siltstone, and conglomerate exposed in northwestern part of quadrangle fringing Nellis Basin (fig. 5) north of Frenchman Mountain. Pale-reddish-brown sandstone and siltstone are poorly to moderately sorted. Conglomerate clasts generally sub-angular and mostly derived from Paleozoic carbonate rocks exposed in Frenchman and Sunrise Mountains and Dry Lake Range. Maximum thickness unknown, but probably more than 700 m (Bohannon and others, 1993)

Tmm **Mainstream fluvial facies**—Gravel deposits of distinctive, very well rounded and polished cobbles of quartzite and other siliceous rocks. Interbedded with fluvial sandstone deposits near top of Muddy Creek Formation where exposed in northernmost part of quadrangle in Overton Arm. Beds are cut by and folded as much as 20 degrees southward along a northeast-striking fault strand of the left-lateral Lake Mead fault system. Deposits are inferred to represent a fluvial system related to the ancestral Virgin River flowing at or near the top of the Muddy Creek basin, prior to incision of Virgin River to modern levels (e.g., Williams and others, 1997)

Tmf **Fine-grained facies**—Interbedded pink sandstone, siltstone and claystone, as well as lesser amounts of gypsum and gypsiferous sandstone and siltstone. Bedding is generally parallel, even and continuous, ranging in thickness from 1 to 50 cm. Closer to margins of the basins, unit includes pebbly lenses and beds with angular clasts. Although formation is not generally considered tuffaceous, outcrops on the east side of the River Mountains and in the Virgin Basin area mapped as Tmf include thin white tuff deposits. These deposits are included in the Muddy Creek on the basis of preliminary tephracorrelation ages of 6.27 ± 0.04 Ma (Walcott Tuff, Idaho) and 7.00 ± 0.5 Ma (tuff below Roblar Tuff) (A. Sarna-Wojcicki, written communication, 2002; Table 2). In addition, unit as mapped includes salt in the Overton Arm area, exposed only in small domes at Salt Cove but also present in subsurface drill-holes where salt is associated with white tuffs. Bohannon (1984) suggests that the salt could be either within the Muddy Creek Formation or in older buried Tertiary clastic rocks. The salt body is composed of halite crystals stratified with glauberite, clay and tuff and is as much as 500 m thick locally

Tmg **Gypsum facies**—Pale gray to white gypsum and evaporite deposits that occur in two main exposures, one east of Sunrise Mountain in the western part of the quadrangle and the other in the Virgin Basin area. Western outcrops, described in detail in Castor and others (2000), extend from east side of Sunrise Mountain to Government Wash to north flank of the River Mountains. Outcrops expose white to grayish-orange gypsum and variable amounts of silt and clay. Upper part is locally light greenish gray clay and siltstone. Mined for gypsum by Pabco Mining Company. The other main exposure in Virgin Basin area is tan, pale-brown to reddish-brown, well-bedded to massive gypsum and anhydrite. Beds are typically several centimeters to 1 m thick and locally contain 1 to 10-cm thick layers of gray to white, highly reworked volcanic ash

Tmt **Tuff bed**—White to light gray tuff, tuffaceous siltstone and calcareous tuffaceous mudstone. Contains altered glass and feldspars but no dark minerals. Displays laminations <1 mm thick, suggesting pluvial deposition. Interbedded with **Tmg** in Virgin Basin area. Tephra from two tuffs near the top of the section were geochemically correlated to the Walcott Tuff at 6.27 ± 0.04 Ma (Heise volcanic field, Idaho; A. Sarna-Wojcicki, written communication, 2002; Table 2). Thickness 0 to about 35 m at Pabco Mine (Castor and others, 2000). Thickness about 1-2 m

Tml **Limestone facies**—Pale orange limestone, weathering light gray, laminated to thickly bedded. Exposed in western part of quadrangle north of Frenchman Mountain, where interbedded with or overlying gypsum facies (**Tmg**). Described in detail in Castor and others (2000)

Tmml **Marl and limestone facies**—Yellowish gray or white marl and limestone exposed locally beneath limestone facies (**Tml**) north of Frenchman Mountain. Castor and Faulds (2001) reported a geochemical correlation age of 5.59 Ma (Tuff of Wolverine Creek) on tephra from a vitric tuff collected from the marl unit in Nellis basin north of Sunrise Mountain (reported as 6 Ma in Castor and others, 2000). As much as 50 m thick (Castor and others, 2000)

Tmc **Coarse-grained facies**—Locally derived conglomerate and sandstone accumulated as marginal facies to main Muddy Creek basins. Both clast- and matrix-supported, containing angular to sub-rounded clasts reflecting the local geology of nearby ranges. Generally undeformed to slightly tilted. Unit caps or intertongues with other Muddy Creek facies rocks and is unconformable on older Tertiary deposits. May locally include younger or older deposits equivalent in age to **Tg** or **Trsc**, respectively. In northern Overton Arm conglomerate is probably derived from Paleozoic rocks in blocks bounded by northeast-striking left-slip fault scarps. In western part of quadrangle main outcrop areas are: (1) North and east of River Mountains, where deposits are brown to yellowish brown conglomerate that is mostly clast-supported and poorly sorted, with locally-derived clasts of volcanic and plutonic rocks (Scott, 1988). (2) West of Hamblin Mountain, where deposits are mostly conglomerate and sandstone exposed in five small depocenters (Anderson, 2003), composed of angular clasts of mostly volcanic rock. Locally includes angular to sub-rounded clasts of Paleozoic and Tertiary sedimentary rock. (3) East of Frenchman Mountain, where conglomerates are slightly gypsiferous with some pale red sandstone and siltstone layers that may intertongue laterally with **Tmg** deposits (Castor and others, 2000)

Tmv **Lava flows interbedded with Muddy Creek deposits**—Mafic volcanic flows interbedded with fine-grained sediments of the Muddy Creek Formation on west side of Overton Arm near Overton Beach (fig. 1; Bohannon, 1984). Consist of thin olivine flows, sometimes also bearing augite. A flow that extends from Overton Beach south to Black Point was dated by Feuerbach and others (1991) at 6.02 ± .39 Ma (K/Ar) and by M. Kunk (written communication, 2000) at 6.15 and 6.6 Ma (preliminary $^{40}Ar/^{39}Ar$ isochron ages)

Tmb **Breccia and landslide masses**—Brecciated masses of volcanic rocks interbedded with coarse-grained Muddy Creek rocks **(Tmc)** on east side of River Mountains. Originally mapped as fault blocks of River Mountain volcanics by Smith (1984) that were overlapped by Muddy Creek Formation. Reinterpreted by R.E. Anderson (written communication, 1997) as landslide and rock avalanche deposits interbedded with conglomerate. May actually be older, equivalent to red sandstone landslide deposits (**Trsl)**

Th **Hualapai Limestone (upper Miocene)**—Very-light-gray to pink algal-laminated limestone. Interbedded at base and laterally with red sandstone, pink limy sandstone, gypsiferous mudstone and locally derived, poorly sorted coarse sandstone. Our definition of 'Hualapai Limestone' follows Bohannon (1984) in retaining its formational rank.

Occurs in southeastern part of quadrangle where uppermost part of unit extends about 40 km from the east in the Grand Wash trough (Wallace and others, 2006), westward across Gregg Basin to Temple Basin (Howard and others, 2003). Mostly equivalent in age to and laterally intertongues with Muddy Creek Formation (**Tm**) although lower part of section in central parts of both Temple Basin and the Grand Wash trough (to east of quadrangle) apparently intertongues with deposits as old as 12 Ma. Bohannon (1984) reported fission track ages from 10.8 to 11.6 Ma (Table 1) from the sandstone and siltstone facies of the Rocks of the Grand Wash trough (**Tgws**) just below the base of the limestone in Grand Wash trough. Faulds and others (2001b; also Wallace and others, 2006) report an $^{40}Ar/^{39}Ar$ age of 11.08 ± 0.27 Ma and a geochemical correlation age of 10.94 ± 0.05 Ma for a tuff in the lower part of the Hualapai (Tuff of Grapevine Mesa). Tuff in the uppermost part of Hualapai Limestone in its westernmost outcrops just south of the study area yielded an $^{40}Ar/^{39}Ar$ age of 5.97 ± 0.07 Ma (Spencer and others, 2001). In addition, Wallace and others (2006) report an age of 7.43 ± 0.22 Ma on a tuff interbedded with limestone at Grapevine Mesa in the southeast part of quadrangle. A series of tuff samples from the Hualapai in the south central part of the quadrangle west of Temple Bar did not yield precise $^{40}Ar/^{39}Ar$ ages, but one contaminated sample yielded a maximum age of 6.87 Ma. This maximum age is strengthened by tephracorrelation ages of 6.27 and 7.0 Ma for tuffs near the top of the section and of about 9-10 Ma for a tuff near the lower part of the section (A. Sarna-Wojcicki, written communication, 2002; Table 2). Hualapai Lake may have been fed at least in part by groundwater discharge from springs that may be outflows of carbonate aquifer of Colorado Plateau to east (Crossey and others, 2002)

Rocks of Overton Arm (upper and middle Miocene)—Deposits not studied in detail; herein are informally grouped as rocks of Overton Arm. Include sandstone, limestone, gypsum and conglomerate, deposited in basin in vicinity of Overton Arm, Virgin Basin and Temple Basin (fig. 5), southeast of the Lake Mead fault system. Largest and stratigraphically highest exposures of limestone are mapped separately as Hualapai Limestone (**Th**). The eastern margin of basin is defined by highlands of the South Virgin Mountains and Hiller Mountains, where coarse-grained deposits mostly lap onto older rocks. Coarse-grained deposits also lap against southeast side of Cleopatra volcano (**Tvc**). Western margin of basin is uncertain because rocks are tilted and faulted along the east side of the Black Mountains; however, coarse-grained deposits there suggest western margin was nearby. Basalts intercalated near the top of the conglomerate facies (**Toac**) are about 8 to 9 Ma (**Tb**). Locally, in area west of Gold Butte, deposits unconformably overlie Horse Spring-age deposits in Overton Arm. However, elsewhere in basin the basal part of unit is older and is probably laterally equivalent to the Horse Spring rocks (Plate 2). Divided into:

Toac **Conglomerate facies**—Alluvial fan deposits exposed predominantly on east side of Overton Arm except in vicinity of Middle Point (fig. 5) on west side, and isolated outcrops on the east side of Black Mountains to south. Conglomerate composed of tan to gray, angular to sub-angular cobbles to boulders, interbedded with minor amounts of tan conglomeratic sandstone and pale-red to tan coarse, poorly sorted sandstone. Bedding weakly developed or absent. Locally as much as 175 m exposed; total thickness unknown. Clasts are typically locally derived, reflecting composition of nearby source areas. As mapped, upper part of unit is flat-lying to gently tilted and generally onlaps bedrock source areas, burying older faults such as the Gold Butte fault and the Salt Spring Wash fault (fig. 4). In Quail Spring Wash area (fig. 5), the conglomerate facies unconformably overlies conglomeratic Horse Spring age rocks of Overton Arm (**Thoc**). At this location, a tuff just above the unconformity yielded a preliminary isochron age of 8.9 Ma and the Gold Butte basalt, which is interbedded near the top of the conglomerate, yielded a preliminary age of

9.14 ± 0.05 Ma. A tuff in **Thoc** below the unconformity yielded an age of 10.94 ± 0.06 Ma ($^{40}Ar/^{39}Ar$, M. Kunk, written communication, 2000; Table 2).

Extensive outcrops in Temple Basin area overlie older basalt (**Tob**; ~ 13.3 Ma) and unconformably underlie Hualapai Limestone (**Th**); clasts indicate deposit mostly derived from Garrett Butte and Hiller Mountains to east. Deposits are coarser on east side of Temple Basin and fine westward. Large breccia deposits (**Toab**) derived from the east are interbedded within or at base of conglomerate.

The lowest part of conglomeratic facies is locally exposed by faulting in the Temple Bar to Gregg Hideout area. About 1 km south of the Lake Mead quadrangle near Gregg Hideout, Blythe (2005) reported $^{40}Ar/^{39}Ar$ dates of 14.46 ± 0.07 and 13.13 ± 0.53 Ma on tuff near the base of the section, which is tilted as much as 40 degrees and is interlayered with basaltic andesites (**Tafb**). He also reported an $^{40}Ar/^{39}Ar$ age of 10.78 ± .4 Ma on a tuff near the top of the section, which is only tilted about 10 degrees. Unlike the Quail Springs Wash area, there is no mapped unconformity in the section, so the lowest part of **Toac** in the Salt Spring Bay area is equivalent in age to the Horse Spring age rocks to the north and northwest (**Thof, Thoc**). Conglomerate facies with distinctive mappable clast types indicating source areas are subdivided into:

Toacg **Conglomerate facies, bearing Gold Butte Granite clasts**—Alluvial fan conglomerate distinguished by abundant clasts and boulders of Gold Butte Granite (**Yg**) shed to the NW from the Gold Butte area. Outcrop patterns suggest alluvial fan originated in the Cedar Basin area (fig. 5) in Gold Butte. Mostly tan to tan-gray coarse conglomerate with coarse sand matrix of decomposed granite. Locally interbedded with lenticular coarse pebbly sandstone beds. Granite boulders typically sub-rounded and range in size from a few centimeters to as much as 5 m diameter, commonly concentrated as lag on hillsides. Also includes boulders of garnet gneiss. Exposed thickness about 90 m. Interbedded near top with and overlain by Gold Butte basalt flows (**Tbgb**), dated at about 9 Ma. Rests unconformably on coarse-grained **Thoc** deposits that include a tuff dated at 10.94 ± 0.06 Ma just below the unconformity in Quail Spring Wash ($^{40}Ar/^{39}Ar$, M. Kunk, written communication, 2000; Table 2)

Toacl **Conglomerate facies, bearing limestone clasts**—Alluvial fan deposits derived from Paleozoic limestone cliffs exposed in Lime Ridge (fig 5) to the east. Composed of gray angular to sub-angular cobbles to boulders of limestone and some sandstone, in poorly sorted tan to reddish-tan sandy matrix. Exposed thickness about 65 m. Interbedded with **Toacg** in Lime Wash area, indicating coalescing of Gold Butte granite bearing and limestone-clast alluvial fans

Toacv **Conglomerate facies, bearing volcanic clasts**—Consists of volcanic clast debris-flows and conglomerates derived from and both interbedded with and overlying Cleopatra volcano units. Mostly dark-green to black angular to sub-angular andesite and pyroxene andesite clasts in dark-tan, coarse volcaniclastic matrix, poor to moderately sorted. Also includes interbedded tan sandstone, well-sorted and well-bedded. In Middle Point area overlies **Tb** flow; flow in similar stratigraphic position to south dated at 11.44 Ma (preliminary isochron age, Kunk, written communication, 2000). Thickness about 0 to 30 m

Toas **Sandstone, siltstone and mudstone facies**—Fine-grained clastic rocks exposed in Overton Arm, Middle Point and east side of Black Mountains. Pink, pale reddish tan, well-laminated mudstone, siltstone, and minor sandstone. Very thinly bedded, with beds about .5 cm to 5 cm thick. Rare thin (3 to 10 cm thick) white tuff beds and isolated basalt flows a few meters thick. In area between Middle Point and Boulder Wash, sandstones include pale-green volcaniclastic beds that are up to 4 cm thick, interbedded with 20-cm thick lenses of poorly-sorted purple sandstones (Naumann, 1987). Interbedded with gypsiferous facies (**Toag**) in central and western part of basin, and with conglomerate facies (**Toac**) on eastern side, between Quail Springs and Trail Springs Washes. Interbedded basalt (**Tb**) at Middle Point dated at 11.44 Ma (preliminary $^{40}Ar/^{39}Ar$ Ma isochron age; M. Kunk, written communication, 2000). Overlain by 9 Ma Gold Butte basalt (**Tbgb**) south of Quail Springs Wash

Toag **Gypsiferous facies**—Locally very thick, extensive gypsum and gypsiferous sandstones, exposed on west side of Overton Arm at south flank of Cleopatra lobe of Hamblin-Cleopatra volcano and west side of Wilson Ridge. Massive gypsum and anhydrite is white to pale-tan, in beds up to 20 m thick (Naumann, 1987). Gypsiferous sandstones are brown to red-brown, in ripple-laminated beds several cm thick. Unit includes some thin ash beds. Maximum thickness about 500 m. Interbedded with **Tb**; overlies dacite flows (**Tbwd**), tuffs (**Tbwdt**) and breccias (**Tbwdb**) and overlain by rhyolite flows (**Tbwr**) and breccias (**Tbwrb**) of volcanic rocks of Boulder Wash. Thompson (1985) reported a K/Ar age on biotite of 9.4 ± 0.6 Ma on a tuff that plots within the **Toag** unit north of Boathouse Cove

Toam **Manganiferous sandstone facies**—Bedded deposits of manganiferous sandstones at Middle Point that directly overlie Cleopatra volcano rocks (**Tvc**). Manganese beds are greenish gray tuffaceous sandstone and siltstone, about 3-8 m thick, and extend for about 300 to 900 m laterally. Manganese occurs as soft black or dark-brown ‘earthy material’ (McKelvey and others, 1949), ranging from isolated blebs to massive beds (‘wad’); manganese content of the beds ranges from about 3 to 7 percent. Outcrop thickness about 10 to 50 m. High concentrations such as in the deposits shown on the map were discovered and mined in the early part of the century. Other manganiferous deposits not shown on this map are also found about 3 to 4 km to the west where they were mined as the Bauer Dollery deposit, and in the red sandstone unit at the north end of the River Mountains (Three Kids Mine). Similar deposits are also found about 10 km south of the mapped deposits, on the east side of the Black Mountains, and south of the Lake Mead quadrangle on both sides of Black Canyon below Hoover Dam

Toab **Breccia facies**—Scattered outcrops between Greggs Hideout and Lime Wash (fig. 5). Breccia composed of angular clasts from .5 cm to 5-m diameter of biotite gneiss, orthogneiss and biotite schist in a tan, sandy matrix. Monolithologic to heterolithologic; locally exhibits weak horizontal stratification. Thickness typically about 75 m, but locally as much as 100 m. Breccia outcrops are in depositional contact with partly retrograded garnet gneiss (**Xgp**) at Walker Wash, and just south of Lime Wash rest on equigranular granite of Lime Wash (**Xwe**). On west side of Temple Basin, large brecciated blocks overlie basalt (**Tob**) and are overlain by or interbedded with **Toac**. Blocks were probably derived from the Garrett Butte and Jumbo Peak to west. Includes two small outcrops at south edge of quadrangle: (1) A small exposure is interbedded with **Toac** just above the andesite flow and breccia unit (**Tafb**) to west of Gregg Hideout; (2) To the east in the hanging wall of the Salt Spring Wash fault, an outcrop mapped by Howard and others (2003) is described as at least in part fault breccia, and possibly correlative to about 15 Ma landslide breccia mapped by Duebendorfer and Sharp (1998) about 5 km south of the quadrangle in Salt Spring Wash. It is possible that this outcrop and some of the others could be older, equivalent to the Horse Spring (?) rocks (**Thof**, **Thoc**) in Overton Arm. Longwell (1936) described outcrops near Bonelli salt mine, now beneath Lake Mead, of landslide breccia composed of granite and gneiss that he thought were derived from the Gold Butte block. These deposits are probably interbedded with **Toac**

Rocks of the Grand Wash Trough (upper and middle Miocene)—Basin deposits informally named rocks of the Grand Wash Trough by Bohannon (1984) who defined their age as ranging from 11.6 to 10.6 Ma or younger. Deposits originally referred to as Muddy Creek Formation (Longwell, 1936; Lucchitta, 1966) but recognized by Bohannon (1984) as being deposited in separate basin from and being in general older than Muddy Creek. The basin sediments were deposited to the east against the Grand Wash Cliffs, which form the western margin of the Colorado Plateau. The western margin of the basin is defined by Wheeler, Iceburg, Azure and Pakoon Ridges (fig. 5). Hualapai Limestone (**Th**) intertongues with the upper part and overlies the basin-fill deposits. Includes fine-grained clastic rocks (**Tgws**) and gypsum (exposed east of the Lake Mead quadrangle in the Grand Wash trough), which intertongue laterally with coarse conglomeratic facies (**Tgwc**). Conglomeratic alluvial fan facies locally differentiated by dominant clast lithology, reflecting source area (**Tgwcl**, **Tgwcb**, **Tgwcp**, **Tgwcx**). See Wallace and others (2006) for detailed descriptions of deposits in Grapevine Mesa area.

Bohannon (1984) reported fission track ages of 10.8 ± 0.8 Ma, 11.3 ± 0.3 Ma, and 11.6 ± 1.2 Ma from tuffs within the fine-grained clastic rocks (**Tgws**). Tephracorrelation ages reported in Billingsley and others (2004) include matches to tuffs at about 12 Ma. Damon and others (1978) dated an airfall tuff within thin laminated mudstones (**Tgws**) at 12.67 ± 0.3 Ma. Brady and others (2002) report a $^{40}Ar/^{39}Ar$ age of 13.94 ± 0.12 Ma for a tuff intercalated within the sandstone and siltstone unit about 2 km north of Pearce Ferry, just east of the quadrangle boundary (not reported in Table 1 because location coordinates unknown). In addition, older $^{40}Ar/^{39}Ar$ ages of 15.34 ± 0.05 Ma (Blythe, 2005) and 15.29 ± 0.07 Ma (Wallace and others, 2006) were reported for tuffs in isolated outcrops of conglomerate resting on bedrock just west of Wheeler Ridge. These could be remnants of older deposits that either represent the depositional base of the Grand Wash basin or are unconformable below the rocks of the Grand Wash trough and representative of an earlier depositional system (Blythe, 2005) Consists of:

Tgws **Sandstone and siltstone facies**—Pale reddish brown to light-brown interbedded sandstone, siltstone and mudstone with minor lenses of pebbly sandstone. Sand and silt are quartz-rich, but pebbles have variable composition from carbonate, sandstone, and metamorphic rock to granite. Even to lenticular bedding, with thicknesses ranging from a few to tens of centimeters. Commonly weathers to soft slopes except in overhangs and fresh exposures. Thickness unknown; thickest exposures north of Grapevine Mesa are up to 300 m. Exposed both east and west of Wheeler Ridge fault (fig. 4a). Laterally intertongues with and overlies conglomerate facies rock; also interstratified with or underlies Hualapai Limestone (**Th**). Exposures at north end of Grapevine Mesa include tuffs as old as 13.94 ± 0.12 Ma (mentioned above) and as young as 10.94 ± Ma (tephra correlation age; Wallace and others, 2006).

Deposits in the Black Wash area south of Pakoon Ridge (fig. 5) unconformably onlap conglomeratic facies of the Thumb Member of the Horse Spring Formation (**Thtc**). Typically form reddish slopes and very poorly exposed beneath a series of stacked basalt flows (**Tgb**) that flowed down Grand Wash. Basal flow is dated at 4.71 ± 0.03 Ma ($^{40}Ar/^{39}Ar$, M. Kunk, written communication, 2000). Although mapped as **Tgws** here, these deposits may be significantly younger than **Tgws** at Grapevine Mesa, based on preliminary tephra correlation age of "between 4.1 and 3.33 Ma" on two tuffs exposed to east of quadrangle in similar sediments in Cottonwood Wash, upper Grand Wash trough (A. Sarna-Wojcicki, written communication, 2002; reported in Billingsley and others, 2004). Those deposits are also overlain by basalt flows sourced from a volcanic field at Black Rock Mountain (fig. 1), which has a single K/Ar age of 3.7 ± 0.6 Ma (Wenrich and others, 1995). Further study is needed to resolve the age of these deposits

Tgwc **Conglomerate facies**—Gray to tan boulder to cobble conglomerate and conglomeratic sandstone deposits representing alluvial fan facies. Mostly derived from local cliffs such as Grand Wash Cliffs or Wheeler Ridge or from south Virgin Mountains to west. Some outcrops include boulders up to car-size in debris-flow and landslide deposits. Two large paleochannels have been identified that drained eastward off of highlands to the west around Gold Butte and are filled with **Tgwc**. The southern one is marked by the truncation of tilted Paleozoic strata along Wheeler Ridge south of Sandy Point (Wallace and others, 2006). The northern paleochannel is exposed west of Pearce Ferry, infilling low area along tilted Paleozoic strata of Wheeler Ridge. Total thickness unknown; up to 250 m is exposed. Deposits with distinctive clasts reflecting source are locally subdivided into:

Tgwcl **Conglomerate facies, bearing limestone clasts**—Chiefly composed of limestone clasts derived from ridges formed by tilted Paleozoic rocks. Exposed mostly along east side of Azure Ridge and west side of Pakoon Ridge. In southeastern corner of quadrangle, exposures represent alluvial fan deposits shed westward from Grand Wash Cliffs (east of quadrangle). Exposed thickness about 120 m but probably much thicker in subsurface

Tgwcp **Conglomerate facies, bearing granitic and metamorphic clasts**—Exposed on south, east and north sides of Wheeler Ridge and Azure Ridge where rests with angular unconformity on east-tilted ridges of Paleozoic strata. Derived from basement rocks exposed in Gold Butte area. Total thickness unknown; up to 250 m exposed

Tgwcb **Limestone-clast breccia facies**—Brecciated landslide and talus deposits of Paleozoic limestone breccia generally resting on or near Paleozoic bedrock and overlain by or interbedded with limestone-clast conglomerate facies. Occurs in isolated outcrops on east side of Azure Ridge, west of Pearce Ferry, in southern paleochannel, and overlying southern end of Wheeler Ridge. Individual breccia lenses from a few meters to as much as 80 m thick

Tgwcx **Proterozoic-clast breccia facies**—Brecciated landslide and talus deposits of Proterozoic clasts, exposed at southern end of Wheeler Ridge and most likely derived from Gold Butte area. Lenticular outcrops at base of **Tgwc** overlie tilted lower Paleozoic strata just west of Meadview (fig. 1). Also crops out along or near southern margin of southern paleochannel. Swaney (2005) obtained a $^{40}Ar/^{39}Ar$ maximum age of 14.01 ± 0.18 for a tuff within 10 m of the base of the section at southern paleochannel. Thicknesses from about 10 to 80 m

Red sandstone unit (upper and middle Miocene)—The informally named red sandstone unit (Bohannon, 1984) is exposed in a northeast trending belt mostly on the northwest side of the Lake Mead fault system, extending from Frenchman Mountain to Overton Arm. Rocks of similar age and tectonic setting to the southeast of the Lake Mead fault system include the informally named Rocks of Overton Arm (defined herein) and Rocks of the Grand Wash trough (Bohannon, 1984) and are described above. Bohannon (1984), Duebendorfer and Wallin (1991) and Anderson (2003) discuss the synvolcanic and basinal tectonic settings of the red sandstone unit and its regional significance. The red sandstone unit is interbedded with and partly correlative to volcanic rocks of Callville Mesa (Duebendorfer, 2003) and is interstratified with the upper flows of Hamblin Mountain volcanic complex (Anderson, 2003). Bohannon (1984) originally defined the age of the red sandstone unit as from 11.9 to 10.6 Ma based on fission track ages (Table 1). More recent ages obtained on interbedded tuffs and volcanic rocks range from 10.05 ± 0.03 Ma ($^{40}Ar/^{39}Ar$ whole rock age on interbedded basalt flow, Anderson and others, 1994) to at least as old as 11.70 ± 0.08 Ma ($^{40}Ar/^{39}Ar$ on biotite, Harlan and others, 1998) but younger than a 12.93 ± 0.10 Ma age ($^{40}Ar/^{39}Ar$ biotite age, Harlan and others, 1998) obtained on a hornblende biotite dacite clast within a megabreccia block (**Trsl**). Castor and others (2000) obtained a $^{40}Ar/^{39}Ar$ date of 11.47 ± 0.05 Ma from a tuff near the base of the unit east of Lava Butte and 11.59 ± 0.06 Ma from a tuff on the north side of Sunrise Mountain. Williams (2003) reported a $^{40}Ar/^{39}Ar$ age of 11.72 ± 0.06 Ma for a tuff near Hoover Dam 48 m above the base of a conglomeratic section of the Black Canyon Conglomerate which is herein included with the red sandstone unit. Koski and others (1990) used both fission track and K-Ar techniques on two tuffs associated with the Three Kids manganese deposits at the north end of the River Mountains. The reported ages ranged from 12.4 ±1.1 Ma to 14.0 ± 0.3 Ma which are in the range of the Horse Spring Formation. However, unpublished mapping by R.E. Anderson for this report identified these rocks as red sandstone unit, suggesting that the Koski and others (1990) dates are too old. Consists of:

Trs **Red sandstone unit, undivided**—Rhythmically interbedded red, reddish-tan, and tan sandstone, siltstone, and claystone, and tan pebbly sandstone. Gray and white tuff beds abundant, especially in lower part. Locally includes poorly bedded gypsum and gypsiferous sandstone and mudstone. Also includes conglomerate and local megabreccia blocks, locally mapped separately as **Trsc** and **Trsl**, respectively. Most complete section of unit is exposed at White Basin in the Muddy Mountains (see Bohannon, 1984 for detailed descriptions). Can be difficult to distinguish from other basin-fill deposits; Duebendorfer (2003) established criteria for mapping red sandstone as: must (1) be unconformably overlain by Muddy Creek Formation, and (2) either unconformably overlie Horse Spring Formation, contain clasts of youngest Horse Spring Formation or contain clasts of Callville Mesa volcanics. Bohannon (1983, 1984) considered unit to be between 100 and 500 m thick in the White Basin, and Castor and others (2000) report up to 700 m of section east of Frenchman Mountain

Trsc **Coarse-grained facies**—Tan, tan-gray and pinkish-gray conglomerate and sandstone deposits, poorly bedded to thin .5 to 1 m beds. Exposed in two areas within quadrangle: (1) North of Muddy Mountains, deposits are exposed near fault scarps and contain angular clasts of Paleozoic rocks. (2) East of Hoover Dam, deposits overlie the volcanic rocks of Hoover Dam and underlie the Fortification Hill basalt. Conglomerate clasts are mostly derived from Wilson Ridge pluton (**Twr**), as well as locally the Patsy Mine volcanics (**Tpm**), volcanic rocks of Hoover Dam (**Tvhd**), and the Paint Pots pluton (**Tpp**). Previously mapped as Muddy Creek Formation (Longwell, 1963, Bohannon, 1984), and mapped by Mills (1994) as Black Mountains conglomerate. However, herein included with red sandstone unit because (1) deposits underlie both Fortification Hill Basalt and volcanic rocks of Callville Mesa thus indicating older than 8 to 9 Ma, and (2) include an 11.72 ± 0.06 Ma tuff

($^{40}Ar/^{39}Ar$) near the base of the section (Williams, 2003), placing it within the time-stratigraphic red sandstone sequence

Trsl **Landslide masses**—Massive landslide breccia and debris-flow deposits described in detail by Anderson (2003). Composed of Tertiary porphyritic granodiorite probably derived from Wilson Ridge area to east and south

Horse Spring Formation (?) rocks in Overton Arm (middle Miocene)—Unstudied clastic rocks, correlative in age to Horse Spring Formation, exposed in isolated outcrops in southern part of Overton Arm, from south of Lime Wash to Walker Wash. Consists of:

Thof **Fine-grained facies**—Largest exposures north of Walker Wash form low, poorly exposed outcrops of upward coarsening sequence of yellow sandstone with interbedded conglomerate and tuff

Thoc **Conglomerate facies**—Gray to tan coarse conglomerate containing clasts derived from Gold Butte Granite (**Yg**), partially retrograded granite gneiss (**Xgp**), and other metamorphic rocks exposed in Gold Butte block. Conglomerate facies (**Thoc**) mapped between Lime Wash and Quail Springs Wash are inferred to correlate laterally with **Thof** to south based on similar angular unconformity with overlying **Toac** (conglomerate of Overton Arm). Preliminary $^{40}Ar/^{39}Ar$ age of 13.28 ± 0.07 Ma was reported by M. Kunk (written communication, 2000) for a tuff in **Thof** north of Walker Wash

Horse Spring Formation (middle and lower Miocene and upper Oligocene)—The Horse Spring Formation is a pre- to syn-extension basin deposit defined by Longwell (1921, 1922) and divided into four members by Bohannon (1984). The four members are, in descending order, the Lovell Wash, Bitter Ridge Limestone, Thumb, and Rainbow Gardens Members. They range in age from as young as 13 Ma to about 24 Ma or older. Geochronologic data published since Bohannon (1984) originally defined the Horse Spring Formation members indicates that the stratigraphic relations between the members are quite complex, because deposition was mostly syntectonic with basin evolution. Although Bohannon originally defined the Lovell Wash Member as about 13 to 12 Ma and Bitter Ridge Member as 13.5 to 13 Ma, more recent geochronologic data have suggested that the upper part of the Bitter Ridge Member may be time correlative to the Lovell Wash Member, and the lower part of the Bitter Ridge Member may be time correlative to upper parts of the Thumb Member (Castor and others, 2000, Lamb and others, 2005). We consider the revised range of the two upper members to be from 14.3 to 13.0 Ma.

Bohannon (1984) bracketed the Thumb Member to be between 17.2 and 13.5 Ma in age (Table 1; see this reference for a detailed discussion of early dating of the Horse Spring Formation). In the south Virgin Mountain area this unit is more tightly constrained between ~16.2 and 14.2 Ma (Beard, 1996). New $^{40}Ar/^{39}Ar$ dates on sanidine and biotite (Donatelle and others, 2005; Martin, 2005) from the Thumb Member within the Echo Wash area range from 16.4 (biotite) to 14.6 Ma (sanidine). We consider the Thumb Member age to be most likely between about 14.2 to 16.4 Ma. Beard (1996) recognized a disconformity to angular unconformity between the Thumb and underlying Rainbow Gardens Members. Although Bohannon considered the Rainbow Gardens Member to be no older than 20 Ma, Beard (1996) reported $^{40}Ar/^{39}Ar$ ages ranging from ~26.0 to less than 18.8 Ma in the South Virgin Mountains (Table 1). Carpenter and others (1989) also reported a K/Ar age on biotite of 24.3 ± 1.0 Ma from a vitric tuff in the Rainbow Gardens Member in the northern Grand Wash trough. Consists of:

Thu **Horse Spring Formation, undivided (middle and lower Miocene and upper Oligocene)**—Isolated exposures of rocks inferred to be age-correlative to Horse Spring Formation (24 to 13 Ma) but not dated or distinctive enough to assign to particular member. Includes three outcrops: one at Saddle Island on west side of Lake Mead, and the other two in the Grand Wash trough area. The northern of these two is on the east side of Azure Ridge and the other is between Gregg basin and Grapevine Mesa- (fig. 1) (at the north end of the **Ydg** outcrops). Saddle Island exposure is of poorly sorted and poorly bedded conglomerate, siltstone and limestone, and brecciated masses of Precambrian rock, exposed in fault blocks at Saddle Island. Duebendorfer and others (1990) correlated these deposits with the Rainbow Gardens and Thumb Member of the Horse Spring Formation. Brady (1998) mapped isolated outcrops of Tertiary limestone exposed beneath **Tgwcl** at Azure Ridge; it is possible that these outcrops are actually landslide blocks within the **Tgwcl** conglomerate. Rocks exposed at the base of Wheeler Ridge include non-welded tuffs and volcaniclastic sandstone, in a zone about 10 to 20 m thick, that are deposited on an eroded surface cut into Cambrian strata. Wallace and others (2006) reported a $^{40}Ar/^{39}Ar$ age of 15.29 ± .07 Ma on sanidine from a tuff in the sequence. Blythe (2005) reported a similar $^{40}Ar/^{39}Ar$ sanidine age of 15.34 ± 0.05 Ma from a very small isolated outcrop (too small to show at scale of map) of tuff to the west

Thl **Lovell Wash Member, limestone and sandstone facies (middle Miocene)**—Complex sedimentary unit that is dominantly limestone, dolomite, claystone, tuff and tuffaceous sandstone. Rare marginal clastic facies are inferred to have been shed from active basin-margin faults (Bohannon, 1984). Member is characteristically white or, where intercalated basalts are present, has highly variegated colors of white, gray, tan and black. Brown chert is locally common as thin beds to irregularly shaped masses. Tuff and tuffaceous sandstone beds are a meter to tens of meters thick. Castor (1993), in a study of borate deposits in the upper part of the Horse Spring Formation, noted that tuffaceous sandstones at the base of the Lovell Wash Member in White Basin and Lovell Wash represented a time-stratigraphic horizon that marks the initial availability of widespread intermediate volcanic detritus. Up to 500 m thick.

The Lovell Wash Member is interstratified with the base of the Hamblin volcano in eastern exposures and with other volcanic flows (**Thlb**) westward towards Frenchman Mountain. Exposed in sigmoidal band from east side of Frenchman Mountain to Callville

Wash, then northeastward to White Basin. Although considered younger than Bitter Ridge by Bohannon (1984), more recent work suggests that the Lovell Wash may be in part laterally equivalent to Bitter Ridge Limestone Member (Castor, 1993, Castor and Faulds, 2001). Bohannon (1984) considered the Lovell Wash to range in age from 13.0 to 11.9 Ma. However, Harlan and others (1998) reported 13.28 and 13.17 Ma ages (discussed below) from basalts interbedded with the Lovell Wash in Boulder Basin and suggested it could be at least in part time correlative with the Bitter Ridge Limestone. Castor and others (2000) also reported multiple $^{40}Ar/^{39}Ar$ ages for tuffs in the Lovell Wash exposed on the east side of Frenchman Mountain that range from 13.40 ± 0.05 (biotite) to 13.12 ± 0.24 (on both plagioclase and hornblende) Ma and indicated they could find no discernable difference in age between the Bitter Ridge and Lovell Wash in the Frenchman Mountain area

Thlb **Lovell Wash Member, interbedded basalt flows and vents (middle Miocene)**—Medium-gray to dark-greenish-gray olivine- and plagioclase-phenocrystic basalt and andesite flows, flow breccias, and dikes. Interbedded with Lovell Wash strata or separating it from the overlying red sandstone unit (**Trs**) in the Government Wash and Frenchman Mountain 7.5-minute quadrangles (Duebendorfer, 2003, Castor and others, 2000). Ages range from 13.28 to 13.16 Ma. Harlan and others (1998) reported a 13.17 ± 0.10 Ma age ($^{40}Ar/^{39}Ar$) for an olivine phyric flow in the easternmost outcrops. Two basaltic andesite vent areas, with volcanic flows, dikes and cinders, are exposed north of Las Vegas Wash. The western vent area yielded an $^{40}Ar/^{39}Ar$ age of 13.16 ± 0.18 Ma (Castor and others, 2000), and the eastern vent an $^{40}Ar/^{39}Ar$ age of 13.28 ± 0.09 Ma (Harlan and others, 1998). The eastern vent area and some volcanic rock outcrops just to the north were previously mapped as Callville Mesa basalts (**Tcm**) by Duebendorfer (2003), but here are mapped as **Thlb** because of the association with Lovell Wash Member sediments and because of the 13.28 Ma age. Unit also includes diabase sill dated at 13.19 ± 0.12 Ma ($^{40}Ar/^{39}Ar$, Harlan and others, 1998) that is both spatially associated with and within age range of Lovell Wash Member basalts. As mapped by Duebendorfer (2003), the diabase sill intrudes the Thumb Member

Thbl **Bitter Ridge Limestone and Lovell Wash Members, undivided (middle Miocene)**—Light gray limestone interbedded with white to yellow calcareous siltstone and shale. Mapped on north side of River Mountains and west of Frenchman Mountain fault where separating the two members is problematic.

Thblv **Bitter Ridge Limestone and Lovell Wash Members, undivided, with intercalated dacite and basalt flows (middle Miocene)**—Mapped where strata are intercalated with dacite and basalt flows. Dacite flows and breccias are flow banded and contain phenocrysts of plagioclase, biotite and hornblende. Basalt flows are commonly brecciated and are augite-bearing (Bell and Smith, 1980)

Thb **Bitter Ridge Limestone Member (middle Miocene)**—Exposed on the east side of Frenchman Mountain, at the southern end of California Wash, and in the Gale Hills and White Basin. Best exposures are at the type locality in the Bitter Ridge area in White Basin where it forms a prominent, very thick south-facing cliff that extends from Lovell Wash eastward to West Longwell Ridge. The member is almost exclusively a distinctive thick-bedded, algal-laminated limestone with teepee structures, oncolitic textures, and stromatolitic bioherms. At Lava Butte the member includes yellowish sandstone with some pebbly beds that interfingers with limestone beds near the top of the section, as well as a 6 m thick tuff bed and thin ash-flow tuff (Castor and others, 2000). The limestone pinches out northward and the unit is represented by the sandstone and tuff until it also pinches out between the Thumb and Lovell Wash Members. Along Lovell Wash the member includes sandstone and mudstone ‘red beds’ in the upper part above the main limestone cliff, overlain by borate-bearing limestone, both of which grade laterally to a conglomeratic facies that records faulting at the basin margin (Bohannon, 1984, Castor, 1993, Anderson, 2003). A similar clastic sequence is found above the main carbonate cliff at White Basin, which is also overlain by borate-bearing limestone. The borate deposits were mined in both the Lovell Wash and White Basin areas in the 1920's (see Castor, 1993, for greater detail on the borate deposits).

Bohannon (1984) placed the age of the Bitter Ridge Limestone at between about 13.5 and 13.0 Ma, based on fission track ages. Castor and others (2000) reported a $^{40}Ar/^{39}Ar$ age of 13.07 ± 0.08 Ma for an ash-flow tuff in the Bitter Ridge Limestone obtained south of Lava Butte, but this age is younger than ages they obtained for the 'overlying' Lovell Wash Member and they suggested the two members may be at least in part lateral equivalents. Donatelle and others (2005) reported a $^{40}Ar/^{39}Ar$ age of 14.32 ± 0.10 Ma (sanidine) from a thick, vitric tuff in the Bitter Ridge Limestone Member in the Echo Wash area. This is within the upper age range of the Thumb Member and suggests that the lower Bitter Ridge may be the same age as the uppermost Thumb Member in other areas

Thbx **Bitter Ridge Limestone Member, breccia facies (middle Miocene)**—Crops out on east side of Frenchman Mountain east of Lava Butte. As mapped and described in detail by Castor and others (2000), consists of lahars and bedded breccias of andesite lava, cinders, silicified volcanic rocks and limestone, as much as 30 m thick. Breccia occurs just below the tuff described above that was dated at 13.07 ± 0.08 Ma (Castor and others, 2000)

Thumb Member (middle Miocene)—Most widely distributed member of the Horse Spring Formation. Includes fine-grained siliciclastics, sandstones and pebbly conglomerates (**Thtf**), limestone (**Thtl**), gypsum, gypsiferous limestone and mudstone (**Thtg**), cobble to boulder conglomerates with Proterozoic, Cambrian and Paleozoic (undifferentiated) provenance (**Thtc**), and breccia and landslide masses (**Thtb**). Interbedded mafic volcanic rocks (**Thtv**) are rare. Typified by rapid lateral and vertical facies changes and highly variable thickness, from a few hundred meters to 1300 m in the Echo Wash area (Bohannon, 1984). In the

Virgin Mountain area, Beard (1996) demonstrated that the rapid facies changes were the result of deposition during active extensional tectonism: Divided into:

Thtf **Thumb Member, fine-grained facies**—Dominant lithofacies of Thumb exposed from east side of Frenchman Mountain, through the Gale Hills (fig. 5) to Echo Bay (fig. 1), and in northeast part of quadrangle. Mostly brown, fine-grained, well-sorted sandstone or siltstone in thin, parallel continuous beds, which are commonly calcareous, sometimes ripple-laminated, sometimes with thin granule or pebbly layers. Elsewhere, clastic rocks are brown to red, fine- to coarse-grained sandstone and siltstone, commonly cross-stratified, with parallel to lenticular bedding and thin, channel-filling conglomeratic sandstone beds. Locally includes medium to thick beds of crudely-stratified, poorly-sorted sandstone with floating pebbles and granules. Also includes pale-green zeolitized to white or gray, fine-grained, airfall tuff with rare to common phenocrysts of biotite, hornblende, sanidine and plagioclase; tuff is commonly reworked at base and top and sometimes contains lithic fragments. Tuff beds are massive and structureless or channel-filling and cross-bedded; occur as thin to thick beds throughout most of the section. Bohannon (1984) reported a fission track age of 13.2 ± 0.9 Ma from an airfall tuff south of Lava Butte. $^{40}Ar/^{39}Ar$ dates from the **Thtf** facies in the Black Wash area, South Virgin Mountains (fig. 5), is 15.1 ± 0.08 Ma (M. Kunk, written communication, 2000) which matches well with an age of 15.13 ± 0.03 Ma from the lower of two tuffs on the west side of Pakoon Ridge (Beard, 1996). Unit thickness unknown but exceeds 1200 m in thickest part of sections.

Outcrop at north end of Wilson Ridge is tentatively correlated to Thumb Member. Described by Naumann (1987) as dominantly red-brown cross-bedded fine-grained quartz sandstone that is thin bedded, with abundant ripple laminations;

lesser amounts of light-gray shale and yellowish siltstone increase in abundance up section. Intruded by Wilson Ridge pluton

Thtl **Thumb Member, algal limestone facies**—Shown only in northeast part of quadrangle, at East Longwell Ridge and in the Virgin Mountains. These rocks were originally mapped as part of the upper limestone unit of the Rainbow Gardens Member (Bohannon, 1983, 1984; Beard and Campagna, 1991, Beard, 1992), but were determined to be facies of the Thumb Member by Beard (1996) and to overlie an unconformity at the top of the Rainbow Gardens in the Virgin Mountain area. Similar facies rocks are also probably in the Frenchman Mountain area but not shown separately here.

Limestone is dark to medium gray, typically well bedded with algal laminations and locally hemispheroidal algal mounds and oncolites. They grade rapidly laterally or upward to white thin bedded dolomitic limestone with spring mound features or to fine-grained clastic rocks (**Thtf**) and gypsum (**Thtg**). The base of the section is locally marked by granule to small cobble conglomerate containing clasts of underlying Rainbow Gardens upper carbonate unit, or in rare outcrops, landslide breccia masses of Rainbow Gardens carbonate that intertongue laterally with the algal limestone

Thtg **Thumb Member, gypsum facies**—Widespread facies of Thumb deposits, but mapped separately only on east side of Frenchman Mountain (Castor and others, 2000) and in central part of quadrangle at Gale Hills and west side of Bitter Spring Valley (Anderson, 2003). Rocks are typically light gray to pale reddish gray massive gypsum, with beds up to 8 m thick, interbedded with well-bedded gypsiferous mudstone or sandstone. Intertongues laterally with fine-grained clastic facies (**Thtf**) or algal limestone facies (**Thtl**)

Thtc **Thumb Member, conglomeratic rocks**—Tan to reddish-tan to gray coarse clastic conglomerates and conglomeratic sandstones, laterally interfingering with or overlying fine-grained facies (**Thtf**) and gypsum facies (**Thtg**). Clast sizes, degree of angularity and lithology vary widely through the exposures. Mostly composed of debris flow, sheet flow and stream flow deposits formed in an alluvial fan environment, although some local deposits may represent axial fluvial systems (e.g., Beard, 1996, Anderson, 2003). Thickness highly variable, ranging from 0 to at least 400 m. In Frenchman Mountain area the conglomerates occur only in southern part of Thumb exposures, but in central and northeast part of quadrangle they are common, especially along margins of basin. At East Longwell Ridge on the east side of the Muddy Mountains, conglomerate fills paleocanyons cut into the Paleozoic bedrock. A tuff from the base of one paleocanyon yielded an $^{40}Ar/^{39}Ar$ age of 15.12 ± .11 Ma (L.S. Beard and L.W. Snee, unpublished data). In the south Virgin Mountains includes tuffs dated at 13.93 ± 0.08 Ma ($^{40}Ar/^{39}Ar$, sanidine, M. Kunk, written communication, 2000) just north of the Gold Butte fault, 13.92 ± 0.5 Ma in conglomerate just north of the Lime Ridge fault, and 14.4 ± 0.3 Ma at Horse Spring in clastic sediments overlying conglomerate derived from Gold Butte ($^{40}Ar/^{39}Ar$, Beard, 1996).

Outcrop south of Hamblin Mountain and at the north end of Wilson Ridge is incompletely studied. Described by Naumann (1987) as a very poorly-sorted, matrix-supported breccia of angular to rounded clasts of rapakivi granite, quartz monzonite, gneiss, schist, sandstone, and dolomite. He interpreted the deposit to be a contact breccia formed by intrusion of Wilson Ridge pluton. Anderson (written communication, 2000) reinterpreted the deposit as a Thumb-age angular-clast conglomerate intruded by the pluton. Unit is about 400 m thick

Thtv **Thumb Member, interbedded mafic volcanic rocks**—Mapped in two occurrences: (1) Mafic flows and possible intrusive rock interbedded with Thumb clastic deposits on southeast side of Frenchman Mountain, just north of Las Vegas Wash, where Anderson and others (1972) report a K/Ar age of 15.6 ± 0.3 Ma on a flow. (2) Dark green to black, highly vesicular basalt or andesite on southwest side of Pakoon Ridge (fig. 5), in north eastern part of quadrangle; large volcanic bombs suggest rocks are proximal vent deposits. Volcanic cinders and bombs from the vent are incorporated into base of Thumb section, indicating volcanic vent erupted through and was deposited on underlying Rainbow Gardens Member (Beard, 1996)

Thtb **Thumb Member, breccia and landslide masses**—Widely distributed across the quadrangle, from the east side of Frenchman Mountain at Rainbow Gardens (Parolini, 1986, Castor and others, 2000, Fryxell and Duebendorfer, 2005), to the central part of the quadrangle at Boulder Basin (Anderson, 2003), and to the northeast part of the quadrangle in the south Virgin Mountains (Beard and Campagna, 1991, Beard, 1992). Comprised of lenses and beds, meters thick and meters long, of Proterozoic crystalline rocks, Paleozoic rocks, and rarely Rainbow Gardens Member of the Horse Spring Formation. Breccias can be monolithologic or contain a variety of rocks types that are in close proximity to each other in source areas. They range from coarse, matrix supported debris flows to massive crackle breccia of probable landslide or rock avalanche origin. In the Frenchman Mountain area, distinctive breccia deposits of rapakivi granite and other lithologies common to the Gold Butte area have been used to suggest that the Frenchman Mountain structural block has been tectonically transported to the west as much as 60 km (Anderson, 1973, Rowland and others, 1990, Fryxell and Duebendorfer, 2005)

Thr **Rainbow Gardens Member (lower Miocene and upper Oligocene)**—Widely distributed basal member of the Horse Spring Formation, in Rainbow Gardens on the east side of Frenchman Mountain, through Pinto Valley, and in northeast part of quadrangle in the south Virgin Mountains. Where full section is exposed comprises three lithostratigraphic units (not mapped separately): a capping limestone, a middle slope-forming sequence, and a basal conglomerate. Age ranges from younger than 18.8 Ma to older than 26 Ma (Beard, 1996).

Upper limestone unit is white to reddish-white, coarsely crystalline limestone; poorly bedded, locally brecciated, locally vuggy with white, coarsely crystalline laminated infillings. Base of the unit typically contains abundant calcite filled tubes (Bohannon, 1984; Beard, 1996) that are probably root casts. In the Virgin Mountains, contact with overlying Thumb is erosional unconformity. There, upper surface of Rainbow Gardens is manganese coated karstic white sparry limestone breccia. Karst surface is locally infilled by reddish siltstone and karst-clast conglomerate of overlying Thumb. Elsewhere, break is marked by abrupt change from reddish massive limestone to algal laminated limestone of Thumb (**Thtl**) (Beard, 1996).

Middle slope-forming unit, of variable thickness, is complex intertonguing sequence of clastic and carbonate lithofacies with abundant volcaniclastic and pyroclastic material in northern and eastern outcrops (Beard, 1996). Clastic rocks vary from pebbly lithic to volcaniclastic sandstones. Lithic sandstone beds are commonly orange-pink to reddish brown and are structureless, unsorted, and matrix supported. Volcaniclastic sandstones are pale gray or greenish gray, pebbly, and commonly exhibit planar or trough cross-stratification. Carbonate lithofacies rocks are typically thin-bedded calcareous mudstone to micrite that alternate with recessive claystone; thin white airfall tuffs are common.

Basal conglomerate is dark-brown to red-brown, pebble to cobble conglomerate, composed mostly of sub-angular to sub-rounded, poorly- to non-imbricated, Paleozoic carbonate and chert clasts, in calcareous, sandy matrix. Locally includes sandy channels with well-rounded pebbles recycled from underlying Mesozoic rocks. The conglomerate lies on surface that gradually truncates, from north to south, the underlying Cretaceous deposits and Jurassic Navajo Sandstone (Bohannon, 1984)

Pliocene and Miocene Volcanic and Plutonic Rocks

Tgb **Basalt flows and minor gravels of Grand Wash (lower Pliocene)**—Multiple basalt flows interbedded with and underlain by sandy gravel, in far eastern part of quadrangle. Basalt (**Tgb**) is dark gray to black containing olivine and plagioclase phenocrysts in a matrix of plagioclase, olivine, clinopyroxene and Fe-Ti oxide (Cole, 1989). Olivine is typically altered to iddingsite. Lowest basalt on mesa to north of Black Wash (fig. 5) dated at 4.71 ± 0.03 Ma ($^{40}Ar/^{39}Ar$, M. Kunk, written communication, 2000). This basalt rests on paleosol developed on roundstone gravels. Damon and others (1978) reported a 3.24 ± 0.05 Ma age on a flow, at equivalent elevation but northeast about 4 km, from a small outcrop shown on the quadrangle edge on east side of the lake at Grand Wash. These flows, which also include the eastern basalt outcrops north of Iceberg Ridge, may be younger than the main group of **Tgb.** A basalt flow at Sandy Point that also overlies rounded river gravels is dated at 4.41 ± 0.03 Ma (Wallace and others, 2006). Gravel locally mapped separately as:

Tgbg **Interbedded mainstream gravels (lower Pliocene)**—Tan to buff gravel interbedded with red to moderate orange pink sandstone and mudstone. Includes clast-supported, well cemented conglomerate in which beds with pebble imbrication indicate south and west paleocurrent directions. Clasts are mostly well-rounded cobbles and boulders of limestone, quartzite, black and red chert, gneiss, and rare petrified wood. Other conglomerate beds are matrix-rich, poorly-sorted, and unconsolidated, containing locally derived angular clasts of gneiss and limestone as well as the rounded-clast assemblage. Local 15 cm thick clay horizon at top of gravel and beneath basalt flows may be paleosol. Thickness of gravel deposits variable, ranging up to 50 m and thinning to east and west

Tfb **Fortification Hill basalt (upper Miocene)**—dark gray to gray basalt containing olivine, plagioclase and, locally, clinopyroxene phenocrysts as long as 2 mm, in an aphanitic matrix. Vesicular to massive. At Fortification Hill (fig. 5) east of Hoover Dam, consists of as many as 55 flows (Mills, 1994) of olivine basalt that originated from cinder cones and fissure eruptions along a north-south fault beneath the current extent of basalt flows. Originally named Fortification Basalt Member of Muddy Creek Formation by Longwell (1963), but member designation not used here because not demonstrably part of Muddy Creek Formation. As mapped, unit also includes series of basalt flows to the east of Wilson Ridge at Petroglyph Wash, which are comprised of from one to five flows that emanated from separate sources but have a similar age to **Tfb** at Fortification Hill. Displays prominent columnar jointing where exposed in washes. Fortification Hill basalt has yielded K/Ar ages of 5.89 ± 0.18 Ma for the lowest flow, 5.73 ± 0.13 and 5.43 ± 0.16 Ma for flows erupted from cinder cones, and 5.42 ± 0.13 Ma from a plug that intrudes a cinder cone and is the youngest volcanism at Fortification Hill (Feuerbach and others, 1991). A basalt at Petroglyph Wash yielded age of 5.43 ± 0.16 Ma (K/Ar) (Feuerbach and others, 1991)

Tbi **Basaltic dikes (upper Miocene)**—Plagioclase-olivine-phyric basaltic dikes and plugs. Dike in Quail Spring Wash dated at 5.72 ± 0.33 Ma (K/Ar, Cole, 1989), intrudes granite of Lime Wash (**Xwe**). Also includes pyroxene-olivine basalt dikes and plugs intruded into Paleozoic rocks in northeastern Muddy Mountains (Bohannon, 1984) and one small outcrop along unnamed fault just southwest of Bitter Ridge on the east side of Overton Arm

Tdi **Diorite (upper to middle Miocene?)**—Intrusive mass of biotite-hornblende diorite with chilled margin, exposed in the Garrett Butte area (fig. 5) in southeast part of quadrangle. Age unknown, but inferred to be Tertiary because intrusive rock is undeformed and cuts chloritic gneiss (**Xgc**) that was probably retrograded during low-angle faulting event of Tertiary age

Volcanic and sedimentary rocks of Callville Mesa (upper Miocene)

Tcm **Volcanic and sedimentary rocks of Callville Mesa, undivided**—Grayish-black to medium-gray and reddish-gray basaltic andesite and basalt with minor andesite. Divided into four map units (**Tcm1**, **Tcm2**, **Tcm3**, **Tcm4**) and described in detail by Anderson (2003). Mapped as undivided (**Tcm**) in areas west of main volcanic center at Callville Mesa where stratigraphic position is uncertain. Dates on Callville volcanic rocks range from 11.41 ± 0.14 Ma ($^{40}Ar/^{39}Ar$; Harlan and others, 1998) in the westernmost exposure of the field to 8.49 ± 0.20 Ma on the upper flow at Callville Mesa (K/Ar; Feuerbach and others, 1991)

Tcm4 **Volcanic and sedimentary rocks of Callville Mesa, unit 4**—Grayish-black to medium-gray, massive to vesicular basalt and basaltic andesite. Uppermost part of unit, consisting of one to 8 or more flows, caps Callville Mesa. Feuerbach and others (1991) reported K/Ar ages of 8.49 ± 0.20 Ma for an upper flow in this sequence and 8.53 ± 0.22 Ma from a basaltic andesite plug. Anderson and others (1994) and Anderson (2003) obtained an $^{40}Ar/^{39}Ar$ age of 10.05 ± 0.03 Ma on a thin flow within the red sandstone unit (**Trs**) near Callville Bay and correlated it to **Tcm4**. Up to 60 m thick

Tcm3 **Volcanic and sedimentary rocks of Callville Mesa, unit 3**—Medium-gray to brownish-gray, and locally red basalt to basaltic andesite. Massive to brecciated. Mostly unconformable on lower Callville volcanic rocks. Circular outcrop exposed beneath **Tcm4** flows is vent area where thin flows dip outward from center and are interlayered with breccia zones containing volcanic bombs. Feuerbach and others (1991) reported K/Ar ages of 9.11 ± .30 Ma from the vent center and 10.21 ± 0.23 Ma for a flow on the flank of the vent area. Thickness up to 80 m

Tcm2 **Volcanic and sedimentary rocks of Callville Mesa, unit 2**—Gray to brownish-gray, brecciated basaltic andesite flows, interbedded with moderately to steeply dipping volcaniclastic conglomerate. Unconformable relations between these rocks and overlying **Tcm3** and **Tcm4** indicate synvolcanic deformation, erosion, and sedimentation (Anderson, 2003). Up to 220 m thick

Tcm1 **Volcanic and sedimentary rocks of Callville Mesa, unit 1**—Gray, porphyritic andesite flow, overlain by grayish-brown andesite flow breccia. Found in small exposure just west of Hamblin Mountain. Dips steeply north. Contact with older Thumb Member of the Horse Spring Formation (**Thtf**) mapped as reverse fault, but may rest depositionally on Thumb. Feuerbach and others (1991) report a K/Ar age of 10.46 ± 0.23 Ma on an olivine-pyroxene basalt at the base. About 60 m thick

Tb **Basalt (upper Miocene)**—Olivine basalt flows and breccias exposed in Bonelli Bay, Temple Bar, and Overton Arm areas that are mostly interbedded with sedimentary rocks of Overton Arm (**Toac**) except west of Temple Bar where they unconformably overlie older basalts (**Tob**). Ages mostly cluster in two groups described below, the older ranging from around 11.5 to 12 Ma and the younger around 8.5 Ma. The exception is a basalt flow at Middle Point that is dated at 9.5 ± 0.3 Ma (K/Ar, Thompson, 1985), similar in age to the basalt of Gold Butte (**Tbgb**)

Younger group—Between Temple Bar and Greggs Hideout, three flows occur in thick section of conglomerate (**Toac**). Lowest flow, about 5 m thick, lies directly on andesite flows and breccias (**Tob**) and dips northeast about 10 degrees. Middle flow, about 10 m thick, dips north-northeast about 3 degrees. Eroded vent for middle flow yielded a $^{40}Ar/^{39}Ar$ plateau age of 8.56 to 8.57 Ma (no error given; M. Kunk, written communication, 2000). Uppermost flow, about 70 m thick, dips very gently north and thins northward across Lake Mead to about 5 m thick where exposed below base of Hualapai Limestone (**Th**) at Temple Mesa. Samples from Temple Mesa yielded $^{40}Ar/^{39}Ar$ plateau age of 8.39 Ma (no error given; M. Kunk, written communication, 2000).

Older group—Exposed in area west of Temple Bar and in Overton Arm area. Highest flow overlying rhyolitic pyroclastic flows at head of Trail Rapids Bay, just west of Temple Bar, yielded $^{40}Ar/^{39}Ar$ plateau ages of 11.48 and 11.7 Ma (no error given; M. Kunk, written communication, 2000). Similar flow interbedded with conglomerate (**Toac**) a few kilometers to north yielded a $^{40}Ar/^{39}Ar$ isochron age of 11.9 Ma (no error given; M. Kunk, written communication, 2000). At Middle Point, includes basalts overlying gypsum (**Toag**) and volcanic-clast conglomerate (**Toacv**) of Overton Arm. Thompson (1985) reported a K/Ar plagioclase age of 11.1 ± 1.1 Ma on a basalt located just above **Toag** north of Boathouse Cove. A basalt sample from islands south of Middle Point yielded a $^{40}Ar/^{39}Ar$ isochron age of 11.42 Ma (no error given; M. Kunk, written communication, 2000). Also includes olivine basalts exposed at Overton Islands which yielded $^{40}Ar/^{39}Ar$ plateau ages (M. Kunk, written communication, 2000) of 12.04 ± 0.07 Ma and 12.14 ± 0.07 Ma

Tbgb **Basalt of Gold Butte (upper Miocene)**—Dark-gray to black, porphyritic olivine basalt. As many as seven flows at thickest section, each ranging from about 1 to 3 m thick (Cole, 1989). Includes from 2 to 15 percent phenocrysts of olivine (partly altered to iddingsite), 0 to 10 percent of plagioclase, and 0 to 7 percent clinopyroxene. Flows probably fed by feeder dikes intruded along trace of Gold Butte fault; Cole (1989) suggested flows could be cut by Gold Butte fault based on a particularly linear northeast flow margin. However, because field investigations found no evidence of faulting, a more likely explanation is that the basalt banked against a pre-existing fault scarp. Basalt flows overlie conglomerate of Overton Arm (**Toacg**) at eastern end of exposures but to the west are interbedded with uppermost part of conglomerate. Basalt is also downdropped into a graben on north side of Quail Spring Wash where it appears to have flowed downslope westward and filled shallow channels. $^{40}Ar/^{39}Ar$ ages of 9.14 ± 0.05 and 9.24 ± 0.05 Ma were obtained on the uppermost and lowest flows, respectively, of the seven flows at thickest exposures at head of Quail Spring Wash (M. Kunk, written communication, 2000)

Volcanic rocks of Hamblin-Cleopatra volcano (upper and middle Miocene)—The Hamblin-Cleopatra volcano is a 10-12 Ma stratovolcano that was cut by the left-lateral Hamblin Bay fault system, offsetting it by as much as 20 km (Anderson, 1973). Hamblin Mountain (fig. 5) is the eroded western part of the original volcano, on the northwest side of the fault system. Cleopatra volcanic rocks, exposed in two fault blocks, form the eastern part of the volcano on southeast side of the Hamblin Bay fault system. Geochronologic ages derived from the Hamblin lobe range from 10.07 to 11.71 Ma whereas ages from the Cleopatra lobe range from about 11.0 to 13.1 Ma. However, the Hamblin ages are from the younger part of the volcano so the age of the base of that part of the volcano is unknown. The younger part of the Hamblin lobe overlaps in age with the lower part of the Callville volcanics. Because of differing dating techniques and unsystematic sampling, these differences are not considered significant. Consists of the following units:

Tvh **Volcanic and sedimentary rocks of Hamblin Mountain, undivided**—Mostly brownish or greenish gray, altered, massive to flow-banded andesite, with lighter-colored autobrecciated flows up to 300 m thick. Locally includes mud-flow breccias and volcaniclastic and tuffaceous sedimentary rocks. Flows more common in lower part, breccias dominant in upper part. Rocks typically altered. Volcanic rocks at Hamblin Mountain are undivided, whereas rocks on the west flank are divided into upper, middle and lower units (**Tvhu**, **Tvhm**, **Tvhl**) (Anderson, 2003). Upper flows of the western flank of the volcano are interstratified with strata of the red sandstone unit (**Trs**). Basal flows of the Hamblin Mountain part of the volcano are locally interstratified with rocks of Lovell Wash Member of Horse Spring Formation (**Thl**). Anderson and others (1972) reported a K/Ar age of 11.3 ± 0.3 for a flow in the upper unit. More recent work by Anderson (2003; also Anderson and others, 1994) reports two $^{40}Ar/^{39}Ar$ ages for the **Tvh** unit: 10.07 ± 0.07 and 11.71 ± 0.03 Ma; see his report for detailed mapping and descriptions

Tvhu **Volcanic and sedimentary rocks of Hamblin Mountain, upper unit**—Mainly medium-gray to purplish-gray, porphyritic two-pyroxene andesite flows. Also includes porphyritic dacite flows bearing biotite and hornblende and andesite breccia flows with clasts up to 3 m. Breccia layers separated by volcaniclastic debris flow and tuffaceous sandstone interbeds. Locally interbedded with rocks mapped as red sandstone (**Trs**). Thickness from about 100 to over 300 m

Tvhm **Volcanic and sedimentary rocks of Hamblin Mountain, middle unit**—Pale-greenish-gray to brownish-gray andesite and dacite autobreccia and debris-flow breccia, in thick (up to 300 m), massive sheets. Weathers lighter than lava flow dominated units because of porosity of breccias

Tvhl **Volcanic and sedimentary rocks of Hamblin Mountain, lower unit**—Olive-gray weathering andesite, dacite flows, and autoclastic breccia. Upper part dominated by breccia, lower part by massive lava flows. Rocks cut by many siliceous to mafic dikes in radial pattern outward from central vent complex

Tvc **Volcanic and sedimentary rocks of Cleopatra volcano**—Eastern half of Hamblin-Cleopatra volcano, exposed in two fault blocks, as described in detail by Thompson (1985). Composed of andesite lava flows, radial dikes, and volcanic autobreccia and debris-flow breccia. The entire sequence is mostly altered. Unpublished preliminary $^{40}Ar/^{39}Ar$ ages of 11.0 ± 0.06 and 11.11 ± 0.05 Ma from M. Kunk (written communication, 2000) were obtained from exposures of upper flows east of Cleopatra Mountain; these match K/Ar ages reported by Thompson (1985) of 11.5 ± 0.5 and 11.1 ± 1.4 Ma for flows in similar stratigraphic position in the upper part. Thompson (1985) also reported K/Ar ages for rocks lower in the volcanic sequence of 12.5 ± 0.9 and 12.9 ± 0.8 Ma (recalculated from 12.7 Ma reported by Anderson and others, 1972), and a date of 13.1 ± 0.8 Ma from a basaltic andesite at the core of the stratovolcano. Basalt flows (**Tb**) and the volcanics of Boulder Wash (see below) are stratigraphically lateral volcanic equivalents to the Hamblin-Cleopatra stratovolcano; all these volcanic rocks are interstratified with the sedimentary rocks of Overton Arm.

Thompson (1985) describes two sequences of lava and breccia for the Cleopatra volcano, separated by erosional unconformity of unknown duration. Upper sequence was probably erupted from a series of vents parallel to long dimension of stratovolcano core, which strikes NNE (Thompson, 1985), suggesting that volcanic activity of second sequence was related to the faulting that segmented Hamblin-Cleopatra volcano into its three parts. Upper sequence flows are more commonly basaltic andesite bearing clinopyroxene, orthopyroxene, and olivine phenocrysts, and breccias more abundant than lava flows. The lower sequence flows are intermediate in composition. Flows in the upper part of the lower sequence are more hydrous than the base as shown by abundant biotite phenocrysts along with clinopyroxene; rocks tend to be poorly vesicular to massive, and contain larger plagioclase phenocrysts than lower flows. Flows near the base of the lower sequence contain plagioclase and large orthopyroxene and clinopyroxene phenocrysts, typically exhibit distinctive 'turkey-track' trachyitic texture and are highly vesicular. Andesitic to basaltic dikes cut both sequences and are arrayed in distinctive radial pattern, ranging from a few inches to nearly 100 feet thick. Near the core of the stratovolcano dikes make up nearly 80 to 90 percent of rock. All dikes contain pyroxene phenocrysts, most also bear biotite, and fewer dikes contain amphibole or, rarely, olivine

Ti **Intrusive sills and plugs (upper and middle Miocene)**—Medium- to dark-gray intrusive andesite and dacite, weakly porphyritic to equigranular. Includes common phenocrysts of plagioclase and variable portions of biotite, augite and hornblende. Closely associated with

Hamblin-Cleopatra volcano and exposed mostly as intrusive masses against the Hamblin Bay fault in central part of quadrangle. Anderson (2003; also Anderson and others, 1994) reported an $^{40}Ar/^{39}Ar$ Ma age of 11.9 ± 0.04 from an outcrop just north of Hamblin Mountain. Small masses in Callville Bay area are mostly sills in fine-grained Thumb (**Thtf**) or red sandstone unit (**Trs**) deposits

Volcanic rocks of Boulder Wash (middle Miocene)—Unstudied rhyolite and dacite flows, breccia, and tuff exposed between Cleopatra lobe of Hamblin-Cleopatra volcano to the east and Wilson Ridge to the west. Dacite units include flows (**Tbwd**), carapace breccia (**Tbwdb**) and local tuffaceous facies (**Tbwdt**). Thompson (1985) reported a K/Ar age of 14.2 ± 0.05 Ma for a dacite flow; a preliminary $^{40}Ar/^{39}Ar$ age of 12.52 ± 0.04 Ma was also obtained on a dacite flow (M. Kunk, written communication, 2000). Dacitic rocks are grayish-purple to reddish-brown biotite dacite, containing phenocrysts of embayed quartz and rounded plagioclase (Naumann, 1987). Dacite flows and breccias are overlain by distal basaltic andesite flows (**Tvc**) from the Cleopatra lobe, and by massive gypsum (**Toag**) that includes interbedded basalt flows (**Tb**). Rhyolitic flows (**Tbwr**) and flow breccias (**Tbwrb**) mostly overlie the gypsum, except at the eastern limit where they overlie **Tb** or the dacitic rocks (**Tbwd**). Mapped originally by Naumann (1987) as diamictite facies of Muddy Creek Formation but remapped as rhyolitic flows and carapace breccias by M. Kuntz (unpublished mapping for this report, 1998,). Boulder Wash volcanics considered by Naumann (1987) to represent structurally disrupted stratovolcano, probably coeval with Hamblin-Cleopatra volcano. He also noted that geochemical data indicates that the Boulder Wash lavas are volcanic equivalents to the Wilson Ridge pluton, and cogenetic, but not comagmatic, with the River Mountain volcanics. Consists of the following mapped units:

Tbwr **Rhyolitic flows**

Tbwrb **Rhyolitic flow breccias**

Tbwd **Dacite flows**

Tbwdb **Breccia carapace of dacite flows**

Tbwdt **Tuffaceous facies of dacite rocks**

Volcanic Rocks of the River Mountains (middle Miocene)—Complexly faulted volcanic field that includes: (1) an andesite stratovolcano complex, surrounded by (2) dacitic domes and flows; (3) an intrusive core to the stratovolcano exposed in the southern part; and (4) a basalt shield volcano on the northern and eastern side of the mountains. $^{40}Ar/^{39}Ar$ ages reported by Faulds and others (1999) range from 13.45 Ma on dacite flows to 12.17 Ma on the youngest basalt flow. K/Ar ages from 13.2 to 11.8 Ma obtained by Anderson and others (1972; Table 1) generally fit within this range. Koski and others (1990) reported both fission track and K/Ar ages from tuffs within sedimentary rocks that host the Three Kids manganese deposit on the northern side of the River Mountains. These deposits were reported to unconformably overlie volcanics of the River Mountains; however, E. Anderson (written communication, 1998) indicates that these sediments, here mapped as red sandstone unit (**Trs**), are probably interlayered with the upper parts of the River Mountain volcanics. The fission track ages reported by Koski and others, 1990, of 12.4 ± 1.1 and 12.8 ± 1.0 Ma fit this correlation; however, the older K/Ar ages they report of 13.4 ± 1.0, 13.6 ± 0.4, 14.0 ± 0.3 and 16.5 ± 0.4 Ma are most likely too old. Divided into:

Trmd **Dacite flows and breccias**—Upper dacite flows and breccias of the River Mountain stratovolcano. Gray–purple to tan biotite, plagioclase and hornblende-bearing dacite deposited as debris-flow and carapace breccia, pyroclastic flows, base-surge deposits and flow banded domes. Locally spherulitic and zeolitized. Rare exposures indicate unit rests both unconformably and conformably on **Trmb**. Faulds and others (1999) reported a $^{40}Ar/^{39}Ar$ age of 13.0 ± 0.02 Ma on a flow from this unit in the northeast part of the River Mountains

Trmb **Basalt flows**—Basalt flows interbedded with agglomerate and breccia, as well as minor andesitic flows. Basalts of several varieties, including: (1) phenocrysts of augite and plagioclase in a grayish purple matrix; (2) porphyritic olivine up to .5 cm in diameter in an augite and plagioclase-bearing glassy matrix; and (3) aphyric platy basalt. Minor andesite flows contain plagioclase, hornblende, and augite phenocrysts (Bell and Smith, 1980). Faulds and others (1999) report a $^{40}Ar/^{39}Ar$ age of 12.17 ± 0.02 Ma for the uppermost flow in this sequence at the north end of the River Mountains; however the bulk of the unit is probably older than **Trmd**

Trmi **Intrusive stock**—Fine to medium grained composite quartz monzonite pluton bearing plagioclase, orthoclase, and biotite. Dated at 13.23 ± 0.01 Ma by Faulds and others (1999) ($^{40}Ar/^{39}Ar$). Near edge of quartz monzonite pluton fine-grained texture resembles dacite

Trmip **Composite plutons**—Intrusive stock (**Trmi**) is surrounded by composite plutons formed mostly by plugs and dikes of porphyritic dacite, andesite and rhyodacite. Anderson and others (1972) obtained K/Ar ages of 12.5 ± 0.5 Ma, 12.6 ± 0.5 Ma and 13.1 ± 0.5 Ma on this unit, and Faulds and others (1999) report an $^{40}Ar/^{39}Ar$ age of 13.45 ± 0.02 Ma on a 'dacite flow' that plots within the **Trmip** unit. Includes numerous zenoliths of highly altered andesite and Paleozoic limestone (Smith, 1984)

Trmv **Volcanic flows and domes**—Complex unit of dacite, rhyolite and andesite flows and domes and intercalated tuffs and tuffaceous sedimentary rocks. Unit includes 'Volcanic rocks of Powerline Road' and 'Volcanic rocks of Bootleg Wash' of Smith (1984; see this reference for detailed descriptions). Locally includes:

Trmvb **Flows, breccias and volcanogenic sedimentary rocks**—Dark purple basalt flows and breccia and volcanogenic sedimentary rocks

Tvhd **Volcanic rocks of Hoover Dam, undivided (middle Miocene)**—Equivalent to Black Canyon assemblage of Mills (1994), Hoover Dam volcanic rocks of Metcalf and others (1993), and dacite, basalt, and andesite unit of Hoover Dam area of Smith (1984). See Mills (1994) for detailed descriptions. Composed of two basalt to basaltic andesite flows, two interbedded or overlapping dacite flows, and volcaniclastic conglomerate and tuffaceous sandstone. Basalt to basaltic andesite flows are dark-grayish-red to black, include flow breccias, and bear plagioclase, clinopyroxene and altered olivine phenocrysts. Pink to gray, biotite- and hornblende-bearing dacite occurs as flows, plugs and dikes; flows exhibit dark, perlitic bases and light-colored rubbly flow-top. Conglomerate interbeds are well-stratified and have reddish to orange, coarse-grained sandy matrix. Clasts are mostly derived from underlying Patsy Mine Volcanics (**Tpm**), but also locally include those derived from the Boulder City (**Tbci**) and Wilson Ridge (**Twr**, **Twd**) plutons. Tuffaceous sandstone is greenish-yellow to green, and is locally conglomeratic with clasts derived from underlying volcanic rocks. Younger than 13.88 ± 0.1 Ma Tuff of Hoover Dam (**Tthd**) (Faulds and others, 1999). Lower dacite flow dated at 13.11± 0.02 Ma and upper basaltic andesite flow dated at 12.57± 0.03 Ma ($^{40}Ar/^{39}Ar$) (Faulds and others, 1999; reported as 12.66 ± 0.1 Ma by Mills, 1994)

Wilson Ridge pluton (middle Miocene)—Texturally diverse, fine- to coarse-grained quartz diorite intrusion. Cut by abundant dikes, locally in dike-on-dike array, of granite, granite to granitic porphyry, aplite, basalt, and biotite lamprophyre. Pervasively fractured and faulted, with many fractures coated with riebeckite and less commonly actinolite (Mills, 1994). Larsen and Smith (1990) define two plutonic suites, the older Horsethief Canyon diorite (**Twd**), and the more voluminous Teakettle Pass suite (**Twr**). Interpreted as a sub-volcanic intrusion by Anderson (1973) and later geochemically correlated by Feuerbach and Smith (1986) to volcanic rocks of the River Mountains. They proposed that the volcanic rocks were originally adjacent to or above Wilson Ridge pluton but tectonically transported westward to their present location in the River Mountains (Weber and Smith, 1987) along detachment fault system. Dated at 15.1 ± 0.6 and 13.6 ± 0.6 Ma by Anderson and others (1972, K/Ar). Subsequent K/Ar ages by Larsen and Smith (1990) reported as 13.34 ± 0.4 Ma for dioritic Horsethief Canyon suite and 13.5 ± 0.4 Ma on Teakettle Pass rocks, but intrusive relationships clearly show that the diorite is the older phase.

In general, the accepted age is about 13.5 Ma. Northern end of pluton, exposed in Boulder Canyon reach of Lake Mead, yielded younger $^{40}Ar/^{39}Ar$ ages of 12.57± 0.05, 12.62 ± 0.03, and 12.65± 0.04 Ma (Anderson and others, 1994). These younger ages were interpreted to reflect cooling of the north end through about 300°C, whereas older ages were presumed to reflect emplacement age. Divided into:

Twr **Wilson Ridge pluton, Teakettle Pass suite**

Twd **Wilson Ridge pluton, Horsethief Canyon diorite**

Tril **Rhyolite intrusive of Lava Butte (middle Miocene)**—Light gray to brownish-gray, locally yellowish-gray, porphyritic rhyolite. Phenocrysts of white plagioclase up to 5 mm long are common, but rhyolite also contains smaller hornblende and biotite phenocrysts. Castor and others (2000) provide rock chemistry data indicating that unit is low-silica rhyolite although previously called dacite because of phenocryst mineralogy. Lenticular (in map view) laccolithic intrusion into Thumb Member of Horse Spring Formation on east side of Frenchman Mountain; thickest and best exposed at Lava Butte. Castor and others (2000) report $^{40}Ar/^{39}Ar$ ages of 13.16 ± 0.05 Ma on biotite, and 13.50 ± 0.16 Ma on hornblende

Tpp **Paint Pots pluton of Mills, 1994 (middle Miocene)**—White with bright red and yellow hues, medium-grained to hypabyssal monzonite with highly altered plagioclase phenocrysts. Hematitically altered, fractured and sheared. Some fractures cutting hematitically altered rocks are filled with gypsum. Exposed west of Fortification Hill and informally called the Paint Pots because of brightly colored appearance due to the hematitic alteration. Age unknown, but locally intrudes tuff of Hoover Dam, dated at 13.88 ± 0.1 Ma (Faulds and others, 1999; reported as 13.9 by Mills, 1994). Contains roof pendants of Cambrian limestone and shale just west of Fortification Hill (too small to be shown on map; see Mills, 1994, for detail). Metcalf and others (1993) suggest that Paint Pots may be subjacent plutonic source for tuff of Hoover Dam that intruded its own volcanic cover

Tthd **Tuff of Hoover Dam (middle Miocene)**—Described in detail by Mills (1994). Grayish-brown to white, poor to moderately welded, lithic-bearing, dacitic ash flow tuff (Smith, 1984). Contains phenocrysts of plagioclase, biotite, and hornblende. Exhibits moderately to poorly welded eutaxitic texture as defined by flattened pumice. As mapped includes underlying well-stratified conglomerate and sandstone derived from underlying Boulder City pluton, Patsy Mine volcanics, and Proterozoic basement. Exposed in southwest part of quadrangle. Both tuff and conglomerate are local to Hoover Dam area, thickening from feather edge at southern edge of quadrangle to abrupt termination about 3 km north of Hoover Dam. Interpreted by Smith and others (1990) as erupted from sag-graben or trap-door style caldera. Not exposed north of Fortification Hill. $^{40}Ar/^{39}Ar$ age of 13.88± 0.1 Ma obtained from base of tuff (Mills, 1994, Faulds and others, 1999)

Tax **Andesite breccia of Wilson Ridge (middle Miocene)**—Reddish-brown, massive-bedded and well-indurated volcaniclastic breccia exposed in Wilson Ridge just south of Boulder Canyon (Eschner, 1989). Composed exclusively of angular to sub-rounded brown, gray, and purple andesite porphyry clasts with plagioclase phenocrysts up 3 mm in length. As much as 100 m thick, but thins to about 10 m to south. In fault contact with and overlies Patsy Mine volcanics. Volcanic clasts are unaltered, unlike underlying altered and propylitized Patsy Mine volcanics (**Tpm**). Source is enigmatic

Tbci **Boulder City pluton (middle Miocene)**—Gray, equigranular to porphyritic monzonite and granite; nonfoliated. Contains feldspar, hornblende and minor biotite phenocrysts that are commonly flow aligned at margins (Mills, 1994). Exposed in southwest part of quadrangle west of Hoover Dam. Within quadrangle unit is in fault contact with Patsy Mine volcanic rocks (**Tpm**) but to south of quadrangle intrudes Patsy Mine and is overlain by Mount Davis-age volcanic rocks which are deposited on an erosion surface developed on the pluton (Anderson, 1969). Considered by Weber and Smith (1987) as the most likely source for volcanic units in the Eldorado and McCullough Mountains (west and south of the quadrangle). Includes horizontal red-brown hematitic, cliff-forming zone at about 720 m elevation that was interpreted by Anderson (1969) as formed by a stable paleo-water table horizon. Dated at 14.17 ± 0.6 Ma (revised by NAVDAT (http://navdat.kgs.ku.edu/) from original 13.8 Ma K/Ar age reported by Anderson and others, 1972)

Volcanic rocks near Temple Bar (middle Miocene)

Tob **Olivine basalt and basaltic andesite flows, breccias and mudflows (middle Miocene)**—Dark-gray to black olivine- and plagioclase-bearing basalt and basaltic andesite flows, breccias, mudflows and volcanic necks. Coarse rocks contain phenocrysts of plagioclase, olivine, clinopyroxene and magnetite as long as 4 mm in a dense matrix of the same minerals. Occur mostly as flows and breccias. Typically faulted and variably tilted. Overlies rhyolite (**Tri**) near Temple Bar and locally mixed volcanic unit (**Tvsb**) and is locally overlain by conglomerates of Overton Arm (**Toac**). Crops out in White Hills and Temple Bar area, south-central part of quadrangle. Overlies 13.38 Ma **Tvsb** unit and is older than or interstratified with **Thof** containing 13.28 Ma tuff

Tvsb **Volcanic sediments, breccias, mudflows and minor, thin ignimbrites (middle Miocene)**—Light-gray to olive-tan matrix, comprised of pumice, feldspar, quartz and glass fragments, containing mixed volcanic clasts. Clasts are dark gray and reddish-brown dense dacite, basalt and andesite, as well as basaltic cinders. Crops out discontinuously as thin unstratified breccia and colluvial deposits. Pumice from this unit yielded a preliminary $^{40}Ar/^{39}Ar$ age of 13.38 ± 0.05 Ma (M. Kunk, written communication, 2000)

Trbi **Rhyolite breccia and ignimbrite (middle Miocene)**—Rhyolite ignimbrite and breccias exposed northwest of Temple Bar, forming steep cliffs and extensive exposures in northern part of the peninsula between Temple Bar and Bonelli Bay. Rhyolite ignimbrite is light-gray, tan and white, representing pyroclastic flows and related deposits. Pyroclastic flows are weakly to moderately welded and contain phenocrysts of quartz, sanidine, plagioclase and biotite. As many as three cooling units present, separated by basal, crystal-rich air-fall tuff, but most exposures display only one or two cooling units. Each cooling unit is typically reversely graded and contains conspicuous maroon fragments of dense dacite and scattered dense brown, gray and light purple dacitic lithic clasts. Basalt, granite and biotite schist lithic fragments are rare. Flows range from 50 to 120 m thick and are locally mapped separately as **Tri**. Rhyolite breccias, locally mapped separately as **Trb**, are tan, reddish-tan and tan-gray rhyolitic breccias that cap pyroclastic flows in western part of peninsula. Blocks in breccia from 0.1 to 3 m in longest dimension, weathers into flaggy layers 0.1 to 0.5 m thick. Possibly reworked upper surface of pyroclastic flow. Total thickness about 10 m. Cascadden (1991) reported a K/Ar age of 16.4 ± 0.5 Ma from the ignimbrite unit and correlated it with the Tuff of Bridge Spring. Three $^{40}Ar/^{39}Ar$ ages from this unit yielded preliminary ages of 13.90, 13.81 and 13.70 Ma within the quadrangle and an ignimbrite exposed just south of the quadrangle yielded an age of 14.88 ± .06 Ma (M. Kunk, written communication, 2000). Locally includes:

Tri **Rhyolite ignimbrite**

Trb **Rhyolite breccia**

Tafb **Pyroxene andesite flows and breccias (middle Miocene)**—Dark-gray to black, pyroxene andesite and minor basaltic andesite plugs, flows, breccias and lahars. Phenocrysts of plagioclase, olivine, and clinopyroxene, each typically less than 2 mm in diameter, are set in a dense matrix of same minerals plus magnetite. Flows, flow breccias and lahars locally mapped separately as **Taf** (andesite flows) and **Tab** (andesite breccias and lahars). Pyroxene andesite and basaltic andesite inferred by Cascadden (1991) to be related to a large andesitic volcanic complex south of Lake Mead. Preliminary $^{40}Ar/^{39}Ar$ ages of 14.40, 14.70 and 14.77 Ma reported by M. Kunk (written communication, 2000). Base of unit not exposed but exposed thickness exceeds 600 m. Locally includes:

Taf **Andesite flows**

Tab **Andesite breccias and lahars**

Tpm **Patsy Mine Volcanics (middle Miocene)**—Dark-greenish-brown to dark-gray basalt and basaltic andesite flows and flow breccias. Contain phenocrysts of plagioclase, hornblende, pyroxene and olivine, typically altered. Includes interbedded gray to red volcaniclastic sandstone, conglomerate and breccia deposited by both stream and debris flow. Highly faulted, tilted and intruded by younger plutonic rocks. Correlated to Patsy Mine Volcanics widely exposed south of quadrangle (Longwell, 1963), which range in age from 15.2 to 18.5 Ma (Anderson and others, 1972, Faulds and others, 2001a). In McCullough Range, southwestern corner of map, previously mapped as volcanic rocks of Bootleg Wash by Smith (1984) and Patsy Mine Volcanics by Page and others (2005). Also exposed in isolated outcrops from Hoover Dam area eastward across Wilson Ridge to south of Boulder Canyon. Mills (1994) reports a $^{40}Ar/^{39}Ar$ age of 14.19 ± 0.03 Ma from the uppermost flow about .5 km south of Hoover Dam (data location in Faulds and others, 1999). In the Wilson Ridge area, rocks are highly altered basalts that have been intruded by the Wilson Ridge pluton. As mapped, also includes dark-red and dark-gray andesite and dacite flows, containing biotite and some hornblende, that are also highly altered and locally intruded by Wilson Ridge pluton (Feuerbach, 1986). Thickness not measured

Mesozoic and Paleozoic Rocks

Kmg **Muscovite granite at Walker Wash (Upper Cretaceous)**—White, fine- to medium-grained, equigranular to pegmatitic muscovite-biotite granite with relatively abundant apatite and monazite as accessory minerals (Brady and others, 2000). Exposed just west of Garrett Butte, at western end of Gold Butte crystalline block. Brady (1998) obtained a U/Pb monazite age of 65.2 ± 0.6 Ma. Equivalent to the two-mica granite of Fryxell and others (1992) and gray muscovite granite of Volborth (1962)

Foreland basin deposits

Baseline Sandstone (Upper? to Lower Cretaceous)—White to red, fine- to medium-grained sandstone with minor lenses of conglomerate. Along with underlying Willow Tank Formation (**Kw**), comprises foreland basin deposits of the Sevier thrust belt in southeast Nevada. For more complete discussions, see Bohannon (1984) and Fillmore (1993). Discontinuously exposed in central part of quadrangle and in Wechech Basin beneath Tertiary deposits. Bohannon (1983) divided formation into the following members, all of which are exposed in the Lake Mead 30' x 60' quadrangle: (1) upper red sandstone member (**Kbr**) which intertongues northward with (2) Overton ConglomerateMember (**Kbo**) in Valley of Fire, both of which are underlain by (3) white sandstone member (**Kbw**), and (4) conglomerate (**Kbc**) at base of section in Gale Hills that underlies **Kbw**. K-Ar ages obtained by Carpenter and Carpenter (1987) on tuff include 96.9 ± 3.6 Ma and 95.8 ± 3.5 Ma from the white member and 93.1 ± 3.4 Ma from the red member, indicating a Cenomanian age. Baseline Sandstone is equivalent in age to Iron Springs Formation in southern Utah (Fillmore, 1993), and possibly the conglomerate of Brownstone Basin in the Muddy Mountains (Axen, 1985, Page and others, 2005). Consists of:

Kbo **Overton Conglomerate Member (Upper? to Lower Cretaceous)**—Grayish-brown pebble, cobble and boulder conglomerate, poorly to moderately sorted, clast-supported with sandy matrix. Boulders mostly up to 1 m diameter, although to north of map area includes blocks of Muddy Peak Limestone as large as 50 m diameter (Bohannon, 1983, 1992). Intertongues laterally with, and dies out southward in red sandstone member of Baseline Sandstone (**Kbr**). Mostly coarse angular, locally derived alluvial fan facies in quadrangle; clasts are derived mostly from Paleozoic and Mesozoic sandstone and carbonate rock exposed in Weiser syncline (north of quadrangle; Bohannon, 1992) and from the upper plate of Muddy Mountain thrust. To north, deposit overlapped the Summit-Willow Tank thrust and was subsequently overridden by latest movement on the Muddy Mountain thrust. Thickness 0 to over 400 m (Bohannon, 1992)

Kbr **Red sandstone member (Upper? to Lower Cretaceous)**—Red, purple-red, and yellow-tan quartz sandstone, fine to medium grained, well-sorted. Bedding 20 to 50 cm thick, commonly cross-bedded. Fluvial deposits are lithologically similar to and probably derived from Jurassic Aztec Sandstone (**Ja**). Overlies white sandstone member (**Kbw**) and intertongues laterally with Overton Conglomerate Member (**Kbo**). Crops out in northern part of quadrangle, in Valley of Fire (fig. 5) and east of Overton Arm between Bitter Ridge and Wechech Basin. Thickness from 60 to about 600 m

Kbw **White sandstone member (Lower Cretaceous)**—White to light tan, fine to medium grained fluvial sandstone, well sorted, composed mostly of rounded quartz grains. Includes thin discontinuous lenses of pebbly chert and limestone-clast conglomerate. Exposed in Valley of Fire and Gale Hills areas. In Valley of Fire, includes white to light pink, poorly sorted, nearly structureless conglomerate, composed of quartz arenite clasts derived from Jurassic Aztec Sandstone (Bohannon, 1983). Paleocurrent data from Fillmore (1993) obtained in Valley of Fire area indicate northeast paleoflow. Thickness up to 500 m

Kbc **Conglomerate (Lower Cretaceous)**—Fluvial conglomerate, sandstone, and siltstone. Yellow-gray and brown, well-indurated boulder to cobble conglomerate, clasts typically well-rounded. Gray calcareous sandstone and light tan siltstone occur in thin lenticular interbeds. Exposed only in east end of Gale Hills, above Willow Tank (**Kw**) and below white member of Baseline Sandstone (**Kbw**). Thickness about 250 m

Kw **Willow Tank Formation (Lower Cretaceous)**—Claystone and siltstone, carbonaceous shale, sandstone and sandy conglomerate. Upper part is variegated gray to green bentonitic claystone, interbedded with white to tan siltstone and dark gray to black carbonaceous shale. Locally includes thin bentonitic tuff horizons. Lenticular brown and yellow-brown sandstone beds, locally pebbly, with 2-4 cm diameter clasts of black and gray chert, reddish-brown quartzite and orange-brown pebbly lithic sandstone occur throughout section. White to tan to gray basal conglomerate is variable in thickness (5 - 35 m), averaging about 4 to 5 m (Reese, 1989). Conglomerate clast types laterally variable, but include quartzite, chert, silicified rocks reworked from Shinarump Conglomerate Member of Chinle Formation (₮c), carbonate, and friable white and red sandstone. Unit rests on erosional surface cut into the Jurassic Aztec Sandstone (Ja). Exposed in Gale Hills and Valley of Fire State Park. Fleck (1970) reported K-Ar ages of 98.4 and 96.4 Ma on tuff. Troyer and others (2006) report SHRIMP-RG U-Pb zircon ages of 101.6 ± 1 to 99.9 ± 2 Ma from three tuff beds in the Willow Tank Formation. Deposit is at base of foreland basin of Sevier thrust belt in southeast Nevada, and is laterally equivalent to Dakota Sandstone exposed to the east on the Colorado Plateau (Fillmore, 1993). Conglomerate compositions indicate source was the highlands of older Wheeler-Gass Peak thrust plate to the west. Interpreted by Reese (1989) and Schmitt and Aschoff (2003) as braided fluvial systems on an alluvial plain at the front of the thrust belt. Subsequently overridden by Muddy Mountain thrust fault. Mostly conformably overlain by Baseline Sandstone except north of the trace of the Summit-Willow Tank thrust, where the Overton Conglomerate Member is unconformable on the Willow Tank Formation. Thickness about 150 m

Formations exposed in upper plate of Dry Lake thrust

PMb **Bird Spring Formation (Lower Permian to Upper Mississippian)**—Medium- to light-gray, yellowish- to brownish-gray weathering, thin to thick bedded limestone to dolomite. Includes reddish-brown weathering calcareous sandstone and siltstone, and layers and nodules of reddish-brown chert. Abundant fossils, including fusulinids, ostracodes, brachiopods, bryozoans, corals, gastropods, pelecypods, and sponges. Stair step ledge-cliff-slope, yielding striped appearance, characteristic of formation. Equivalent to both Bird Spring Formation and Pakoon Formation as mapped to east in upper plate of Muddy Mountain thrust and in autochthon. Base of formation as mapped includes about 40 to 60 m of the Late Mississippian Indian Springs Formation (Webster, 1969), which consists of thin-bedded reddish sandstone and siltstone, gray to grayish-tan limestone, and intraclastic gray limestone conglomerate. Disconformable on Monte Cristo Group (**Mm**). Total thickness as much as 2,500 m in the Las Vegas 30' x 60' quadrangle to west (Page and others, 2005)

Mm **Monte Cristo Group (Upper and Lower Mississippian)**—Composed of Yellowpine Limestone, Bullion Limestone, Anchor Limestone, and Dawn Limestone (Page and others, 2005). Generally is gray to black, fine to coarse crystalline limestone with interbedded chert; fetid, locally crinoidal. Yellowpine Limestone is thick-bedded black limestone, weathering dark gray, that contains abundant large rugose corals and colonial corals. Bullion Limestone is medium- to light-gray crinoidal limestone with yellowish-brown weathering chert. Also includes pelmatozoan ossicles, brachiopods and solitary rugose corals. Contact with overlying Yellowpine is gradational and placed at base of darker, thinner bedded limestone with higher content of rugose corals (Page and others, 2005). Anchor Limestone is distinctive, alternating thin-bedded limestone and chert. Limestone is medium gray and finely crystalline, locally burrowed, brachiopod and coral-bearing. Chert is dark gray, weathering dark orange to brown. Forms distinctive striped cliff. Dawn Limestone is dark-gray to brownish-gray oolitic limestone. Commonly contains stringers and nodules of brown chert; thin to thick bedded. Fossiliferous, containing brachiopods, gastropods, bryozoans, solitary rugose corals, and colonial corals. Thickness unknown, but measured at about 400 to 480 m in Las Vegas Range to west of quadrangle (Lundstrom and others, 1998)

MDcp **Crystal Pass Limestone (Lower Mississippian and Upper Devonian)**—Light-gray, yellowish-gray to white weathering, thin- to thick-bedded, micrite to limy mudstone. Locally cross-bedded, burrow-mottled, sparsely fossiliferous. Forms prominent white cliff below the dark Monte Cristo

(**Mm**) rocks and above the underlying Guilmette Limestone(**Dg**). Exposed on west side of Interstate 15 near Apex (fig. 1). About 60 to 70 m thick

Dg **Guilmette Limestone (Upper and Middle Devonian)**—Medium- to dark-gray fossiliferous dolomite and limestone and minor dolomitic quartzite. Dolomite and limestone typically burrow-mottled and laminated. Fossils include brachiopods, corals, gastropods and stromatoporoids. Upper half of formation contains several yellowish-brown weathering dolomitic quartzite beds. Middle part is massive stromatoporoid-bearing dolomite; forms cliffs. Lower slope-forming part of Guilmette is thin to medium-bedded dolomite and limestone containing abundant thin interbeds of yellowish-gray micritic dolomite. Formation only exposed near quarry at Arrolime both east and west of Interstate 15. Although not exposed in quadrangle, there most likely are about 200 m of Lower Devonian Simonson Dolomite and Silurian Laketown Dolomite in the subsurface (Page and others, 2006). Thickness in quadrangle unknown; about 420 m thick to north in Arrow Canyon Range (Page, 1998)

Oes **Ely Springs Dolomite (Upper Ordovician)**—Medium-dark-gray, light-gray weathering, thin- to thick-bedded, fossiliferous dolomite. Burrow mottled, common planar laminations along bedding. Lower contact with Eureka Quartzite (**Oe**) is major disconformity. Thickness about 100 m

Oe **Eureka Quartzite (Middle Ordovician)**—White to tan, light-brown to yellowish-brown-weathering, thin- to thick-bedded quartzite and sandstone. Fine- to medium-grained, moderately well sorted. Thin- to thick-bedded, commonly cross-bedded, abundant *Skolithus* burrows. Found only in small outcrop in Dry Lake Range, near base of Dry Lake thrust plate. Exposed thickness less than 10 m (Longwell and others, 1965)

O€p **Pogonip Formation (Middle Ordovician to Upper Cambrian)**—Includes rocks equivalent to the Antelope Valley and Goodwin Limestones of the Pogonip Group. Antelope Valley Limestone is yellowish-gray, light-gray weathering, massive to medium-bedded, fossiliferous grainstone to packstone. Also contains dark yellow-orange silty laminae and nodules and layers of yellow-brown-weathering chert. Fossils include brachiopods, cephalopods, gastropods, pelecypods, sponges, and trilobites. Forms cliff. Goodwin Limestone is medium-gray to grayish-orange weathering, thick-bedded, burrow-mottled to laminated grainstone to packstone. Typically oolitic, contains chert layers and nodules as well as orange silty partings. Lowest beds in Las Vegas 30' x 60' quadrangle to west of Lake Mead quadrangle contain latest Cambrian conodonts (Page and others, 2005). Exposed in small faulted outcrops near base of upper plate of Dry Lake thrust, on west side of Dry Lake Range. Thickness unknown

Formations exposed in upper plate of Muddy Mountain thrust

Pkt **Kaibab and Toroweap Formations, undivided (Lower Permian)**—Limestone, chert, gypsum, and siltstone. Upper part of Kaibab Formation, except where removed by erosion, is slope-forming gray limestone, gypsum, and siltstone. Underlain by yellowish-gray cherty fossiliferous limestone that forms prominent cliff. Upper part of Toroweap Formation is slope-forming unit of pale-red and yellow gypsiferous siltstone. Middle part is prominent gray, cliff-forming cherty limestone, locally gypsiferous. Limestone cliff is underlain by slope-forming unit of limestone, dolomite, gypsum, siltstone, and minor amounts of sandstone. Total thickness about 400 m

Pr **Permian red beds, undivided (Lower Permian)**—Medium- to fine-grained, dull red, reddish-pink, and white sandstone and siltstone, locally gypsiferous. Thick to thin bedded, massive to cross-bedded. Weathers in alternating thin, slightly resistant beds and intervening soft slopes, forming stair step topography. Outcrops commonly mantled by colluvium derived from overlying Toroweap and Kaibab Formations. Mapped as Lower Permian red beds in Las Vegas quadrangle to west (Page and others, 2005); partly correlative to Hermit and Esplanade Formations (**Phe**) as mapped to east in autochthonous rocks. About 400 m thick

Pp **Pakoon Limestone (Permian)**—Light gray, thin-bedded limestone, dolomite, and gypsum. Exposed in Dry Lake Range, northwest part of quadrangle, in vicinity of Dry Lake thrust and within thrust fault slivers. Equivalent to upper part of Bird Spring Formation (**PMb**) in upper plate of Dry Lake thrust to west. Thickness unknown, perhaps as much as 100 m

PMb **Bird Spring Formation (Lower Permian to Upper Mississippian)**—Medium- to light-gray, yellowish- to brownish-gray weathering, thin to thick bedded limestone and dolomite. Includes reddish-brown weathering calcareous sandstone and siltstone, and layers and nodules of reddish-brown chert. Abundant fossils, including fusulinids, ostracodes, brachiopods, bryozoans, corals, gastropods, pelecypods, and sponges. Slope to cliff-forming. Equivalent to Callville Formation in autochthonous rocks below Muddy Mountain thrust, exposed at Frenchman Mountain and in eastern part of quadrangle. Mapped separately from Pakoon Formation in Dry Lake Range but as mapped in Muddy Mountains may include Pakoon Limestone (**Pp**). Thickness in quadrangle unknown; incomplete thickness in Arrow Canyon 7.5-minute quadrangle to north is 1640 m (Page, 1992)

Mm **Monte Cristo Group (Upper and Lower Mississippian)**—Medium-gray, cliff-forming limestone with brown, cherty zones. Uppermost Yellowpine Limestone is resistant cherty limestone. Bullion Limestone is poorly bedded, ledge-forming, light-gray limestone. Anchor Limestone is gray limestone with abundant chert lenses and stringers that define discontinuous bedding. Basal Dawn Limestone is cliff-forming, light-gray limestone and dolomite, commonly fossiliferous. Thickness about 250 to 300 m in Muddy Mountains (Bohannon, 1983)

MDs **Sultan Limestone (Mississippian and Devonian)**—Limestone and dolomite, divided into three members (Hewett, 1931). Upper Crystal Pass Member is light gray, medium- to thick bedded, fossiliferous limestone. Valentine Member is resistant medium gray, medium to thick bedded, fossiliferous limestone. Basal Ironside Member is dark-gray to brown limestone to dolomite with stromatoporoids. Thickness about 190 m

Op **Pogonip Formation (Lower Ordovician)**—Originally defined as the Monocline Valley Formation of Longwell and Mound (1967); herein renamed Pogonip based on conodont-based correlations by A.G. Harris (written communication, 2002). Formation capped by 35 m of medium-gray dolomite with thin irregular beds, alternating with layers and lenses of brown-weathering chert. Underlain by about 14 m of impure 'weak' dolomite with distinctive brown color and then about 170 m of gray dolomite, thin to medium-bedded with lenses and thin layers of chert. Basal 25 m is yellowish to yellow-brown, thin-bedded silty to sandy dolomite. Total thickness about 240 m (Bohannon, 1983). Conodont correlations indicate that these rocks are correlative to the lower two-thirds of the Goodwin Limestone of the Pogonip Group in Central Nevada and lower part of the Mountain Springs Formation in the Spring Mountains (A.G. Harris, written communication, 2002)

Ꞓn **Nopah Formation (Upper Cambrian)**—Medium- to dark-gray, medium- to thick-bedded dolomite. Mottled, locally contains brown to yellowish-brown chert in discontinuous layers and nodules. Dolomite forms cliff, about 150 m thick. Dunderberg Shale Member at base forms recessive slope, about 40 m thick. Dunderberg consists of yellowish-tan to gray, silty limestone and olive-green shale. That part of unit above Dunderberg originally named Buffington Formation of Longwell and Mound (1967) (see Bohannon, 1983), but herein correlated to Nopah Formation on basis of stratigraphic position and description. Thickness about 150 m

Ꞓbk **Bonanza King Formation (Upper and Middle Cambrian)**—Two members, Banded Mountain and Papoose Lake, exposed in north central part of quadrangle. Banded Mountain is black or light to dark gray, thin- to medium-bedded dolomite, with alternating light and dark gray colors giving the member a distinctive banded appearance. Dark-gray to dark-brown or orange burrow mottling is common. Papoose Lake Member is dark-gray dolomite with distinctive, dark-brown to orange discontinuous horizontal burrow mottling. Minimum thickness about 300 m (Bohannon, 1983)

Autochthonous rocks exposed below Muddy Mountain and Dry Lake thrusts

Ja **Aztec Sandstone (Lower Jurassic)**—Reddish-orange, medium-grained eolian sandstone, typically weathering red in lower part of formation, and white in upper part. Composed of well-sorted, well-rounded, frosted quartz sand grains, cemented with hematitic matrix. Mostly displays large-scale cross-bedding; including trough, wedge-planar and trough-planar. Less commonly contains horizontally stratified or contorted sandstone. Locally includes discontinuous limestone lenses. Moderately indurated, forms rounded knobs or large cliffs. Thickness up to 1200 m where not eroded at sub-Tertiary unconformity

Jmk **Moenave and Kayenta Formations, undivided (Lower Jurassic)**—Bulk of unit is Kayenta Formation, except basal conglomerate and locally, buff-colored sandstone which is tentatively correlated with Springdale Sandstone Member of the Moenave Formation (Beard, 1992). Erosional unconformity with underlying Chinle Formation (Ꞧc) marked by red-brown to green-brown pebble conglomerate or buff sandstone of Moenave Formation. Conglomerate contains trough cross stratification; pebbles mostly well-rounded, highly-polished quartzite and chert, with some limestone and sandstone clasts. Buff sandstone is medium grained, cross-stratified, and deposited in lenticular channels. Lower part of Kayenta is dark red, lenticular trough-bedded sandstone and brick red, parallel-bedded, cross-stratified siltstone, with minor thin limestone beds and gypsiferous claystone. Where conglomerate or sandstone is missing at base, lower part of unit is dominated by gypsiferous claystone. Upper part of Kayenta is slope forming red and orange gypsiferous sandstone and siltstone, parallel-bedded, cross-stratified. Thickness up to 300 m

Ꞧc **Chinle Formation (Upper Triassic)**—Variegated bentonitic mudstone, fine to very coarse grained sandstone, limestone, and pebble conglomerate. Includes two members, not separately mapped. Petrified Forest Member is brown, gray, and pale red to pale purple, interbedded sandstone, siltstone and bentonitic claystone; exhibits abundant stacked paleosol horizons. Forms badlands.

Shinarump Member at base is yellow-or green-brown to dark-brown pebble to cobble fluvial conglomerate and sandstone. Clasts are well-rounded to rounded, composed of chert, quartzite and, to a lesser extent, carbonate. Locally includes dark gray limestone, sometimes sandy to pebbly. Thickness about 250 m

Ꞧm **Moenkopi Formation (Middle? and Lower Triassic)**—Mudstone, siltstone, sandstone, conglomerate, gypsum, limestone and dolomite. Includes, in descending order, six members as described by Reif and Slatt, (1979): the upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, and lower red member. The upper red member is red, massive bedded, resistant siltstone and sandstone with nodular gypsum, grading upward to dark red ripple laminated, thin bedded mudstone separated by thin recessive green shale with vertical silt-filled mud cracks. Locally includes white to yellow, fine-grained sandstone lenses in lower part, and purple and white mottled conglomeratic sandstone about 5-10 m below top. Shnabkaib Member is pale-gray to pale-green thin interlayered beds of white gypsum, gray limestone, dolomite, and laminated gypsiferous mudstone. Middle red member is very thin or not present in study area and where present, comprises no more than 5 m of pale-green or pale-red siltstone and mudstone. Virgin Limestone Member is light-gray to white, resistant limestone and dolomite interlayered with pale-gray siltstone. Locally fossiliferous and oolitic. Lower red member is slope-forming red mudstone with thin interbeds of gypsum and limestone. Beds and veins of gypsum common in lower part of member. Timpoweap Member is basal conglomerate overlain by fining upward sequence of conglomeratic sandstone, fine-grained sandstone and siltstone. Occurs in paleovalleys cut into underlying Kaibab Limestone (Reif and Slatt, 1979). Total thickness about 650 m

Pkt **Kaibab and Toroweap Formations, undivided (Lower Permian)**—Formations form distinctive cliff-slope-cliff topography at top of carbonate/clastic sequence of Paleozoic stratigraphy.

Kaibab Formation includes, in descending order, Harrisburg and Fossil Mountain Members, as defined by Sorauf and Billingsley (1991). Harrisburg Member is white-gray, gray and light-red interbedded limestone dolomite, gypsum, and siltstone. Gypsum and siltstone form slopes, limestone and dolomite beds form stair-step topography. Fossil Mountain member is pale-yellow-brown, gray, medium to thick bedded fossiliferous limestone. Chert is very common as nodules, ribbons, or fine disseminated networks. Forms cliff overlying Toroweap Formation. Thickness variable due to sub-Triassic unconformity, ranging from 120 to 170 m.

Toroweap Formation includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members. Woods Ranch Member is white, yellow-gray, or medium-gray, interbedded gypsum, calcareous siltstone and sandstone, and minor limestone and dolomite. Forms slope. Brady Canyon Member is medium gray, thick-bedded limestone and dolomite with rounded nodules and ribbons of chert. Fossil fragments, especially crinoids and brachiopods, are common. Forms cliff. Seligman Member is tan to red- and yellow-tan, slope-forming unit that contains siltstone, sandstone, and limestone. Locally, gypsum deposits dominate member. At base, includes lenses of white to buff, coarse- to medium-grained, well-rounded, well-sorted quartz sandstone probably equivalent to Coconino Sandstone. Includes both low- to high-angle cross-bedded and planar-bedded sets 1-2 m in height. Coconino is thin to nonexistent (15 to 0 m) in map area; where present, forms ledge. Total thickness about 110 m

Phe **Hermit Formation and Esplanade Sandstone, undivided (Lower Permian)**—Reddish brown to orange-pink or white sandstone, with minor mudstone and siltstone. Hermit Formation is medium- to fine-grained, dull red to reddish-pink sandstone and siltstone; thick to thin bedded, massive to cross-bedded. Weathers in alternating thin, slightly resistant beds and intervening soft slopes, forming stair-step topography. Outcrops commonly mantled by colluvial deposits derived from overlying Toroweap and Kaibab Formations. Gradational contact with underlying Esplanade Sandstone. About 250 to 300 m thick at Frenchman Mountain, thinning slightly toward eastern edge of quadrangle to about 200 m. Esplanade Sandstone is white to pinkishwhite sandstone, fine- to medium-grained, and cross-bedded. Sandstone is well sorted, friable to moderately resistant, and slightly calcareous. Forms massive ledge to cliff in otherwise recessive slope of Hermit Formation. Partly equivalent to Queantoweap Sandstone and has been mapped as such in Lake Mead quadrangle, but herein we use Esplanade. Thickness about 60 to 80 m

PMpc **Pakoon Limestone and Callville Formation, undivided (Lower Permian to Upper Mississippian)**—Pakoon Limestone is medium to light-gray or buff, micritic to finely crystalline dolomite, locally cherty. Commonly includes white to light gray, thick-bedded gypsum deposits. Dolomite in thin to medium beds, weathers into stair-step beds and gypsum weathers to form low hills. Intertongues upward and laterally eastward with Esplanade Sandstone. Gradational contact with underlying Callville Formation generally placed at change from limestone to dolomite. Ranges in thickness from about 130 m at Frenchman Mountain to 70 m at Azure Ridge in eastern part of quadrangle. Callville Formation is dark to medium-gray micritic limestone and pale-brown to orange-brown calcareous sandstone to sandy dolomite, commonly cross-bedded. Orange to brown chert nodules and bands common. Upper part contains reddish-brown to gray weathering, cross-bedded silty to sandy limestone. Correlative to Bird Spring Formation (**PMb**) to west in upper plate of Dry Lake thrust. To the east in the Grand Canyon region, correlative to and intertongues with upper Watahomigi, Manakacha, and Wescogame Formations of the Supai Group (McKee, 1992) (fig. 3b). Basal 10 to 15 m is distinctive slope-forming reddish to purplish-brown sandstone and siltstone sequence that is disconformable on underlying Redwall Limestone. Basal sequence correlative to Upper Mississippian Indian Springs Formation to west (Page and others, 2005) and to lower Watahomigi Formation of the Supai Group to the east. Overlain by thick-bedded, cliff-forming, commonly oolitic, fossiliferous, and cherty limestone beds. Thickness ranges from about 250 m at Frenchman Mountain to about 200 m at eastern end of quadrangle

Mr **Redwall Limestone (Upper and Lower Mississippian)**—Medium-gray, fine to coarsely-crystalline, cherty and fossiliferous limestone. Includes, in ascending order, the Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members defined by McKee (1963) and McKee and Gutschick (1969). Lower part of Redwall and upper part of underlying Temple Butte Formation commonly dolomitized. Typically forms single massive cliff. Distinctive banded chert horizon (Thunder Springs Member), about 45 m above base of formation forms marker bed, contains 5-10 cm thick bands of white to gray chert that weather dark gray or yellow. Because of dolomitization, base is mapped at bottom of chert horizon in Thunder Springs Member. Equivalent to Monte Cristo Limestone (**Mm**) in upper plate of Muddy Mountain and Dry Lake thrusts (fig. 3b). In Wilson Ridge area occurs as isolated and highly altered remnants but inferred to be Redwall Limestone on the basis of rugose horn coral and crinoid fossils (Feuerbach, 1986). Thickness ranges from 240 m at Frenchman Mountain to about 200 m in the eastern part of the quadrangle

Dtb **Temple Butte Formation (Upper and Middle Devonian)**—Widely exposed in eastern part of quadrangle as well as at Frenchman Mountain, where mapped as Sultan Formation by Castor and others (2000). Rocks in the upper part are composed of cliff-forming, light-gray, micritic limestone that weathers very light-gray and is commonly dolomitized. Upper part present everywhere except in far southeast part of quadrangle (Rowland and others, 1990). Lower part is brown to black-gray, medium bedded, fine-grained fetid dolomite, with interbedded red-brown sandstone and sandy shale in lower 10 m. Locally includes reddish-brown dolomitic sandstone beds with rip-up clasts preserved in channels at base. An outcrop of these sandstone beds just to north of quadrangle on South Virgin Peak Ridge yielded fish plate fossils identified as *Holonema*, *Asterolepis* and “crossopterygians” of Middle Devonian age (Elliott and Johnson, 1997). Overlying sandstone is 1-3 m thick, light-gray to brown, sugary dolomite, thin to medium bedded. Dolomite forms cliffs and sandstone forms slopes creating ledge topography. Basal contact is erosional unconformity on Cambrian rocks. As mapped, lowest 1 to 12 m correlates to the "c member" of the Mountain Springs Formation (Rowland and others, 1990, Rowland, written communication, 1993). The Temple Butte Formation is partly correlative to Sultan Limestone (**MDs**) in upper plate of Muddy Mountain thrust (Rowland and others, 1990) and Guilmette Formation (**Dg**) in the upper plate of the Dry Lake thrust (see descriptions above) Total thickness of Temple Butte Formation is about 180 m

€u **Cambrian rocks, undifferentiated (Cambrian)**—Exposed in isolated, faulted outcrops in Boulder Canyon and Wilson Ridge area. Altered quartzite, shale and carbonate rocks, locally mineralized and intruded by Tertiary andesite and dacite dikes and stocks. Most likely equivalent to Tapeats Sandstone, Bright Angel Shale, and Muav Formation (Feuerbach, 1986, Eschner, 1989)

€n **Nopah Formation (Upper Cambrian)**—Exposed only in Frenchman Mountain area, west-central part of quadrangle. Absent at sub-Devonian boundary in eastern part of quadrangle, but occurs just to north of quadrangle boundary in Whitney Ridge, where it is about 37 m thick. Nopah Formation is light gray to pale brown, thick-bedded dolomite, locally stromatolitic. At Frenchman Mountain (Castor and others, 2000), the basal Dunderberg Shale Member consists of greenish shale and siltstone and brown dolomite interbeds, with a middle interval (10 m thick) of light gray, vuggy dolomite with glauconite pellets and rip-up clasts. Nopah Formation forms distinctive bench, about 35 m thick

€m **Muav Formation (Middle Cambrian)**—Widely exposed in eastern part of quadrangle, as well as in one small exposure at Wilson Ridge, and at Frenchman Mountain. Unit includes Frenchman Mountain Dolomite (Castor and others, 2000) and Unclassified Dolomites of McKee and Resser (1945). Korolev and Rowland (1998) and Rowland and others (1990) indicate that Muav is correlative to Papoose Lake and lower part of Banded Mountain Members of Bonanza King Formation, and that the overlying Unclassified Dolomites and Frenchman Dolomite correlate to upper and middle part of the Banded Mountain Member. Thickens from east to west, from about 520 m at Azure Ridge to about 630 m at Frenchman Mountain.

At Frenchman Mountain, upper part (Frenchman Dolomite of Castor and others, 2000), consists of cliff forming pale-orange weathering, thickly bedded medium- to coarsely crystalline dolomite, underlain by color-banded light- and dark-gray, thin to thick-bedded dolomudstone. Dark bands intensely burrowed and light bands wavy laminated. Lower part is dark-gray and buff-orange, burrow-mottled dolomite, underlain by light and medium-gray limestone and dolomite, with limestone increasing downward in section. Forms stair-step topography.

In eastern part of quadrangle, upper part (Unclassified Dolomites of McKee and Resser, 1945) is massive light-gray, medium-grained to coarsely crystalline dolomite, underlain by less resistant white and gray banded unit, with distinctive white, thin-bedded, slope-forming dolomite at base. Forms slope-cliff topography. Lower part is medium- to dark-gray, medium to thin bedded dolomite, interbedded with thin-bedded, light gray sandy dolomite and finely crystalline limestone. Medium to dark-gray beds most common, and are characteristically mottled yellow-gray or light-gray on weathered surface because of intensive burrowing. Forms series of prominent cliffs

Ꞓtb **Tapeats Sandstone and Bright Angel Shale, undivided (Middle and Lower Cambrian)**— Widely exposed in eastern part of quadrangle; also includes one outcrop at Wilson Ridge just south of Lake Mead, and small outcrop at Frenchman Mountain. Total thickness about 185 m. Bright Angel Shale is dominantly green micaceous shale, finely laminated, and complexly burrowed. Lower 3-4 m consists of red-brown micaceous and glauconitic shale interbedded with thin red-brown sandstone. Upper contact gradational with Muav Formation. Forms slope. Thickness about 90 to 120 m. Tapeats Sandstone is typically divided into two units. Upper unit is highly resistant, light brown to tan, medium-bedded, cross-bedded orthoquartzite that is locally burrowed. Gradational with overlying Bright Angel Shale. Thickness of upper unit about 65 m. Lower unit is dark-red, thin-bedded, trough cross-stratified arkosic sandstone, locally pebbly, that rests unconformably on underlying Proterozoic basement rocks and is locally absent. Thickness varies from 0 to about 10 m in eastern part of quadrangle to as much as 48 m at Frenchman Mountain

Proterozoic Rocks

Ydg **Diorite and gabbro (Middle Proterozoic)**—Gray to greenish-gray, medium to coarse-grained generally unfoliated pyroxene-bearing diorite and gabbro exposed at Jumbo Peak (fig. 5) and on the west side of Grapevine Mesa, in southeast part of quadrangle. In Jumbo Peak area, occurs as small outcrop within but near margin of Gold Butte Granite (**Yg**); granite surrounding exposure is commonly granodiorite to quartz monzonite and marked by enclave- and inclusion-rich zones. At Grapevine Mesa exposures contains poikilitic plagioclase phenocrysts as large as 3 cm across. Hornblende and pyroxene are locally altered to chlorite and biotite

Yg **Gold Butte Granite (Middle Proterozoic)**—Described by Volborth (1962) as rapakivi granite. Coarse-grained porphyritic to locally equigranular biotite and biotite-hornblende granite. Contains 5 to 50 percent phenocrysts of potassium feldspar 1to 3 cm across; Fryxell and others (1992) mapped phenocryst content as decreasing generally westward. Mafic mineral content about 10 to 20 percent. Preferred alignment of tabular phenocrysts and biotite define faint igneous foliation. Locally gneissic. Age of 1.45 ± 0.25 Ga has been reported by Silver and others (1977; no location information available)

YXb **Granite of Burro Spring (Middle to Early Proterozoic)**—Exposed in Hiller Mountains area in southeast part of quadrangle. Porphyritic biotite granite containing abundant pale-gray to tan potassium feldspar phenocrysts about 2 cm in length. Mafic mineral content about 10 to 15 percent, including biotite and magnetite. Closely resembles Gold Butte Granite, although Blacet (1975) correlated with porphyritic granite of Garnet Mountain (1680 Ma, Chamberlain and Bowring, 1990)

Xu **Metamorphic and plutonic rocks, undivided (Early Proterozoic)**—Mixed metamorphic and plutonic rocks exposed at Saddle Island and Wilson Ridge; not mapped in detail. At Saddle Island, consists of complex of gneissic biotite-hornblende gneiss, quartz diorite, hornblendite, and amphibolite, cut by rare pegmatite and interleaved with felsic mylonitic gneiss (Deubendorfer and others, 1990). At Wilson Ridge, consists of well foliated hornblende-plagioclase-quartz gneiss and granite (Eschner, 1989)

Xlg **Leucogranite and pegmatite gneiss (Early Proterozoic)**—Composed of quartz, potassium feldspar, plagioclase, and less than 5 percent biotite. Ranges from equigranular to coarsely pegmatitic in texture. Locally contains partially retrograded garnets. Commonly altered to a red color, mostly beneath the paleo-erosional surface on which the Tapeats Sandstone (**Ꞓtb**) was deposited

Xlgb **Leucogranite and pegmatite gneiss, brecciated (Early Proterozoic)**—Brecciated bodies of leucogranite along Gold Butte fault zone. Interpreted as fault breccia along a low-angle fault by Fryxell and others (1992). However, based on intercalated lenticular Tertiary conglomerate and debris flow deposits (too small to show on map), an alternate interpretation for at least part of the brecciation is that unit is large landslide mass of Proterozoic rocks resting on the eroded fault scarp (Beard, unpublished mapping)

Xwe **Granite of Lime Wash, equigranular phase (Early Proterozoic)**—Equigranular phase of granitic intrusion exposed in Lime Wash area. Medium-grained biotite-hornblende granite and biotite-granite with rare potassium feldspar phenocrysts and 8 to 15 percent mafic minerals. Contains mafic enclaves; exhibits faint gneissic foliation

Xwp **Granite of Lime Wash, porphyritic phase (Early Proterozoic)**—Biotite granite and hornblende-biotite granite, containing rectangular phenocrysts, from 3 to 20 cm long, of potassium feldspar with sharp to rounded corners and locally white plagioclase rims. Contains 8 to 10 percent mafic minerals. Alignment of elongate phenocrysts defines flow foliation; locally mylonitic. Contains inclusions of hornblende granite gneiss

Xgw **Porphyritic granite of Whitney Ridge (Early Proterozoic)**—Pale pink to tan, microcline-rich granite to granitic gneiss, locally mylonitic with microcline augen and quartz ribbons on foliation surfaces. Weathers to distinctive red or dark pink-brown hue. Composed of medium-grained microcline and quartz with minor (1 to 5 percent) biotite, muscovite, and oligoclase; locally abundant veins and patches of coarse-grained microcline and granular epidote. Exposed beneath Tapeats Sandstone (Ꞓtb) on Whitney Ridge

Xhg **Hornblende granite gneiss (Early Proterozoic)**—Equigranular, medium-grained, biotite-bearing hornblende granite to granitic gneiss. Exposed in Lime Wash and Garden Wash areas. At Lime Wash, intruded by porphyritic granite phase of Lime Wash Granite. Closely associated with and may be foliated variant of equigranular granite facies of granite of Lime Wash (Xwe). At Garden Wash, unit is unfoliated and is equivalent to hornblende granite of Fryxell and others (1992) and hornblende-microcline granite of Volborth (1962)

Xum **Mafic and ultramafic metamorphic rocks, undivided (Early Proterozoic)**—Medium- to coarse-grained, porphyritic, hornblende-rich mafic to ultramafic gneiss, including pyroxenite gneiss. Sheared, serpentized locally. Intrudes the garnet gneiss (Xgn) and quartz syenite gneiss (Xqs) units as dikes and small irregular bodies

Xgg **Granitic gneiss (Early Proterozoic)**—Gray, medium-grained biotite granodiorite and granitic gneiss. Mafic mineral content 10 to 15 percent. Mapped in part by interpretation from TIMS imagery provided by Simon Hook, Jet Propulsion Laboratory, 1998

Xqs **Quartz syenite gneiss (Early Proterozoic)**—Medium- to coarse-grained porphyritic hornblende-biotite quartz syenite, syenite, and quartz monzonite gneiss having 80 percent potassium feldspar megacrysts 1 to 2 cm long, and 5 to 10 percent mafic minerals, mainly biotite. Described as syenite by Volborth (1962). As mapped, may include bodies of mafic and ultramafic rock.

Mapped in part from interpretation from TIMS imagery provided by Simon Hook, Jet Propulsion Laboratory, 1998

Xqd **Quartz diorite gneiss (Early Proterozoic)**—Medium-grained, locally schistose, quartz diorite and diorite gneiss, with 15 to 45 percent fine-grained biotite, hornblende, and chlorite. Long thin bodies NW of Gold Cross Peak in SE corner of quadrangle are largely metadiorite. Locally includes porphyritic quartz syenite gneiss. Mapped in part from interpretation from TIMS imagery provided by Simon Hook, Jet Propulsion Laboratory, 1998

Xc **Charnokite gneiss (Early Proterozoic)**—Granitic gneiss containing plagioclase, quartz, hypersthene, potassium feldspar, biotite, and clinopyroxene bearing gneiss. Megascopically folded with garnet gneiss and shares its principle foliation (see orthogneiss description, Fryxell and others, 1992)

Xcb **Charnokite gneiss, brecciated (Early Proterozoic)**—Small exposure of brecciated charnokite gneiss, adjacent to Gold Butte fault

Xgn **Garnet gneiss (Early Proterozoic)**—Dark garnet-quartz-plagioclase paragneiss, chlorite-biotite paragneiss, cordierite-sillimanite gneiss, migmatite, pods of leucogranite gneiss, and local amphibolite, meta-andesite (?), and feldspathic gneiss. Garnet and garnet pseudomorph abundance decreases from Gold Butte area southward to White Hills, where correlated with paragneiss unit mapped by Blacet (1975) and gneiss unit described by Theodore and others (1987). Protolith age 1700 Ma or greater (Wasserburg and Lanphere, 1965; Chamberlain and Bowring, 1990; Wooden and DeWitt, 1991). Locally retrograded, most likely during Mesozoic or Miocene event. Based on degree of retrograde textures mapped by Fryxell and others (1992), includes:

Xgp **Partly retrograded garnet gneiss**—Chloritic and sericitic halos rim and partially replace the garnets

Xgr **Completely retrograded garnet gneiss**—Chloritic and sericitic pseudomorphs replace the garnets

Xgc **Chloritic brecciated gneiss**—gneiss is brecciated and completely retrograded to chlorite and epidote; mylonite zones common

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Table 1. Published Geochronologic Data, Lake Mead 30' x 60' Quadrangle

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
UAKA 89-24	770874.87	4018370.24	basalt	**3.24 +/- 0.05**	whole rock	K/Ar	Tgb	uppermost basalt flow at Grand Wash Bay	Damon and others, 1996
28-B91	790778.18	4075214.00	basalt	**3.7 +/- 0.6**	unknown	K/Ar	Tgb	top basalt flow, Black Rock Mountain	Wenrich and others, 1995
JF-97-76	759999.95	4000537.81	basalt	**4.41 +/- 0.03**	groundmass, weighted mean plateau	$^{40}Ar/^{39}Ar$	Tgb	Sandy Point basalt, overlies Colorado River gravels (T2a)	Wallace and others, 2006
87-38-143-LN	709250.68	3992046.83	olivine-plagioclase-pyroxene basalt plug	**5.42 +/- 0.13**	plagioclase	K/Ar	Tfb	plug intrudes cinder cones, youngest volcanism at Fortification Hill	Feurbach and others, 1991
F8-42-82-LN	716520.65	3995165.27	olivine basalt flow	**5.43 +/- 0.16**	plagioclase	K/Ar	Tfb	flow from cinder cone at Petroglyph Wash	Feurbach and others, 1991
JF99-455	684744.01	4014006.43	tuff	**5.59 +/- 0.05**	geochemical correlation	$^{40}Ar/^{39}Ar$	Tmml	in limestone/marl in Muddy Creek Formation, Nellis basin. Correlated to Wolverine Creek Tuff	Castor and Faulds, 2001
G8-2-2-LN	744361.30	4017514.39	alkali olivine basaltic dike	**5.72 +/- 0.33**	plagioclase	K/Ar	Tbi	dike in Quail Springs Wash	Cole, 1989
87-38-142-LN	708823.31	3992335.48	oliv-plag-pyx basalt flow	**5.73 +/- 0.13**	plagioclase	K/Ar	Tfb	flow erupted from cinder cones on Fortification Hill	Feurbach and others, 1991
F7-38-13-LN	708753.48	3993367.05	olivine basalt	**5.89 +/- 0.18**	plagioclase	K/Ar	Tfb	lowest flow at Fortification Hill (located on north end of Fortification Hill)	Feurbach and others, 1991
6501	733243.96	3984251.35	tuff	**5.97 +/- 0.07**	biotite, plateau	$^{40}Ar/^{39}Ar$	Th	Hualapai Limestone, 2080 ft elevation southwest of Temple Bar	Spencer and others, 2001
87-10-129-LN	734580.62	4032827.12	olivine-pyx basalt	**6.02 +/- 0.39**	plagioclase	K/Ar	Tmv	flow east of feeder dike at Black Point	Feurbach and others, 1991
MW-98-36	766001.90	3989180.08	air fall tuff	**7.43 +/- 0.22**	sanidine, laser fusion	$^{40}Ar/^{39}Ar$	Th	tuff interbedded in upper part of limestone, Grapevine Wash, just east of Meadview	Wallace and others, 2006
F8-24-85-LN	703956.29	4004539.45	basaltic andesite flow	**8.49 +/- 0.20**	plagioclase	K/Ar	Tcm4	youngest rock dated in Callville Mesa volcanic field	Feurbach and others, 1991

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
F8-24-90-LN	704049.00	4005707.17	basaltic andesite plug	**8.53 +/- 0.22**	plagioclase	K/Ar	Tcm4	within volcanic center on west side of West End Wash	Feurbach and others, 1991
F8-24-88-LN	703446.31	4005822.60	basaltic andesite plug	**9.11 +/- 0.30**	plagioclase	K/Ar	Tcm3	in volcanic center on Callville Mesa	Feurbach and others, 1991
KT82401	726303.47	4007757.32	tuff	**9.4 +/- 0.6**	biotite	K/Ar	Toag	pyroclastic flow with flattened white pumice fragments, roadcut on Boathouse Cove Road	Thompson, 1985
KT82FB	726013.26	4007379.72	subalkalic basalt	**9.5 +/- 0.3**	whole rock	K/Ar	Tyb	basalt lava flow	Thompson, 1985
12-799-11	705506.36	4003511.40	basalt flow	**10.05 +/- 0.03**	whole rock, plateau	$^{40}Ar/^{39}Ar$	Trs	thin flow in red sandstone unit	Anderson and others, 1994
11-714-71	710943.57	4007187.22	basalt flow	**10.07 +/- 0.07**	whole rock, minor excess 40 Ar	$^{40}Ar/^{39}Ar$	Tvh	Hamblin volcano	Anderson and others, 1994
88-24-146-LN	702873.63	4005938.77	basaltic andesite flow	**10.21+/- 0.23**	plagioclase	K/Ar	Tcm3	flow on flank of complex cinder cone	Feurbach and others, 1991
F8-24-100-LN	706109.85	4005459.59	olivine-pyroxene basalt	**10.46 +/- 0.23**	plagioclase	K/Ar	Tcm1	interbedded with tilted red sandstone unit, oldest volcanism associated with Calville Mesa	Feurbach and others, 1991
1-13-2	687190.38	4001518.53	white airfall tuff	**10.6 +/- 0.9**	zircon	fission track	Trs	red sandstone unit, SE of Lava Butte	Bohannon, 1984
SSW1	747314.52	3987860.39	tuff	**10.78 +/- 0.4**	biotite	$^{40}Ar/^{39}Ar$	Toac	in conglomerate just below basalt in Salt Spring Wash	Blythe, 2005
2-80-1a	767616.06	4002131.32	gray airfall tuff	**10.8 +/- 0.8**	zircon	fission track	Tgws	rocks of the Grand Wash trough, below Hualapai Limestone	Bohannon, 1984
JF-97-144	768905.80	3994204.92	tuff of Grapevine Wash	**10.94 +/- 0.03**	glass, geochemical correlation	$^{40}Ar/^{39}Ar$	Th	tuff of Grapevine Wash	Wallace and others, 2006
2-131-73	708690.06	4024818.31	gray airfall tuff	**11 +/- 0.9**	zircon	fission track zircon	Trs	red sandstone unit, White Basin	Bohannon, 1984
JF-97-144	768905.80	3994204.92	tuff ofGrapevine Wash	**11.08 +/- 0.27**	sanidine, laser fusion	$^{40}Ar/^{39}Ar$	Th	tuff of Grapevine Wash	Faulds and others, 2001b

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
KT8250	725254.18	4007730.15	lava flow	**11.1 +/- 1.1**	plagioclase	K/Ar	Tvc	upper lava flow in graben in Muddy Creek Formation, above gypsum	Thompson, 1985
KT8273	733800.09	4019058.21	trachyte	**11.1 +/- 1.4**	plagioclase	K/Ar	Tvc	trachyte lava flow, south of Hill 1417 on Bighorn Island	Thompson, 1985
1-13-1	688533.84	4003230.80	white airfall tuff	**11.2 +/- 1.2**	zircon	fission track	Trs	red sandstone unit, E of Lava Butte	Bohannon, 1984
1-67-273	710806.69	4023333.81	gray airfall tuff	**11.2 +/- 1.1**	zircon	fission track	Trs	red sandstone unit, White Basin	Bohannon, 1984
2-80-2	767616.06	4002131.317	airfall tuff	**11.1 +/- 1.3**	zircon	fission track	Tgws	rocks of the Grand Wash trough, same level as 2-80-1a	Bohannon, 1984
977	707870.55	4005223.83	basalt	**11.3 +/- 0.3**	whole rock	K/Ar	Tvhu	Hamblin volcanics, in Callville Wash	Anderson and others, 1972
TV92-5	696733.54	4005520.66	clinopyroxene-plagioclase basalt flow	**11.41 +/- 0.14**	whole rock, plateau	$^{40}Ar/^{39}Ar$	Tcm	part of Callville Mesa volcanic sequence	Harlan and others, 1998
C95-3	687169.44	4001795.56	tuff	**11.47 +/- 0.05**	mean laser fusion	$^{40}Ar/^{39}Ar$	Trs	tuff bed near base of red sandstone unit	Castor and others, 2000
KT8276	734174.23	4016292.48	hawaiite	**11.5 +/- 0.5**	whole rock	K/Ar	Tyb	hawaiite lava flow, SW of Hill 1378 on Heron Island	Thompson, 1985
JF99-452	681741.96	4012651.36	air-fall tuff	**11.59 +/- 0.06**	single crystal sanidine	$^{40}Ar/^{39}Ar$	Trs	red sandstone unit, north of Sunrise Mountain	Castor and others, 2000
2-80-1b	767616.06	4002131.32	gray airfall tuff	**11.6 +/- 1.2**	zircon	fission track	Tgws	rocks of the Grand Wash Trough, below 2-80-1a	Bohannon, 1984
1-67-272B	712184.04	4022719.80	gray airfall tuff	**11.7 +/- 1.3**	zircon	fission track	Trs	red sandstone unit, White Basin	Bohannon, 1984
TV92-2	697214.61	4012099.02	crystal vitric tuff	**11.7 +/- 0.08**	biotite, plateau	$^{40}Ar/^{39}Ar$	Trs	50 m above base of red sandstone unit above Lovell Wash Member	Harlan and others, 1998
08-801-17	708831.40	4006703.46	basalt flow	**11.71 +/- 0.03**	whole rock, minor excess 40 Ar	$^{40}Ar/^{39}Ar$	Tvhu	Hamblin volcano	Anderson and others, 1994
01BC19	705419.98	3986956.64	airfall tuff	**11.72 +/- 0.06**	sanidine	$^{40}Ar/^{39}Ar$	Trs	red sandstone unit (Black Mtn Conglomerate)	Williams, 2003
25	689420.75	3994833.11	basaltic andesite	**11.8 +/- 0.5**	whole rock	K/Ar	Trmb	N flank of River Mountains	Anderson and others, 1972

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
11-714-84	705354.00	3986503.19	dacitic plug	**11.9 +/- 0.04**	unknown	$^{40}Ar/^{39}Ar$	Ti	sills, dikes and plugs of andesite and dacite intrusive	Anderson and others, 1994
1-67-272A	712184.04	4022719.80	white airfall tuff	**11.9 +/- 0.9**	zircon	fission track	Trs	red sandstone unit, White Basin	Bohannon, 1984
JF-92-07	687033.70	3997511.70	Basalt flow	**12.17 +/- 0.02**	whole rock	$^{40}Ar/^{39}Ar$	Trmb	basalt flows of River Mountains	Faulds and others, 1999
486-I8-1C	688467.32	3994479.56	.3 m-thick white tuff	**12.4 +/- 1.1**	sphene	fission track	Trs	white tuff bed in pink tuffaceous sandstone and manganiferous sandstone	Koski and others, 1990
30	693996.17	3988255.13	dacite porphyry	**12.5 +/- 0.5**	biotite	K/Ar	Trmip	intrusive, River Mountains	Anderson and others, 1972
KT82209	729961.43	4016920.24	latite	**12.5 +/- 0.9**	plagioclase	K/Ar	Tvc	thin latite lava flow, Cleopatra volcano	Thompson, 1985
11-713-43	712454.46	4002629.21	quart monzonite	**12.57 +/- 0.05**	biotite, plateau	$^{40}Ar/^{39}Ar$	Twr	quartz monzonite, Wilson Ridge, probably cooling age	Anderson and others, 1994
92-MIL-9	703160.10	3987217.20	basaltic andesite	**12.57 +/- 0.03**	whole rock, plateau	$^{40}Ar/^{39}Ar$	Tvhd	Kingman Wash Road basaltic andesite, volcanic rocks of Hoover Dam	Faulds and others, 1999
13	693996.17	3988255.13	biotite dacite porphyry	**12.6 +/- 0.5**	biotite	K/Ar	Trmip	intrusive, River Mountains	Anderson and others, 1972
11-712-23	712871.53	4002978.66	diorite	**12.62 +/- 0.03**	biotite, plateau	$^{40}Ar/^{39}Ar$	Twr	diorite, Wilson Ridge, probably cooling age	Anderson and others, 1994
10-626-96	718282.61	4005610.09	rhyodacite dike	**12.65 +/- 0.04**	biotite, plateau	$^{40}Ar/^{39}Ar$	Twr	rhyodacite dike, Wilson Ridge, probably cooling age	Anderson and others, 1994
UAKA 76-99	766868.87	4002018.60	glassy tuff	**12.67 +/- 0.3**	glass	K/Ar	Tgws	air-fall tuff between thin laminated mud beds, Rocks of the Grand Wash trough	Damon and others, 1996
382-20-2C	688467.32	3994479.56	tuff clasts	**12.8 +/- 1.0**	sphene	fission track	Trs	clasts of white pumice and tuff in a manganiferous sandstone bed	Koski and others, 1990
1-71-2	730835.35	4017868.64	andesite	**12.9 +/- 0.8**	whole rock	K/Ar	Tvc	lava flow 0.5 miles S of Echo Bay (age recalculated from Anderson and others, 1972)	Thompson, 1985, reporting Anderson and others, 1972
TV92-8	701136.28	4001920.96	hornblende biotite dacite clast	**12.93 +/- 0.10**	biotite, plateau	$^{40}Ar/^{39}Ar$	Trs	in megabreccia within red sandstone unit	Harlan and others, 1998

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
1-96-147	706383.98	4009721.35	gray airfall tuff	**13 +/- 0.8**	zircon	fission track	Thl	Lovell Wash Member, in Lovell Wash	Bohannon, 1984
JF-92-08	693059.40	3996549.20	rhyolite flow	**13 +/- 0.02**	sanidine	$^{40}Ar/^{39}Ar$	Trmd	River Mountains dacite flows and breccias	Faulds and others, 1999
C95-38	685508.21	4000890.71	ash-flow tuff bed	**13.07 +/- 0.08**	sanidine, single crystal mean	$^{40}Ar/^{39}Ar$	Thb	Bitter Ridge Limestone Member of Horse Spring Formation	Castor and others, 2000
29	693982.68	3988865.30	diorite porphyry	**13.1 +/- 0.5**	biotite	K/Ar	Trmip	intrusive, River Mountains	Anderson and others, 1972
KT82158	728706.09	4013371.29	shoshonite	**13.1 +/- 0.8**	amphibole	K/Ar	Tvc	shoshonite lava flow, Cleopatra volcano	Thompson, 1985
92-MIL-7	703029.50	3987370.80	dacite	**13.11 +/- 0.02**	biotite, plateau	$^{40}Ar/^{39}Ar$	Tvhd	Sugarloaf dacite, which intrudes Tuff of Hoover Dam	Faulds and others, 1999
C95-64	688374.20	4005761.67	tuff bed	**13.12 +/- 0.12**	hornblende, step-heating	$^{40}Ar/^{39}Ar$	Thl	Lovell Wash Member of Horse Spring Formation	Castor and others, 2000
C95-50	686980.05	4000829.59	tuff bed	**13.12 +/- 0.24**	plag, isochron	$^{40}Ar/^{39}Ar$	Thl	Lovell Wash Member of Horse Spring Formation	Castor and others, 2000
NBSWV01	747837.89	3986835.95	Tuff of Salt Spring Wash	**13.13 +/- 0.53**	sanidine	$^{40}Ar/^{39}Ar$	Toac	conglomerate of Overton Arm, at Salt Spring Wash	Blythe, 2005
C95-29	685474.05	4002499.33	bio-hbl dacite porphyry	**13.16 +/- 0.05**	biotite, plateau	$^{40}Ar/^{39}Ar$	Tril	Lava Butte dacite porphyry, interpreted as laccolith into Thumb Member of Horse Spring Formation	Castor and others, 2000
TV92-7	696546.15	4005849.44	olivine phyric basalt flow	**13.17 +/- 0.10**	whole rock, plateau	$^{40}Ar/^{39}Ar$	Thlb	interbedded with tuffaceous and calcareous sandstone and siltstone and sltst of Lovell Wash Member of Horse Spring Formation	Harlan and others, 1998
TV92-3	694502.45	4006025.63	diorite sill	**13.19 +/- 0.12**	hornblende, plateau	$^{40}Ar/^{39}Ar$	Thlb	diorite sill intrudes Thumb Member, yields upper age limit for Thumb in western Lake Mead	Harlan and others, 1998
53-L-59	695188.18	3990741.95	silicic lava	**13.2 +/- 0.3**	biotite	K/Ar	Trmv	central part of River Mountains	Anderson and others, 1972
12-L-59	692712.08	3989244.27	silicic lava	**13.2 +/- 0.4**	biotite	K/Ar	Trmvb	central part of River Mountains	Anderson and others, 1972

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
1-13-3	685199.22	4001309.62	green airfall tuff	**13.2 +/- 0.9**	zircon	fission track	Tht	Thumb Member, SW of Lava Butte	Bohannon, 1984
JF-92-09	695245.70	3988265.60	quartz monzonite stock	**13.23 +/- 0.01**	biotite	$^{40}Ar/^{39}Ar$	Trmi	River Mountains intrusive stock	Faulds and others, 1999
TV92-4	692633.70	4003024.30	aphanitic basalt flow	**13.28 +/- 0.09**	whole rock, isochron	$^{40}Ar/^{39}Ar$	Thlb	intercalated with Lovell Wash Member of Horse Spring Formation	Harlan and others, 1998
41			diorite	**13.34 +/- 0.4**	biotite	K/Ar	Twr	Wilson Ridge pluton, Horsethief Canyon diorite phase	Larsen and Smith, 1990
C95-64	688374.20	4005761.67	tuff bed	**13.4 +/- 0.05**	biotite, step-heating	$^{40}Ar/^{39}Ar$	Thl	Lovell Wash Member of Horse Spring Formation	Castor and others, 2000
486-I8-1C	688467.32	3994479.56	.3 m-thick white tuff	**13.4 +/- 1.0**	apatite	fission track apatite	Trs	white tuff bed in pink tuffaceous sandstone and manganiferous sandstone	Koski and others, 1990
Jf-92-11	693244.80	3987929.60	dacite flow? porphyry?	**13.45 +/- 0.02**	biotite	$^{40}Ar/^{39}Ar$	Trmip	River Mountains. Described as flow, but location within quartz monzonite composite pluton	Faulds and others, 1999
C95-29	685474.05	4002499.33	bio-hbl dacite porphyry	**13.5 +/- 0.16**	hornblende, plateau	$^{40}Ar/^{39}Ar$	Tril	Lava Butte dacite porphyry, interpreted as laccolith into Thumb Member	Castor and others, 2000
192			qtz monzonite	**13.5 +/- 0.4**	biotite	K/Ar	Twr	Wilson Ridge pluton, Teakettle Pass quartz monzonite phase	Larsen and Smith, 1990
BC305	711881.71	3991351.47	adamellite	**13.6 +/- 0.6**	biiotite	K/Ar	Twr	intrusive, west flank Wilson Ridge	Anderson and others, 1972
486-I8-1C	688467.32	3994479.56	.3 m-thick white tuff	**13.6 +/- 0.4**	biotite	K/Ar	Trs	white tuff bed in pink tuffaceous sandstone and manganiferous sandstone	Koski and others, 1990
92MIL-5	703158.50	3987284.00	tuff	**13.88 +/- 0.1**	biotite, mean of plateau/isochro n	$^{40}Ar/^{39}Ar$	Tthd	Tuff of Hoover Dam	Faulds and others, 1999

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
B-89-52-DT	753159.18	4032557.01	white lapilli tuff	**13.92 +/- 0.5**	biotite, plateau	$^{40}Ar/^{39}Ar$	Thtc	lapilli tuff, in Thumb Member within lower part of conglomeratic unit near Lime Ridge - Tramp Ridge fault.	Beard, 1996
382-20-2C	688467.32	3994479.56	tuff clasts	**14 +/- 0.3**	biotite	K/Ar	Trs	clasts of white pumice and tuff in a manganiferous sandstone bed	Koski and others, 1990
S-1	762367.40	3989229.60	tuff	**14.01 +/- 0.18**	sanidine	$^{40}Ar/^{39}Ar$	Tgwcx	considered maximum age; sampled 10 m above base of section	Swaney, 2005
23	696063.00	3985176.50	granodiorite porphyry	**14.14 +/- 0.6**	biotite	K/Ar	Tbci	Boulder City pluton, age is recalcuted from original age of 13.8. Source of recalculation is: *http://navdat.kgs.ku.edu/* #15128	Anderson and others, 1972
92-MIL-4	702775.00	3987520.00	basalt	**14.19 +/- 0.03**	whole rock, modified plateau	$^{40}Ar/^{39}Ar$	Tpm	Patsy Mine Volcanics	Faulds and others, 1999
KT82R	724223.91	4006963.46	rhyolite	**14.2 +/- 0.5**	plagioclase	K/Ar	Tdbw	rhyolite flow below Cleopatra volcanics	Thompson, 1985
04-BS-416A	719334.00	4020487.00	tuff	**14.32 +/- 0.10**	sanidine	$^{40}Ar/^{39}Ar$	Thb	tuff interbedded with Bitter Ridge Limestone	Donatelle and others, 2005
B-88-71-AR	758273.62	4026630.79	white biotite tuff	**14.4 +/- 0.3**	sanidine, plateau	$^{40}Ar/^{39}Ar$	Thtf	tuff in red clastic sediments overlying Proterozoic-clast conglomerate derived from Gold Butte	Beard, 1996
SSW2	747500.56	3986519.37	tuff	**14.46 +/- 0.07**	sanidine, laser fusion	$^{40}Ar/^{39}Ar$	Toac	Salt Spring Wash, conglomerate lateral to lower basalt	Blythe, 2005
BSQ 9 Ash 2	720941.00	4021319.00	tuff	**14.58 +/- 0.06**	sanidine	$^{40}Ar/^{39}Ar$	Thtf	between East and West Longwell Ridges	Martin, 2005
04 BSQ E1	724424.00	4018822.00	tuff	**14.85 +/- 0.07**	plagioclase	$^{40}Ar/^{39}Ar$	Thtf	Thumb Member in Echo Wash	Martin, 2005
BSQ 10	721008.00	4021015.00	tuff	**14.91 +/- 0.01**	sanidine	$^{40}Ar/^{39}Ar$	Thtf	between East and West Longwell Ridges	Martin, 2005
BC303	712268.56	3991508.84	granite	**15.1 +/- 0.6**	biotite	K/Ar	Twr	intrusive, west flank Wilson Ridge	Anderson and others, 1972

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
89-DC-1-EB	724491.56	4025628.33	greenish tuff, containing huelandite	**15.12 +/- 0.11**	sanidine, plateau	$^{40}Ar/^{39}Ar$	Thtc	tuff in Thumb Member that occurs within basal conglomerate of paleocanyon eroded into upper plate of Muddy Mountain thrust	S. Beard and L. Snee, USGS, unpublished data
B-90-33-STG	766878.00	4034913.14	white airfall tuff	**15.13 +/- 0.03**	sanidine, plateau	$^{40}Ar/^{39}Ar$	Thtf	airfall tuff on west side of Pakoon Ridge. Beds near vertical, faulted by oblique slip fault. Lower of two tuffs	Beard, 1996
KLM11140300 1	722041.00	4024267.00	tuff	**15.19 +/- 0.03**	sanidine	$^{40}Ar/^{39}Ar$	Thtf	interbedded with sedimentary breccia that overlies Paleozoic between Longwell Ridges	Martin, 2005
JF-98-308	761937.68	3993500.16	nonwelded tuff	**15.29 +/- 0.07**	sanidine, laser fusion	$^{40}Ar/^{39}Ar$	Tgwcx	tuff in older, tilted fanglomerate sequence, too small to show at 1:100,000 scale	Wallace and others, 2006
1-69-165	724870.25	4019671.50	green airfall tuff	**15.3 +/- 2.0**	zircon	fission track	Thtf	Thumb Member, Echo Wash	Bohannon, 1984
89-DC-2-DV	750197.43	4042681.49	greenish tuff, containing huelandite	**15.31 +/- 0.05**	biotite, plateau	$^{40}Ar/^{39}Ar$	Tht	tuff in Thumb Member on east side of Overton arm. Outcrop at north end of Bitter Ridge, cut by Bitter Ridge strike-slip fault	Beard, 1996
NB-5-03-5	761142.02	3993289.64	tuff	**15.34 +/- 0.05**	sanidine	$^{40}Ar/^{39}Ar$	Thu?	tuff on east side of Gregg basin (outcrop too small to show on map	Blythe, 2005
B-89-46-DT	756785.02	4037260.50	white tuff	**15.36 +/- 0.1**	biotite, total gas	$^{40}Ar/^{39}Ar$	Tht	tuff, near top of fine-grained part of Thumb Member, from west side of Gold Butte Road in Wechech Basin	Beard, 1996
89-DC-2-DV	750197.43	4042681.49	greenish tuff, containing huelandite	**15.37 +/- 0.06**	sanidine, plateau	$^{40}Ar/^{39}Ar$	Tht	tuff in Thumb Member on east side Overton arm. Outcrop at north end of Bitter Ridge, cut by Bitter Ridge strike-slip fault	Beard, 1996

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
B-89-46-DT	756785.02	4037260.50	white tuff	**15.38 +/- 0.04**	sanidine, plateau	$^{40}Ar/^{39}Ar$	Thtf	tuff, near top of fine-grained part of Thumb member, in Wechech Basin	Beard, 1996
1-67-270	718402.55	4018951.36	green airfall tuff	**15.4 +/- 0.8**	zircon	fission track	Thtf	Thumb Member, Bitter Spring Valley	Bohannon, 1984
KLM12130300 1	719895.00	4020519.00	tuff	**15.52 +/- 0.07**	biotite, plateau	$^{40}Ar/^{39}Ar$	Thtc	interbedded with conglomerate on south end of West Longwell Ridge	Martin, 2005
1-67-271	715192.27	4020351.49	green airfall tuff	**15.6 +/- 1.0**	zircon	fission track	Tht	Thumb Member, Bitter Spring Valley	Bohannon, 1984
1-14-21	685038.69	3999678.38	pyroxene-olivine andesite lava	**15.6 +/- 3.0**	whole rock	K/Ar	Thtv	Rainbow Gardens, SE of Red Needle	Anderson and others, 1972
KLM112203003	722584.00	4020993.00	tuff	**15.68 +/- 0.04**	sanidine	$^{40}Ar/^{39}Ar$	Thtc	interbedded with basal breccia, overlying Paleozoic strata at East Longwell Ridge	Martin, 2005
B-88-28a-STG	767241.54	4032024.20	white biotite-lapilli tuff	**15.7 +/- 0.15**	sanidine, plateau	$^{40}Ar/^{39}Ar$	Thtf	tuff in Thumb Member, overlying Rainbow Gardens carbonate and basaltic vent rocks at base of west side of Pakoon Ridge	Beard, 1996
B-88-28a-STG	767241.54	4032024.20	white biotite-lapilli tuff	**15.78 +/- 0.05**	biotite, plateau	$^{40}Ar/^{39}Ar$	Thtf	tuff in Thumb Member, overlying Rainbow Gardens carbonate and basaltic vent rocks at base of west side of Pakoon Ridge	Beard, 1996
1-23-1	754320.63	4041714.55	green airfall tuff	**15.9 +/- 1.9**	zircon	fission track	Thtf	Thumb Member, Wechech Basin	Bohannon, 1984
B-88-70-AR	761445.47	4023239.77	white biotite tuff	**16 +/- 0.1**	sanidine, isochron	$^{40}Ar/^{39}Ar$	Thtf	tuff in Tertiary section exposed at east end of Garden Wash, where faulted against Cambrian section along Gold Butte fault	Beard, 1996
1-121-2	687336.19	4006608.76	gray airfall tuff	**16.1 +/- 1.5**	zircon	fission track	Thtf	Thumb Member, NE of Lava Butte	Bohannon, 1984
04-BS-407A	723207.00	4019993.00	tuff	**16.15 +/- 0.12**	biotite	$^{40}Ar/^{39}Ar$	Thtl	interbedded with limestone east of East Longwell Ridge	Donatelle and others, 2005

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
04 BS 03	722190.00	4018923.00	tuff	**16.19 +/- 0.11**	biotite	$^{40}Ar/^{39}Ar$	Thtg	interbedded with gypsum southeast of East Longwell Ridge	Donatelle and others, 2005
B-90-33-STG	766878.00	4034913.14	white airfall tuff	**16.2 +/- 0.5**	biotite, plateau	$^{40}Ar/^{39}Ar$	Thtf	airfall tuff, exposed on west side of Pakoon Ridge. Beds near vertical, faulted by Pakoon Ridge oblique slip fault	Beard, 1996
1-121-3	688475.94	4005911.86	gray airfall tuff	**16.2 +/- 0.8**	zircon	fission track	Thtf	Thumb Member, NE of Lava Butte	Bohannon, 1984
1-23-2	754951.84	4042103.39	green airfall tuff	**16.3 +/- 1.9**	zircon	fission track	Thtf	Thumb Member, Wechech Basin	Bohannon, 1984
KLM111003002	722173.00	4018791.00		**16.36 +/- 0.05**	biotite	$^{40}Ar/^{39}Ar$	Thtg	interbedded with silty gypsum; lowest tuff in the area southeast of East Longwell Ridge	Martin, 2005
486-I8-1C	688467.32	3994479.56	.3 m-thick white tuff	**16.5 +/- 0.4**	hornblende	K/Ar	Trs	white tuff bed in pink tuffaceous sandstone and manganiferous sandstone. Date probably too old	Koski and others, 1990
B-91-46-GB	757366.40	4025246.42	white welded tuff	**18.81 +/- 0.25**	plateau	$^{40}Ar/^{39}Ar$	Thr	welded tuff, in recessive middle unit of Rainbow Gardens at Horse Ridge, south of Horse Spring and north of Garden Wash. Bohannon obtained an age, which he thought was too young, of 15.1 ±0.8 Ma (fission track zircon)	Beard, 1996
B-90-20a-STH	766426.53	4034189.60	white lapilli tuff	**26**	biotite, total gas	$^{40}Ar/^{39}Ar$	Thr	lapilli tuff, from Rainbow Gardens member, southwest side of Pakoon Ridge	Beard, 1996
GB-2mg	743958.72	4009305.89	biotite-muscovite granite	**65.2 +/- 0.6**	monazite, concordia	U/Pb	Kmg	location very approximate, placed within Kmg unit along Walker Wash	Brady, 1998; Brady and others, 2000

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_type	Age(Ma)	Comments	Technique	Unit	Summary	Reference
35010-2	718809.95	4032099.21	biotite-bearing vitric tuff, white member of the Baseline Sandstone	**95.8 +/- 3.5**	biotite	K/Ar	Kb	North Muddy Mountains	Carpenter and Carpenter, 1987
35017-3	723137.22	4039426.57	biotite-bearing vitric tuff, white member of the Baseline Sandstone	**96.9 +/- 3.6**	biotite	K/Ar	Kb	North Muddy Mountains	Carpenter and Carpenter, 1987

Table 2. Unpublished Geochronologic data used in Description of Map Units

Preliminary $^{40}Ar/^{39}Ar$ Data, U.S. Geological Survey

Source: M. Kunk, written communication, 2000

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_ type	Age (Ma)	Comments	Unit	Summary
H98AR-23-1	769102	4027547	basalt	**4.71 +/- 0.03**	plateau	Tgb	olivine basalt flow, basal unit. Overlies possible paleosol on top of baked (?) sandy roundstone conglomerate. Gravel overlies red fine-grained facies of Rocks of the Grand Wash trough. Mislocated? (plots too far east)
K-97-12-4I-2	735357	4030614	basalt	**6.15**	isochron	Tmv	steeply dipping above Muddy Creek Formation
K-97-12-4I-1	735357	4030614	basalt	**6.60**	isochron	Tmv	steeply dipping above Muddy Creek Formation
K-97-4-24C-1	748766	3990620	basalt	**8.39**	plateau	Tyb	overlain by fan deposits, then Hualapai Limestone, capping mesa.
K-97-4-24D-1	747578	3987700	basalt	**8.56**	plateau	Tyb	basaltic andesite volcanic neck at south end of Mesa Cove, feeds upper flow
K-97-4-24D-2	747578	3987700	basalt	**8.57**	plateau	Tyb	basaltic andesite volcanic neck at south end of Mesa Cove, feeds upper flow
K-97-12-3D-1	743601	4018188	basalt	**8.90**	isochron	Tbgb	basalts on north side of Quail Spring Wash, intercalated with fanglomerates
K-97-12-3F-2	747048	4016736	basalt	**9.14 +/- 0.05**	plateau	Tbgb	top basalt in stack of 7, Gold Butte basalts
K-97-12-3E-1	746685	4016975	basalt	**9.24 +- 0.05**	plateau	Tbgb	basal basalt in stack of 7, Gold Butte basalts
K-97-12-3B-1	743605	4018134	airfall	**10.94 +/- 0.06**	laser	Toac	airfall tuff in Quail Spring Wash, below basalt. Reworked, in tuffaceous conglomerate at top of lower tilted section
K-97-12-4G-1	735783	4019657	andesite	**11.0 +/- 0.06**	plateau	Tvc	andesite that directly overlies gypsum
K-97-12-5F	733720	4015943	andesite	**11.11 +/- 0.05**	plateau	Tvc	basalt directly overlying fine-grained sediments, east of Cleopatra volcano
K-98-5-8B-1	728805	4003648	basalt	**11.44**	isochron	Tyb	basalt on Middle Point Island, overlying sandstone, siltstone and mudstone facies of Overton Arm (**Toas**)
K-97-4-25E-1	738612	3990752	basalt	**11.48**	plateau	Tyb	youngest flow of tilted sequence, Trail Rapids Wash
K-97-4-25E-2	738612	3990752	basalt	**11.70**	plateau	Tyb	youngest flow of tilted sequence, Trail Rapids Wash
K-97-12-5B-2	739538	3996827	basalt	**11.90**	isochron	Tyb	in conglomerate below lower part of Hualapai Limestone. Outcrop where sampled too small to be shown at 1:100,000-scale, but same flow is shown directly to west
K-97-12-5G-1	736220	4019301	basalt	**11.90**	isochron	Tyb	basalt overlying sandstone, siltstone and mudstone facies of Overton Arm (**Toas**)

K-97-12-4F-1	734300	4016650	basalt	**12.04 +/- 0.07**	plateau	Tyb	olivine basalt on island east of Cleopatra volcano; overlies gypsum which overlies Cleopatra andesites
K-97-12-5G-2	736220	4019301	basalt	**12.14 +/- 0.07**	plateau	Tyb	basalt overlying sediments of Overton Arm (Toas)
K-98-5-8A-2	724218	4005055	rhyolite	**12.52 +/- 0.04**	plateau	Tbwd	Boulder Canyon dacite
K-97-12-4C-2	737546	4009668	tuff	**13.28 +/- 0.07**	laser	Thof	tuff in tilted section in Twin Spings Wash
K-97-4-25C-2	739342	3992748	pumices	**13.38 +/- 0.05**	laser	Tvsb	below Hualapai Limestone, in volcaniclastic breccias and sediments above main ignimbrite
K-97-4-26I-1	738253	3996780	tuff	**13.70**	plateau	Tri	Main ignimbrite
K-97-4-25D-2	739097	3995233	pumices	**13.81**	plateau	Tri	Main ignimbrite
K-98-5-7A-1	750053	4019162	tuff	**13.93 +/- 0.08**	laser	Thtc	upper of two tuffs in upper Lime Wash, west side of road, interbedded with Thumb Member conglomerate and breccia (Thtc)
K-97-4-24B-1	731024	3987195	basalt	**14.40**	plateau	Taf	tilted volcanic sequence below Hualapai Limestone
K-97-4-26K	737579	3986186	pyroxene andesite	**14.70**	isochron	Taf	ignimbrite exposed in Senator Mountain Quadrangle
K-97-4-24E-1	745209	3988477	basalt lahar	**14.77**	plateau	Taf	Gateway Bay, lowest of four flows, oldest flow of tilted sequence?
K-97-4-26L-2	736038	3986335	rhyolitic ignimbrite	**14.88 +/- 0.06**	laser	Tri	similar in age to main ignimbrite(?). Just south of southern quadrangle boundary
K-98-5-7D-1	765725	4029848	tuff	**15.1 +/- 0.08**	laser	Thtf	lower of two tuffs,both tuffs are steeply dipping and in the uppermost exposed part of the Thumb Member, about 40-60 ft below conglomerate (Thtc)

Tephracorrelation Data, U.S. Geological Survey

Source: A. Sarna-Wojcicki, written communication, 2002

Sample	UTM_easting (zone 11)	UTM_northing (zone 11)	Rock_ type	Age	Comments	Unit	Summary
K-97-12-4H-1	737195	4027187		**.744 Ma to 1.20 Ma**	Bishop Tuff or Glass Mountain Ash	Q2a	1 meter thick ash in alluvial fan terrace deposits. *Tephracorrelation--Bishop Ash (0.759 to 0.744 Ma, or younger Glass Mountain ash (0.79 to 1.20 Ma)*
K-97-12-5C-1	740188	3996633	ash	**6.27 +/- 0.04**	Walcott Tuff, Idaho	Th	in base of Hualapai Limestone. *Tephracorrelation--matchs K-97-4.26D,correlated to 6.27 +/- 0.04 Ma Walcott Tuff, Heise volcanic field, Idaho. Also matches FLV-116-WW, FishLake Valley, lower of two tuffs in Black Hole section of Willow Wash (Reheis and others, 1991)*

K-97-4-26D-1	732030	3998267	tuff	**6.27 +/- 0.04**	Walcott Tuff, Idaho	Tmg	lower of 2 tuffs at outcrop near top of gypsum. 40Ar/39Ar age of <=6.87 (see above). *Tephracorrelation is 6.27 +/- 0.04 Ma, Walcott Tuff, Heise volcanic field, Idaho. Also similar to FLV-115-WW, Fish Lake Valley (Black Hole section of Willow Wash , Reheis and others, 1991)*
K-97-4-25A-1	735695	4001340	tephra	**7.0 +/- 0.5**	tuff below Roblar Tuff	Th	upper tephra in Hualapai Limestone. *Tephrocorrelation is about 7.0 +/- .5 Ma. Matchs tuff about 200 m below Roblar Tuff, 6.26 Ma, San Francisco Bay area*
K-97-12-5D-1	737137	4000110	ash	**7.0 +/- 0.5**	tuff below Roblar Tuff	Th	highest of 4 ashes in Hualapai Limestone at this outcrop. *Tephracorrelation suggests probably same tuff as K-97-4-25A, at 7.0 +/- .5 Ma. Matchs tuff about 200 m below Roblar Tuff, 6.26 Ma, San Francisco Bay area*
K-97-12-5E-1	737137	4000110	ash	**9-10 Ma?**	Aldrich Station section, Walker Lake	Th	lowest of 4 ashes in Hualapai Limestone at this outcrop. *Tephracorrelation uncertain, either 9-10 Ma of Aldrich Station section west of Walker Lake or 2.14-2.22 Ma Blind Spring Valley tuff (formerly tuffs of Taylor Canyon). Based on geology, fits Aldrich Station*

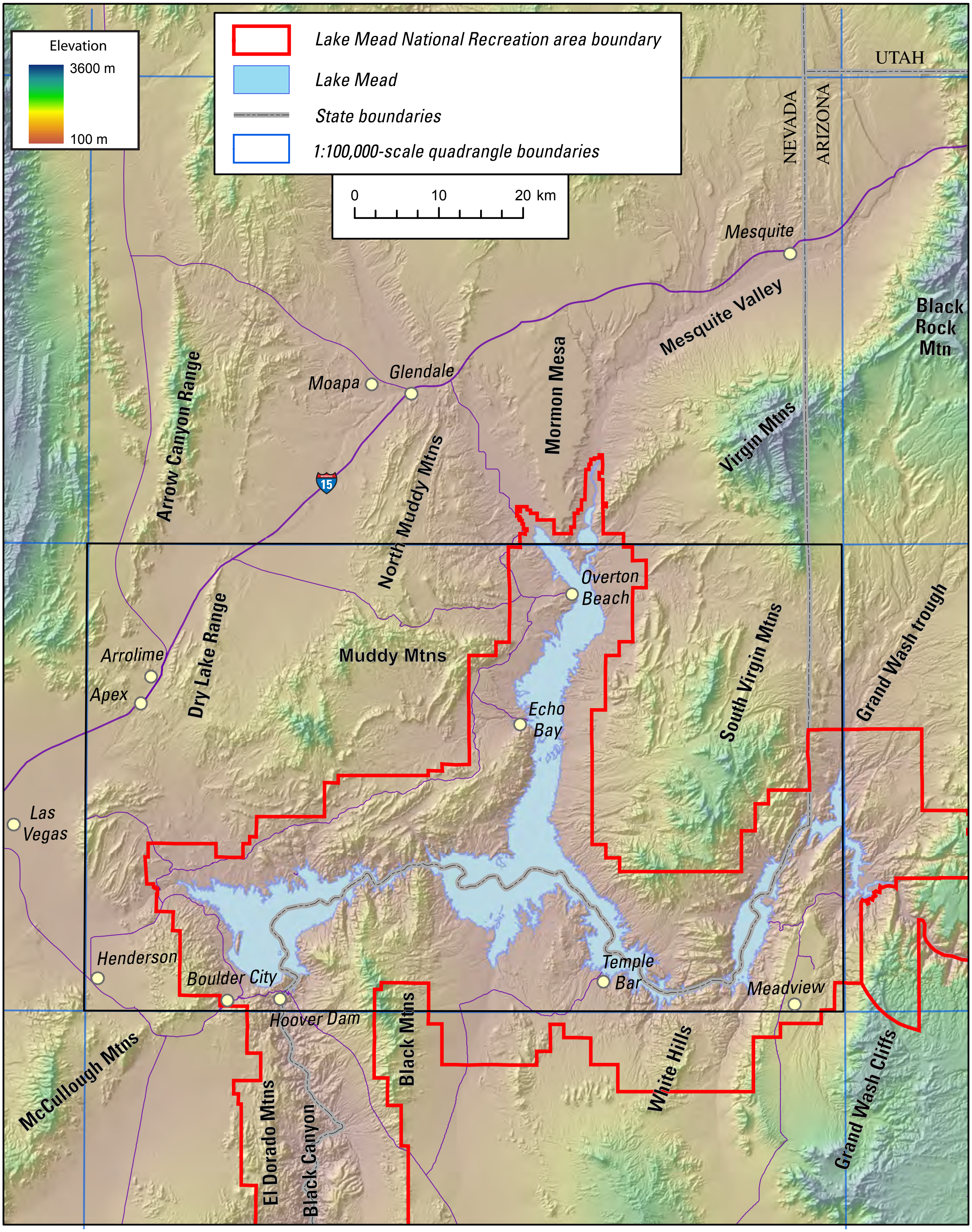

Figure 1. Location of Lake Mead relative to Lake Mead 30’ x 60’ quadrangle (heavy black box). Base is shaded-relief map created from 30-meter DEM.

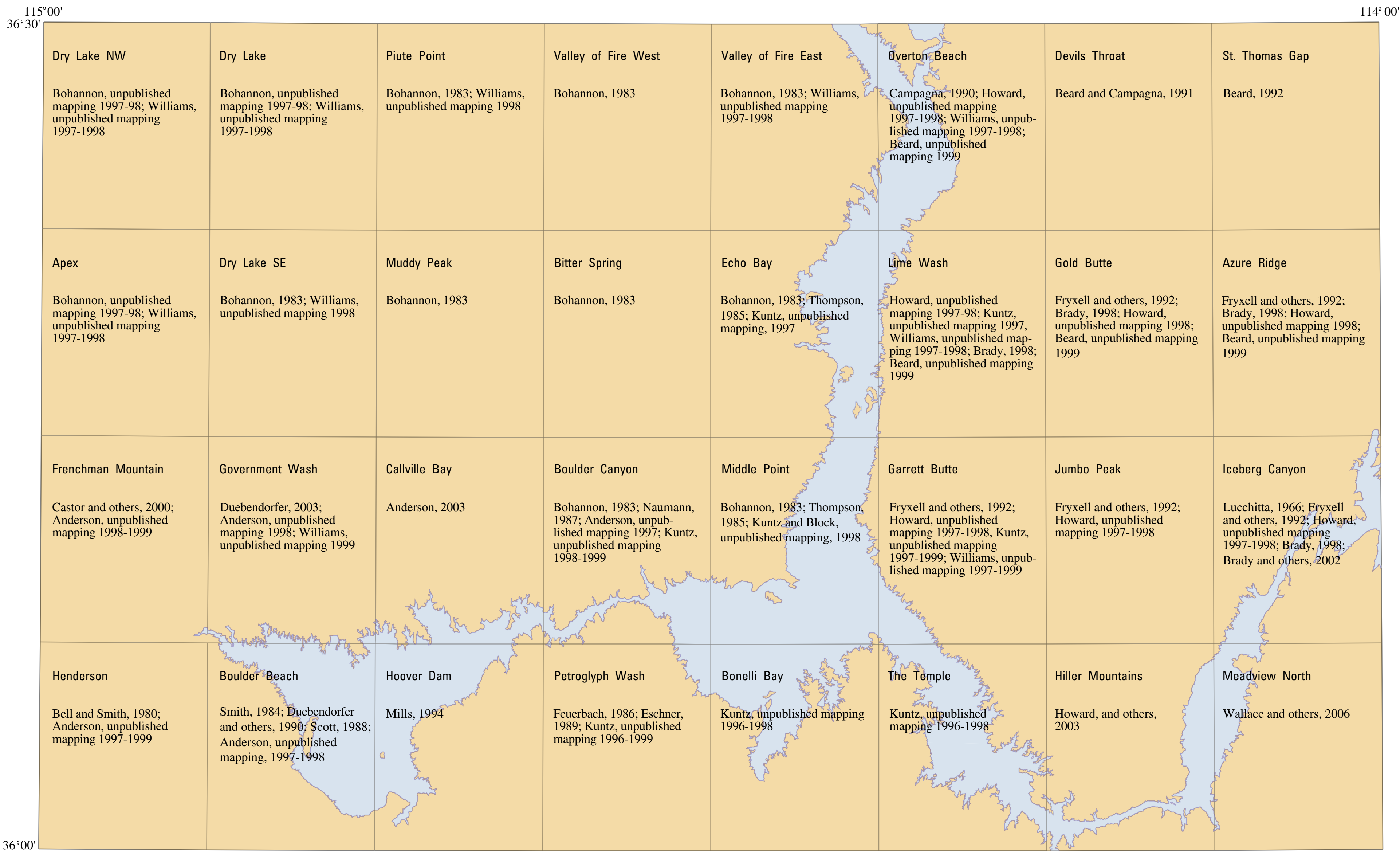

Figure 2. Lake Mead 30' x 60' quadrangle showing 7.5' quadrangles and sources of mapping used in compilation of the geologic map.

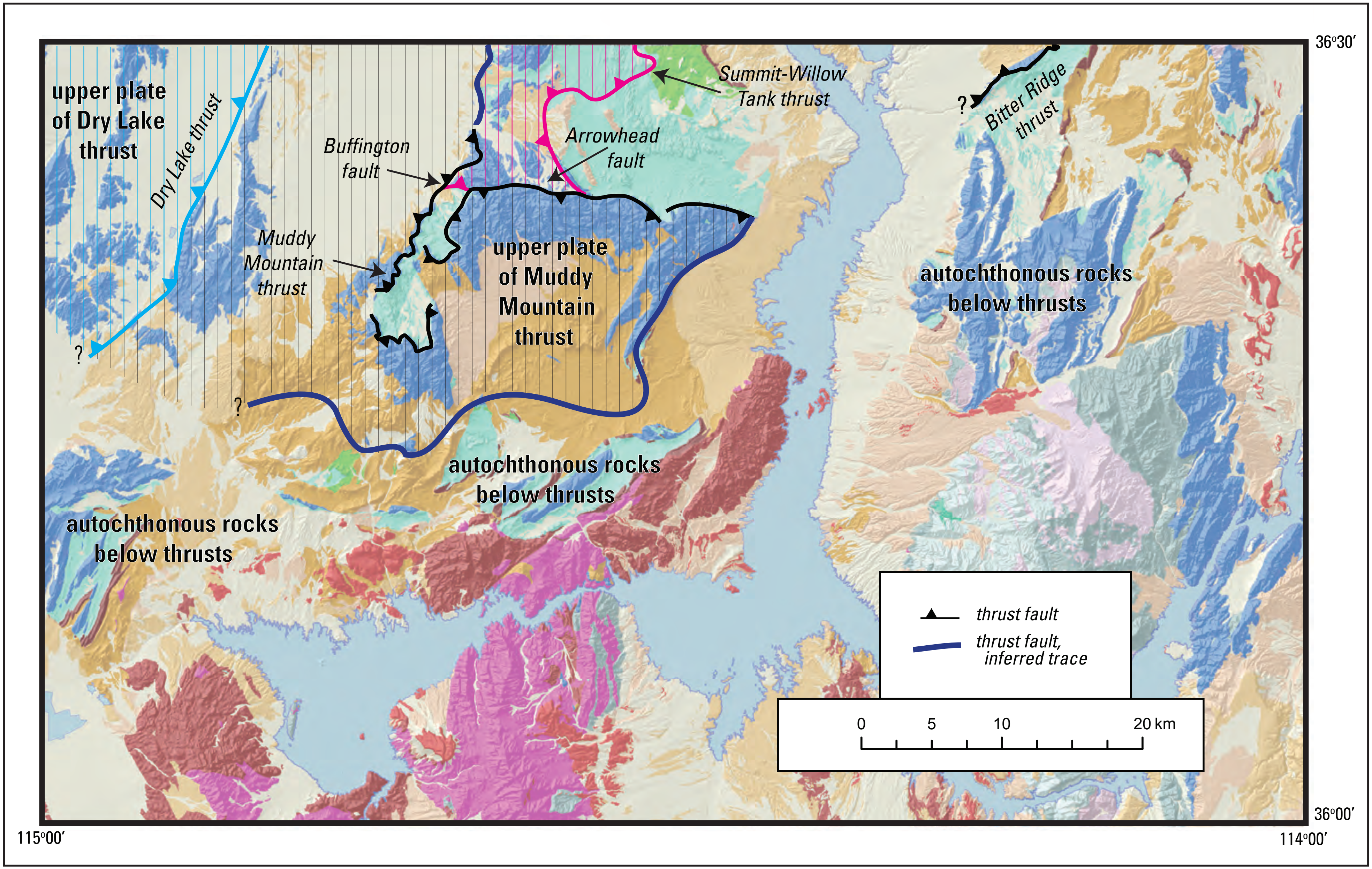

Figure 3a. Location of thrust faults and upper plate rocks for the Lake Mead 30' x 60' quadrangle. Geologic unit colors as shown in Figure 4b. Major thrust plates shown as follows: black -- Muddy Mountain thrust fault and plate; pink -- Summit-Willow Tank thrust fault and plate; blue -- Dry Lake thrust fault and plate.

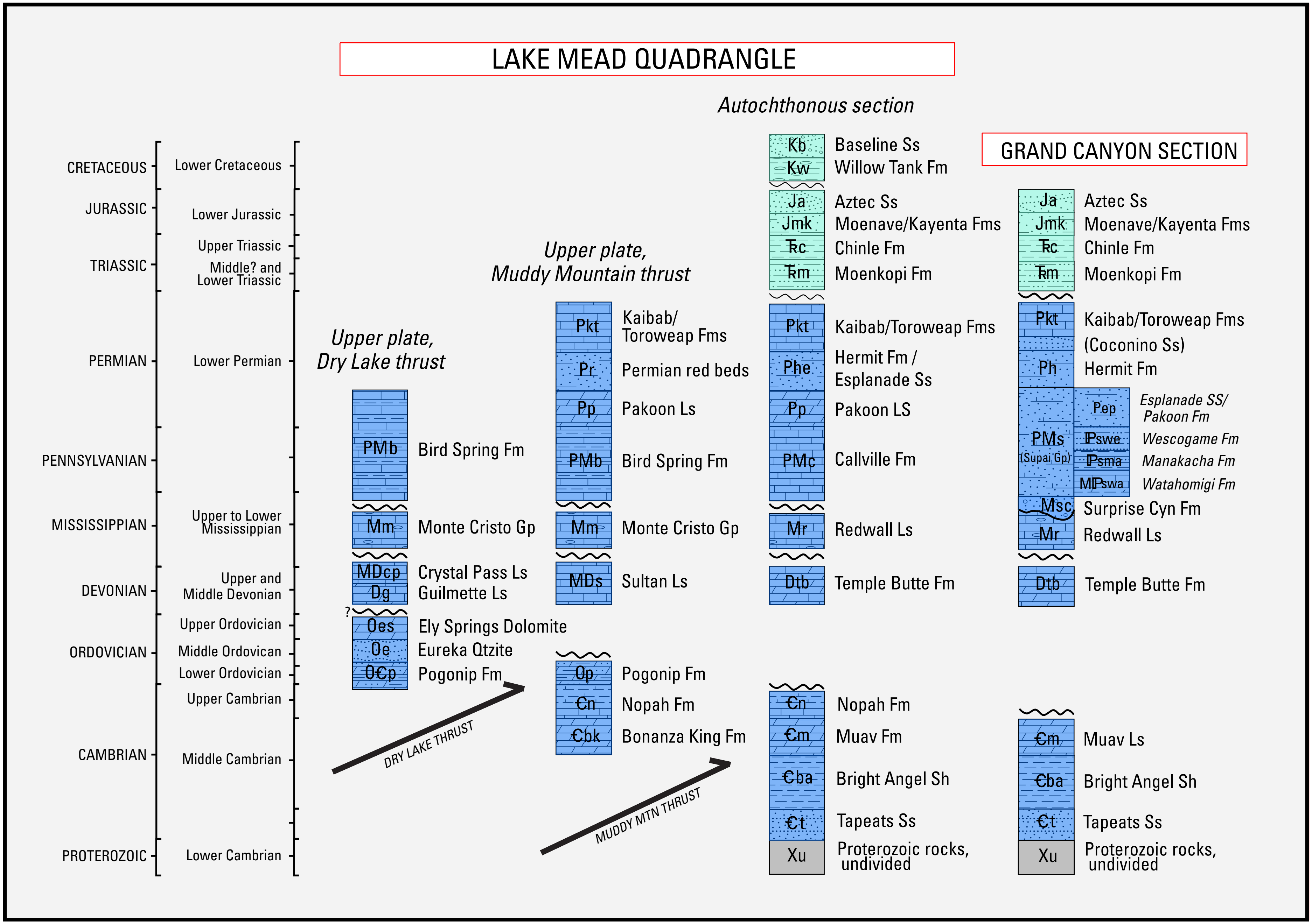

Figure 3b. Correlation chart showing stratigraphic nomenclature used for Paleozoic and Mesozoic strata in the Lake Mead 30' x 60' quadrangle. Grand Canyon section is modified from Billingsley and others (2004) and shown for comparison with autochthonous units of this map area. Unconformity between Guilmette Limestone (**Dg**) and Ely Springs Dolomite (**Oes**) in Dry Lake thrust column is queried because Devonian and Silurian strata may be in subsurface between **Dg** and **Oes** (Page and others, 2006).

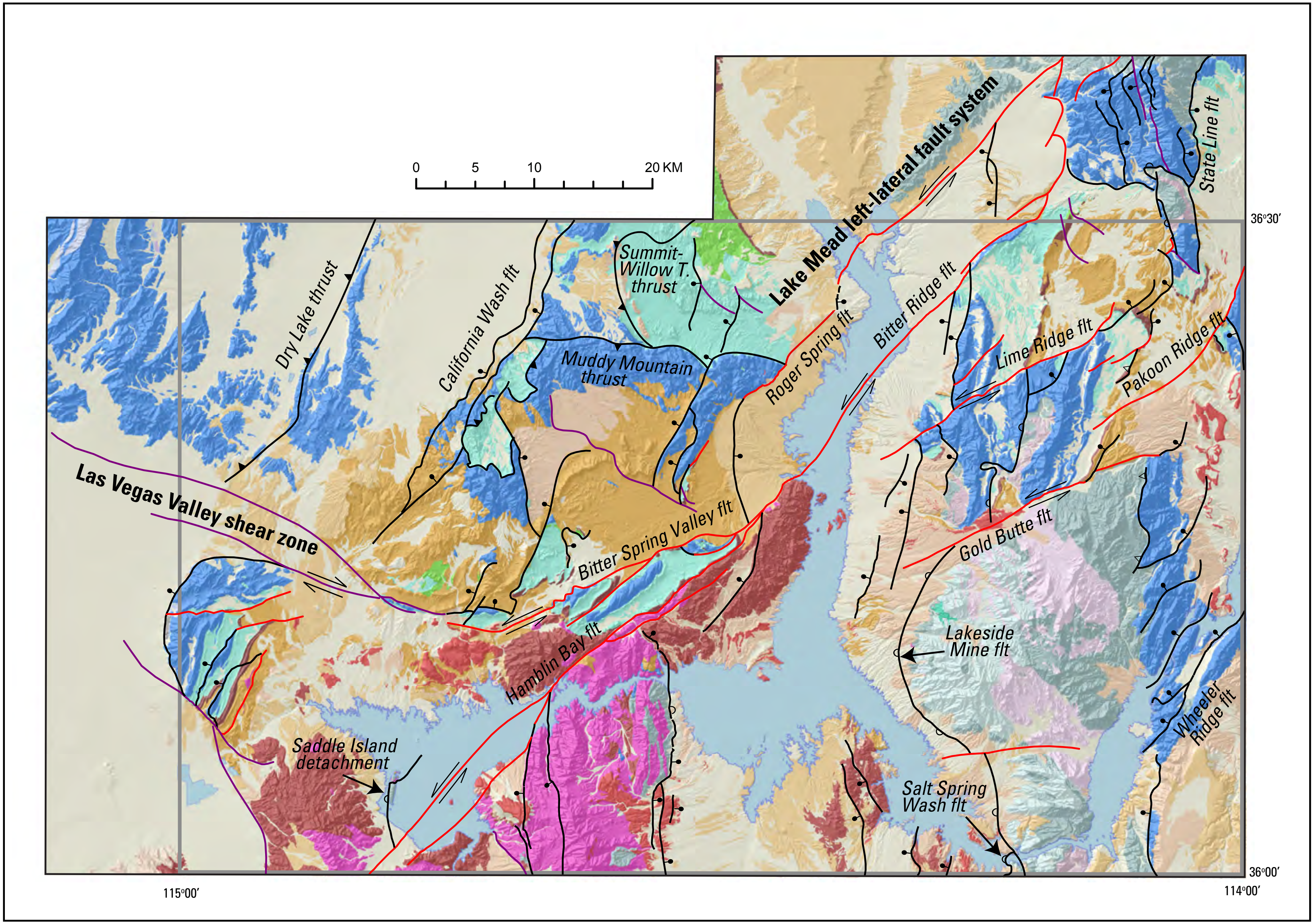

Figure 4a. Generalized geologic map of the Lake Mead Quadrangle, showing names of major faults. The area of the 30' x 60' quadrangle is shown by the gray box. Regional left-lateral strike-slip faults are shown in red, right-lateral faults are shown in purple. See explanation on Fig. 4b.

EXPLANATION

Quaternary and Late Tertiary surficial deposits

Miocene-Pliocene Muddy Creek Formation

Miocene red sandstone unit and equivalent strata

Miocene upper part of Horse Spring Formation

Oligocene-Miocene Rainbow Gardens Member of the Horse Spring Formation

Miocene basalt and basaltic andesite flows

Miocene intermediate to felsic volcanic rocks

Miocene intrusive rocks

Late Cretaceous granite

Cretaceous foreland basin deposits

Mesozoic sedimentary rocks

Paleozoic sedimentary rocks

Proterozoic rapakivi granite

Proterozoic granite

Proterozoic metamorphic rocks

Proterozoic metamorphic rocks, retrograded

Fault--normal, bar and ball on downthrown side

Low-angle normal fault--barb on upper plate

Reverse fault--barb on upthrown side

Left-lateral strike-slip fault--arrows show direction of relative motion

Right-lateral strike-slip fault--arrows show direction of relative motion

Thrust fault--barb on upper plate

Figure 4b. Explanation for generalized geology of Lake Mead 30’ x 60’ quadrangle, as shown in Figures 3a, 4a, and 5.

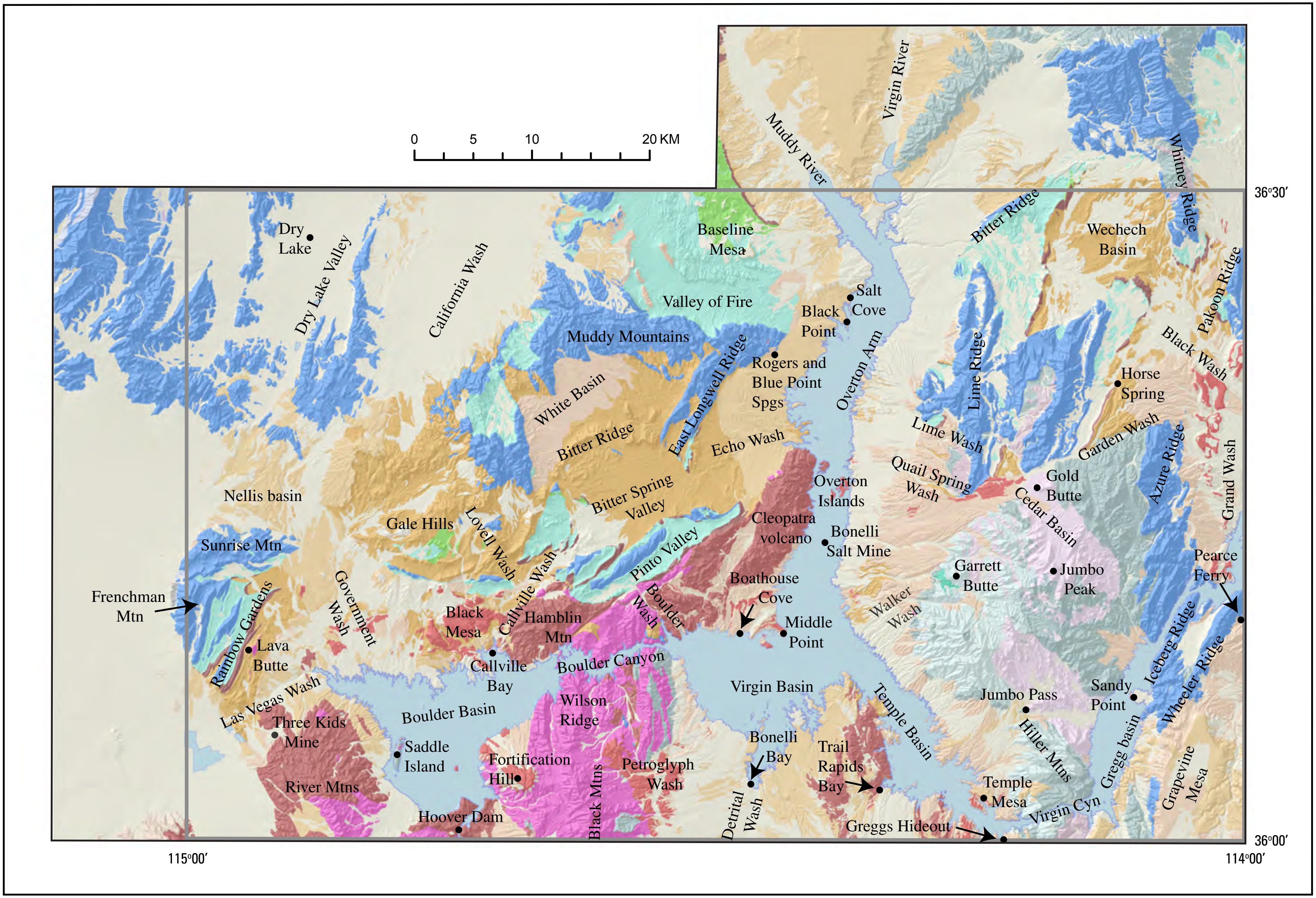

Figure 5. Geographic and cultural names used in Description of Map Units. Features mentioned in text that are not shown here are on Figure 1. Outline of the Lake Mead 30' x 60' quadrangle is shown by the gray box.