U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Lake Mead National Recreation Area

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Lake Mead National Recreation Area

lake_geology.pdf

Version: 8/28/2013

Geologic Resources Inventory Map Document for Lake Mead National Recreation Area

Table of Contents

Geologic Resources Inventory Map Document 1
About the NPS Geologic Resources Inventory Program 2
GRI Digital Map and Source Map Citation 4
Map Unit List 5
Map Unit Descriptions 12
Qdl - Disturbed land (latest Holocene) 12
Qrc - Active river channel deposits (Recent) 12
Qay - Younger alluvial deposits (Holocene and latest Pleistocene?) 12
Qai - Intermediate-age alluvial deposits (Pleistocene) 12
Qao - Older alluvial deposits (Pleistocene) 12
Qry - Young river deposits (latest Pleistocene? to Recent) 12
Qr - River deposits, undifferentiated (Pleistocene) 12
Qri - Intermediate-age river deposits (Holocene (?) and Pleistocene) 13
Qro - Older river deposits (Pleistocene) 13
Qe - Eolian deposits (Holocene and Pleistocene) 13
Spring deposits (Pleistocene) 13
Qsi - Intermediate-age spring deposits (Pleistocene) 13
Qso - Older spring deposits (Pleistocene) 13
QTtc - Talus and colluvium (Holocene, Pleistocene, and Pliocene) 13
QTl - Landslide deposits (Pliocene? to Pleistocene) 14
QTa - Oldest alluvial deposits (upper Pliocene to Pleistocene) 14
QTk - Calcrete (upper Pliocene? to low er Pleistocene) 14
QTs - Spring deposits of uncertain age (Pliocene to Pleistocene) 14
QTr - River deposits (Pliocene to Pleistocene) 14
Tk - Calcrete (low er Pliocene) 14
Ta - Alluvial fan deposits (Pliocene) 14
Tmk - Mormon Mesa calcrete (Pliocene) 15
Trb - Bullhead alluvium and equivalent age deposits (Pliocene) 15
Deposits of Jumbo Pass (Pliocene?) 15
Tj - Deposits of Jumbo Pass, limestone, conglomerate and sandstone (Pliocene?) 15
Tje - Deposits of Jumbo Pass, eolian sandstone (Pliocene?) 16
Tgc - Paleozoic-clast conglomerate in Grand Wash trough (Pliocene) 16
Tgr - Red siltstone, sandstone and conglomerate in Grand Wash trough (Pliocene) 16
Tb - Bouse Formation (Pliocene) 16
Tdh - Deposits of Hualapai Wash (Pliocene) 16
Tsu - Sedimentary rocks, undifferentiated (Miocene to Pliocene) 17
Tsy - Younger sedimentary rocks (Pliocene and upper Miocene) 17
Tsp - Pyramid gravel of House and others (2008) (Pliocene and upper Miocene) 17
Tsn - New berry Mountain fanglomerate of House and others (2008) (Pliocene and upper Miocene) 17
Tsb - Black Mountain fanglomerate of House and others (2008) (Pliocene and upper Miocene) 17
Tsmy - Intermediate-age sedimentary rocks, younger (upper and middle Miocene) 18
Tsmm - Intermediate-age sedimentary rocks, megabreccia deposits (upper and middle Miocene) 18
Tsmo - Intermediate-age sedimentary rocks, older (middle Miocene) 19
Tgb - Basalt flow s and minor gravels of Grand Wash (low er Pliocene) 19
Tgbg - Interbedded mainstream gravels (low er Pliocene) 19

Tby - Younger basalts (Pliocene and upper Miocene) ... 19
Muddy Creek Formation (Pliocene and upper Miocene) ... 20
Tm - Muddy Creek Formation, undivided (Pliocene and upper Miocene) ... 21
Tmm - Muddy Creek Formation, mainstream fluvial conglomerate and sandstone (Pliocene and upper Miocene) ... 21
Tmf - Muddy Creek Formation, sandstone, siltstone, and claystone (Pliocene and upper Miocene) ... 21
Tmt - Muddy Creek Formation, tuff beds (Pliocene and upper Miocene) ... 21
Tmc - Muddy Creek Formation, conglomerate and sandstone (Pliocene and upper Miocene) ... 21
Tmg - Muddy Creek Formation, gypsum (Pliocene and upper Miocene) ... 22
Tmv - Muddy Creek Formation, interbedded lava flows (Pliocene and upper Miocene) ... 22
Tmb - Muddy Creek Formation, breccia and landslide masses (Pliocene and upper Miocene) ... 22
Th - Hualapai Limestone (upper Miocene) ... 22
Tcm - Volcanic and sedimentary rocks of Callville Mesa, undivided (upper Miocene) ... 23
Tcm4 - Volcanic and sedimentary rocks of Callville Mesa, unit 4 (upper Miocene) ... 23
Tcm3 - Volcanic and sedimentary rocks of Callville Mesa, unit 3 (upper Miocene) ... 23
Tcm2 - Volcanic and sedimentary rocks of Callville Mesa, unit 2 (upper Miocene) ... 24
Tcm1 - Volcanic and sedimentary rocks of Callville Mesa, unit 1 (upper Miocene) ... 24
Rocks of Overton Arm (upper and middle Miocene) ... 24
Toas - Rocks of Overton Arm, sandstone, siltstone and mudstone (upper and middle Miocene) ... 24
Toag - Rocks of Overton Arm, gypsum and gypsiferous sandstone (upper and middle Miocene) ... 24
Toam - Rocks of Overton Arm, manganiferous sandstone (upper and middle Miocene) ... 25
Toac - Rocks of Overton Arm, conglomerate (upper and middle Miocene) ... 25
Toacv - Rocks of Overton Arm, conglomerate, bearing volcanic clasts (upper and middle Miocene) ... 26
Toacl - Rocks of Overton Arm, conglomerate, bearing limestone clasts (upper and middle Miocene) ... 26
Toacg - Rocks of Overton Arm, conglomerate, bearing Gold Butte Granite clasts (upper and middle Miocene) ... 26
Toab - Rocks of Overton Arm, breccia (upper and middle Miocene) ... 26
Rocks of Grand Wash Trough (upper and middle Miocene) ... 27
Tgws - Rocks of the Grand Wash Trough, sandstone and siltstone (upper and middle Miocene) ... 27
Tgwg - Rocks of the Grand Wash Trough, gypsum (upper and middle Miocene) ... 27
Tgwc - Rocks of the Grand Wash Trough, conglomerate (upper and middle Miocene) ... 28
Tgwcx - Rocks of the Grand Wash Trough, Proterozoic-clast breccia (upper and middle Miocene) ... 28
Tgwcb - Rocks of the Grand Wash Trough, limestone-clast breccia (upper and middle Miocene) ... 28
Tgwcl - Rocks of the Grand Wash Trough, conglomerate, bearing limestone clast (upper and middle Miocene) ... 28
Tgwcp - Rocks of the Grand Wash Trough, conglomerate, bearing granitic and metamorphic clast (upper and middle Miocene) ... 28
Tbo - Older basalts (middle to upper Miocene) ... 29
Tim - Mafic dikes (middle to upper Miocene) ... 29
Tqv - Quartz veins (middle to upper Miocene) ... 29
Tcv - Quartz veins (middle to upper Miocene) ... 29
Tfbr - Newberry fault breccia (middle to upper Miocene) ... 29
Red sandstone unit (upper and middle Miocene) ... 29
Trs - Red sandstone unit, undivided (upper and middle Miocene) ... 30
Trsc - Red sandstone unit, conglomerate and sandstone (upper and middle Miocene) ... 30
Trsl - Red sandstone unit, landslide mass (upper and middle Miocene) ... 30
Volcanic rocks of Hamblin-Cleopatra volcano (upper and middle Miocene) ... 30
Tvc - Volcanic and sedimentary rocks of Cleopatra volcano (upper and middle Miocene) ... 31
Tvh - Volcanic and sedimentary rocks of Hamblin Mountain, undivided (upper and middle Miocene) ... 31
Tvhu - Volcanic and sedimentary rocks of Hamblin Mountain, upper unit (upper and middle Miocene) ... 31
Tvhm - Volcanic and sedimentary rocks of Hamblin Mountain, middle unit (upper and middle Miocene) ... 32
Tvhl - Volcanic and sedimentary rocks of Hamblin Mountain, lower unit (upper and middle Miocene) ... 32
Horse Spring Formation (middle and lower Miocene and upper Oligocene) ... 32
Thu - Horse Spring Formation, undivided (middle and lower Miocene and upper Oligocene) ... 33
Horse Spring Formation, Lovell Wash Member ... 33

Thl - Horse Spring Formation, Lovell Wash Member, limestone and sandstone (middle Miocene) 33
Thlb - Horse Spring Formation, Lovell Wash Member, interbedded basalt flows and vents (middle Miocene) 33
Thof - Horse Spring Formation (?) rocks in Overton Arm (middle Miocene) 34
Horse Spring Formation, Bitter Ridge Limestone Member 34
Thb - Horse Spring Formation, Bitter Ridge Limestone Member (middle Miocene) 34
Horse Spring Formation,Thumb Member (middle Miocene) 35
Thtc - Horse Spring Formation, Thumb Member, conglomerate and conglomeratic sandstone (middle Miocene) 35
Thtf - Horse Spring Formation, Thumb Member, sandstone and siltstone (middle Miocene) 35
Thtb - Horse Spring Formation, Thumb Member, breccia and landslide masses (middle Miocene) 36
Thtg - Horse Spring Formation, Thumb Member, gypsum and gypsiferous mudstone and sandstone (middle Miocene) 36
Thtl - Horse Spring Formation, Thumb Member, limestone (middle Miocene) 36
Horse Spring Formation, Rainbow Gardens Member 36
Thr - Horse Spring Formation, Rainbow Gardens Member (lower Miocene and upper Oligocene) 36
Volcanic rocks of the River Mountains (middle Miocene) 37
Trmb - Volcanic rocks of the River Mountains, basalt flows (middle Miocene) 37
Trmvb - Volcanic rocks of the River Mountains, flows, breccias and volcanogenic sedimentary rocks (middle Miocene) 38
Trmd - Volcanic rocks of the River Mountains, dacite flows and breccias (middle Miocene) 38
Trmv - Volcanic rocks of the River Mountains, flows, domes, breccia, and volcanogenic sedimentary rocks (middle Miocene) 38
Trmip - Volcanic rocks of the River Mountains, composite plutons (middle Miocene) 38
Trmi - Volcanic rocks of the River Mountains, intrusive stock (middle Miocene) 38
Volcanic rocks of Boulder Wash (middle Miocene) 38
Tbwrb - Volcanic rocks of Boulder Wash, rhyolite flow breccias (middle Miocene) 39
Tbwr - Volcanic rocks of Boulder Wash, rhyolite flows (middle Miocene) 39
Tbwd - Volcanic rocks of Boulder Wash, dacite flows (middle Miocene) 39
Tbwdt - Volcanic rocks of Boulder Wash, dacitic tuffaceous rocks (middle Miocene) 39
Tbwdb - Volcanic rocks of Boulder Wash, breccia carapace of dacite flows (middle Miocene) 39
Mount Davis Volcanics (middle Miocene) 39
Tdv - Mount Davis Volcanics, undivided volcanic and sedimentary rocks (middle Miocene) 39
Tds - Mount Davis Volcanics, sedimentary rocks (middle Miocene) 40
Mount Davis Volcanics, upper part 40
Tdum - Mount Davis Volcanics, upper part, mafic lavas (middle Miocene) 40
Tdur - Mount Davis Volcanics, upper part, rhyolite and dacite (middle Miocene) 40
Tdri - Mount Davis Volcanics, upper part, dacite intrusion (middle Miocene) 40
Mount Davis Volcanics, middle part 40
Tdmm - Mount Davis Volcanics, middle part, mafic lavas (middle Miocene) 41
Tdmr - Mount Davis Volcanics, middle part, rhyolite and rhyodacite (middle Miocene) 41
Thd - Mount Davis Volcanics, middle part, tuff of Hoover Dam (middle Miocene) 41
Tdc - Mount Davis Volcanics, middle part, dam conglomerate (middle Miocene) 41
Mount Davis Volcanics, lower part 42
Tdlm? - Mount Davis Volcanics, lower part, mafic lavas (middle Miocene) 42
Tax - Andesite breccia of Wilson Ridge (middle Miocene) 42
Volcanic rocks near Temple Bar (middle Miocene) 42
Tob - Volcanic rocks near Temple Bar, olivine basalt and basaltic andesite flows, breccias and mudflows (middle Miocene) 42
Tvsb - Volcanic rocks near Temple Bar, volcanic sediments, breccias, mudflows and minor, thin ignimbrites (middle Miocene) 42
Trbi - Volcanic rocks near Temple Bar, rhyolite breccia and ignimbrite (middle Miocene) 43
Trbx - Volcanic rocks near Temple Bar, rhyolite breccia (middle Miocene) 43
Tri - Volcanic rocks near Temple Bar, rhyolite ignimbrite (middle Miocene) 43
Tafb - Volcanic rocks near Temple Bar, pyroxene andesite flows and breccias (middle Miocene) 43

Tab - Volcanic rocks near Temple Bar, andesite breccias and lahars (middle Miocene) 43
Taf - Volcanic rocks near Temple Bar, andesite flows and breccias (middle Miocene) 43
Tdt - Tuff of Mount Davis (middle Miocene) 43
Tbt - Tuff of Bridge Spring (middle Miocene) 44
Tt - Ash-flow tuff, undifferentiated (middle Miocene) 44
Ti - Intrusive rocks, undifferentiated (middle Miocene) 44
Wilson Ridge pluton (middle Miocene) 44
Tiw - Wilson Ridge pluton, Teakettle Pass phase (middle Miocene) 45
Tiwd - Wilson Ridge pluton, Horsethief Canyon diorite (middle Miocene) 45
Tip - Paint Pots pluton of Mills (1994) (middle Miocene) 45
Boulder City pluton (middle Miocene) 45
Tibu - Boulder City pluton, undifferentiated (middle Miocene) 45
Tib - Boulder City pluton, unaltered quartz monzonite (middle Miocene) 46
Tibb - Boulder City pluton, unaltered quartz monzonite border facies (middle Miocene) 46
Tif - Felsic dikes (middle Miocene) 46
Tii - Intermediate dikes (middle Miocene) 46
Tin - Nelson pluton (middle Miocene) 46
Tism - Spirit Mountain pluton (middle Miocene) 47
Tismu - Spirit Mountain pluton and Proterozoic gneiss, undifferentiated (middle Miocene) 47
Tisml - Spirit Mountain pluton, leucogranite (middle Miocene) 47
Aztec Wash pluton (middle Miocene) 47
Tiai - Aztec Wash pluton, intermediate rocks (middle Miocene) 47
Tiag - Aztec Wash pluton, granitic rocks (middle Miocene) 47
Searchlight pluton (middle Miocene) 48
Tisu - Searchlight pluton, upper (middle Miocene) 48
Tisl - Searchlight pluton, lower (middle Miocene) 48
Pasty Mine Volcanics (middle and lower Miocene) 48
Tpv - Patsy Mine Volcanics, volcanic rocks, undivided (middle and lower Miocene) 48
Tpu - Patsy Mine Volcanics, upper part (middle and lower Miocene) 48
Tpm - Patsy Mine Volcanics, middle part, undivided (middle and lower Miocene) 49
Tpma - Patsy Mine Volcanics, altered dacite (middle and lower Miocene) 49
Tpl - Patsy Mine Volcanics, lower part (middle and lower Miocene) 49
Volcanics of Fire Mountain (middle and lower Miocene) 49
Tf - Volcanics of Fire Mountain, undivided (middle and lower Miocene) 49
Tfu - Volcanics of Fire Mountain, upper mafic lavas (middle and lower Miocene) 49
Tfb - Volcanics of Fire Mountain, volcanic breccia (middle and lower Miocene) 50
Volcanics of Red Gap Mine (middle and lower Miocene) 50
Tg - Volcanics of Red Gap Mine, undivided (middle and lower Miocene) 50
Tgl - Volcanics of Red Gap Mine, rhyolite lava (middle and lower Miocene) 50
Tgt - Volcanics of Red Gap Mine, tuffaceous rocks (middle and lower Miocene) 50
Volcanics of Dixie Quene Mine (middle and lower Miocene) 50
Tq - Volcanics of Dixie Queen Mine, undivided (middle and lower Miocene) 50
Tqd - Volcanics of Dixie Queen Mine, dacite lavas (middle and lower Miocene) 50
Tqdd - Volcanics of Dixie Queen Mine, dacite domes (middle and lower Miocene) 51
Tu - Union Pass volcanics of Murphy (2005) (lower Miocene) 51
Tso - Older sedimentary rocks (lower Miocene) 51
Tpt - Peach Spring Tuff (lower Miocene) 51
Tcmv - Cook Mine volcanics of Ferguson (2013), undivided (lower Miocene) 51
Tca - Arkosic conglomerate (lower Miocene and Oligocene) 51
Ki - Intrusive rocks (Upper Cretaceous) 52
Kii - Ireteba pluton (Upper Cretaceous) 52
Kiw - White Rock Wash pluton (Upper Cretaceous) 52
Ja - Aztec Sandstone (Lower Jurassic) 52
Jmk - Moenave and Kayenta Formations, undivided (Lower Jurassic) 52

TRc - Chinle Formation (Upper Triassic) ... 53
TRm - Moenkopi Formation (Middle? and Low er Triassic) ... 53
Pkt - Kaibab and Torow eap Formations, undivided (Low er Permian) ... 53
Phe - Hermit Formation and Esplanade Sandstone, undivided (Low er Permian) ... 54
Supai Group (Low er Permian, Pennsylvanian, ans Upper Mississippian) ... 54
Pep - Supai Group, Esplanade Sandstone and Pakoon Limestone (Low er Permian) ... 54
PMpc - Supai Group, Pakoon Limestone and Callville Formation, undivided (Upper Mississippian to Low er Permian) ... 54
PNMs - Supai Group, undivided (Pennsylvanian and Upper Mississippian) ... 55
Ms - Surprise Canyon Formation (Upper Mississippian) ... 55
PZr - Sedimentary Rocks (Paleozoic) ... 55
Mr - Redw all Limestone (Upper and Low er Mississippian) ... 55
Mm - Monte Cristo Group (Upper and Low er Mississippian) ... 56
MDs - Sultan Limestone (Mississippian and Devonian) ... 56
Dtb - Temple Butte Formation (Upper and Middle Devonian) ... 56
Op - Pogonip Formation (Low er Ordovician) ... 56
Cu - Cambrian rocks, undifferentiated (Cambrian) ... 57
Cm - Muav Formation (Middle Cambrian) ... 57
Cba - Bright Angel Shale (Middle Cambrian) ... 57
Ctb - Tapeats Sandstone and Bright Angel Shale, undivided (Middle and Low er Cambrian) ... 57
Ydb - Diabase dikes (Mesoproterozoic) ... 57
Yig - Granitic dikes (Mesoproterozoic) ... 58
Yd - Diorite and gabbro (Mesoproterozoic) ... 58
Yg - Gold Butte Granite (Mesoproterozoic) ... 58
Yb - Granite of Burro Spring (Mesoproterozoic) ... 58
Ydg - Davis Dam granite (Mesoproterozoic) ... 58
Xu - Metamorphic and plutonic rocks, undifferentiated (Paleoproterozoic) ... 58
Xlg - Leucogranite and pegmatite gneiss (Paleoproterozoic) ... 59
Xum - Mafic and ultramafic metamorphic rocks, undivided (Paleoproterozoic) ... 59
Xgn - Gneiss, undivided (Paleoproterozoic) ... 59
Xogn - Granitic to dioritic orthogneiss (Paleoproterozoic) ... 59
Xhgn - Hornblende-biotite gneiss (Paleoproterozoic) ... 59
Xgg - Granitic gneiss (Paleoproterozoic) ... 59
Xqs - Quartz syenite gneiss (Paleoproterozoic) ... 59
Xqd - Quartz diorite gneiss (Paleoproterozoic) ... 60
Xggn - Garnet gneiss (Paleoproterozoic) ... 60
Xgp - Garnet gneiss, partly retrograded (Paleoproterozoic) ... 60
Xgr - Garnet gneiss, completely retrograded (Paleoproterozoic) ... 60
Xgc - Garnet gneiss, chloritic brecciated gneiss (Paleoproterozoic) ... 60
Xs - Schist (Paleoproterozoic) ... 60
Lake Mead NRA (Beard S., et. al, In Press) ... 61
Correlation of Map Units ... 61
Index to Geologic Mapping Sources ... 61
Map Legend ... 62
Report ... 63
References ... 64
GRI Digital Data Credits ... 76

Geologic Resources Inventory Map Document

Lake Mead National Recreation Area, Nevada and Arizona

Document to Accompany Digital Geologic-GIS Data

lake_geology.pdf

Version: 8/28/2013

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Lake Mead National Recreation Area, Nevada and Arizona (LAKE).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

For information about the status of GRI digital geologic-GIS data for a park contact:

Tim Connors
Geologist/GRI Mapping Contact
National Park Service Geologic Resources Division
P.O. Box 25287
Denver, CO 80225-0287
phone: (303) 969-2093
fax: (303) 987-6792
email: Tim_Connors@nps.gov

For information about using GRI digital geologic-GIS data contact:

Stephanie O'Meara
Geologist/GIS Specialist/Data Manager
Colorado State University Research Associate, Cooperator to the National Park Service
1201 Oak Ridge Drive, Suite 200
Fort Collins, CO 80525
phone: (970) 491-6655
fax: (970) 225-3597
e-mail: stephanie.omeara@colostate.edu

About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park

(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

Bruce Heise
Inventory Coordinator
National Park Service Geologic Resources Division
P.O. Box 25287
Denver, CO 80225-0287
phone: (303) 969-2017
fax: (303) 987-6792
email: Bruce_Heise@nps.gov

The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citation

The GRI digital geologic-GIS map for Lake Mead National Recreation Area, Nevada and Arizona (LAKE):

GRI Digital Geologic Map of Lake Mead National Recreation Area, Nevada and Arizona. (*GRI MapCode LAKE)*

Beard, S., Felger, T.J., House, P.K., and Howard, K.A., In Press, Geologic Map of the Lake Mead National Recreation Area, Nevada and Arizona, U.S. Geological Survey, Open-File Report, OR XXXX-XXXX, 1:62,500 (Lake Mead NRA). (*GRI Source Map ID 75657*).

GIS database of the source map was obtained and converted to GRI data model (v2.1), with all geologic features captured and attributed as per the source data by the GRI.

Note: This version of the GIS database and ancillary document are considered pre-review draft. Once the final USGS version has been published, the final version of the GIS database and ancillary document will be updated.

The far eastern portion of the Lake Mead NRA (LAKE) administrative boundary extends to Grand Canyon National Park and is divided into two portions. The northern portion is the NPS part of Grand Canyon-Parashant National Monument. The southern portion encompasses part of the Hualapai reservation. Lake Mead NRA currently does not actively manage these areas, and the geology of the areas is not included on the LAKE map.

The eastern edge of the LAKE map also extends into the Mount Trumbull 30' x 60' quadrangle. The geologic map of the Mount Trumbull 30 'x 60' by Billingsley and Wellmeyer (2004; see reference below) contains stratigraphic units and nomenclature in line with Colorado Plateau geology. The LAKE geologic map, however, contains stratigraphic units and nomenclature in line with the Basin and Range geology. In the area of overlap with the Mount Trumbull 30' x 60' quadrangle, the LAKE map authors reworked the data to to match the LAKE Basin and Range geologic data.

Billingsley, G.H., and Wellmeyer, J.L., 2004, Geologic Map of the Mount Trumbull 30' x 60' Quadrangle, Mohave and Coconino Counties, Northwestern Arizona, U.S. Geological Survey, Geologic Investigations Series Map I-2766, 1:100,000 scale.

The **GRI Digital Geologic Map of the Mount Trumbull 30' x 60' Quadrangle, Arizona (*GRI MapCode MTRB*)** used the Billingsley and Wellmeyer (2004) as its sole source map. Those working with both GRI maps and within the area of map overlap should simply be aware that there are differences between stratigraphic units and nomenclature, as well as possibly differing opinions on the geology between geologists of the two source maps.

Additional information pertaining to the LAKE source map is also presented in the GRI Source Map Information (LAKEMAP) table included with the GRI geology-GIS data.

Map Unit List

The bedrock geologic units present in the digital geologic-GIS data produced for Lake Mead National Recreation Area, Nevada and Arizona (LAKE) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qrc - Active river channel deposit). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (LAKEUNIT) table included with the GRI geology-GIS data.

Cenozoic Era

Quaternary Period
Qdl - Disturbed land
Qrc - Active river channel deposits
Qay - Younger alluvial deposits
Qai - Intermediate-age alluvial deposits
Qao - Older alluvial deposits
Qry - Young river deposits
Qr - River deposits, undifferentiated
Qri - Intermediate-age river deposits
Qro - Older river deposits
Qe - Eolian deposits

Spring Deposits
- Qsi - Intermediate-age spring deposits
- Qso - Older spring deposits

Quaternary and Tertiary Periods
QTtc - Talus and colluviumc
QTl - Landslide deposits
QTa - Oldest alluvial deposits
QTk - Calcrete
QTs - Spring deposits of uncertain age
QTr - River deposits

Tertiary Period
Tk - Calcrete
Ta - Alluvial fan deposits
Tmk - Mormon Mesa calcrete
Trb - Bullhead alluvium and equivalent age deposits

Deposits of Jumbo Pass
- Tj - Deposits of Jumbo Pass, limestone, conglomerate and sandstone
- Tje - Deposits of Jumbo Pass, eolian sandstone

Tgc - Paleozoic-clast conglomerate in Grand Wash trough
Tgr - Red siltstone, sandstone and conglomerate in Grand Wash trough
Tb - Bouse Formation
Tdh - Deposits of Hualapai Wash
Tsu - Sedimentary rocks, undifferentiated

Tsy - Younger sedimentary rocks
- Tsp - Pyramid gravel of House and others (2008)
- Tsn - Newberry Mountain fanglomerate of House and others (2008)

Tsb - Black Mountain fanglomerate of House and others (2008)

Tsmy - Intermediate-age sedimentary rocks, younger
Tsmm - Intermediate-age sedimentary rocks, megabreccia deposits
Tsmo - Intermediate-age sedimentary rocks, older
Tgb - Basalt flows and minor gravels of Grand Wash
Tgbg - Interbedded mainstream gravels
Tby - Younger basalts

Muddy Creek Formation
Tm - Muddy Creek Formation, undivided
Tmm - Muddy Creek Formation, mainstream fluvial conglomerate and sandstone
Tmf - Muddy Creek Formation, sandstone, siltstone, and claystone
Tmt - Muddy Creek Formation, tuff beds
Tmc - Muddy Creek Formation, conglomerate and sandstone
Tmg - Muddy Creek Formation, gypsum
Tmv - Muddy Creek Formation, interbedded lava flows
Tmb - Muddy Creek Formation, breccia and landslide masses

Th - Hualapai Limestone

Volcanic and sedimentary rocks of Callville Mesa,
Tcm - Volcanic and sedimentary rocks of Callville Mesa, undivided
Tcm4 - Volcanic and sedimentary rocks of Callville Mesa, unit 4
Tcm3 - Volcanic and sedimentary rocks of Callville Mesa, unit 3
Tcm2 - Volcanic and sedimentary rocks of Callville Mesa, unit 2
Tcm1 - Volcanic and sedimentary rocks of Callville Mesa, unit 1

Rocks of Overton Arm
Toas - Rocks of Overton Arm, sandstone, siltstone and mudstone
Toag - Rocks of Overton Arm, gypsum and gypsiferous sandstone
Toam - Rocks of Overton Arm, manganiferous sandstone
Toac - Rocks of Overton Arm, conglomerate
Toacv - Rocks of Overton Arm, conglomerate, bearing volcanic clasts
Toacl - Rocks of Overton Arm, conglomerate, bearing limestone clasts
Toacg - Rocks of Overton Arm, conglomerate, bearing Gold Butte Granite clasts
Toab - Rocks of Overton Arm, breccia

Rocks of the Grand Wash Trough
Tgws - Rocks of the Grand Wash Trough, sandstone and siltstone
Tgwg - Rocks of the Grand Wash Trough, gypsum
Tgwc - Rocks of the Grand Wash Trough, conglomerate
Tgwcx - Rocks of the Grand Wash Trough, Proterozoic-clast breccia
Tgwcb - Rocks of the Grand Wash Trough, limestone-clast breccia
Tgwcl - Rocks of the Grand Wash Trough, conglomerate, bearing limestone clast
Tgwcp - Rocks of the Grand Wash Trough, conglomerate, bearing granitic and metamorphic clast

Tbo - Older basalts
Tim - Mafic dikes
Tqv - Quartz veins
Tcv - Quartz veins
Tfbr - Newberry fault breccia

Red sandstone unit
- Trs - Red sandstone unit, undivided
- Trsc - Red sandstone unit, conglomerate and sandstone
- Trsl - Red sandstone unit, landslide mass

Volcanic rocks of Hamblin-Cleopatra volcano
- Tvc - Volcanic and sedimentary rocks of Cleopatra volcano
- Tvh - Volcanic and sedimentary rocks of Hamblin Mountain, undivided
  - Tvhu - Volcanic and sedimentary rocks of Hamblin Mountain, upper unit
  - Tvhm - Volcanic and sedimentary rocks of Hamblin Mountain, middle unit
  - Tvhl - Volcanic and sedimentary rocks of Hamblin Mountain, lower unit

Horse Spring Formation
- Thu - Horse Spring Formation, undivided

Horse Spring Formation, Lovell Wash Member
- Thl - Horse Spring Formation, Lovell Wash Member, limestone and sandstone
- Thlb - Horse Spring Formation, Lovell Wash Member, interbedded basalt flows and vents

Thof - Horse Spring Formation (?) rocks in Overton Arm

Horse Spring Formation, Bitter Ridge Limestone Member
- Thb - Horse Spring Formation, Bitter Ridge Limestone Member

Horse Springs Formation, Thumb Member
- Thtc - Horse Spring Formation, Thumb Member, conglomerate and conglomeratic sandstone
- Thtf - Horse Spring Formation, Thumb Member, sandstone and siltstone
- Thtb - Horse Spring Formation, Thumb Member, breccia and landslide masses
- Thtg - Horse Spring Formation, Thumb Member, gypsum and gypsiferous mudstone and sandstone
- Thtl - Horse Spring Formation, Thumb Member, limestone

Horse Spring Formation, Rainbow Gardens Member
- Thr - Horse Spring Formation, Rainbow Gardens Member

Volcanic rocks of the River Mountains
- Trmb - Volcanic rocks of the River Mountains, basalt flows
- Trmvb - Volcanic rocks of the River Mountains, flows, breccias and volcanogenic sedimentary rocks
- Trmd - Volcanic rocks of the River Mountains, dacite flows and breccias
- Trmv - Volcanic rocks of the River Mountains, flows, domes, breccia, and volcanogenic sedimentary rocks
- Trmip - Volcanic rocks of the River Mountains, composite plutons
- Trmi - Volcanic rocks of the River Mountains, intrusive stock

Volcanic rocks of Boulder Wash
- Tbwrb - Volcanic rocks of Boulder Wash, rhyolite flow breccias
- Tbwr - Volcanic rocks of Boulder Wash, rhyolite flows
- Tbwd - Volcanic rocks of Boulder Wash, dacite flows
- Tbwdt - Volcanic rocks of Boulder Wash, dacitic tuffaceous rocks
- Tbwdb - Volcanic rocks of Boulder Wash, breccia carapace of dacite flows

Mount Davis Volcanics

Tdv - Mount Davis Volcanics, undivided volcanic and sedimentary rocks
Tds - Mount Davis Volcanics, sedimentary rocks

Mount Davis Volcanics, upper part
Tdum - Mount Davis Volcanics, upper part, mafic lavas
Tdur - Mount Davis Volcanics, upper part, rhyolite and dacite
Tdri - Mount Davis Volcanics, upper part, dacite intrusion

Mount Davis Volcanics, middle part
Tdmm - Mount Davis Volcanics, middle part, mafic lavas
Tdmr - Mount Davis Volcanics, middle part, rhyolite and rhyodacite
Thd - Mount Davis Volcanics, middle part, tuff of Hoover Dam
Tdc - Mount Davis Volcanics, middle part, dam conglomerate

Mount Davis Volcanics, lower part
Tdlm? - Mount Davis Volcanics, lower part, mafic lavas

Tax - Andesite breccia of Wilson Ridge

Volcanic rocks near Temple Bar
Tob - Volcanic rocks near Temple Bar, olivine basalt and basaltic andesite flows, breccias and mudflows
Tvsb - Volcanic rocks near Temple Bar, volcanic sediments, breccias, mudflows and minor, thin ignimbrites
Trbi - Volcanic rocks near Temple Bar, rhyolite breccia and ignimbrite
Trbx - Volcanic rocks near Temple Bar, rhyolite breccia
Tri - Volcanic rocks near Temple Bar, rhyolite ignimbrite
Tafb - Volcanic rocks near Temple Bar, pyroxene andesite flows and breccias
Tab - Volcanic rocks near Temple Bar, andesite breccias and lahars
Taf - Volcanic rocks near Temple Bar, andesite flows and breccias

Tdt - Tuff of Mount Davis
Tbt - Tuff of Bridge Spring
Tt - Ash-flow tuff, undifferentiated
Ti - Intrusive rocks, undifferentiated

Wilson Ridge pluton
Tiw - Wilson Ridge pluton, Teakettle Pass phase
Tiwd - Wilson Ridge pluton, Horsethief Canyon diorite

Tip - Paint Pots pluton of Mills (1994)

Boulder City Pluton
Tibu - Boulder City pluton, undifferentiated
Tib - Boulder City pluton, unaltered quartz monzonite
Tibb - Boulder City pluton, unaltered quartz monzonite border facies

Tif - Felsic dikes
Tii - Intermediate dikes
Tin - Nelson pluton

Tism - Spirit Mountain pluton
Tismu - Spirit Mountain pluton and Proterozoic gneiss, undifferentiated

Tisml - Spirit Mountain pluton, leucogranite

Aztec Wash pluton
Tiai - Aztec Wash pluton, intermediate rocks
Tiag - Aztec Wash pluton, granitic rocks

Searchlight pluton
Tisu - Searchlight pluton, upper
Tisl - Searchlight pluton, lower

Patsy Mine Volcanics
Tpv - Patsy Mine Volcanics, volcanic rocks, undivided
Tpu - Patsy Mine Volcanics, upper part
Tpm - Patsy Mine Volcanics, middle part, undivided
Tpma - Patsy Mine Volcanics, altered dacite
Tpl - Patsy Mine Volcanics, lower part

Volcanics of Fire Mountain
Tf - Volcanics of Fire Mountain, undivided
Tfu - Volcanics of Fire Mountain, upper mafic lavas
Tfb - Volcanics of Fire Mountain, volcanic breccia

Volcanics of Red Gap Mine
Tg - Volcanics of Red Gap Mine, undivided
Tgl - Volcanics of Red Gap Mine, rhyolite lava
Tgt - Volcanics of Red Gap Mine, tuffaceous rocks

Volcanics of Dixie Queen Mine
Tq - Volcanics of Dixie Queen Mine, undivided
Tqd - Volcanics of Dixie Queen Mine, dacite lavas
Tqdd - Volcanics of Dixie Queen Mine, dacite domes

Tu - Union Pass volcanics of Murphy (2005)
Tso - Older sedimentary rocks
Tpt - Peach Spring Tuff
Tcmv - Cook Mine volcanics of Ferguson (2013), undivided
Tca - Arkosic conglomerate

Mesozoic Era

Cretaceous Period
Ki - Intrusive rocks
Kii - Ireteba pluton
Kiw - White Rock Wash pluton

Jurassic Period
Ja - Aztec Sandstone
Jmk - Moenave and Kayenta Formations, undivided

Triassic Period
TRc - Chinle Formation
TRm - Moenkopi Formation

Paleozoic Era

Permian Period
Pkt - Kaibab and Toroweap Formations, undivided
Phe - Hermit Formation and Esplanade Sandstone, undivided

Permian and Mississippian Periods
Supai Group
- Pep - Supai Group, Esplanade Sandstone and Pakoon Limestone
- PMpc - Supai Group, Pakoon Limestone and Callville Formation, undivided
- PNMs - Supai Group, undivided

Mississippian Period
Ms - Surprise Canyon Formation
Mr - Redwall Limestone
Mm - Monte Cristo Group

Mississippian and Devonian Periods
MDs - Sultan Limestone

Devonian Period
Dtb - Temple Butte Formation

Ordovician Period
Op - Pogonip Formation

Cambrian Period
Cu - Cambrian rocks, undifferentiated
Cm - Muav Formation
Cba - Bright Angel Shale
Ctb - Tapeats Sandstone and Bright Angel Shale, undivided

Paleozoic Era
PZr - Sedimentary Rocks

Precambrian Era

Mesoproterozoic Era
Ydb - Diabase dikes
Yig - Granitic dikes
Yd - Diorite and gabbro
Yg - Gold Butte Granite
Yb - Granite of Burro Spring
Ydg - Davis Dam granite

Paleoproterozoic Era
Xu - Metamorphic and plutonic rocks, undifferentiated
Xlg - Leucogranite and pegmatite gneiss
Xum - Mafic and ultramafic metamorphic rocks, undivided
Xgn - Gneiss, undivided

Xogn - Granitic to dioritic orthogneiss
Xhgn - Hornblende-biotite gneiss
Xgg - Granitic gneiss
Xqs - Quartz syenite gneiss
Xqd - Quartz diorite gneiss
Xggn - Garnet gneiss
- Xgp - Garnet gneiss, partly retrograded
- Xgr - Garnet gneiss, completely retrograded
- Xgc - Garnet gneiss, chloritic brecciated gneiss

Xs - Schist

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Qdl - Disturbed land (latest Holocene)

Areas where major excavation or filling has disturbed the land surface to the extent that its geologic character cannot be accurately determined. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qrc - Active river channel deposits (Recent)

Mud, sand and minor gravel in active channel of Muddy River in far northern part of the Lake Mead National Recreation Area. Channel mostly constricted because of anthropogenic changes related to roads and farming and mostly vegetated. Channel feeds into Lake Mead, and extends below high-stand lake level used in geologic map. Thickness unknown. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qay - Younger alluvial deposits (Holocene and latest Pleistocene?)

Active to recently active alluvial stream, wash, alluvial fan and piedmont deposits, composed of unconsolidated to partly consolidated silt, sand and gravel. Typically exhibits bar and channel topography, weak to no soil development, and weak to no desert pavement. Maximum thickness approximately 20 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qai - Intermediate-age alluvial deposits (Pleistocene)

Moderately to poorly sorted, weakly to moderately consolidated alluvium composed of gravel with subordinate sand and silt. Surfaces have well-developed desert pavement and moderate carbonate soil development. Commonly forms flat alluvial surfaces with 1-4 m or more incision. Thickness 0 – 20 m or more. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qao - Older alluvial deposits (Pleistocene)

Moderately to poorly sorted gravel, sand, and silt. Poorly bedded to massive, moderately consolidated. Moderately to deeply dissected deposits (5-10 m) commonly have slightly rounded surfaces, and typically mantled by strongly developed carbonate soils, Stage III or higher. Exposed thickness 5 to 20 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qry - Young river deposits (latest Pleistocene? to Recent)

Non-indurated mud, sand, and minor gravel of the Colorado and Virgin Rivers. Includes some delta deposits in the Overton Arm area where deposition is influenced by fluctuation in the level of Lake Mead. Also includes pre-dam river channel and floodplain deposits in the Bullhead City, Arizona area at the southern end of the map (Faulds and others, 2004). Other pre-dam deposits are now below lake level. Thickness unknown. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qr - River deposits, undifferentiated (Pleistocene)

Non-indurated to slightly indurated mud, sand, and gravel of the Colorado River. Unit includes distinctive strata of the Chemehuevi Formation (Lee, 1908; Longwell, 1936; Malmon and others, 2011) and a series

of younger inset terrace deposits. Maximum observed thickness of the Chemehuevi Formation ranges from approximately 30 to 140 m. Chemehuevi Formation includes a lower well-bedded, reddish-brown fluvial mud and sand overlain by a looser, poorly bedded yellow-brown to tan fluvial sand and gravel with a mixture of tributary gravels. Locally, a basal cobble-rich fluvial gravel facies is present. A tephra bed collected from the Chemehuevi Formation at three locations in the lower Colorado River corridor has an estimated age of approximately 70 ka (Malmon and others, 2011). Inset deposits are primarily gravelly fluvial terrace deposits that occur as cut-terraces and thin cut-and-fill terraces atop Chemeheuvi Formation remnants and bedrock at progressively decreasing elevation above the river (or reservoir). Unit may also include thin strath veneers on older, exhumed river gravel deposits. Thickness 0 – 140 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qri - Intermediate-age river deposits (Holocene (?) and Pleistocene)

Non-indurated to slightly indurated fluvial sediments of the Virgin and Colorado Rivers (Beard and others, 2007). Thickness unknown. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qro - Older river deposits (Pleistocene)

Non-indurated to moderately indurated fluvial sediments of the Virgin and Colorado Rivers (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qe - Eolian deposits (Holocene and Pleistocene)

Non-indurated to slightly indurated, intermittently active to inactive sand sheet and sand dune deposits. Derived from wind erosion of primarily late Pleistocene to historical channel and floodplain deposits (many now submerged beneath Lakes Mead and Mohave) of the Colorado and Virgin Rivers. Thickness 0 to as much as 5 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Spring deposits (Pleistocene)

Gray, white and tan travertine deposits, formed by chemical precipitation of calcium carbonate from springs. Deposits on east side of Overton Arm are divided into:. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qsi - Intermediate-age spring deposits (Pleistocene)

Carbonate travertine and gypsum spring deposits from outflow of Rogers and Blue Point Springs on west side of Overton Arm. Deposits inset into Qso. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Qso - Older spring deposits (Pleistocene)

Small isolated outcrops of Rogers and Blue Point Springs outflow deposits of gypsum and travertine that are topographically higher than Qsi. (*GRI Source Map ID 75657)* (Lake Mead NRA).

QTtc - Talus and colluvium (Holocene, Pleistocene, and Pliocene)

Talus and hillslope deposits composed of angular to subangular, poorly sorted cobbles and boulders of locally derived material. Widespread in recreation area but mapped only locally. Generally less than 20 m thick. (*GRI Source Map ID 75657)* (Lake Mead NRA).

QTl - Landslide deposits (Pliocene? to Pleistocene)

Rubble and massive brecciated blocks of rock that have collapsed down slope from cliffs. Includes small landslide blocks of Callville Mesa basalts (Tcm) that rim Black Mesa in Boulder Basin and large landslide blocks of basalt surrounding mesas capped by basalt flows of Grand Wash (Tgb), in far eastern part of recreation area. Other blocks are mapped along the margins of Hualapai Limestone (Th) outcrops south of Lake Mead. (*GRI Source Map ID 75657)* (Lake Mead NRA).

QTa - Oldest alluvial deposits (upper Pliocene to Pleistocene)

Poorly to well-cemented conglomerate of angular to subangular cobbles and boulders forming highly dissected (>10 m) alluvial fans with broadly rounded surfaces. Typically exhibits thick or highly eroded carbonate soil horizons (QTk). Exposed thickness approximately 10 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

QTk - Calcrete (upper Pliocene? to lower Pleistocene)

Calcrete soil deposit, developed on QTa and mapped separately in Lake Mead area 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 (*GRI Source Map ID 75657)* (Lake Mead NRA).

QTs - Spring deposits of uncertain age (Pliocene to Pleistocene)

Includes unstudied spring deposits. One small outcrop is at the southern tip of the Coxcomb east of Grand Wash Bay and is dominantly travertine that commonly encased angular talus clasts and rounded Colorado River clasts (Billingsley and Wellmeyer, 2003). Another exposure on the east side of Overton Arm includes carbonate travertine, gypsum beds, and gypsum-cemented beds of fine sediment, with local plant and animal fossils. Faulted or fault-controlled on east side of exposure. Thickness 0 – 25 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

QTr - River deposits (Pliocene to Pleistocene)

Weakly-indurated to strongly indurated deposits of the Colorado and Virgin Rivers composed of dominantly river gravel and sand, subordinate mud. Unit includes sediments occupying intermediate landscape positions between the Qr and Trb units, and may contain remnants of each of them. Thickness unknown . (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tk - Calcrete (lower Pliocene)

Thick calcrete developed on post-Muddy Creek deposits or surfaces inset into Muddy Creek Formation. Soil is stage IV-V or greater petrocalcic soil. Exposed extensively in the Overton Arm area where developed on Ta, Tmf, Tmm, and Toacg deposits. 5 to 10 m thick. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ta - Alluvial fan deposits (Pliocene)

Consolidated sand and gravel deposits of old dissected alluvial fan conglomerates. In Lake Mead area, deposited on pediment surface developed on or inset into depositional top of Muddy Creek Formation (Tm) and similar age deposits prior to deep dissection by Colorado River; 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 also Williams and others, 1997). In Lake Mohave area, includes alluvial fan deposits on southwest side of Cottonwood Valley that post-date integration of the Colorado River and intertongue with or are slightly older than Bullhead alluvium (Trb; House and others, 2008; House and Faulds, 2009). Thickness 0 – 20 m or more locally. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmk - Mormon Mesa calcrete (Pliocene)

Oldest and highest calcrete (petrocalcic soil) in the recreation area, developed on gently sloping surfaces on the Muddy Creek Formation in Overton Arm. Outcrops within recreation area are small part of large Mormon Mesa calcrete that caps mesa between the Muddy and Virgin Rivers. Brock and Buck (2009) describe calcrete as amalgam of four separate soil horizons. The development of the calcrete was interrupted by an erosional event, accompanied by eolian sedimentation, attributed to a shift to drier climate at about 3.2 to 2.8 Ma. Thickness about 1 – 4 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trb - Bullhead alluvium and equivalent age deposits (Pliocene)

Gravel, sand, silt, and minor mud of the early Colorado River (House and others, 2005, 2008). Includes a thick fluvial deposit characterized by complex sedimentary structures dominated by sand and gravel. Exposures of fluvial mud in the Bullhead alluvium occur locally but are rare overall. Unit age is between approximately 5 and 4 Ma based on tephrochronologic correlation of a volcanic ash bed below the unit and one within its upper portion (House and others, 2008) which is correlated to the 4.1 ± 0.5 Ma lower Nomlaki Tuff. Cross-cutting alluvial fan deposits in the Bullhead City area contain the 3.3 Ma Nomlaki Tuff. In Cottonwood Valley the Bullhead alluvium has an aggregate thickness of at least 230 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Deposits of Jumbo Pass (Pliocene?)

Dominantly conglomerate with subordinate limestone and sandstone. Includes talus blocks of 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; see also Howard and others, 2008; Howard and others, 2010). Deposits inferred to be related to initial downcutting of Colorado River. Subdivided into two units described below; stratigraphic relationship between two units unknown: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tj - Deposits of Jumbo Pass, limestone, conglomerate and sandstone (Pliocene?)

Light gray limestone and reddish orange sandstone and conglomerate. Limestone exhibits travertine flowstone structures, stromatolites and algal-laminated structures, as well as tubular plant casts. Encases 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 (Howard and others, 2003). Conglomerate is dominantly angular gneiss and granite-derived pebbles but also 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 unit of ‘Rocks of Overton Arm’ (Toac). Thickness about 10 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tje - Deposits of Jumbo Pass, eolian sandstone (Pliocene?)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgc - Paleozoic-clast conglomerate in Grand Wash trough (Pliocene)

Sandstone and conglomerate that underlies a series of stacked basalt flows (Tgb) that flowed down Grand Wash. Clasts include basalt derived from flows exposed in the northern Grand Wash trough, and chert, sandstone, limestone and dolomite derived from Paleozoic and Mesozoic strata. Unconformably overlies red siltstone unit (Tgr), and pinches out westward against Iceburg Ridge and east against the Cockscomb (Billingsley and others, 2004). May be laterally equivalent to Tgbg unit that is interbedded with Grand Wash basalts (Tgb) to the west. Thickness 0 – 300 m or more. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgr - Red siltstone, sandstone and conglomerate in Grand Wash trough (Pliocene)

Red to orange, slope-forming gypsiferous siltstone and medium to fine-grained sandstone. Typically very poorly exposed below Grand Wash basalts (Tgb) units in Grand Wash. Sandstone is locally channeled, and exhibits low-angle cross-stratification. Basal basalt flow on west side of Grand Wash is dated at 4.71 ± 0.03 Ma (40Ar/39Ar, Beard and others, 2007); on east side of wash the overlying flow is about 3.32 ± 0.05 Ma (Damon and others, 1996). Deposits underlie the Tgc unit on the east side of Grand Wash. Tuff samples a few meters below the top of a similar unit at the north end of the Grand Wash trough, about 35 km north of the map area, yielded tephra correlation ages of between 3.3 and 4.1 Ma (Billingsley and others, 2004), and basalt flows overlying the deposits are sourced from a volcanic field in the northern Grand Wash trough, which has a single K/Ar age of 3.7 ± 0.6 Ma (Wenrich and others, 1995). Although originally mapped as part of rocks of Grand Wash trough (Tgws; Billingsley and others, 2004) the ages indicate these deposits are younger than Tgws east of the Wheeler fault. Exposed thickness about 140 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tb - Bouse Formation (Pliocene)

Limestone, tufa, and fine-grained clastic muds, sands, and minor gravel. Unit is xposed from Cottonwood Valley to the southern end of the recreation area. Outcrops are erosional remnants that are small in extent and thin. The Bouse Formation is interpreted as deltaic to lacustrine deposits related to influx of river sediment into a lake environment. In Cottonwood and Mohave Valleys, basal limestone of the Bouse Formation overlies sediments that contain the 5.5. to 5.6 Ma Tuff of Wolverine Creek (House and others, 2005, 2008). The Bouse Formation contains the 4.78 Ma Lawlor tuff at two locations ~250 km downstream from Davis Dam. Exposed thickness 0 – 10 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdh - Deposits of Hualapai Wash (Pliocene)

Laminated quartz-rich sand, silt, massive mud, muddy diamictite, and rare rounded pebbles of chert, quartzite, and limestone. Contains gastropods. Overlies the Hualapai Limestone with no angular relation (Howard, unpublished mapping, 2013). Matmon and others (2011) report a 5.35 ± 0.65/0.97 Ma cosmogenic profile age for the deposits. Thickness 0 – 15 m. (*GRI Source Map ID 75657)* (Lake Mead

NRA).

Tsu - Sedimentary rocks, undifferentiated (Miocene to Pliocene)

Conglomerate and sandstone, exposed west of Colorado River and north of Davis Dam. Not studied in detail nor dated, but probably equivalent to Tsy or Tsmy. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tsy - Younger sedimentary rocks (Pliocene and upper Miocene)

Includes fine-grained basinal deposits that filled interior drained basins, but are now dissected and exposed because of integration and downcutting by the Colorado River and its tributaries. Mapped south of Hoover Dam, and generally equivalent in age to the Muddy Creek Formation in Lake Mead area. Deposits are fine-grained sandstone, siltstone, mudstone, gypsum, and halite. Locally includes conglomerate, tuff, and megabreccia deposits. Mostly undeformed. About 5 to 10 Ma (Felger and Beard, 2010). Interstratified at top with basalt flows dated from ~ 5.47 ± 0.06 Ma to 4.86 ± 0.027 Ma, and dissected a few 10's of meters by the time of eruption of a camptonite vent at 4.56 ± 0.01 Ma (Felger and others, 2011). Maximum exposed thickness is about 100 m.

In southern part of Cottonwood Valley, includes Lost Cabin beds of House and others (2008) and laterally equivalent alluvial fan deposits. Lost Cabin beds are fine-grained sandstone, siltstone, and mudstone with minor gravel that were deposited in a closed-basin that occupied Cottonwood Valley prior to integration of the Colorado River system. Lost Cabin beds grade laterally east, west and south into locally-derived alluvial fan deposits. A tuff near the top of the Lost Cabin beds on the east side of Cottonwood Valley was geochemically correlated to the Tuff of Wolverine Creek, at 5.59 ± 0.05 Ma (House and others, 2008). A more recently reported age for the tuff is 5.84 ± 0.03 Ma (Anders and others, 2009). Alluvial fan deposits mapped locally as: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tsp - Pyramid gravel of House and others (2008) (Pliocene and upper Miocene)

Coarse-grained fluvial conglomerate and sandstone, crudely to moderately stratified, composed of pebble to cobble-sized clasts of Davis Dam granite. Boulders up to 1 m diameter are common in the lower part of the unit. Deposited in a paleocanyon, named Pyramid Canyon, that was carved by the Colorado River as it connected Cottonwood Valley to the north with Mohave Valley (Faulds and others, 2000; House and others, 2008). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tsn - Newberry Mountain fanglomerate of House and others (2008) (Pliocene and upper Miocene)

Conglomerate and sandstone containing abundant clasts of Spirit Mountain pluton (Tsim) derived from the Newberry Mountains and deposited in alluvial fans that extended eastward from the range. The deposits grade into axial valley deposits and/or intermix with the Black Mountains fan (Tsb). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tsb - Black Mountain fanglomerate of House and others (2008) (Pliocene and upper Miocene)

Conglomerate and sandstone containing clasts of Miocene volcanic and Proterozoic crystalline rocks derived from the Black Mountains east of the Colorado River. These are alluvial fan deposits that grade westward into valley axis gravel deposits (Tsy) and intertongue with alluvial fan deposits derived from the

Newberry Mountains (Tsn) to the west. The intermixing of easterly-derived and westerly-derived alluvial fans and axial valley deposits occurs about 2 km east of the Colorado River and marks the pre-river axis of Cottonwood Valley (Faulds and others, 2000; House and others, 2008). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tsmy - Intermediate-age sedimentary rocks, younger (upper and middle Miocene)

Mainly clastic strata equivalent in age to unit mapped widely in the Lake Mead area as the informal red sandstone unit (Bohannon, 1983), in Black Canyon area as lower Muddy Creek Formation (Anderson, 1978) or by Mills (1994) as Black Mountains conglomerate, and as Quaternary-Tertiary alluvium in Cottonwood Valley (Faulds, 1996). Dominantly red to tan sandstone and conglomerate, but also includes gypsum, limestone, siltstone and mudstone in northern Black Canyon. Conglomerate clasts are mostly derived from Wilson Ridge pluton (Twr), as well as the Patsy Mine Volcanics (Tpv), Mount Davis Volcanics (Tdv), and the Paint Pots pluton (Tip). Locally includes landslide and megabreccia deposits, with largest mass mapped west of Highway 93 (Tsmm; Anderson, 1978) at top of unit. Deposited in an east-tilted fault-controlled basin between Wilson Ridge and the Colorado River in northern Black Canyon, and a west-tilted fault-controlled basin between Eldorado Mountains and the Colorado River south of Nelsons Landing. In this southern basin, dips suggest a synclinal fold along the west side. The boundary between the north and south basins is defined by the Black Mountains accommodation zone (Faulds and others, 2001). About 10 to 12 Ma. At Malpais Flattop Mesa, unit lies above a basalt flow of the upper part of the Mount Davis Volcanics (Tdv) with an age of 12.73 ± 0.30 Ma (40Ar/39Ar; Faulds and others, 1999) and below the Malpais Flattop Mesa basalts (Tbo) with ages of about 11.3 – 11.6 Ma (40Ar/39Ar; Faulds and others, 1999). East of Hoover Dam, a tuff near base of unit yielded a 40Ar/39Ar age of 11.72 ± 0.06 Ma (Williams, 2003). Near Nelsons Landing, unit includes ash-fall tuff dated at 11.53 ± 0.01 Ma (Faulds, 1996) and exposures are capped by basalt dated at 11.35 ± 0.1 Ma (Faulds, 1996) west of Opal Mountain. Exposures on northeast flank of Newberry Mountains are undated, but inferred to be part of unit based on association with Tsmm megabreccia deposits and degree of tilting. Maximum exposed thickness approximately 250 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tsmm - Intermediate-age sedimentary rocks, megabreccia deposits (upper and middle Miocene)

Paleo landslide and rock avalanche debris of predominantly Tertiary volcanic or Proterozoic rocks, exposed south of Hoover Dam. Largest mass in Black Canyon is Precambrian debris derived from the Black Mountains to the east (Anderson, 1978; Felger and others, at SPN). Interbedded with Tsmy or at contact with overlyingTsy unit. On the west side of Malpais Flattop Mesa, a landslide mass of Proterozoic debris, overlain by a lens of Tertiary volcanic debris, was probably derived from west (Anderson, 1978). Other small masses are mapped on the west flank of Wilson Ridge. North and south of Nelsons Landing and east of Fire Mountain, breccia sheets are composed of mafic lavas of Mount Davis Volcanics (Tdv) or Tuff of Bridge Spring (Tbs), one of which is intercalated in sediments stratigraphically just below an air-fall tuff dated at 11.5 Ma (Tsmy; Faulds, 1996). Landslide breccias mapped at the north end of the Newberry Mountains are composed of Proterozoic orthogneiss and are also intercalated in Tsmy sediments. Similar breccias west of Davis Dam are composed of granite, intermediate to mafic volcanic rocks, tuff, and conglomerate intercalated in the older intermediate-age sedimentary rocks (Tsmo). Maximum exposed thickness approximately 250 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tsmo - Intermediate-age sedimentary rocks, older (middle Miocene)

Sandstone, mudstone, siltstone, limestone, gypsum, and conglomerate. Exposed as northwest striking band of outcrops from Boulder City to east of Fire Mountain, and in isolated outcrops west of Davis Dam. Deposited in fault-controlled basins and subsequently faulted and folded. Locally includes megabreccia deposits and airfall tuff. East of Boulder City and just outside the recreation area, the unit contains conspicuous manganiferous gypsum. Also exposed on the west side of Malpais Flattop Mesa, on the east side of the Eldorado Mountains, and east of Fire Mountain. West of Davis Dam, rocks are conglomerates, sandstones and rock avalanche deposits that are tilted westward in the hanging wall of the Newberry Detachment fault (Roadside and Recreation conglomerates of Faulds and others, 2000). The lower Roadside is alluvial fan conglomerate that is derived from Proterozoic basement rocks and early Miocene volcanic rocks and contains numerous landslide breccias (Tsmm). The dominantly granitic clasts of the overlying Recreation conglomerate are derived almost exclusively from the Spirit Mountain pluton exposed in the footwall of the Newberry detachment fault.

Inferred to be about 12 to 16 Ma in age. At Malpais Flattop Mesa, unit lies between the lower part of the Patsy Mine Volcanics (Tpv) with a 40Ar/39Ar age of 15.72 ± 0.03 Ma (Faulds and others, 1999), and a basalt flow of the upper Mount Davis Volcanics (Tdvu) with a 40Ar/39Ar age of 12.73 ± 0.3 Ma (Faulds and others, 1999). To west of river, includes basalt flow dated at 13.68 ± 0.16 Ma (40Ar/39Ar; Gans and Bohrson, 1998). Unit is equivalent to sedimentary rocks of the Mount Davis Volcanics (Tdv). West of Davis Dam, rocks are bracketed between about 16.5 and 13 Ma (J.E. Faulds, 2013, personal commun.). Maximum exposed thickness approximately 75 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgb - Basalt flows and minor gravels of Grand Wash (lower Pliocene)

Multiple basalt flows interbedded with and underlain by sandy gravel in Grand Wash trough. 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. Basal flow on north side of Black Wash (north of recreation area) was dated at 4.71 ± 0.03 Ma (40Ar/39Ar, Beard and others, 2007). This basalt rests on paleosol developed on roundstone gravels. A basalt flow at Sandy Point that also overlies rounded river gravels is dated at 4.41 ± 0.03 Ma (Wallace and others, 2006). These flows are part of a sequence that extends north to multiple vent areas in upper Grand Wash trough. Damon and others (1978) reported a 3.24 ± 0.05 Ma age from a small outcrop on east side of the lake at Grand Wash. These flows and the eastern basalt outcrops north of Iceberg Ridge (Lava Point) may be a slightly younger set of flows. Gravel locally mapped separately as:. (*GRI Source Map ID 75657)* (Lake Mead NRA).

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tby - Younger basalts (Pliocene and upper Miocene)

Dark-gray to black basalt flows and associated pyroclastic deposits. Flows are mostly thin and vesicular. Olivine phenocrysts present in varying amounts. Exposed at Fortification Hill and at several

locations on both sides of Wilson Ridge. Typically intercalated with or overlying Tsy unit. At Fortification Hill 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. Flows further south on the west side of Wilson Ridge originate at fissures and dikes, and overlie Proterozoic basement rocks or Tsy unit. Basalt flows to the east of Wilson Ridge at Petroglyph Wash include from one to five flows that have separate sources but similar ages to Tfb at Fortification Hill. Ages range from about 4.7 to 5.9 Ma (Reynolds and others, 1986; Feuerbach and others, 1991; Felger and others, 2011). 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). More recently, basalt flows on the west side of Wilson Ridge yielded 40Ar/39Ar ages from ~ 5.47 ± 0.06 Ma to 4.56 ± 0.01 Ma, and 5.743 ± 0.014 and 5.711± 0.02 Ma at Petroglyph Wash (Felger and others, 2011). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Muddy Creek Formation (Pliocene and 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 Lake Mead area. 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 Valley and Virgin River depression to the north of the Lake Mead National Recreation Area (Stock, 1921; Bohannon and others, 1993; Schmidt and others, 1996). A basalt flow interbedded near the top of the section near Overton Beach is dated at about 6 Ma (Beard and others, 2007). North of the recreation area, near Mesquite Nevada, basalt interbedded with eolian and fluvial sediments in the uppermost Muddy Creek is dated at 4.1 ± 0.6 Ma (Williams, 1996) and may represent the uppermost surface of the basin.

A second sedimentary basin centered in the Virgin Basin area 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 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 (fig. 1) (Castor and others, 2000). Only the southeastern part of the basin is in the recreation area. Large masses of salt (halite) occur in the northern Overton Arm. 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 (Campagna and Aydin, 1994). 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 (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,

transported by an ancestral Virgin River to the Lake Mead area and deposited in the Overton Arm area. Muddy Creek Formation consists of the following units: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tm - Muddy Creek Formation, undivided (Pliocene and upper Miocene)

Sandstone, siltstone, and conglomerate exposed fringing Nellis basin northeast of recreation area, with small part of unit exposed along Lake Mead Boulevard. 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). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmm - Muddy Creek Formation, mainstream fluvial conglomerate and sandstone (Pliocene and upper Miocene)

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 Overton Arm. 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 (Williams and others, 1997, Muntean, 2012). Thickness 0 – 100 m or more. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmf - Muddy Creek Formation, sandstone, siltstone, and claystone (Pliocene and upper Miocene)

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 that are 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 and 7.00 ± 0.5 Ma (Beard and others, 2007; Howard and others, 2010) from outcrops in the Virgin Basin. Muntean (2012) reports a tephracorrelation age of 6.62 ± 0.03 for a tuff near Overton Beach. In addition, unit as mapped includes salt in the Overton Arm area, exposed only in small domes a few km south of Echo Bay (before Lake Mead) but also present in subsurface drill-holes where salt is associated with white tuffs. The salt body is composed of halite crystals stratified with glauberite, clay and tuff and is as much as 500 m thick locally. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmt - Muddy Creek Formation, tuff beds (Pliocene and upper Miocene)

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 the 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 (Beard and others, 2007). Thickness about 1-2 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmc - Muddy Creek Formation, conglomerate and sandstone (Pliocene and upper Miocene)

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 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. Main outcrop areas in recreation area 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) Northeast of Rogers and Blue Point springs (fig. 3) on the west shore of Overton Arm, where conglomerate overlies the sandstone, siltstone, and claystone unit (Tmf). Exposed thickness 40 m or more. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmg - Muddy Creek Formation, gypsum (Pliocene and upper Miocene)

Pale gray to white gypsum and evaporite deposits that occur in two main exposures, one near and north of Las Vegas Bay 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 the 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 just outside the recreation area north of Lake Mead Boulevard. The exposure in the 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. Thickness 0 to about 35 m at Pabco Mine (Castor and others, 2000). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmv - Muddy Creek Formation, interbedded lava flows (Pliocene and upper Miocene)

Mafic volcanic flows interbedded with fine-grained sediments of the Muddy Creek Formation on west side of Overton Arm near Overton Beach (Bohannon, 1984; Beard and others, 2007). 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 (in Beard and others, 2007) at 6.15 and 6.6 Ma (preliminary 40Ar/39Ar isochron ages). Thickness 0 – 10 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tmb - Muddy Creek Formation, breccia and landslide masses (Pliocene and upper Miocene)

Brecciated masses of volcanic rocks interbedded with coarse-grained Muddy Creek rocks (Tmc) on east side of River Mountains. Originally mapped by Smith (1984) as fault blocks of River Mountain volcanics that were overlapped by Muddy Creek Formation, but reinterpreted as landslide and rock avalanche deposits interbedded with conglomerate in Beard and others (2007). May actually be older, equivalent to red sandstone landslide deposits (Trsl). (*GRI Source Map ID 75657)* (Lake Mead NRA).

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.

Uppermost part of unit extends about 40 km from the Grand Wash trough (Wallace and others, 2006), westward across Gregg Basin to Temple Basin (Howard and others, 2003, 2007). 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 intertongues with deposits as old as 12 Ma (Tgws) just below the base of the limestone in Grand Wash trough. Faulds and others (2001; also Wallace and others, 2006) report an 40Ar/39Ar 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). Lopez-Pearce (2010) reports a tephracorrelation age range of 12.07 to 11.31 Ma on a tuff sampled two meters below the 11.08 Ma tuff. Tuff in the uppermost part of Hualapai Limestone in its westernmost outcrops east of Detrital Valley yielded a 40Ar/39Ar age of 5.97 ± 0.07 Ma (Spencer and others, 2001). In addition, Wallace and others (2006) report a minimum age of 7.43 ± 0.22 Ma on a tuff interbedded with limestone at Grapevine Mesa. A series of tuff samples from the Hualapai west of Temple Bar did not yield precise 40Ar/39Ar 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 (see Beard and others, 2007, and Howard and others, 2010). 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, 2009; Lopez-Pearce, 2010). Thickness in Grand Wash trough up to 300 m, in Gregg basin up to 170 m (Wallace and others, 2005). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tcm - Volcanic and sedimentary rocks of Callville Mesa, undivided (upper Miocene)

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 (40Ar/39Ar; 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). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tcm4 - Volcanic and sedimentary rocks of Callville Mesa, unit 4 (upper Miocene)

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 a 40Ar/39Ar 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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tcm3 - Volcanic and sedimentary rocks of Callville Mesa, unit 3 (upper Miocene)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tcm2 - Volcanic and sedimentary rocks of Callville Mesa, unit 2 (upper Miocene)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tcm1 - Volcanic and sedimentary rocks of Callville Mesa, unit 1 (upper Miocene)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Rocks of Overton Arm (upper and middle Miocene)

Deposits not studied in detail; informally grouped as rocks of Overton Arm by Beard and others (2007) and described by Howard and others (2010). Include sandstone, limestone, gypsum and conglomerate, deposited in basin in vicinity of Overton Arm, Virgin Basin and Temple Basin. Limestone is mapped separately as Hualapai Limestone (Th). The eastern margin of the 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). The western margin of the basin is uncertain because rocks are tilted and faulted along the east side of the Black Mountains; however, coarse-grained deposits there suggest it was nearby. Basalts intercalated near the top of the conglomerate unit (Toac) are about 8 to 9 Ma (Tbo). Locally, deposits unconformably overlie Horse Spring-age deposits in Overton Arm (Thof). However, elsewhere in basin the basal part of unit is older and is probably laterally equivalent to these rocks. Roughly equivalent to units B and C, and lower part of unit D of Howard and others (2010). Divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toas - Rocks of Overton Arm, sandstone, siltstone and mudstone (upper and middle Miocene)

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 west of Middle Point, 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 gypsum and gypsiferous sandstones (Toag) in central and western part of basin, and with conglomerate (Toac) on eastern side. Interbedded basalt (Tbo) at Middle Point dated at 11.44 Ma (preliminary 40Ar/39Ar Ma isochron age; Beard and others, 2007; Howard and others, 2010). Thickness unknown. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toag - Rocks of Overton Arm, gypsum and gypsiferous sandstone (upper and middle Miocene)

Locally very thick, extensive gypsum and gypsiferous sandstones, exposed on west side of Overton Arm at Middle Point and west side of the Black Mountains. 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 interbedded with Tbo; 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 at Middle Point. Maximum thickness about 500 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toam - Rocks of Overton Arm, manganiferous sandstone (upper and middle Miocene)

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. 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 (Trs) 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 Hoover Dam on both sides of Black Canyon (not mapped). Outcrop thickness about 10 to 50 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toac - Rocks of Overton Arm, conglomerate (upper and middle Miocene)

Alluvial fan deposits exposed predominantly on east side of Overton Arm except in vicinity of Middle Point on west side, and isolated outcrops on the east side of Black Mountains. 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. 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-White Hills detachment fault. East of the recreation area boundary, the conglomerate unit unconformably overlies conglomeratic rocks that are part of the Horse Spring age rocks of Overton Arm (see Beard and others, 2007). At this location, a tuff just above the unconformity yielded a preliminary isochron age of 8.9 Ma and basalt 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 (40Ar/39Ar, Beard and others, 2007; Howard and others, 2010). Locally as much as 175 m exposed; total thickness unknown.

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 the conglomerate unit is locally exposed by faulting east of Temple Bar. Near Greggs Hideout, Blythe (2005) reported 40Ar/39Ar 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 a 40Ar/39Ar age of 10.78 ± .4 Ma on a tuff near the top of the section, which is only tilted about 10 degrees. Conglomerate rocks with distinctive and mappable clast types indicating source areas are subdivided into:. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toacv - Rocks of Overton Arm, conglomerate, bearing volcanic clasts (upper and middle Miocene)

Alluvial fan conglomerate distinguished by abundant clasts and boulders of Gold Butte Granite (Yg) shed to the northwest from the Gold Butte area. Mostly tan to tan-gray coarse conglomerate with coarse sand matrix of decomposed granite. Locally interbedded with lenticular, coarse-grained 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. Just east of recreation area, unit is interbedded near top with basalt flows dated at about 9 Ma. Also just east of boundary, units rest unconformably on coarse-grained deposits that include a tuff dated at 10.94 ± 0.06 Ma (40Ar/39Ar, Beard and others, 2007; Howard and others, 2010). Exposed thickness about 90 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toacl - Rocks of Overton Arm, conglomerate, bearing limestone clasts (upper and middle Miocene)

Alluvial fan deposits derived from Paleozoic limestone cliffs exposed east of Overton Arm. Composed of gray angular to sub-angular cobbles to boulders of limestone and some sandstone, in poorly sorted tan to reddish-tan sandy matrix. Interbedded with Toacg in Lime Wash area, indicating coalescing of Gold Butte granite bearing and limestone-clast alluvial fans. Exposed thickness about 65 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toacg - Rocks of Overton Arm, conglomerate, bearing Gold Butte Granite clasts (upper and middle Miocene)

Alluvial fan conglomerate distinguished by abundant clasts and boulders of Gold Butte Granite (Yg) shed to the northwest from the Gold Butte area. Mostly tan to tan-gray coarse conglomerate with coarse sand matrix of decomposed granite. Locally interbedded with lenticular, coarse-grained 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. Just east of recreation area, unit is interbedded near top with basalt flows dated at about 9 Ma. Also just east of boundary, units rest unconformably on coarse-grained deposits that include a tuff dated at 10.94 ± 0.06 Ma (40Ar/39Ar, Beard and others, 2007; Howard and others, 2010). Exposed thickness about 90 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Toab - Rocks of Overton Arm, breccia (upper and middle Miocene)

Scattered outcrops exposed in eastern part of Virgin Basin and in Temple Basin. 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. Breccia outcrops are in depositional contact with partly retrograded garnet gneiss (Xgp). 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 Gold Butte area to the east. Includes other small outcrops south of Temple Basin: (1) Two small exposures interbedded with Toac just above the andesite flow and breccia unit (Tafb). (2) In the hanging wall of the Salt Spring-White Hills detachment fault, including fault breccia and landslide breccia that is the 15-14 Ma landslide breccia described by Duebendorfer and Sharp (1998). 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. Thickness typically about 75 m, but locally as much as 100 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Rocks of 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 and Iceburg ridges. Hualapai Limestone (Th) intertongues with the upper part and overlies the basin-fill deposits. Includes sandstone and siltstone (Tgws) and gypsum (Tgwg), which intertongue laterally with coarse conglomerates (Tgwc). Conglomeratic alluvial fan deposits are 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 40Ar/39Ar age of 13.94 ± 0.12 Ma for a tuff intercalated within the sandstone and siltstone unit about 2 km north of Pearce Ferry. In addition, older 40Ar/39Ar ages of 15.34 ± 0.05 Ma (Blythe, 2005, Blythe and others, 2010) 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: (*GRI Source Map ID 75657*) (Lake Mead NRA).

Tgws - Rocks of the Grand Wash Trough, sandstone and siltstone (upper and middle Miocene)

Pale reddish brown to light-brown interbedded sandstone, siltstone and minor mudstone with thin 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. Laterally intertongues with and overlies conglomerate (Tgwc); 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). Thickness unknown; thickest exposures north of Grapevine Mesa are up to 300 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgwg - Rocks of the Grand Wash Trough, gypsum (upper and middle Miocene)

Gray, slope-forming, interbedded gypsum, gysiferous siltstone and siltstone. Overlies and in part laterally interlayered with Tgws unit; underlies and locally intertongues with lowest Hualapai limestone beds. Tephracorrelation age of ‘slightly older than 11.93 Ma’ reported on tuff at base of unit where intertongues with Tgws northeast of north end of the Cockscomb (Billingsley and others, 2004). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgwc - Rocks of the Grand Wash Trough, conglomerate (upper and middle Miocene)

Gray to tan boulder to cobble conglomerate and conglomeratic sandstone deposits representing alluvial fan facies. Deposits are mostly derived from local highlands such as Grand Wash Cliffs or Wheeler Ridge/Cockscomb 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 the South Virgin Mountain highlands 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:. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgwcx - Rocks of the Grand Wash Trough, Proterozoic-clast breccia (upper and middle Miocene)

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 (Wallace and others, 2006). Also crops out along or near southern margin of southern paleochannel. Swaney (2005) obtained a 40Ar/39Ar maximum age of 14.01 ± 0.18 for a tuff within 10 m of the base of the section at the southern paleochannel. Thicknesses from about 10 to 80 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgwcb - Rocks of the Grand Wash Trough, limestone-clast breccia (upper and middle Miocene)

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. Occurs in isolated outcrops on the east side of Azure Ridge, west of Pearce Ferry, in the southern paleochannel, and overlying the southern end of Wheeler Ridge. Individual breccia lenses from a few meters to as much as 80 m thick. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgwcl - Rocks of the Grand Wash Trough, conglomerate, bearing limestone clast (upper and middle Miocene)

Chiefly composed of limestone clasts derived from ridges formed by tilted Paleozoic rocks. Unit is mostly exposed mostly along east side of Azure Ridge. Exposures represent alluvial fan deposits shed westward from Grand Wash Cliffs. Exposed thickness about 120 m but probably much thicker in subsurface. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgwcp - Rocks of the Grand Wash Trough, conglomerate, bearing granitic and metamorphic clast (upper and middle Miocene)

Exposed on south, east and north sides of Wheeler Ridge/Cockscomb and Azure Ridge where rests with angular unconformity on east-tilted ridges of Paleozoic strata. Derived from basement rocks exposed in Gold Butte area and includes distinctive cobbles to boulders of the rapakivi-textured Gold Butte granite (Yg). Total thickness unknown; up to 250 m exposed. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tbo - Older basalts (middle to upper Miocene)

Dark-gray to black olivine basalt flows and associated pyroclastic deposits. Includes Malpais Flattop Mesa and flows in the Virgin Basin and Temple Basin areas. Equivalent in age to basalts of Callville Mesa (Mills, 1994). Basalts at Malpais Flattop Mesa are about 11.3-11.6 Ma (40Ar/39Ar; Faulds and others, 1999). Basalt flows in Virgin-Temple basins area are interbedded with the rocks of Overton Arm except west of Temple Bar where they unconformably overlie older basalts (Tbo). Ages range from ~ 12.1 to ~ 8.4 Ma (see Beard and others, 2007, for more detail). Maximum thickness approximately 100 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tim - Mafic dikes (middle to upper Miocene)

Includes basalt and basaltic andesite dikes, exposed throughout the Lakes Mead and Mohave area. Northernmost exposures are parallel to and along or near the Roger Springs and Bitter Ridge strike-slip faults in the Overton Arm area. At Hoover Dam, north to northeast-striking dikes and sills intrude volcanic rocks. East of Hoover Dam, numerous northerly striking dikes intrude the Wilson Ridge pluton, Paint Pots pluton, and intermediate-age sedimentary rocks (Tsmy). The longest of these dikes strike north and are most likely the feeder vents for younger basaltic flows at Fortification Hill. Across the Colorado River east from Nelsons Landing, mostly east-northeast striking mafic dikes cut the Fire Mountain volcanic rocks and are probably cogenetic (Faulds, 1996). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tqv - Quartz veins (middle to upper Miocene)

Quartz-filled linear fractures. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tcv - Quartz veins (middle to upper Miocene)

Calcite-filled linear fractures. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tfbr - Newberry fault breccia (middle to upper Miocene)

Brecciated rock along Newberry detachment fault. (*GRI Source Map ID 75657)* (Lake Mead NRA).

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 (Beard and others, 2007) and Rocks of the Grand Wash trough (Bohannon, 1984) as 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. More recent ages obtained on interbedded tuffs and volcanic rocks range from 10.05 ± 0.03 Ma (40Ar/39Ar whole rock age on interbedded basalt flow, Anderson and others, 1994) to at least as old as 11.70 ± 0.08 Ma (40Ar/39Ar on biotite, Harlan and others, 1998) but younger than a 12.93 ± 0.10 Ma age (40Ar/39Ar biotite age, Harlan and others, 1998) obtained on a hornblende biotite dacite clast within a megabreccia block (Trsl). Castor and others (2000) obtained a 40Ar/39Ar 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. 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, Beard and others (2007), based on mapping by R.E. Anderson, 2003) map these rocks as red sandstone unit, suggesting that the Koski and others (1990) dates are too old. Consists of: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trs - Red sandstone unit, undivided (upper and middle Miocene)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trsc - Red sandstone unit, conglomerate and sandstone (upper and middle Miocene)

Tan, tan-gray and pinkish-gray conglomerate and sandstone deposits, poorly bedded to thin .5 to 1 m beds. Exposed north of the Muddy Mountains, where deposits fill paleocanyons cut into Paleozoic rocks and contain angular clasts of Paleozoic rocks. Thickness 0 – 40 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trsl - Red sandstone unit, landslide mass (upper and middle Miocene)

Massive landslide breccia and debris-flow deposit described in detail by Anderson (2003). Composed of Tertiary porphyritic granodiorite probably derived from Wilson Ridge area to east and south. (*GRI Source Map ID 75657)* (Lake Mead NRA).

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 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. However, because of differing dating techniques and unsystematic sampling, these differences are not considered significant. Consists of the following units: (*GRI Source Map ID 75657*) (Lake Mead NRA).

Tvc - Volcanic and sedimentary rocks of Cleopatra volcano (upper and middle Miocene)

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. Preliminary 40Ar/39Ar ages of 11.0 ± 0.06 and 11.11 ± 0.05 Ma (Beard and others, 2007) were obtained from exposures of upper flows east of Cathedral Peaks south of Echo Bay; 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. 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 (Tob) and the volcanics of Boulder Wash (see below) are lateral volcanic equivalents to the upper part of the Hamblin-Cleopatra stratovolcano; all these volcanic rocks are interstratified with the 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 north-northeast (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 breccias. The lower sequence flows are intermediate in composition and mostly lava flows. 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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tvh - Volcanic and sedimentary rocks of Hamblin Mountain, undivided (upper and middle Miocene)

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. Anderson (2003; also Anderson and others, 1994) reports two 40Ar/39Ar ages for the Tvh unit: 10.07 ± 0.07 and 11.71 ± 0.03 Ma; see his report for detailed mapping and descriptions. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tvhu - Volcanic and sedimentary rocks of Hamblin Mountain, upper unit (upper and middle Miocene)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tvhm - Volcanic and sedimentary rocks of Hamblin Mountain, middle unit (upper and middle Miocene)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tvhl - Volcanic and sedimentary rocks of Hamblin Mountain, lower unit (upper and middle Miocene)

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

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 (Thl, Thlb), Bitter Ridge Limestone (Thb), Thumb (Thtc, Thtf, Thtb, Thtg, Thtl), and Rainbow Gardens (Thr) 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 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). More recently, Hickson and others (2010) and Anderson (2012) restricted the age of the Bitter Ridge Limestone to 14.5 to 13.7 Ma, and the Lovell Wash from 13.7 to older than 11.9 Ma (the oldest age of the overlying red sandstone unit (Trs). We consider the revised range of the two upper members to be from 14.5 to ~ 13.0 Ma, slightly younger than basalt flows at or near the top of the Lovell Wash (Thlb).

Bohannon (1984) bracketed the Thumb Member to be between 17.2 and 13.5 Ma in age. In the south Virgin Mountain area this unit is more tightly constrained between ~16.2 and 14.2 Ma (Beard, 1996). New 40Ar/39Ar 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). Anderson (2012) reports ages for the Thumb ranging from about 16.5 to 14.5 Ma. We consider the Thumb Member age to be most likely between about 14.2 to ~ 17 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 40Ar/39Ar ages ranging from ~26.0 to less than 18.8 Ma in the south Virgin Mountains. 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.

Clastic deposits that are age equivalent to the upper Horse Spring rocks are mapped in the Overton Arm area as Thof. Rocks inferred to be age-correlative but not dated are mapped as Thu. (*GRI Source Map ID 75657)* (Lake Mead NRA).

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 an outcrop at Saddle Island on west side of Lake Mead and one at the southern end of Wheeler Ridge. 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 Thumb Member of the Horse Spring Formation. 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 40Ar/39Ar age of 15.29 ± .07 Ma on sanidine from a tuff in the sequence. Blythe (2005) reported a similar 40Ar/39Ar 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. Most likely equivalent to Thumb Member. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Horse Spring Formation, Lovell Wash Member

Thl - Horse Spring Formation, Lovell Wash Member, limestone and sandstone (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 band from east side of Frenchman Mountain 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 40Ar/39Ar 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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Thlb - Horse Spring Formation, 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 (40Ar/39Ar) 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 Bay. The western vent area yielded a 40Ar/39Ar age of 13.16 ± 0.18 Ma (Castor and others, 2000), and the eastern vent a 40Ar/39Ar 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 (40Ar/39Ar, 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. We use the dates on these flows to suggest the Lovell Wash is probably not much younger than about ~ 13 Ma. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Thof - Horse Spring Formation (?) rocks in Overton Arm (middle Miocene)

Unstudied clastic rocks, correlative in age to Horse Spring Formation, exposed in isolated outcrops on the southeast side of Overton Arm. Consists of fine grained sandstones (Thof) and conglomerates that are exposed just east of the recreation area boundary (see Beard and others, 2007). Largest exposures of fine-grained deposits form low, poorly exposed outcrops of upward coarsening sequence of yellow sandstone with interbedded conglomerate and tuff. 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. Preliminary 40Ar/39Ar age of 13.28 ± 0.07 Ma was reported for a tuff in Thof north of Walker Wash (Beard and others, 2007; Howard and others, 2010). Thickness unknown. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Horse Spring Formation, Bitter Ridge Limestone Member

Thb - Horse Spring Formation, Bitter Ridge Limestone Member (middle Miocene)

Exposed in the Lake Mead area, from the east side of Frenchman Mountain to White Basin, mostly outside the recreation area boundary. At White Basin the limestone forms a prominent, south-facing cliff up to 375 m thick (Bohannon, 1984). The member is almost exclusively a distinctive thick-bedded, algal-laminated limestone with teepee structures, oncolitic textures, and stromatolitic bioherms. East of Frenchman Mountain, 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 40Ar/39Ar 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 40Ar/39Ar 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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Horse Spring Formation,Thumb Member (middle Miocene)

Most widely distributed member of the Horse Spring Formation. Includes fine-sandstone and siltstone (Thtf), limestone (Thtl), gypsum and gypsiferous siltstone and mudstone (Thtg), cobble to boulder conglomerate and conglomeratic sandstone (Thtc), and breccia and landslide masses (Thtb). Interbedded mafic volcanic rocks 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 south Virgin Mountain area, Beard (1996) demonstrated that the rapid facies changes were the result of deposition during active extensional tectonism. Divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Thtc - Horse Spring Formation, Thumb Member, conglomerate and conglomeratic sandstone (middle Miocene)

Tan to reddish-tan to gray coarse clastic conglomerates and conglomeratic sandstones, laterally interfingering with or overlying fine-grained deposits (Thtf) and gypsum (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). Just outside the recreation area 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 a 40Ar/39Ar 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 (40Ar/39Ar, sanidine, Beard and others, 2007), 13.92 ± 0.5, and 14.4 ± 0.3 Ma (40Ar/39Ar, Beard, 1996). Thickness highly variable, ranging from 0 to at least 400 m.

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 (2003) reinterpreted the deposit as a Thumb-age angular-clast conglomerate intruded by the pluton. Unit is about 400 m thick. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Thtf - Horse Spring Formation, Thumb Member, sandstone and siltstone (middle Miocene)

Dominant lithofacies of Thumb exposed from east side of Frenchman Mountain and the south Virgin Mountains east of the recreation area to Overton Arm. 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 and are dated from about 16.5 to 15.1 Ma (Beard and others, 2007; Anderson, 2010). 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. (*GRI Source Map ID 75657)* (Lake

Mead NRA).

Thtb - Horse Spring Formation, Thumb Member, breccia and landslide masses (middle Miocene)

Widely distributed in Lake Mead region (Beard and others, 2007). 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, and are intercalated into the Thtf unit. Distinctive breccia deposits of rapakivi granite and other lithologies in the Frenchman Mountain area (mostly outside the map area northwest of Las Vegas Bay) are common to the Gold Butte area and have been used to suggest that the Frenchman Mountain structural block has been tectonically transported to the west as much as 60 km (e.g., Anderson, 1973, Rowland and others, 1990, Fryxell and Duebendorfer, 2005, Umhoefer and others, 2010). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Thtg - Horse Spring Formation, Thumb Member, gypsum and gypsiferous mudstone and sandstone (middle Miocene)

Widespread facies of Thumb deposits, but mapped separately only on the west side of White Basin (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 rocks (Thtf) or algal limestone (Thtl). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Thtl - Horse Spring Formation, Thumb Member, limestone (middle Miocene)

Exposed in recreation area along the north side of the Echo Hills, but also found outside the area at East Longwell Ridge, Frenchman Mountain, and the south 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 in the south Virgin Mountain area by Beard (1996; Beard and Campagna, 2012) and to overlie an unconformity at the top of the Rainbow Gardens.

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 unit in the south Virgin Mountains 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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Horse Spring Formation, Rainbow Gardens Member

Thr - Horse Spring Formation, 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, along North Shore Drive of the Lake Mead National Recreation Area, and 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 root casts. Many of the limestone beds towards the base are pedogenically overprinted, interpreted as occurring in a palustrine environment (Beard, 1996). In the south 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 the overlying Thum conglomerate containing pebble-sized clasts of the karsted rocks. 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). (*GRI Source Map ID 75657)* (Lake Mead NRA).

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 River Mountains (Bell and Smith, 1980, Smith, 1984; also Beard and others, 2007). 40Ar/39Ar ages reported by Faulds and others (1999) range from 13.45 Ma on dacite flows to 12.17 Ma on the youngest basalt flow. Honn (2012) reported U-Pb zircon ages of 12.66 to 13.83 Ma and an antecryst date of 14.49 Ma (a crystal that predates the volcanic system but grew in an earlier pulse of the same magma system. K/Ar ages from 13.2 to 11.8 Ma obtained by Anderson and others (1972) are generally within this range. Divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trmb - Volcanic rocks of the River Mountains, basalt flows (middle Miocene)

Basalt flows interbedded with agglomerate and breccia, as well as minor andesitic flows. Basalts of several varieties, including: (1) basalt with phenocrysts of augite and plagioclase in a grayish purple matrix; (2) basalt with porphyritic olivine phenocrysts up to 0.5 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 40Ar/39Ar age of 12.17 ± 0.02 Ma for the uppermost flow in this sequence at the north end of the River Mountains. Estimated maximum thickness approximately 100 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trmvb - Volcanic rocks of the River Mountains, flows, breccias and volcanogenic sedimentary rocks (middle Miocene)

Dark purple basalt flows and breccia and volcanogenic sedimentary rocks. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trmd - Volcanic rocks of the River Mountains, dacite flows and breccias (middle Miocene)

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 40Ar/39Ar age of 13.0 ± 0.02 Ma on a flow from this unit in the northeast part of the River Mountains. Honn (2012) obtained a U-Pb zircon age of 13.55±0.42 Ma from a hypabyssal dacite sill of the stratovolcano. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trmv - Volcanic rocks of the River Mountains, flows, domes, breccia, and volcanogenic sedimentary rocks (middle Miocene)

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). Estimated maximum thickness is approximately 300 m. Honn (2012) reported a U-Pb zircon age of 13.12± 0.38 Ma from a dacite intrusion and 13.12±13.12 from a rhyolite dome. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trmip - Volcanic rocks of the River Mountains, composite plutons (middle Miocene)

Composite plutons formed mostly by plugs and dikes of porphyritic dacite, andesite and rhyodacite that surround intrusive stock (Trmi). 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. Faulds and others (1999) report a 40Ar/39Ar age of 13.45 ± 0.02 Ma on a 'dacite flow' of this unit and Honn obtained U-Pb zircon ages of 13.83±0.34 and 13.75±0.52 Ma. Includes numerous zenoliths of highly altered andesite and Paleozoic limestone. (Smith, 1984). (*GRI Source Map ID 75657*) (Lake Mead NRA).

Trmi - Volcanic rocks of the River Mountains, intrusive stock (middle Miocene)

Fine to medium grained composite quartz monzonite pluton bearing plagioclase, orthoclase, and biotite. Fine-grained texture near edge of pluton resembles dacite. This is River Mountain stock of Honn and Smith (2008), dated by Faulds and others (1999) at 13.23 ± 0.01 Ma (40Ar/39Ar), and by Honn (2012) at 13.83±0.34 Ma and 13.75±0.42 Ma (U-Pb zircon). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Volcanic rocks of Boulder Wash (middle Miocene)

Rhyolite and dacite flows, breccia, and tuff exposed between Cleopatra lobe of Hamblin-Cleopatra volcano to the east and Wilson Ridge to the west (Naumann, 1987; Beard and others, 2007). Dacite units include flows (Tbwd), carapace breccia (Tbwdb) and local tuffaceous deposits (Tbwdt). Thompson (1985) reported a K/Ar age of 14.2 ± 0.05 Ma for a dacite flow; a preliminary 40Ar/39Ar age of 12.52 ± 0.04 Ma was also obtained on a dacite flow (Beard and others, 2007). 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 (Tbo). Rhyolitic flows (Tbwr) and flow breccias (Tbwrb) mostly overlie the gypsum, except at the eastern limit where they overlie Tbo 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 (Beard and others, 2007). 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. Subdivided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tbwrb - Volcanic rocks of Boulder Wash, rhyolite flow breccias (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tbwr - Volcanic rocks of Boulder Wash, rhyolite flows (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tbwd - Volcanic rocks of Boulder Wash, dacite flows (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tbwdt - Volcanic rocks of Boulder Wash, dacitic tuffaceous rocks (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tbwdb - Volcanic rocks of Boulder Wash, breccia carapace of dacite flows (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Mount Davis Volcanics (middle Miocene)

Named by Longwell (1963) for outcrops near Mount Davis, Arizona, and further described by Anderson (1971, 1977, 1978) and Anderson and others (1972). The Mount Davis includes volcanic rocks ranging in composition from rhyolite to basalt, interbedded with clastic and volcaniclastic deposits and in age from about 12.6 to 15.1 Ma. A detailed volcanic stratigraphy for the Mount Davis Volcanics in the vicinity of Hoover Dam was defined by Mills (1994). Felger and others (at SPN) divided the Mount Davis into upper, middle and lower parts, and interbedded sedimentary rocks. The lower part is not exposed within the recreation area. Descriptions are slightly modified from Felger and others, (at SPN). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdv - Mount Davis Volcanics, undivided volcanic and sedimentary rocks (middle Miocene)

Mostly mafic volcanic flows tentatively correlated to Mount Davis rocks. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tds - Mount Davis Volcanics, sedimentary rocks (middle Miocene)

Clastic and volcaniclastic rocks interbedded with volcanic units of the middle and upper Mount Davis sequence. Includes red and brown sandstone and conglomerate of fluvial and alluvial origin, and white and pale yellow glassy tuffaceous sedimentary rocks, massive air-fall tuff, and lithic tuffs. Maximum thickness approximately 125 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Mount Davis Volcanics, upper part

Upper Mount Davis rocks include mafic lava flows (Tdum) and rhyodacite and dacite flows (Tdur) and intrusions (Tdri) that unconformably overlie or intrude the Boulder City pluton, and generally are only gently tilted. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdum - Mount Davis Volcanics, upper part, mafic lavas (middle Miocene)

Basalt and basaltic andesite flows that post-date upper Mount Davis rhyodacite and dacite (Tdur). The Kingman Wash Road basaltic andesite (Mills, 1994) exposed east of Hoover Dam is most of the unit and has an age of 12.57 ± 0.03 Ma (40Ar/39Ar; Faulds and others, 1999). Basalt lavas with an age of 12.73 ± 0.30 Ma (40Ar/39Ar; Faulds and others, 1999) are intercalated with fanglomerate (Tsmy and Tsmo) underlying Malpais Flattop Mesa. A small outcrop of basalt exposed along highway 60 in the Eldorado Mountains is 13.06 ± 0.06 Ma (40Ar/39Ar; Gans and Bohrson, 1998). Maximum thickness approximately 50 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdur - Mount Davis Volcanics, upper part, rhyolite and dacite (middle Miocene)

Dacite and rhyodacite lava flows and domes in north part of Black Canyon that form prominent brown and tan cliffs, generally with pale yellow zeolitized slope forming lower part composed of tuffaceous bedded sediments and autoclastic flow breccia. Locally includes a basal vitrophyre visible as a gray zone below the brown cliffs, which are formed by the dense, interior part of the flow. Flows are commonly flow-foliated; gray to pinkish or purplish on a fresh surface. Phenocrysts of biotite, hornblende, and plagioclase are present in varying amounts and proportions; sparse quartz present in some flows. Flows are erupted from multiple vents. Includes Sugarloaf and Black Canyon dacite (units Tsd and Tbc of Mills, 1994), Lava of No Name Mesa (unit Tl of Ekren and Anderson, 1996), and unnamed flows and domes on the east side of Black Canyon. Sugarloaf dacite is 13.11 ± 0.02 Ma (40Ar/39Ar; Faulds and others, 1999), and Lava of No Name Mesa is 13.10 ± 0.10 Ma (40Ar/39Ar; Gans and Bohrson, 1998). Maximum thickness approximately 100 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdri - Mount Davis Volcanics, upper part, dacite intrusion (middle Miocene)

Linear dacite dikes and irregular shaped massive intrusions. Many are intruded along faults, and most are inferred to be the feeder systems for the vents that produced the upper Mount Davis dacite and rhyodacite flows and domes (Tdur). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Mount Davis Volcanics, middle part

Rocks of the middle Mount Davis Volcanics include mafic lava flows (Tdmm), rhyolite and rhyodacite (Tdmr), and the Tuff of Hoover Dam (Thd) and Dam conglomerate (Tdc) of Mills (1994). Units of the middle Mount Davis are widely exposed on both sides of Black Canyon, unconformably overlie the Patsy Mine Volcanics, and may be intruded by or coeval with the Boulder City pluton. They range in age from

about 14.2 to 13.3 Ma. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdmm - Mount Davis Volcanics, middle part, mafic lavas (middle Miocene)

Dense to vesicular dark-gray to black olivine basalt and basaltic andesite, that vary from aphanitic to porphyritic. Comprises the bulk of the Mount Davis section. Outcrops previously mapped as Fortification Basalts west of the Colorado River have been assigned to this unit based on stratigraphic relationships and geochronology. A 40Ar/39Ar age of 13.268 ± 0.032 Ma (Felger and others, at SPN) from a basalt sample was collected about 1.5 miles northeast of Boulder City from outcrops that had previously been mapped as Fortification basalt (Anderson and Ekren, 1996, Anderson, 1977). Geochronology suggests that the middle mafic lavas have a lower and upper sequence, with the Tuff of Hoover Dam (Thd) and the felsic lavas of the middle Mount Davis (Tmdr) occupying the middle. Ages for the lower sequence are 14.2 to 14.1 Ma (40Ar/39Ar; Gans and Bohrson, 1998, Faulds and others, 1999). Ages for the upper sequence are 13.77 to 13.27 Ma (40Ar/39Ar; Gans and Bohrson, 1998; Felger and others, at SPN). Maximum thickness approximately 125 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdmr - Mount Davis Volcanics, middle part, rhyolite and rhyodacite (middle Miocene)

Mostly quartz-free rhyolite, rhyodacite, and dacite. Fresh surfaces are pale red, gray, and yellowish gray; weathers reddish brown and tan. Phenocrysts are dominantly plagioclase and biotite; sanidine is conspicuous in some flows and quartz and hornblende are present in trace amounts in some flows. Exposed east and south of Boulder City along the west side of Black Canyon. A flow at the southern end of the outcrops yielded an age of 14.06 ± 0.04 Ma (40Ar/39Ar; Gans and Bohrson, 1998). Maximum thickness approximately 250 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Thd - Mount Davis Volcanics, middle part, tuff of Hoover Dam (middle Miocene)

Gray brown to white, poorly to moderately welded lithic ash-flow tuff with dacitic composition, bearing phenocrysts of plagioclase, biotite, and hornblende. Lithic fragments include Patsy Mine Volcanics and Wilson Ridge pluton(?). About 180 m thick in vicinity of Hoover Dam. Thickness decreases dramatically south where interbedded with clastic and volcaniclastic deposits. Unit has not been identified on the west side of Black Canyon. 40Ar/39Ar age of 13.88 ± 0.1 Ma obtained from base of tuff (Mills, 1994, Faulds and others, 1999). Honn (2012) reports a U-Pb zircon age of 14.3 ± 0.42 Ma. Mapped and described in detail by Smith (1984), and Mills (1985, 1994). Included with the middle part of the Mount Davis Volcanics by Felger and others (at SPN) based on stratigraphic position and age. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdc - Mount Davis Volcanics, middle part, dam conglomerate (middle Miocene)

Dam Breccia of Ransome (U.S. Bureau of Reclamation, 1950). Crudely to moderately stratified, dark red and reddish brown conglomerate and sandstone. Conglomerate is typically clast-supported and poorly sorted, with angular, gravel- to boulder-sized clasts of Patsy Mine Volcanics, Boulder City (?) pluton, and sparse Proterozoic lithologies. Locally grades into a red volcaniclastic sandstone that in places has well-sorted, well-rounded grains, and well-developed planar bedding and cross-bedding. Marks the unconformity between the underlying Patsy Mine Volcanics and overlying middle Mount Davis Volcanics from Hoover Dam to about 2.5 km south. About 4 km further south, red, well-sorted, well-bedded sandstone is observed (but not mapped) at the unconformity between the Patsy Mine and middle Mount Davis Volcanics and may be equivalent (Felger and others, at SPN). Maximum thickness approximately 100 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Mount Davis Volcanics, lower part

Rocks of the lower Mount Davis include rhyolite and rhyodacite and mafic lava flows that range in age from about 15.1 to 14.9 Ma (Gans and Bohrson, 1998, Felger and others, at EPN), and are moderately to steeply tilted. Only mafic lavas inferred to be part of the lower Mount Davis are within the recreation area. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdlm? - Mount Davis Volcanics, lower part, mafic lavas (middle Miocene)

Dark gray and dark grayish red-purple andesite flows above the Tuff of Bridge Spring (Tbt), not studied in detail and correlation to lower Mount Davis rocks is uncertain. Where exposed west of Nelson just outside the recreation area boundary, the unit includes as many as 16 andesite flows with a total thickness of up to 275 m. Distinctly porphyritic varieties contain about 25 percent phenocrysts of plagioclase, augite, and altered olivine with minor altered orthopyroxene as individual grains and as cores surrounded by augite. Principal accessory minerals are iron oxides and apatite. Ages range from 15.1 to 15.00 Ma (40Ar/39Ar; Gans and Bohrson, 1998). (*GRI Source Map ID 75657)* (Lake Mead NRA).

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 to south of recreation area. Volcanic clasts are unaltered, unlike underlying altered and propylitized Patsy Mine Volcanics (Tpm). Source is enigmatic; age is bracketed as younger than ~ 15.1 Ma. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Volcanic rocks near Temple Bar (middle Miocene)

Tob - Volcanic rocks near Temple Bar, 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 mixed volcanic unit (Tvsb) and is locally overlain by conglomerates of Overton Arm (Toac). Overlies 13.38 Ma Tvsb unit and is older than or interstratified with Thof containing 13.28 Ma tuff. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tvsb - Volcanic rocks near Temple Bar, 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 40Ar/39Ar age of 13.38 ± 0.05 Ma (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trbi - Volcanic rocks near Temple Bar, 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. 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. Total thickness is about 10 m. Three 40Ar/39Ar ages from this unit yielded preliminary ages of 13.90, 13.81 and 13.70 Ma (Beard and others, 2007). Locally mapped as: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Trbx - Volcanic rocks near Temple Bar, rhyolite breccia (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tri - Volcanic rocks near Temple Bar, rhyolite ignimbrite (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tafb - Volcanic rocks near Temple Bar, 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 40Ar/39Ar ages of 14.40, 14.70 and 14.77 Ma (Beard and others, 2007), indicate equivalent in age to middle part of Mount Davis Volcanics (Tdmm). Base of unit not exposed but exposed thickness exceeds 600 m. Locally mapped as: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tab - Volcanic rocks near Temple Bar, andesite breccias and lahars (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Taf - Volcanic rocks near Temple Bar, andesite flows and breccias (middle Miocene)

No further unit description. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tdt - Tuff of Mount Davis (middle Miocene)

Poorly welded, rhyolitic ash-flow tuff containing phenocrysts of sanidine, biotite, clinopyroxene and plagioclase with rare sphene. Also contains lithic fragments of basalt. Dated at 14.97 ± 0.02 Ma (Faulds, 1995); distinguished from Tuff of Bridge Spring by poor degree of welding, larger sanidine crystals, and abundant lithic fragments. Exposed on east side of Lake Mohave west of Mount Perkins. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tbt - Tuff of Bridge Spring (middle Miocene)

Welded to non-welded, gray to pale-red, quartz-free rhyolitic ash-flow tuff; purplish-gray andesitic lithic inclusions are common. Phenocrysts of sanidine, plagioclase, biotite, augite, and hornblende are present in varying amounts and proportions. Sphene is principal accessory mineral present in variable amounts. Where exposed about 6 km west of Nelsons Landing, consists of two cooling units that total up to about 180 m thick. Mapped along Lake Mohave from north of Willow Beach to Mount Davis. Originally mapped and described by Anderson (1971), the tuff is inferred to have been erupted from a caldera in the northern Eldorado Mountains (Gans and others, 1994). 40Ar/39Ar ages from outcrops near the type section west of Nelsons Landing in the Eldorado Mountains range from 15.03 ± 0.06 to 15.34 ± 0.06 Ma (Gans and Bohrson, 1998). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tt - Ash-flow tuff, undifferentiated (middle Miocene)

Undated ash-flow tuff units mapped south of Lake Mead and in small outcrop at Black Mountain south of Copper Mountain. Probably correlates to Tuff of Mount Davis or Tuff of Bridge Spring. Beard and others (2007; also Howard and others, 2010) report a date of 14.88 Ma ± 0.06 Ma from the southernmost outcrop on the east side of Detrital Valley that is within the recreation area. In Salt Spring Wash, the unit was dated at 15.19 ± 0.1 Ma (40Ar/39Ar, sanidine; Duebendorfer and others, 2010). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ti - Intrusive rocks, undifferentiated (middle Miocene)

Includes numerous dikes throughout recreation area not differentiated by composition, mapped both as linear dikes and as larger intrusive masses in Lake Mead area found in three main areas in northern part of the recreation area. Clusters of dikes form distinctive patterns; intermediate to mafic dikes that form distinctive radial pattern in both Hamblin and Cleopatra volcanic lobes. At Wilson Ridge, late stage dikes are in a northerly array, whereas at River Mountains the strikes are easterly. A series of northwest striking dikes that are northwest of Nelson Landing and intrude the lower Patsy Mine Volcanics (Tpl) are part of the Eldorado dike swarm. North to northwest-striking late-stage dikes in the Searchlight pluton range in composition from granitic to basaltic and are part of the Newberry dike swarm (Walker, 2006). Three areas of larger mappable intrusive masses include: 1) a small basaltic intrusion that occurs along Wheeler Fault at the north end of the Cockscomb. 2) Intrusive masses closely associated with Hamblin-Cleopatra volcano, exposed from Echo Bay to Callville Bay, are medium- to dark-gray intrusive andesite and dacite, weakly porphyritic to equigranular. Anderson (2003; also Anderson and others, 1994) reported a 40Ar/39Ar Ma age of 11.9 ± 0.04 from an outcrop just north of Hamblin Mountain. Small masses and dikes in the Callville Bay area just west of Hamblin Mountain are mostly sills in fine-grained Thumb (Thtf) or red sandstone unit (Trs) deposits. 3) Aphyric to porphyritic dacite dikes intrude faults in the Boulder City pluton along its northern edge (Smith, 1984; Beard and others, at SPN; Felger and others, at SPN). (*GRI Source Map ID 75657)* (Lake Mead NRA).

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, 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, and the more voluminous Teakettle Pass suite (not mapped separately). Honn (2012) indicates the oldest phase of the pluton is the monzodiorite of Wilson Ridge, exposed on the southeast margin of the pluton and is intruded by the Horsethief Canyon diorite. 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 the Saddle Island 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 Horsethief Canyon suite and 13.5 ± 0.4 Ma on Teakettle Pass rocks. The northern end of the pluton, exposed in Boulder Canyon reach of Lake Mead, yielded younger 40Ar/39Ar 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 300oC, whereas older ages were presumed to reflect emplacement age. More recent U-Pb zircon dates by Honn (2012) indicate ages from 15.18 ± 0.31 for the monzodiorite of Wilson Ridge to 13.29 ± 0.38 Ma on a rhyodacite dike that cuts the Teakettle Pass suite. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tiw - Wilson Ridge pluton, Teakettle Pass phase (middle Miocene)

Unfoliated biotite-quartz monzonite and locally foliated hornblende quartz diorite, monzodiorite and hornblende monzodiorite. Contacts between units are gradational. Contains abundant enclaves of basalt and diorite (Larsen and Smith, 1991; Honn, 2012). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tiwd - Wilson Ridge pluton, Horsethief Canyon diorite (middle Miocene)

Coarse-grained hornblende diorite and pegmatitic diorite (Larsen and Smith, 1991), intruded by and included as xenoliths in Teakettle Pass rocks. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tip - 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 13.9 Ma Tuff of Hoover Dam (Thd; Mills, 1994). Contains roof pendants of Cambrian limestone and shale (Pz) just west of Fortification Hill. Metcalf and others (1993) suggest that Paint Pots may be subjacent plutonic source for Tuff of Hoover Dam that intruded its own volcanic cover. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Boulder City pluton (middle Miocene)

Large composite epizonal batholith exposed mostly northeast and east of Boulder City. Fractures and breccia are pervasive, and are host to hematite, barite, and manganese mineralization. Faults that cut the northern end of the pluton and volcanic rocks in the southern River Mountains to the north locally contain barite-manganese oxide veins. This mineralization is overprinted by sub-horizontal zones of hematization in volcanic rocks (Tdmm), the pluton, and overlying and adjacent clastic rocks (Tsmy) east of Boulder City. The mineralization ends abruptly upward; this sharp upward termination was interpreted by Anderson (1969) as a paleohydrologic feature representing a long-lived, fluctuating water table. Beard and others (at SPN) suggest the paleohydrologic feature is a result, at least in part, of mobilizing the earlier, subjacent, unrelated mineralization and concentrating it along the upper part of the water table. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tibu - Boulder City pluton, undifferentiated (middle Miocene)

Mostly quartz monzonite with lesser amounts of granite, monzonite, and syenodiorite (Ekren and Anderson, 1996). Quartz monzonite is mostly light-gray, fine- to medium-grained, faintly to distinctly porphyritic, nonfoliated pyroxene-bearing, with biotite and hornblende as important mafic constituents.

Rocks either more mafic or more siliceous than quartz monzonite occur mostly as fine-grained to aphanitic dikes and border facies east and southeast of Boulder City. The contacts between the various lithologies are obscure and appear to be gradational in most areas. Locally divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tib - Boulder City pluton, unaltered quartz monzonite (middle Miocene)

Unmineralized parts of the Boulder City pluton, exposed mostly northeast of Boulder City above the paleohydrologic feature of Anderson (1969). Includes masses of light-gray, fine-to medium-grained plutonic rock that grades from near granite in composition to syenodiorite. The rock is faintly to distinctly porphyritic, non-foliated, and highly fractured in most areas. A new U-Pb age of 13.96 ± 0.25 Ma was reported by Felger and others (at SPN); previous K/Ar analyses of biotite yielded ages of 14.17 ± 0.6 Ma (recalculated; Anderson and others, 1972), and 14.65 ± 0.47 Ma (recalculated; Felger and others, at SPN). Honn (2012) reported a U-Pb zircon age of 12.48 ± 0.48 Ma, but this is considered too young since the pluton is overlain by a basalt flow dated at 13.268 ± 0.032 Ma (Tdmm). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tibb - Boulder City pluton, unaltered quartz monzonite border facies (middle Miocene)

Brecciated dioritic and andesitic rocks, and aplite. Unit may include some volcanic rocks, although no depositional contacts or cooling breaks indicative of volcanism were observed. The rocks locally include basaltic dikes that may be related to Mount Davis Volcanics. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tif - Felsic dikes (middle Miocene)

Rhyolite, rhyodacite to granodiorite dikes and irregular intrusive masses, mapped on both sides of Colorado River south of Hoover Dam. Typically associated with plutonic bodies or represent possible source vents for felsic rocks in volcanic sequences. Locally porphyritic . (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tii - Intermediate dikes (middle Miocene)

Irregular shaped andesite to dacite intrusive masses and dikes, commonly intruded along faults. Dacite bodies can be porphyritic. Mapped mostly along Hamblin Bay fault and on both sides of the Colorado River south of Hoover Dam. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tin - Nelson pluton (middle Miocene)

Hypabyssal granodiorite to diorite. Pluton has east-west elongate outcrop (Faulds, 1995). Interpreted to either have intruded as dike-on-dike along an east-west fault (Hansen, 1962; Anderson, 1971) or result from repetition by west dipping low-angle faults that rotated the section and overlying volcanic rocks to steep north dips (Ludington and others, 2006). The pluton is considered the main host to epithermal precious metal mineralization in Eldorado district. A K/Ar biotite age of 16.9 ± 0.5 Ma was reported by Faulds and others (1992). Faulds (1995) suggested the pluton is cogenetic with volcanics of Fire Mountain (Tf, Tfu, Tfb). Possibly intrudes volcanic rocks as young as 15.3 Ma, and younger than Aztec Wash pluton (Ludington and others, 2006). Originally named the Techatticup pluton (Anderson, 1971) who obtained K-Ar ages from about 14.5 to 16.9 Ma. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tism - Spirit Mountain pluton (middle Miocene)

Laterally and vertically gradational leucogranite, granite, and foliated quartz monzonite, forming a granitic batholith that is interpreted to be tilted about 40-50° westward during Miocene extension (Faulds and others, 2002a). Tilting exposes a cross-sectional view of the pluton and shows it grades with depth from high-silica leucogranite intruded as sheets and dikes, downward to coarse grained, foliated quartz monzonite (Hopson and others, 1994). Intrudes Proterozoic gneiss, the Davis Dam granite, and the White Rock pluton and is intruded by Mirage pluton (exposed south of the recreation area boundary). Age ranges from ~ 17.5 to 15.3 Ma (U-Pb zircon; Walker, 2006); the lengthy crystallization age is inferred to result from multistage intrusive events, possibly as sheeted sill-on-sill bodies (Lang and others, 2008). Locally mapped as: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tismu - Spirit Mountain pluton and Proterozoic gneiss, undifferentiated (middle Miocene)

Equigranular granite with abundant pendants of Proterozoic rocks, mapped by Faulds and others (2004) as the southeast and structurally lower border of the pluton. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tisml - Spirit Mountain pluton, leucogranite (middle Miocene)

Unit is composed of subhorizontal sheets of aplite, porphyry, and fine to medium-grained granites, with common vesicles and local pegmatite pods and dikes. Base grades into coarser, less felsic granite typically of the Spirit Mountain pluton (Walker, 2006). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Aztec Wash pluton (middle Miocene)

Includes homogeneous granite and a heterogeneous zone of intermingled mafic and felsic rocks (Faulds, 1996, Harper and others, 2004). Pluton formed by repeated injections of both felsic and mafic magmas (Miller and others, 2011). Contact between these units is sharp. Exposed in three fault blocks along the Black Mountain Accommodation Zone of Faulds and others (2001), of which only the east-northeast-tilted eastern block is within the recreation area. Ryan (2011) obtained 15.7 ± 0.2 Ma U-Pb zircon ages on two mafic sheets, and Cates and others (2003; summarized in Miller and others, 2011) report U-Pb SHRIMP zircon ages indicating the pluton was implaced from about 15.5 – 15.8 Ma. Intrudes Proterozoic gneiss and orthogneiss; intruded by felsic dikes that are only slightly younger than the pluton (Harper and others, 2004). Divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tiai - Aztec Wash pluton, intermediate rocks (middle Miocene)

Olivine-bearing gabbro, diorite, and quartz monzonite as intermingled or sheeted bodies. Where sheeted, mafic and felsic bodies have intermingled or hybridized contacts; locally microgabbro sheets have quenched contacts with felsic rocks. Also includes xenoliths of Proterozoic amphibolite and Cretaceous Ireteba granite (Koteas, 2005; Smith, 2011). Divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tiag - Aztec Wash pluton, granitic rocks (middle Miocene)

Low-silica to high-silica fine to coarse-grained granite, including aplite and porphyry. Contains miarolitic cavities toward structural roof of pluton (Harper and others, 2004). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Searchlight pluton (middle Miocene)

Stratified pluton composed of fine-grained quartz monzonite in upper part grading to granite in middle, and then coarse, more mafic quartz monzonite in the lower part (Bachl and others, 2001). Intrudes Proterozoic basement rock (Xu) in the recreation area; west of the boundary the upper part intrudes overlying Miocene volcanic rocks (volcanics of the Highland Range; Faulds and others, 2002b). Interpreted to be tilted steeply eastward. Only upper and lower parts are exposed within recreation area: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tisu - Searchlight pluton, upper (middle Miocene)

Quartz monzonite, quartz monzodiorite, and granite that coarsens eastward (downward) from fine-grained porphyry to medium-grained equigranular to coarsely porphyritic at the base. In addition, composition becomes more felsic downward (Bachl and others, 2001). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tisl - Searchlight pluton, lower (middle Miocene)

Coarser grained and more felsic than upper unit, and weakly to strongly developed magmagic foliation, overprinted in the lower part by a sub-parallel tectonic foliation Lower part includes syn-intrusion gabbro and diorite enclaves and larger pods, from several meters to 2 km in maximum dimension (Bachl and others, 2001). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Pasty Mine Volcanics (middle and lower Miocene)

Anderson (1971, 1977, 1978) divided the Patsy Mine Volcanics into upper, middle, and lower informal parts. The upper and lower parts are predominantly andesite and the middle part is mostly rhyolite. The Patsy Mine Volcanics are bracketed by the Peach Springs Tuff with an age of 18.78 ± 0.02 Ma (Ferguson and others, 2013) and the Tuff of Bridge Spring (Ttb) with an age of about 15.2 Ma (Gans and Bohrson, 1998). Rocks were erupted prior to extension, and subsequently strongly faulted and tilted. Total thickness as much as 4,000 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tpv - Patsy Mine Volcanics, volcanic rocks, undivided (middle and lower Miocene)

Andesite and basaltic andesite lavas and associated breccia and tuffaceous sedimentary rocks. Inferred to be mostly correlative with the upper (Tpu) and lower (Tpl) parts of the Patsy Mine, but not subdivided due to stratigraphic and structural complexities. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tpu - Patsy Mine Volcanics, upper part (middle and lower Miocene)

Dark-purplish-gray, massive, porphyritic pyroxene-olivine andesite and basaltic andesite flows locally interstratified with thin beds of whitish-gray tuffaceous sedimentary rocks. Includes at least one flow of hornblende-biotite rhyodacite near base; rhyodacite contains sparse quartz and sanidine and common accessory sphene. Within the recreation area, scattered exposures crop out on both sides of Black Canyon south of Malpais Flattop Mesa to Cottonwood Valley. Maximum thickness approximately 500 m (Anderson, 1977, 1978). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tpm - Patsy Mine Volcanics, middle part, undivided (middle and lower Miocene)

Rhyolite lavas and interbedded tuffaceous sedimentary rocks exposed south of Malpais Flattop Mesa (Anderson, 1977, 1978). Outcrops of dacite and interbedded flow breccias and volcaniclastic sedimentary rocks west of Hoover Dam (unit Ted of Smith, 1984) have been tentatively assigned to this unit. Maximum thickness approximately 800 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tpma - Patsy Mine Volcanics, altered dacite (middle and lower Miocene)

Highly altered and locally mineralized dacite flows exposed northwest of Hoover Dam. This is unit Teda of Smith (1984) that is tentatively correlated to middle Patsy Mine Volcanics by Felger and others (at SPN). Maximum exposed thickness approximately 100 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tpl - Patsy Mine Volcanics, lower part (middle and lower Miocene)

Dark-purplish-gray andesite lava and breccia. Mafic phenocryst assemblages vary widely but most rocks are two-pyroxene andesites, with or without olivine. Most rocks are weakly to moderately altered and highly fractured. Basal contact with Proterozoic metamorphic rocks generally complicated by faults, but in some outcrops in the southern part of the map area, a thin rhyolitic ash-flow tuff (possibly the Peach Springs Tuff) and a few tens of meters of prevolcanic clastic rocks separate the volcanic and metamorphic rocks. Exposed along Black Canyon from Hoover Dam to just north of Nelsons Landing road (fig. 1). Outcrops in Black Canyon between Hoover Dam and Willow Beach were assigned to the lower part of the Patsy Mine Volcanics by Felger and others (in SPN), and are inferred to be the core and flanking flows of an andesite dome complex. Maximum thickness approximately 2,700 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Volcanics of Fire Mountain (middle and lower Miocene)

Volcanic sequence defined by Faulds (1996) for a thick volcanic sequence that he inferred were sourced from the Fire Mountain volcano. Exposed around Fire Mountain on east side of river across from Nelsons Landing. Probably equivalent to middle Patsy Mine Volcanics, but mapped separately because can be separated into volcanic rocks sourced from Fire Mountain volcano of Faulds (1996). Age is between ~ 16 Ma and 14.5 Ma (Faulds, 1995). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tf - Volcanics of Fire Mountain, undivided (middle and lower Miocene)

Interstratified basaltic andesite flows, breccias, and volcaniclastic sandstones. Locally divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tfu - Volcanics of Fire Mountain, upper mafic lavas (middle and lower Miocene)

Purple brown to gray basaltic andesite flow and flow breccias with local trachyandesite and trachydacite lava. Age is bracketed between 16.1 and 15.9 Ma (40Ar/39Ar whole rock; Faulds, 1996). Unit thins northward; thickness ranges from 0 – 700 m (Faulds, 1996). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tfb - Volcanics of Fire Mountain, volcanic breccia (middle and lower Miocene)

Thick sequence of green brown to red brown volcanic breccias with varying amounts of interbedded volcaniclastic sandstonesbelow upper mafic lavas. According to Faulds (1996) unit represents clastic debris shed from volcanic centers; the largest unit at 800 m thick may represent debris shed from Fire Mountain volcano. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Volcanics of Red Gap Mine (middle and lower Miocene)

Thick volcanic sequence defined by Faulds (1996) for rocks flanking the Fire Mountain volcanics (Tf, Tfu, Tfb) from north of Nelsons Landing southward to west of Mount Perkins. About 16.0 to 14.5 Ma (Faulds and others, 1995). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tg - Volcanics of Red Gap Mine, undivided (middle and lower Miocene)

Rhyolite flow and tuff. Thickness up to 300-900 m (Faulds, 1996). Locally divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgl - Volcanics of Red Gap Mine, rhyolite lava (middle and lower Miocene)

Gray to white flow-banded rhyolite lavas. Thickness from 0 – 300 m (Faulds, 1995). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tgt - Volcanics of Red Gap Mine, tuffaceous rocks (middle and lower Miocene)

White to yellowish gray pyroclastic flows, surge deposits, air fall tuff, and tuffaceous sedimentary rocks. Thicknesses from 0 – 300 m (Faulds, 1995). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Volcanics of Dixie Quene Mine (middle and lower Miocene)

Andesite flows that underlie and interfinger with dacitic flows, domes, and breccias that are likely part of a pre-extension stratovolcano, subsequently faulted and tilted as much as 90 degrees (Faulds and others, 1995). Unit may interfinger with the lower part of the volcanics of Fire Mountain (Faulds, 1995). Age of unit is bracketed between age of the underlying Peach Spring Tuff at ~ 18.8 Ma (Ferguson and others, 2013) and the age of the base of the Red Gap Mine at 15.8 Ma (40Ar/39Ar; Faulds and others, 1995). Thicknesses 600-800 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tq - Volcanics of Dixie Queen Mine, undivided (middle and lower Miocene)

Locally divided into: (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tqd - Volcanics of Dixie Queen Mine, dacite lavas (middle and lower Miocene)

Reddish to brown, weathering to gray, dacite lavas containing ubiquitous plagioclase and biotite phenocrysts with sanidine, hornblende and quartz in some flows. Locally includes andesite and basaltic andesite flows. Thicknesses up to 800 m (Faulds, 1995). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tqdd - Volcanics of Dixie Queen Mine, dacite domes (middle and lower Miocene)

Reddish brown, gray weathering dacite domes and local breccias with plagioclase, sanidine, biotite, quartz, and sphene phenocrysts. Thicknesses up to 700 m (Faulds, 1995). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tu - Union Pass volcanics of Murphy (2005) (lower Miocene)

Thick sequence of mafic to felsic volcanic rocks exposed west of Davis Dam and mapped at 1:24,000 by Faulds and others (2004) is correlated to volcanic rocks mapped and described at Union Pass, Arizona, by Murphy (2005) that are bracketed between 18.5 Ma and 13.7 Ma in age. Within the recreation area, the volcanics are probably equivalent to the lower Patsy Mine. Lower part of unit is interlayered dacite, andesite, basaltic andesite and basalt flows, with intercalated tuffaceous sedimentary rocks. Basaltic andesite flow dated at 17.52 Ma (no error given; Faulds and others, 2004). Laterally equivalent to older sedimentary unit (Tso) that contains megabreccia deposits (Faulds and others, 2004). Upper part is rhyolite lavas and breccia, dated at 17.26 Ma (no error given; Faulds and others, 2004). Thickness of unit unknown. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tso - Older sedimentary rocks (lower Miocene)

Small outcrop of conglomerate and sandstone west of Davis Dam that is intercalated with and overlying Union Pass volcanic rocks (Tu). Between 18.5 and 17.26 Ma (Faulds and others, 2000, 2004). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tpt - Peach Spring Tuff (lower Miocene)

Regional rhyolitic ash-flow tuff unit, typically phenocryst-rich and sphene-bearing. Outcrops extend from the west margin of the Colorado Plateau near Peach Springs, Arizona, to Barstow, California. Interpreted as a super-eruption event from the Silver Creek Caldera (Ferguson and others, 2013) located south of the recreation area in the southern Black Mountains. Age long considered to be ~ 18.5 Ma but recently revised to 18.78 ± .02 Ma (40Ar/39Ar on sanidine; Ferguson and others, 2013). Up to 100 m thick in recreation area (Faulds and others, 2000). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tcmv - Cook Mine volcanics of Ferguson (2013), undivided (lower Miocene)

dark gray to black basaltic andesite lava flows below Peach Spring Tuff. At Union Pass to east of recreation area, includes ash flow tuff correlated to the ~ 18.5-18.8 Ma Cook Canyon tuff of Buesch and Valentine (1986) (Murphy, 2005). Tentatively correlated herein to Cook Mine volcanics of Ferguson and others (2013), a distinct sequence of volcanic rocks that predate the Peach Spring Tuff (Tps). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Tca - Arkosic conglomerate (lower Miocene and Oligocene)

Mostly reddish brown, poorly sorted conglomerate with angular to subangular clasts of Proterozoic granite and orthogneiss and a coarse arkosic sandy matrix. Also includes thinly bedded layers of sandstone containing a few sub-rounded pebble clasts. To east of the recreation area boundary locally includes thin tuffaceous rocks intercalated in the upper part (Murphy, 2004; Faulds and others, 2004). Typically a few m to 20 m thick; at Davis Dam includes 210 m thick section (Faulds and others, 2000) preserved in probable paleovalley. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ki - Intrusive rocks (Upper Cretaceous)

Includes muscovite-biotite granite in the Black Mountains south of Wilson Ridge and on the east flank of Opal Mountain. Granite south of Wilson Ridge is weakly foliated to massive, muscovite-biotite-bearing quartz monzonite, with local garnets. Commonly altered, dated at about 73.3 ± 1.5 Ma (Faulds and others, 1992). Granite on east side of Opal Mountain is weakly foliated, coarse-grained granite containing potassium feldspar, quartz, plagioclase, and accessory biotite, muscovite, garnet, and sillimanite (Faulds, 1995). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Kii - Ireteba pluton (Upper Cretaceous)

Muscovite-biotite-garnet granite exposed in southern Eldorado Mountains. Numerous dikes of pegmatite phase of the pluton intrude into Proterozoic country rock (D'Andrea, 1998; Kapp and others, 2002), and pluton is in turn intruded by the Miocene Searchlight and Aztec Wash plutons (Townsend and others, 2000). Abundant mafic dikes and inclusions are common in southeastern part of pluton, as well as a weak to strong ductile lineation. Kapp and others (2002) report a pooled U-Pb zircon of ~ 66.4 ± 0.9 Ma, and an interpreted age of 66.5 +- 2.5 Ma. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Kiw - White Rock Wash pluton (Upper Cretaceous)

Medium to coarse grained muscovite-biotite, garnet-bearing granite, about 68.5 Ma (U-Pb zircon; Miller and others, 1997). Exposed in the Newberry Mountains, the pluton intrudes Proterozoic basement rocks and is intruded by the Miocene Searchlight pluton (Walker, 2006). Locally shows gradual migmatic contacts with host Proterozoic rocks. Very similar to Ireteba granite in geochemistry, petrography and age (Kapp and others, 2002). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ja - Aztec Sandstone (Lower Jurassic)

Reddish-orange, medium-grained eolian sandstone, typically weathering red in lower part of formation, and white in upper part. Sandstone is 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. Exposed only along northwest side of recreation area. Thickness up to 1200 m where not eroded at sub-Tertiary unconformity (Beard and others, 2007)(*GRI Source Map ID 75657)* (Lake Mead NRA).

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 (^c) 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. Formations exposed only along northwest side of recreation area. Thickness up to 300 m (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

TRc - Chinle Formation (Upper Triassic)

Variegated bentonitic mudstone, fine to very coarse grained sandstone, limestone, and pebble conglomerate. Exposed only along northwest side of recreation area. 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 (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

TRm - 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. Exposed only along northwest side of recreation area. 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 the Lake Mead region 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 (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Pkt - Kaibab and Toroweap Formations, undivided (Lower Permian)

Formations form distinctive cliff-slope-cliff topography at top of carbonate/clastic sequence of Paleozoic stratigraphy. Exposed along Northshore Drive of Lake Mead National Recreation Area and in Grand Wash trough.

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 to 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 (Beard and others, 2007).

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 (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Phe - Hermit Formation and Esplanade Sandstone, undivided (Lower Permian)

Exposed along Northshore Drive of Lake Mead National Recreation Area and in Grand Wash trough. 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 Cockscomb to about 200 m. Esplanade Sandstone is white to pinkish-white or red 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 area by previous workers, but herein we use Esplanade, following Beard and others (2007). Thickness about 60 to 80 m . (*GRI Source Map ID 75657)* (Lake Mead NRA).

Supai Group (Lower Permian, Pennsylvanian, ans Upper Mississippian)

also Pakoon Linestone (Lower Permian) and Callville Formation (Pennslyvanian and Upper Mississippian) - Includes, in descending order, the Esplanade Sandstone, Wescogame, Manakacha, and Watahomigi Formations of the Supai Group, as defined by McKee (1982). Supai Group rocks transition westward into dominantly carbonate rocks of the Pakoon Limestone and Callville Formation, as defined by McNair (1951). The transition to carbonate lithologies occurs from the Hurricane fault westward to Grand Wash trough. East of the Grand Wash Cliffs, following Billingsley and Wellmeyer (2005), the Esplanade Sandstone and Pakoon Limestone are mapped as a transitional unit (Pep) and the remainder of the Supai Group is mapped as undifferentiated (MIPs). West of the Grand Wash Cliffs, following Beard and others (2007), the Pakoon Limestone and Callville Formations are mapped as undivided (PMpc), and the Esplanade Sandstone is mapped with the Hermit Formation (Phe). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Pep - Supai Group, Esplanade Sandstone and Pakoon Limestone (Lower Permian)

Reddish to white sandstone of Esplanade Sandstone overlies and intertongues with gray limestones and dolomites of Pakoon Limestone, described below. Esplanade is low-angle cross bedded to massive calcareous sandstone. Exposed along Grand Wash Cliffs in far eastern part of recreation area. Unit thins westward from about 60 m to 15 m thick (Billingsley and Wellmeyer, 2003). (*GRI Source Map ID 75657)* (Lake Mead NRA).

PMpc - Supai Group, Pakoon Limestone and Callville Formation, undivided (Upper Mississippian to Lower Permian)

Units mapped in Wheeler and Iceberg Ridges and the Cockscomb in eastern part of recreation area. 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 east of Las Vegas to 70 m at Wheeler Ridge. 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 to west. To the east in the Grand Canyon region, correlative to and intertongues with upper Watahomigi, Manakacha, and Wescogame Formations of the Supai Group (McKee, 1982). 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 Wheeler Ridge (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

PNMs - Supai Group, undivided (Pennsylvanian and Upper Mississippian)

Exposed along Grand Wash Cliffs in far eastern part of recreation area. Wescogame Formation (Upper Pennsylvanian) includes an upper slope forming unit of dark-red siltistone and lower cliff-forming unit of light-red to gray cross-bedded calcareous sandstone. Manakacha Formation (Middle Pennslyvanian), is ledge-forming, thin to medium-bedded limestone interlayered with shaley siltstone, underlain by cliff-forming cross-bedded calcarenite sandstone beds. The Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian) is cherty limestone ledges interlayered with purplish mudstone slopes. Basal part of unit is locally conglomeratic and includes thin reddish sandstone and shale beds. About 170 m thick (Billingsley and Wellmeyer, 2003). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ms - Surprise Canyon Formation (Upper Mississippian)

Dark reddish-brown sandstone and siltstone, limestone, and some conglomerate. Rocks are preserved in erosional paleochannels and as infilling of karst features at top of Redwall Limestone (Mr). Only one channel has been mapped in the recreation area in Pearce Canyon along Grand Wash Cliffs, but unmapped channels may be present to west (Billingsley and Wellmeyer, 2003). Equivalent in age to Indian Springs Formation further west, which is mapped as part of PMpc unit. Thickness 0 - ~ 100 m (Billingsley and Wellmeyer, 2003). (*GRI Source Map ID 75657)* (Lake Mead NRA).

PZr - Sedimentary Rocks (Paleozoic)

(source unit symbol Pz) - Small outcrops of limestone, shale, sandstone, and quartzite on Saddle Island, the eastern River Mountains, and west flank of Fortification Hill. Interpreted as exotic blocks in the River Mountains stock and the Paint Pots pluton by Smith (1984) and Mills (1994). In southern River Mountains, rocks interpreted as in situ exposures of Cambrian strata, intruded and overlain by River Mountains volcanic complex (Timm, 1985). (*GRI Source Map ID 75657)* (Lake Mead NRA).

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 is commonly dolomitized. Unit typically forms a 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) to west. Mostly exposed in Iceberg and Wheeler Ridges, and along Grand Wash Cliffs. Small outcrops at Wilson Ridge area are 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 recreation area (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Mm - Monte Cristo Group (Upper and Lower Mississippian)

Medium-gray, cliff-forming limestone with brown, cherty zones. Exposed in Muddy Mountains within upper plate of Muddy Mountain thrust. 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. Equivalent in age to Redwall Limestone (Mr). Thickness about 250 to 300 m in Muddy Mountains (Bohannon, 1983). (*GRI Source Map ID 75657)* (Lake Mead NRA).

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. Exposed only in Muddy Mountains as part of the upper plate of the Muddy Mountain thrust. Thickness about 190 m (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Dtb - Temple Butte Formation (Upper and Middle Devonian)

Limestone and dolomite exposed in Iceberg and Wheeler Ridges and along Grand Wash Cliffs. At Frenchman Mountain (east of Las Vegas and west of recreation area boundary; Castor and others (2000), equivalent unit is Sultan Formation (MDs). 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 north and east of the recreation area 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 and represents a major stratigraphic break in the Paleozoic in which much of the Late Cambrian, all of the Ordovician, and much of the Early and Middle Devonian were not deposited or eroded. Total thickness of Temple Butte Formation is about 140 – 180 m (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Op - Pogonip Formation (Lower Ordovician)

Originally defined as the Monocline Valley Formation of Longwell and Mound (1967); renamed Pogonip in Beard and others (2007). 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. Exposed only in the Muddy Mountains as part of the upper plate of the Muddy Mountain thrust. Total thickness about 240 m (Bohannon, 1983). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Cu - 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). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Cm - Muav Formation (Middle Cambrian)

Exposed mainly in Iceberg and Wheeler Ridges, and along Grand Wash Cliffs. One small exposure is mapped at Wilson Ridge. Unit is correlative to Frenchman Mountain Dolomite (Castor and others, 2000) and Unclassified Dolomites of McKee and Resser (1945). Thickens from east to west, from about 520 m at Azure Ridge to about 630 m at Frenchman Mountain (Beard and others, 2007).

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. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Cba - Bright Angel Shale (Middle Cambrian)

Green gray to purple gray 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 is gradational with Muav Formation. Weathers to a slope that is typically shiny from a distance. Unit mapped separately only along Grand Wash Cliffs; westward it is mapped with Tapeats Sandstone (_tb; Beard and others, 2007). Thickness about 90 to 120 m. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ctb - Tapeats Sandstone and Bright Angel Shale, undivided (Middle and Lower Cambrian)

Exposed in Iceberg and Wheeler Ridges, and in one small outcrop at Saddle Island. Total thickness about 185 m. Bright Angel Shale is described above (_tb). 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 recreation area to as much as 48 m at Frenchman Mountain east of Las Vegas. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ydb - Diabase dikes (Mesoproterozoic)

Dark gray to green diabase dikes and irregular masses that intrude Davis Dam granite (Faulds and others, 2004). Probably fairly widespread in area, but only largest pods and dikes are shown on map. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Yig - Granitic dikes (Mesoproterozoic)

Light gray to tan equigranular to porphyritic granitic dikes. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Yd - Diorite and gabbro (Mesoproterozoic)

Gray to greenish-gray, medium to coarse-grained generally unfoliated pyroxene-bearing diorite and gabbro exposed at the southern end of Wheeler Ridge. Unit contains poikilitic plagioclase phenocrysts as large as 3 cm across. Hornblende and pyroxene are locally altered to chlorite and biotite (Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Yg - Gold Butte Granite (Mesoproterozoic)

Described by Volborth (1962) as rapakivi granite. Granite is coarse-grained porphyritic to locally equigranular and biotite and biotite-hornblende bearing. 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). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Yb - Granite of Burro Spring (Mesoproterozoic)

Exposed in Hiller Mountains area north of Virgin Canyon. Porphyritic biotite granite contains abundant pale-gray to tan potassium feldspar phenocrysts about 2 cm in length. Mafic mineral content is about 10 to 15 percent, including biotite and magnetite (Howard and others, 2003). Closely resembles Gold Butte Granite, although Blacet (1975) correlated with porphyritic granite of Garnet Mountain (1680 Ma, Chamberlain and Bowring, 1990). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Ydg - Davis Dam granite (Mesoproterozoic)

Tan to brown, locally reddish, megacrystic granite composed of large feldspar crystals in granitic matrix of quartz, plagioclase and biotite. Feldspars, up to 6 cm long, display rapakivi texture formed by outer rims of plagioclase. Unit is weakly to strongly foliated (Faulds and others, 2000). Dated at 1.425 ± 0.25 Ga (Anderson and Bender, 1989). Locally includes small bodies of gneiss and schist that are too small to show at map scale. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xu - Metamorphic and plutonic rocks, undifferentiated (Paleoproterozoic)

Mixed metamorphic and plutonic rocks exposed at Saddle Island, Wilson Ridge, and southwest of Nelsons Landing; not mapped in detail. At Saddle Island, unit is 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). Volborth (1973) described the outcrops near Nelsons Landing as granulite facies rocks, some containing garnet, sillimanite and cordierite, intruded by small mafic bodies and pegmatite and aplite (unit at this location compiled from Ludington, unpublished mapping, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xlg - Leucogranite and pegmatite gneiss (Paleoproterozoic)

Composed of quartz, potassium feldspar, plagioclase, and less than 5 percent biotite. Gneiss 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 (_tb) was deposited (Howard and others, 2003; Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xum - Mafic and ultramafic metamorphic rocks, undivided (Paleoproterozoic)

Medium- to coarse-grained, porphyritic, hornblende-rich mafic to ultramafic gneiss, including pyroxenite gneiss. Sheared, serpentized locally. Intrudes the garnet gneiss (Xggn) and quartz syenite gneiss (Xqs) units as dikes and small irregular bodies (Beard and others, 2007). Probably occurs in other parts of recreation area but not mapped separately. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xgn - Gneiss, undivided (Paleoproterozoic)

Includes felsic to mafic gneisses in White Hills area (Howard, unpublished mapping, 2012) and strongly foliated orthogneiss and schist in the Davis Dam area (Faulds and others, 2004; Ludington, unpublished mapping, 2007; Beard, photoreconnaissance mapping, 2012). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xogn - Granitic to dioritic orthogneiss (Paleoproterozoic)

Foliated, biotite-rich gneisses, commonly with large feldspar augen, that is interlayered with the paragneisses mapped as Xgn. Cut extensively by Proterozoic and Miocene dikes. Mapped along west side of Cottonwood Valley from Nelsons Landing south to the Newberry Mountains. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xhgn - Hornblende-biotite gneiss (Paleoproterozoic)

Medium-gray foliated or banded gneiss containing conspicuous hornblende. Locally includes pods, lenses, and layers of granite pegmatite and amphibolite. Small exposure mapped in recreation area, on southeast flank of Wilson Ridge is part of larger exposure along east side of ridge (Anderson, 1978). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xgg - Granitic gneiss (Paleoproterozoic)

Gray, medium-grained biotite granodiorite and granitic gneiss exposed along Virgin Canyon, eastern Lake Mead. Mafic mineral content 10 to 15 percent (Howard and others, 2003; Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xqs - Quartz syenite gneiss (Paleoproterozoic)

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. Exposed along Virgin Canyon, eastern Lake Mead (Howard and others, 2003; Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xqd - Quartz diorite gneiss (Paleoproterozoic)

Medium-grained, locally schistose, quartz diorite and diorite gneiss, with 15 to 45 percent fine-grained biotite, hornblende, and chlorite. Long thin bodies are largely metadiorite. Locally includes porphyritic quartz syenite gneiss (Howard and others, 2003; Beard and others, 2007). Exposed along Virgin Canyon, eastern Lake Mead. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xggn - Garnet gneiss (Paleoproterozoic)

Dark gray to gray brown garnet-quartz-plagioclase paragneiss, chlorite-biotite paragneiss, cordierite-sillimanite gneiss, migmatite, pods of leucogranite gneiss, and local amphibolite, meta-andesite (?), and feldspathic gneiss. Widely exposed in recreation area, but best studied in outcrops that flank Iceberg Canyon and underlie Lost Basin Range. Here, 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), subdivided below in Hiller Mountains (Howard and others, 2003; Beard and others, 2007). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xgp - Garnet gneiss, partly retrograded (Paleoproterozoic)

Chloritic and sericitic halos rim and partially replace the garnets. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xgr - Garnet gneiss, completely retrograded (Paleoproterozoic)

Chloritic and sericitic pseudomorphs replace the garnets. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xgc - Garnet gneiss, chloritic brecciated gneiss (Paleoproterozoic)

Gneiss is brecciated and completely retrograded to chlorite and epidote; mylonite zones common. (*GRI Source Map ID 75657)* (Lake Mead NRA).

Xs - Schist (Paleoproterozoic)

Green, brown, to gray biotite or biotite-hornblende schist, augen schist, and phyllonite. Strongly foliated, part of small exposure on west side of Wilson Ridge mapped by Anderson (1978). (*GRI Source Map ID 75657)* (Lake Mead NRA).

Lake Mead NRA (Beard S., et. al, In Press)

Beard, S., Felger, T.J., House, P.K., and Howard, K.A., In Press, Geologic Map of the Lake Mead National Recreation Area, Nevada and Arizona, U.S. Geological Survey, Open-File Report, OR XXXX-XXXX, 1:62,500. (*GRI Source Map ID 75657*).

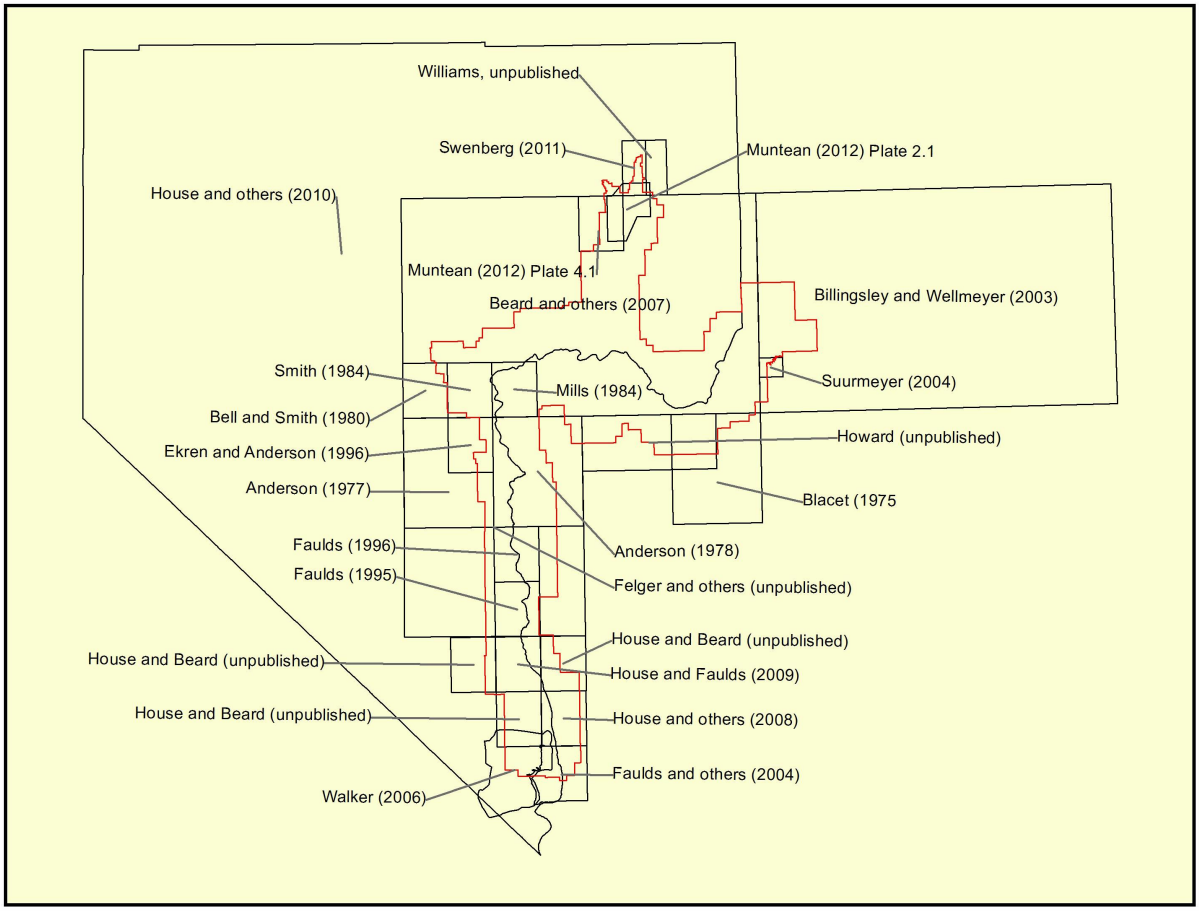
Note: This version of the GIS database and ancillary document are considered pre-review draft. Once the final USGS version has been published, the final version of the GIS database and ancillary document will be updated.

Correlation of Map Units

The Lake Mead NRA Correlation of Map Units and List of Map Units is available as a separate (embedded) PDF (Correlation of Map Units and List of Map Units) ** double-click link to open figure

Extracted from: (Lake Mead NRA).

Index to Geologic Mapping Sources



Extracted from: (Lake Mead NRA).

Map Legend

Explanation

- Contact—Identity and existence certain, location accurate
- Contact—Identity and existence certain, location approximate
- Contact—Identity and existence certain, location concealed
- Contact—Identity and existence certain, location inferred
- Contact—Identity or existence questionable, location accurate
- Contact—Identity or existence questionable, location approximate
- Ductile shear zone
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity and existence certain, location accurate
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity and existence certain, location approximate
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity and existence certain, location concealed
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity and existence certain, location inferred
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity or existence questionable, location accurate
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity or existence questionable, location approximate
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity or existence questionable, location concealed
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity or existence questionable, location inferred
- Internal contact—Identity and existence certain, location accurate
- Internal contact—Identity and existence certain, location approximate
- Internal contact—Identity or existence questionable, location accurate
- Internal contact—Identity or existence questionable, location approximate
- Low-angle fault (unknown or unspecified sense of slip)—Identity and existence certain, location
- Low-angle fault (unknown or unspecified sense of slip)—Identity and existence certain, location
- Low-angle fault (unknown or unspecified sense of slip)—Identity and existence certain, location
- Low-angle fault (unknown or unspecified sense of slip)—Identity and existence certain, location
- Low-angle normal fault—Identity and existence certain, location accurate
- Low-angle normal fault—Identity and existence certain, location approximate
- Low-angle normal fault—Identity and existence certain, location concealed
- Low-angle normal fault—Identity or existence questionable, location concealed
- Main toe of landslide-Inactive, subdued, indistinct, and (or) approximately located
- Map neatline
- Master detachment fault (sense of slip unspecified)—Identity and existence certain, location
- Master detachment fault (sense of slip unspecified)—Identity and existence certain, location
- Master detachment fault (sense of slip unspecified)—Identity and existence certain, location
- Normal fault—Identity and existence certain, location accurate
- Normal fault—Identity and existence certain, location approximate
- Normal fault—Identity and existence certain, location concealed
- Normal fault—Identity and existence certain, location inferred
- Normal fault—Identity or existence questionable, location approximate
- Normal fault—Identity or existence questionable, location concealed
- Normal fault—Identity or existence questionable, location inferred
- Oblique-slip fault, left-lateral offset—Identity and existence certain, location accurate
- Oblique-slip fault, left-lateral offset—Identity and existence certain, location approximate
- Oblique-slip fault, left-lateral offset—Identity and existence certain, location concealed
- Oblique-slip fault, left-lateral offset—Identity or existence questionable, location

Map Legend continued on next page

Reverse fault—Identity and existence certain, location accurate
Reverse fault—Identity and existence certain, location concealed
Strike-slip fault, left-lateral offset—Identity and existence certain, location accurate
Strike-slip fault, left-lateral offset—Identity and existence certain, location approximate
Strike-slip fault, left-lateral offset—Identity and existence certain, location concealed
Strike-slip fault, left-lateral offset—Identity and existence certain, location inferred
Strike-slip fault, left-lateral offset—Identity or existence questionable, location
Strike-slip fault, left-lateral offset—Identity or existence questionable, location concealed
Strike-slip fault, right-lateral offset—Identity and existence certain, location accurate
Strike-slip fault, right-lateral offset—Identity and existence certain, location approximate
Strike-slip fault, right-lateral offset—Identity and existence certain, location concealed
Thrust fault (1st option)—Identity and existence certain, location accurate
Water boundary

LAKE Orientation Points

Minor inclined joint (1st option)—Showing strike and dip
Minor vertical or near-vertical joint (1st option)—Showing strike
Horizontal bedding
Inclined bedding—Showing strike and dip
Vertical bedding—Showing strike
Overturned bedding—Showing strike and dip
Horizontal generic (origin not known or not specified) foliation
Inclined generic (origin not known or not specified) foliation—Showing strike and dip
Vertical generic (origin not known or not specified) foliation—Showing strike
Inclined flow banding, lamination, layering, or foliation in igneous rock—Showing strike and dip
Inclined metamorphic foliation—Showing strike and dip
Vertical metamorphic foliation—Showing strike

Extracted from: (Lake Mead NRA).

Report

The Lake Mead NRA report is available as a separate (embedded) PDF document (Lake Mead NRA Report) ** double-click link to open documents

The Lake Mead NRA report includes four figures. Because the report has not been published, pre-review copies of the figures are available as separate (embedded) PDF documents.

Figure 1. Figure shows lakes Mead and Mohave, and bedrock canyons and basins transected by

Colorado River. Inset in lower left shows location of figure in context of Basin and Range – Colorado Plateau. Outline of Lake Mead National Recreation Area shown as gray line; state boundaries are blue lines. Roads shown by thin brown lines, water features in blue.

Figure 2. Regional geologic map showing features that shaped the landscape prior to Cenozoic extension. Southern and eastern edge of Sevier highlands shown by black dotted line. Approximate boundary of highest part of Kingman uplift shown by black dashed line. Outline of Lake Mead National Recreation Area shown as gray; state boundaries are blue lines. Geologic data generalized from state geologic maps of Utah, Nevada, California, and Arizona. Geologic units: Gray – Proterozoic, purple – lower Paleozoic, light blue – middle Paleozoic, medium blue – upper Paleozoic, dark green – Mesozoic sedimentary rocks, bright-green – Cretaceous plutonic rocks, reddish brown – Cenozoic volcanic rocks, pink – Cenozoic intrusive rocks, and pale yellow – Cenozoic surficial and consolidated sedimentary rocks.

Figure 3. Location of place names used in text. Brown lines are roads. Outline of Lake Mead National Recreation Area shown as gray line; state boundaries are blue lines.

Figure 4. Major Cenozoic fault systems and location of Colorado River extension corridor, shown by thick black dashed line. Black Mountains accommodation zone shown by purple railroad track symbol. Normal-offset and generic faults are black; bar and ball symbol indicate downthrown side. Low-angle normal faults shown by barbs pointed toward hanging wall. Strike-slip faults are blue; arrows show relative lateral movement. Outline of Lake Mead National Recreation Area shown as gray line; state boundaries are blue line. Geologic units: Gray – Proterozoic, purple – lower Paleozoic, light blue – middle Paleozoic, medium blue – upper Paleozoic, dark green – Mesozoic sedimentary rocks, bright-green – Cretaceous plutonic rocks, reddish brown – Cenozoic volcanic rocks, pink – Cenozoic intrusive rocks, and pale yellow – Cenozoic surficial and consolidated sedimentary rocks

Extracted from: (Lake Mead NRA).

References

Amoroso, L., Beard, L. Sue, and Felger, T.J., at SPN, Preliminary surficial geologic map of the Boulder City 30' x 60' Quadrangle, Mohave County, Arizona and Clark County, Nevada: U.S. Geological Survey Open-File Report 13-xxxx, scale 1:100,000.

Anders, M.H., Saltzman, J., and Hemming, S.R., 2009, Neogene tephra correlations in eastern Idaho and Whoming: implications for Yellowstone hotspot-related volcanism and tectonic activity: Geological Society of America Bulletin v. 121, p. 837 – 856.

Anderson, J.L., and Bender, E.E., 1989, Nature and origin of Proterozoic A-type granitic magmatism in the southwestern United States of America: Lithos, v. 23, p. 19 – 52.

Anderson, R.E., 1969, Notes on the geology and paelohydrogeology of the Boulder City pluton, southern Nevada: in Geological Survey research, 1969: U.S. Geological Survey Professional Paper 650-B, p. B35 – B40.

Anderson, R.E., 1971, Thin-skin distension in Tertiary rocks of southeastern Nevada: Geological Society of America Bulletin, v. 82, p. 43 – 58.

Anderson, R.E., 1973, Large-magnitude Late Tertiary strike-slip faulting north of Lake Mead, Nevada: U.S. Geological Survey Professional Paper 794, 18 p.

Anderson, R.E., 1977, Geologic map of the Boulder City 15-minute Quadrangle, Mohave County, Arizona and Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1395, scale 1:62,500.

Anderson, R.E., 1978, Geologic map of the Black Canyon 15-minute Quadrangle, Mohave County, Arizona and

Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1394, scale 1:62,500.

Anderson, R.E., 2003, Geologic Map of the Callville Bay quadrangle, Nevada: Nevada Bureau of Mines and Geology Map 139, scale 1:24,000.

Anderson, R.E., Longwell, C.R., Armstrong, R.L., and Marvin, R.F., 1972, Significance of K-Ar ages of Tertiary rocks from the Lake Mead region, Nevada-Arizona: Geological Society of America Bulletin, v. 83, p.273 – 288.

Anderson, R.E., Barnhard, T.P., and Snee, L.W., 1994, Roles of plutonism, midcrustal flow, tectonic rafting, and horizontal collapse in shaping the Miocene strain field of the Lake Mead area, Nevada and Arizona: Tectonics, v. 13, p. 1381 – 1410.

Anderson, R.E. and Beard, L.S., 2010, Geology of the Lake Mead region: An overview: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p. 1 – 28.

Anderson, Z.W., and Beard, L.S., 2011, Structural and kinematic analysis of Miocene rocks, Black Canyon, Arizona and Nevada: Geological Society of America Abstracts with Program, v. 43, no. 4, p. 82.

Anderson, Z.W., 2012, Structural and basin evolution of the eastern Gale Hills, Lake Mead Miocene extensional domain, Nevada: M.S. Thesis, Northern Arizona University, Flagstaff, 225 p.

Bachl, C.A., Miller, C.F., Miller, J.S., and Faulds, J.E., 2001, Construction of a pluton: Evidence from an exposed cross section of the Searchlight pluton, Eldorado Mountains, Nevada: Geological Society of America Bulletin V. 113, p. 1213 – 1228.

Beard, L.S., 1992, Preliminary geologic map of the St. Thomas 7.5' quadrangle, Clark County, Nevada, and Mohave County, Arizona: U.S. Geological Survey Open-File Report 92-326, scale 1:24,000.

Beard, L.S., 1996, Paleogeography of the Horse Spring Formation in relation to the Lake Mead fault system, Virgin Mountains, Nevada and Arizona, in Beratan, K.K., ed., Reconstructing the history of Basin and Range extension using sedimentology and stratigraphy: Geological Society of America Special Paper 30, p. 27 – 60.

Beard, L.S., and Faulds, J.E., 2010, Kingman uplift, paleovalleys, and extensional foundering in northwest Arizona: in Beard, L.S., Karlstrom, K.E., Young, R.A., and Billingsley, G.H., CRevolution 2—Origin and Evolution of the Colorado River System, Workshop Abstracts: U.S. Geological Survey Open-file Report 2011-1210, p. 28 – 32.

Beard, L.S., and Campagna, D.J., 1991, Preliminary geologic map of the Devils Throat quadrangle, Clark County, Nevada: U.S. Geological Survey Open-File Report 91-132, scale 1:24,000.

Beard, L.S., and Campagna, D.J., 2012, Geologic Map of the Devils Throat Quadrangle, Clark County, Nevada: Nevada Bureau of Mines and Geology Map 181, scale 1:24,000.

Beard, L.S., Anderson, Z.W., Felger, T.J., and Seixas, G.B., at SPN, Geologic framework of thermal springs, Black Canyon, Nevada and Arizona: U.S. Geological Survey Open-file Report 2013 – xxxx.

Beard, L.S., Anderson, Z.W., and Felger, T.J., 2011, Structural controls on thermal springs in Black Canyon, Arizona and Nevada: Geological Society of America Abstracts with Program, v. 43, no. 4, p. 83.

Beard, L.S., Anderson, R.E., Block, D.L., Bohannon, R.G., Brady, F.J., Castor, S.B., Duebendorfer, D.M., Faulds, J.E., Felger, T.J., Howard, K.A., Kuntz, M.A., and Williams, V.S., 2007, Preliminary geologic map of the Lake Mead 30' X 60' Quadrangle, Clark, County, Nevada, and Mohave County, Arizona: U.S. Geological Survey Open-file Report 2007-1010, scale 1:100,000.

Bell, J.W., and Smith, E.I., 1980, Geologic map of the Henderson Quadrangle, Nevada: Nevada Bureau of Mines and Geology Map 67, scale 1:24,000.

Billingsley, G.H., and Wellmeyer, J. L., 2003, Geologic map of the Mount Trumbull 30' x 60' Quadrangle,

Mohave and Coconino Counties, Northwestern Arizona: U.S. Geological Survey Geologic Investigations Series I-2766, scale 1:100,000.

Billingsley, G.H., Beard, L.S., Priest, S.S., Wellmeyer, J.L., and Block, D.L., 2004, Geologic map of the lower Grand Wash Cliffs and Vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-2427, scale 1:31,680.

Blacet, P.M., 1975, Preliminary geologic map of the Garnet Mountain quadrangle, Mohave County, Arizona: U.S. Geological Survey Open-File Report 75-0093, scale 1:62,500.

Blythe, N.O., 2005, Basin analysis associated with Middle-Miocene detachment faulting, eastern Lake Mead region, northwest Arizona: Northern Arizona University, Flagstaff, Arizona, M.S. thesis, 225 p.

Blythe, M., Umhoefer, P.J., Duebendorfer, E.M., McIntosh, W.C., and Peters, L., 2010, Development of Salt Spring basin in the hanging wall of the White Hills detachment fault: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p. 61 – 86.

Bohannon, R.G., 1983, Geologic map, tectonic map and structure sections of the Muddy and northern Black Mountains, Clark County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series I-1406, scale 1:62,500.

Bohannon, R.G., 1984, Nonmarine sedimentary rocks of Tertiary age in the Lake Mead region, southeastern Nevada and Northwestern Arizona: U.S. Geological Survey Professional Paper 1259, 72 p.

Bohannon, R.G., Grow, J.A., Miller, J.J., and Blank, R.H. Jr., 1993, Seismic stratigraphy and tectonic development of Virgin River depression and associated basins, southeastern Nevada and northwestern Arizona: Geological Society of America Bulletin, v. 105, p. 501-520.

Brady, Robert, Fryxell, Joan, and Wernicke, Brian, 2002, Preliminary Geologic Map of the Iceberg Canyon quadrangle, Clark County, Nevada and Mohave County, Arizona: Nevada Bureau of Mines and Geology Open-File Report 03-18, scale 1:24,000.

Brock, A.L., and Buck, B.J., 2009, Polygenetic development of the Mormon Mesa, NV petrocalcic horizons: Geomorphic and paleoenvironmental interpretations: Catena, v. 77, p. 65 – 75.

Buesch, D. C., and Valentine, G.A., 1986, Peach Springs Tuff and volcanic stratigraphy of the southern Cerbat Mountains, Kingman, Arizona, in Cenozoic stratigraphy, structure and mineralization in the Mojave Desert: Geological Society of America, Cordilleran Section, 82d, Los Angeles, Calif., March 1986, Guidebook and Volume, Field Trips 5 and 6, p. 7 – 14.

Campagna, D. J., and Aydin, A., 1994, Basin genesis associated with strike-slip faulting in the Basin and Range, southeasten Nevada: Tectonics, v. 13, p. 327 – 341.

Carpenter, D. G., Carpenter, J. A., Bradley, M. D., Franz, U. A., and Reber, S. J., 1989, On the role of isostasy in the evolution of normal fault systems: Comment: Geology, v. 17, p. 774–775.

Cascadden, T.E., 1991, Style of volcanism and extensional tectonics in the eastern Basin and Range Province; northern Mohave County, Arizona: University of Nevada, Las Vegas, Las Vegas, Nevada; M.S. thesis, 209 p.

Castor, S.B, 1993, Borates in the Muddy Mountains, Clark County, Nevada: Nevada Bureau of Mines and Geology Bulletin 107, 31 p.

Castor, S.B., and Faulds, J.E., 2001, Post-6 Ma limestone along the southeastern part of the Las Vegas Valley shear zone, southern Nevada: in Young, R.A., and Spamer, E.E., Colorado River: Origin and Evolution, Grand Canyon Association Monograph 12, p. 77 – 79.

Castor, S.B., Faulds, J.E., dePaolo, C.M., and Rowland, S.M., 2000, Geologic map of the Frenchman Mountain quadrangle, Nevada: Nevada Bureau of Mines and Geology Map 127, scale 1:24,000.

Cates, N.L., Miller, J.S., Miller, C.F., Wooden, J.L., Ericksen, S., and Means, M., 2003, Longevity of plutonic systems: shrimp evidence from Aztec Wash and Searchlight plutons, Nevada: Geological Society of America Abstracts with Programs, v. 35, no. 4, p. 63.

Chamberlain, K.R, and Bowring, S.A, 1990, Proterozoic geochronologic and isotopic boundary in NW Arizona: Journal of Geology, v. 98, p. 399 – 416.

Crossey, L.J., Karlstrom, K.E., Springer, A.E., Newell, D., Hilton, D.R., and Fischer, T., 2009, Degassing of mantle-derived CO2 and He from springs in the southern Colorado Plateau region—Neotectonic connections and implications for groundwater systems: Geological Society of America Bulletin, v. 121, p. 1034 – 1053.

Damon, P.E., Shafiqullah, M., and Scarborough, R.B., 1978, Revised chronology for critical stages in the evolution of the lower Colorado River: Geological Society of America, Abstracts with Programs, v. 10, p. 101 – 102.

Damon, P.E., Shafiqullah, M., Harris, R.C., and Spencer, J.E., 1996, Compilation of unpublished Arizona K-Ar dates from the University of Arizona Laboratory of Isotope Geochemistry, 1971-1991: Arizona Geological Survey Open-File Report 6-18, 56 p.

D'Andrea, J.L., 1998, Geology and petrogenesis of the Ireteba Pluton: implications for the generation of peraluminous granites: Master Thesis, Vanderbilt University, Nashville, Tennesee; 104 p.

Donatelle, A.R., Hickson, Thomas, and Lamb, Melissa, 2005, Re-evaluation of Miocene stratigraphy in light of new stratigraphic, petrographic and 39Ar-40Ar data, north of Lake Mead, Nevada: Geological Society of America Abstracts with Programs, v. 37, no. 5, p. 54.

Duebendorfer, E.M., 2003, Geologic map of the Government Wash quadrangle, Nevada: Nevada Bureau of Mines and Geology Map 140, scale 1:24,000.

Duebendorfer, E.M., Sewall, A.J., and Smith, E.I., 1990, The Saddle Island detachment; an evolving shear zone in the Lake Mead area, Nevada: in Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Boulder Colorado, Geological Society of America Memoir 176, p. 77 – 97.

Duebendorfer, E.M., Beard, L.S., and Smith, E.I., 1998, Restoration of Tertiary deformation in the Lake Mead region: The role of strike-slip transfer zones in Faulds, J.E., and Stewart, J.H., eds., Accommodation zones and transfer zones: The regional segmentation of the Basin and Range province: Geological Society of America Special Paper 323, p. 127 – 148.

Duebendorfer, E.M., Chamberlain, K.R., Jones, C.S., 2001, Paleoproterozoic tectonic history of the Mojave-Yavapai boundary zone: Perspective from the Cerbat Mountains, northwestern Arizona: Geological Society of America Bulletin, v. 113, p. 575 – 590.

Duebendorfer, E.M., and Sharp, W.D., 1998, Variation in displacement along strike of the South Virgin—White Hills detachment fault: Perspective from the northern White Hills, northwestern Arizona: Geological Society of America Bulletin, v. 110, p. 1574 – 1589.

Duebendorfer, E.M., and Simpson, D.A., 1994, Kinematics and timing of Tertiary extension in the western Lake Mead region, Nevada: Geological Society of America Bulletin, v. 106, p. 1057 – 1073.

Duebendorfer, E.M., and Wallin, E.T., 1991, Basin development and syntectonic sedimentation associated with kinematically coupled strike-slip and detachment faulting, southern Nevada: Geology, v 19, p. 87 – 90.

Duebendorfer, E.M., Faulds, J.E., and Fryxell, J.E., 2010, The south Virgin—White Hills detachment fault, southeastern Nevada and northwestern Arizona: Significance, displacement gradient, and corrugation formation: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p. 275 – 288.

Ekren, E.B., and Anderson, R.E., 1996, Preliminary geologic map of the Boulder City 7 ½-minute Quadrangle,

Clark County, Nevada: Map prepared for the Las Vegas Valley Water District, pamphlet 13 p, map scale 1:24,000.

Elliott, D.K., and Johnson, H.G., 1997, Use of vertebrates to solve biostratigraphic problems; examples from the Lower and Middle Devonian of western North America: in Klapper, G., Murphy, M.A., and Talent, J. A., Paleozoic sequence stratigraphy, biostratigraphy, and biogeography; studies in honor of J. Granville ("Jess") Johnson: Geological Society of America Special Paper 321, p. 179 – 188.

Eschner, Edward, 1989, The geology and structural significance of the Arch Mountain area, northern Black Mountains, Mohave County, Arizona: University of Nevada, Las Vegas, M.S. thesis, 105 p.

Faulds, J.E., 1993, Geologic map of the Black Mountains accommodation zone, Mohave County, Arizona: Arizona Geological Survey Contributed Map CM-93-F.

Faulds, J.E., 1995, Geologic map of the Mt. Davis Quadrangle, Nevada: Nevada Bureau of Mines and Geology Map 105, scale 1:24,000.

Faulds, J.E., 1996, Geologic map of the Fire Mountain Quadrangle, Nevada and Arizona: Nevada Bureau of Mines and Geology Map 106, scale 1:24,000.

Faulds, J.E., Geissman, J.W., and Shafiqullah, Muhammad, 1992, Implications of paleomagnetic data on Miocene extension near a major accommodation zone in the Basin and Range Province, northwestern Arizona and southern Nevada: Tectonics, v. 11, p 204 – 227.

Faulds, J.E., Feuerbach, D.L., Reagan, M.K., Metcalf, R.V., Gans, P., and Waler, J.D., 1995, The Mount Perkins block, northwestern Arizona: An exposed cross section of an evolving, preextensional to synextensional magmatic system: Journal of Geophysical Research, v. 100, p. 15,249 – 15,266.

Faulds, J.E., and Varga, R.J., 1998, The role of accommodation zones and transfer zones in the regional segmentation of extended terranes: in Faulds, J.E., and Stewart, J.H., eds., Accommodation zones and transfer zones: The regional segmentation of the Basin and Range province: Geological Society of America Special Paper 323, p. 1 – 46.

Faulds, J.E., Smith, E.I., and Gans, P., 1999, Spatial and temporal patterns of magmatism and extension in the Northern Colorado River Extensional Corridor, Nevada and Arizona: A preliminary report: in Faulds, J. E., ed., Cenozoic Geology of the Northern Colorado River Extensional Corridor, Southern Nevada and Northwestern Arizona: Economic implications of regional segmentation structures: Nevada Petroleum Society 1999 Field Trip Guidebook, Reno, Nevada, p. 171 – 183.

Faulds, J.E., House, P.K., Shevenell, L., and Ramelli, A., 2000, Geology and natural hazard assessment of the Laughlin area, Clark County, Nevada: Nevada Bureau of Mines and Geology Open-file Report 2000-6.

Faulds, J.E., Feuerbach, D.L., Miller, C.F., and Smith, E.I., 2001, Cenozoic evolution of the northern Colorado River extensional corridor, southern Nevada and northwest Arizona: Pacific Section of the American Association of Petroleum Geologists Publication GB 78 (also Utah Geological Association Publication 30), p. 239 – 272.

Faulds, J.E., Bell, J.W., and Olson, E.L., 2002a, Geologic map of the Nelson SW Quadrangle, Nevada Bureau of Mines and Geology Map 134, scale 1:24,000.

Faulds, J.E., Olson, E.L., Harlan, S.S., and McIntosh, W.C., 2002b, Miocene extension and fault-related folding in the Highland Range, southern Nevada: a three-dimensional perspective: Journal of Structural Geology, v. 24, p. 861 – 886.

Faulds, J.E., House, P.K., Pearthree, P.A., Bell, J.W., and Ramelli, A.R., 2004, Preliminary geologic map of the Davis Dam Quadrangle and eastern part of the Bridge Canyon Quadrangle, Clark County, Nevada, and Mohave County, Arizona: Nevada Bureau of Mines and Geology Map 03-5, scale 1:24,000.

Faulds, J.E., Price, L.M., Snee, L.W., and Gans, P.B., 2010, A chronicle of Miocene extension near the Colorado Pleateau—Basin and Range boundary, southern White Hills, northwestern Arizona: Paleogeographic and tectonic implications: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of

The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p. 87 – 120.

Felger, T.J., and Beard, L.S., 2010, Geologic Map of Lake Mead and surrounding regions, southern Nevada, southwestern Utah, and northwestern Arizona: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p. 29 – 38, one sheet.

Felger, T.J., Beard, L.S., and Fleck, R.J., 2011, Miocene-Pliocene basalt flows on the East and West flanks of Wilson Ridge, Arizona, preserve multiple stages in the depositional history of adjacent Detrital Wash and Black Canyon basins, and may help constrain timing of incision by the Colorado Rover, in Beard, L.S., Karlstrom, K.E., Young, R.A., and Billingsley, G.H., eds., 2011, CRevolution 2—Origin and evolution of the Colorado River system, workshop abstracts: U.S. Geological Survey Open-File Report 2011–1210, 300 p., available at http://pubs.usgs.gov/of/2011/1210/.

Felger, T.J., Beard, L.S., Anderson, Z.A., Fleck, R.J., Wooden, J.L., and Seixas, G.B., at SPN, Geologic Map of Black Canyon and surrounding region, Nevada and Arizona: US Geological Survey Open-File Report xxxx, scale 1:48,000.

Feuerbach, D. L., 1986, Geology of the Wilson Ridge pluton; a Mid-Miocene quartz monzonite intrusion in the northern Black Mountains, Mohave County, Arizona and Clark County, Nevada: University of Nevada, Las Vegas, M.S. thesis, 54 pp.

Feuerbach, D.L., and Smith, E.I, 1986, The mid-Miocene Wilson Ridge Pluton; a subvolcanic intrusion in the Lake Mead region, Arizona and Nevada: EOS, Transactions, American Geophysical Union, v. 67, no. 44, p. 1262.

Feuerbach, D.L., Smith, E.I., Shafiqullah, M., and Damon, P.E., 1991, New K-Ar dates for Late Miocene to Early Pliocene mafic volcanic rocks in the Lake Mead area, Nevada and Arizona: Isochron West, no. 57, p. 17 – 20.

Ferguson, C.A., McIntosh, W.C., and Miller, C.F., 2013, Silver Creek caldera—the tectonically dismembered source of the Peach Spring Tuff: Geology, v. 41, p. 3 – 6.

Fryxell, J.E., Salton, G.G., Selverstone, J., and Wernicke, B., 1992, Gold Butte crustal section, South Virgin Mountains, Nevada: Tectonics, v. 11, p. 1099 – 1120.

Fryxell, J.E., and Duebendorfer, E.M., 2005, Origin and trajectory of the Frenchman Mountain block, an extensional allochthon in the Basin and Range Province, southern Nevada: Journal of Geology, v. 113, p. 355 – 371.

Gans, P. B., Landau, B., and Darvall, P., 1994, Ashes, ashes, all fall down: Caldera-forming eruptions and extensional collapse of the Eldorado Mountains, southern Nevada, Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 53.

Gans, P.B., and Bohrson, 1998, Suppression of Volcanism during rapid extension in the Basin and Range Province, United States: Science, v. 279, p. 66 – 68.

Gardner, L.R., 1972, Pediments and terraces along the Moapa Valley, Clark County, Nevada: Geological Society of America Bulletin, v. 83, p. 3479 – 3486.

Hansen, S.M., 1962, The geology of the Eldorado mining district, Clark County, Nevada: University of Missouri, xxx, Ph.D dissertation, 262 p.

Harlan, S.S., Duebendorfer, E.M., and Deibert, J.E., 1998, New 40Ar/39Ar isotopic dates from the Miocene volcanic rocks in the Lake Mead area and southern Las Vegas Range, Nevada: Canadian Journal of Earth Science, v. 35, p. 495 – 503.

Harper, B.E., Miller, C.F., Koteas, G.C., Cates, N.L., Wiebe, R.A., Lazzareschi, D.S., and Cribb, J.W., 2004, Granites, dynamic magma chamber processes and pluton construction: the Aztec Wash pluton, Eldorado Mountains, Nevada, USA: Earth Sciences, v. 95, p. 277 – 295.

Hewett, D.G., 1931, Geology and Mineral Resources of the Goodsprings quadrangle, Nevada: U.S. Geological Survey Professional Paper 275, 172 p.

Hickson, T.A., Ness, A.J., and Lamb, M.A., 2010, Miocene tectonics and climate in the Lake Mead region recorded by Horse Spring Formation carbonates in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p.121 – 146.

Honn, D.K., 2012, Petrogenesis of the linked River Mountains volcanic section and Wilson Ridge pluton: PhD dissertation, University of Nevada, Las Vegas, 299 p.

Honn, D.K., and Smith, E.I., 2008, The mid-Miocene Wilson Ridge pluton and River Mountains volcanic section, Lake Mead area of Nevada and Arizona: Linking a volcanic and plutonic section, in Duebendorfer, E. M., and Smith, E.I., eds, Field Guide to Plutons, Volcanoes, Faults, Reefs, Dinosaurs, and Possible Glaciation in Selected Areas Of Arizona, California, and Nevada: Geologic Society of America Field Guide 11, p. 1 – 20.

Hopson, C.A., Gans, P.B., Baer, E., Blythe, A., Calvert, A., Pinnow, J., 1994, Spirit Mountain Pluton, southern Nevada: a progress report: Geological Society of America Abstracts with Programs v. 26, p. 60.

House, P.K., Pearthree, P.A., Howard, K.A., Bell, J.W., Perkins, M.E., Faulds, J.E., and Brock, A.L., 2005, Birth of the lower Colorado River–Stratigraphic and geomorphic evidence for its inception near the conjunction of Nevada, Arizona, and California: in Pederson, J.L., and Dehler, C.M., Interior Western United States, Geological Society of America Field Guide 6, p. 357 – 387.

House, P.K., Pearthree, P.A., and Perkins, M.E., 2008, Stratigraphic evidence for the role of lake spillover in the inception of the lower Colorado River in southern Nevada and western Arizona: in Reheis, M.C., Hershler, R., and Miller, D.M., eds., Late Cenozoic Drainage History of the Southwestern Great Basin and Lower Colorado River Region: Geologic and Biotic Perspectives: Geological Society of America Special Paper 439, p. 335 – 353.

House, P.K., and Faulds, J.E., 2009, Preliminary geologic map of the Spirit Mountain NW Quadrangle, Clark County, Nevada and Mohave County, Arizona: Nevada Bureau of Mines and Geology Open-File Report 09-6, scale 1:24,000.

House, P.K., Green, H., Grimmer, A., and Nevada Digital Dirt Mapping Team, 2010, Preliminary surficial geologic map of the Clark County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 10-7, scale 1:250,000.

Howard, K.A., and John, B.E., 1987, Crustal extension along a rooted system of imbricate low-angle faults—Colorado River extensional corridor, California and Arizona, in Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., Continental extensional tectonics: Geological Society of London Special Publication 28, p. 299 – 311.

Howard, K.A., Hook, S.J., Phelps, G.A., and Block, D.L., 2003, Geologic Map of the Hiller Mountains Quadrangle, Clark County Nevada, and Mohave County, Arizona: Nevada Bureau of Mines and Geology Map 137, scale 1:24,000.

Howard, K.A., Lundstrom, S.C., Malmon, D.V., and Hook, S.J., 2008, Age, distribution, and formation of late Cenozoic paleovalleys of the lower Colorado River and their relation to river aggradation and degradation: in Reheis, M.C., Hershler, R., and Miller, D.M., eds., Late Cenozoic Drainage History of the Southwestern Great Basin and Lower Colorado River Region: Geologic and Biotic Perspectives: Geological Society of America Special Paper 439, p. 391 – 410.

Howard, K.A., Beard, L.S., Kuntz, M.A., Kunk, M.J., Sarna-Wojcicki, A.M., Perkins, M.E., and Lucchitta, Ivo, 2010, Erosion of tilted fault blocks and deposition of coarse sediments in half-graben basins during late stages of extension: Gold Butte area, Basin and Range Province: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics of the Lake Mead Region, Central Basin and Range: Geological Society of America Special Paper 463, p. 147 – 170.

Kapp, J.D., Miller, C.F., and Miller, J.S., 2002, Ireteba pluton, Eldorado Mountains, Nevada: Late, deep-source, peraluminous magmatism in the Cordilleran interior: Journal of Geology, v. 110, p. 649 – 669.

Koski, R.A., Hein, J.R., Bouse, R.M., Evarts, R.C., and Pickthorn, L.B., 1990, K-Ar and fission-track ages of tuff beds at the Three Kids Mine, Clark County, Nevada: Implications for manganese mineralization: Isochron West, no. 56, p 30 – 32.

Koteas, G.C., 2005, Documenting the architecture of a stratified, multiply recharged intrusion: M.S. thesis, Vanderbilt University, 103 p.

Lamb, M.A., Umhoefer, P.J., Anderson, E., Beard, L. S., Hickson, T., and Martin, K. L.; 2005, Development of Miocene faults and basins in the Lake Mead region; a tribute to Ernie Anderson and a review of new research on basins: in Pederson, Joel L., and Dehler, Carol M., Interior western United States, Geological Society of America Field Guide, v. 6, p. 389 – 418.

Lamb, M.A., Martin, K.L., Hickson, T.A., Umhoefer, P.J., and Eaton, L., 2010, Stratigraphy and age of the lower Horse Spring Formation in the Longwell Ridges area, southern Nevada: Implications for tectonic interpretation: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p. 171 – 202.

Lang, N.P., Walker, B.J., Clirborne, L.L., Miller, C.F., Hazlett, R.W., and Heizler, M.T., 2008, The Spirit Mountain batholith and Secret Pass Canyon volcanic center: A cross-sectional view of the magmatic architecture of the uppermost crust of an extensional terrain, Colorado River, Nevada-Arizona: in Duebendorfer, E.M., and Smith, E.I., eds., Field Guide to Plutons, Volcanoes, Faults, Reefs, and Dinosaurs, and Possible Glaciation in Selected Areas of Arizona, California, And Nevada: Geological Society of America Field Guide 11, p. 187 – 214.

Larsen, L.L., and Smith, E.I., 1990, Mafic enclaves in the Wilson Ridge pluton, northwestern Arizona: Implications for the generation of calc-alkaline intermediate pluton in an extensional environment: Journal of Geophysical Research, v. 95, no. B11, p. 17,693 – 17,716.

Lee, W.T., 1908, Geologic reconnaissance of a part of western Arizona: U.S. Geolgical Survey Bulletin 0352, 96 p.

Longwell, C.R., 1921, Geology of the Muddy Mountains, Nevada, with a section to the Grand Wash Cliffs in western Arizona: American Journal of Science, 5th series, v. 1, p. 39-62.

Longwell, C.R., 1922, The Muddy Mountain overthrust in southeastern Nevada: Journal of Geology, v. 30, no. 1, p. 63 – 72.

Longwell, C.R., 1936, Geology of the Boulder Reservoir floor: Geological Society of America Bulletin v. 47, no. 9, p. 1393 – 1476.

Longwell, C.R., 1963, Reconnaissance geology between Lake Mead and Davis Dam, Arizona-Nevada: U.S. Geological Survey Professional Paper, 374-E, 51 p.

Longwell, C.R., and Mound, M.C., 1967, A new Ordovician formation in Nevada dated by conodonts: Geological Society of American Bulletin, v. 78, p. 405 – 412.

Lopez-Pearce, J.C., 2010, Syntectonic deposition and paleohydrology of the spring-fed Hualapai Limestone and implications for 5-6 Ma integration of the Colorado River System through Grand Canyon: evidence from sedimentology, geochemistry and detrital zircon analysis: M.S. Thesis, University of New Mexico, Albuquerque, 265 p.

Ludington, S., Castor, S.B., McLaurin, B.T., Flynn, K.S., and Faulds, J.E., 2006, Chapter B. Mineral resource potential of the Piute-Eldorado Tortoice, Crescent Townsite, and Keyhole Canyon Areas of critical environmental concern, Clark County, Nevada: in Ludington, S., ed., Mineral Resource Assessment of Selected Areas in Clark and Nye Counties, Nevada: U.S. Geological Survey Scientific Investigations Report 2006-5197, 67 p.

Lucchitta, Ivo, 1966, Cenozoic geology of the upper Lake Mead area adjacent to the Grand Wash Cliffs, Arizona: University Park, Pennsylvania State University, Ph.D. dissertation, 218 p., map pl., scale 1:63,360.

Malmon, D.V., Howard, K.A., House, P.K., Lundstrom, S.C., Pearthree, P.A., Sarna-Wojcicki, A.M., Wan, E., and Wahl, D.B., 2011, Stratigraphy and depositional environments of the Upper Pleistocene Chemeheuvi Formation along the lower Colorado River: U.S. Geological Survey Professional Paper 2786, 96 p.

Mannion, L.E., 1963, Virgin Valley salt deposits, Clark County, Nevada: Bersticker, ed., Northern Ohio Geological Society, Symposium of Salt, Cleveland, Ohio, May, 1962 [http://www.saltinstitute.org/symposia/symposium1/mannion.pdf]

Martin, K.L., 2005, Miocene stratigraphy and sedimentology in Longwell Ridges area, and implications for extension, Lake Mead region, Nevada: Northern Arizona University, Flagstaff, Arizona, M.S. thesis, 155 p.

Matmon, Ari, Stock, G.M., Granger, D.E., and Howard, K.A., 2012, Dating of Pliocene Colorado River sediments: Implications for cosmogenic burial dating and the evolution of the lower Colorado River: Geological Society of America Bulletin, v. 124, p. 626 – 640.

McKee, E.D., 1963, Nomenclature for lithologic subdivisions of the Mississippian Redwall Limestone, Arizona: U.S. Geological Survey Professional Paper 475-C, p. 21 – 22.

McKee, E.D., 1982, The Supai Group of Grand Canyon: U.S. Geological Survey Professional Paper 1173, 504 p.

McKee, E.D., and Resser, C.E., 1945, Cambrian history of the Grand Canyon region: Washington, D.C., Carnegie Institution of Washington Publication 563, 232 p.

McKee, E.D., and Gutschick, R.C., 1969, History of the Redwall Limestone in northern Arizona: Geological Society of America Memoir, v. 114, 726 p.

McKelvey, V.E., Wiese, J.H., and Johnson, V.H., 1949, Preliminary report on the bedded manganese of the Lake Mead region, Nevada and Arizona: U.S. Geological Survey Bulletin 948-D, p. 83 – 101.

McNair, A.H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: American Association of Petroleum Geologists Bulletin, v. 35, p. 503 – 541.

Metcalf, R. V., Smith, E.I., and Mills, J.G., 1993, Magma mixing and commingling in the northern Colorado River extensional corridor; constraints on the production of intermediate magmas—Part 1, in Lahren, M.M; Trexler, J.H., Jr, and Spinosa, Claude, Crustal evolution of the Great Basin and the Sierra Nevada: University of Nevada, Reno, NV, p. 35 – 55.

Miller, C.F., D'Andrea, J.L., Ayers, J.C., Coath, C.D., Harrison, T.M., 1997. BSE imaging and ion probe geochronology of zircon and monazite from plutons of the Eldorado and Newberry Mountains, Nevada —age, inheritance, and subsolidus modification; EOS, v78, p. F783.

Miller, C.F., Furbish, D.J., Walker, B.A., Claiborne, L.L., Koteas, G.C., Bleick, H.A., and Miller, J.S., 2011, Growth of plutons by incremental emplacement of sheets in crystal-rich host: Evidence from Mioene intrusions of the Colorado River region, Nevada, USA: Tectonophysics, v. 500, p. 65 – 77.

Mills, J.G., Jr., 1985, The geology and geochemistry of volcanic and plutonic rocks in the Hoover Dam 7 1/2 minute quadrangle, Clark County, Nevada and Mohave County, Arizona: MS thesis, Las Vegas, University of Nevada, 119 p.

Mills, J.G., Jr., 1994, Geologic Map of the Hoover Dam quadrangle, Arizona and Nevada: Nevada Bureau of Mines and Geology, Map 102, scale 1:24,000.

Muntean, T.W., 2012, Muddy Creek Formation: A record of late Neogene tectonics and sedimentation in southern Nevada: PhD. Dissertation, University of Nevada, Las Vegas, 272 p.

Murphy, Ryan, 2004, Tectono-magmatic interactions and extensional folding in the Union Pass area, northern

Colorado River extensional corridor, northwest Arizona: MS thesis, University of Nevada, Reno; 134 p.

Naumann, T.R., 1987, Geology of the central Boulder Canyon quadrangle, Clark County, Nevada: Las Vegas, University of Nevada, M.S. thesis, 58 p., map pl., scale 1:24,000.

Page, W.R., Lundstrom, S.C., Harris, A.G., Langenheim, V.E., Workman, J.B., Mahan, S.A., Paces, J.B., Dixon, G.L., Rowley, P.D., Burchfiel, B.C., Bell, J.W., and Smith, E.I, 2005, Geologic and geophysical maps of the Las Vegas 30' x 60' quadrangle, Clark and Nye Counties, Nevada, and Inyo County, California: U. S. Geological Survey Scientific Investigations Map 2814, 54 p., 2 plates, scale 1:100,000.

Reif, Douglas M., and Slatt, R.M., 1979, Red bed members of the Lower Triassic Moenkopi Formation, southern Nevada: Sedimentology and paleogeography of a muddy tidal flat deposit: Journal of Sedimentary Petrology, v. 49, p. 879 – 890.

Reynolds, S.J, Florence, F.P., Welty, J.W., Roddy, M.S., Currier, D.A., Anderson, A.V., and Keith, S.B., 1986, Compilation of radiometric age determinations in Arizona: Arizona Geological Survey Bulletin 197, 258 p., scale 1:1,000,000.

Rowland, S.M, Parolini, J.R, Eschner, E., McAllister, A.J., and Rice, J.A., 1990, Sedimentologic and stratigraphic constraints on the Neogene translation and rotation of the Frenchman Mountain structural block, Clark County, Nevada: in Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Boulder Colorado, Geological Society of America Memoir 176, p. 99 – 122.

Ryan, M., 2011, Mixing and melt sources in the Miocene Aztec Wash pluton (Nevada, USA) as revealed by Zircon Hf and O and whole rock Sr, Nd and Hf Isotopes: MS thesis, San Jose State University, California; 395 p.

Schmidt, D.L., 1994, Preliminary geologic map of the Farrier quadrangle, Clark and Lincoln Counties, Nevada: U.S. Geological Survey Open-File Report 94-625, scale 1:24,000.

Schmidt, D.L., Page, W.R., and Workman, J.B., 1996, Preliminary geologic map of the Moapa West quadrangle, Clark County, Nevada: U.S. Geological Survey Open-File Report 96-521, scale 1:24,000.

Scott, A.J., 1988, The Muddy Creek Formation: depositional environment, provenance, and tectonic significance in the western Lake Mead area, Nevada and Arizona: University of Nevada, Las Vegas M.S. thesis, 144 p.

Silver, L.T., Bickford, M.E., Van Schmus, W.R., Anderson, J.L., Anderson, T.H., and Medaris, L.G., Jr., 1977, The 1.4-1.5 b.y. transcontinental anorogenic plutonic perforation of North America: Geological Society of America Abstracts with Programs, v. 9, p. 1176-1177.

Smith, E.I., 1984, Geologic map of the Boulder Beach quadrangle, Nevada: Nevada Bureau of Mines and Geology Map 81, scale 1:24,000.

Smith, J.N., 2011, Incorporation of host rock blocks during the growth of the Aztec Wash Pluton, Eldorado Mountains, Nevada: M.S. thesis, San Jose State University, California, 83 p.

Sorauf, J.E. and Billingsley, G.H., 1991, Members of the Toroweap and Kaibab Formations, Lower Permian, northern Arizona and southwestern Utah: Mountain Geologist, v. 28, p. 9 – 24.

Spencer, J.E., Peters, L. McIntosh, W.C., and Patchett, P.J, 2001, 40Ar/39Ar geochronology of the Hualapai Limestone and Bouse Formation and implications for the age of the lower Colorado River: in Young, R.A, and Spamer, E.E., eds., Colorado River: Origin and Evolution: Grand Canyon Association Monograph 12, p. 89 – 91.

Spencer, J.E., Ferguson, C.A., Pearthree, P.A., and Richard, S.M., 2007, Geologic map of the Boundary Cone 7.5-minute Quadrangle, Mohave County, Arizona: Arizona Geological Survey Digital Geologic Map DGM-54, scale 1:24,000.

Stock, Chester, 1921, Later Cenozoic mammalian remains from the Meadow Valley region, southeastern Nevada: American Journal of Science, 5th series, v. 2, p. 250 – 264.

Swadley, W.C., Schmidt, D.L., Shroba, R.R., Williams, V.S., and Hoover, D.L., 1995: U.S. Geological Survey Bulletin 2056-F, p. 181 – 202.

Swaney, Z.A., 2005, Tilting history of the Lost Basin Range and western Grand Wash trough, western Arizona: Regional Implications: Northern Arizona University, Flagstaff, Arizona; M.S. thesis, 140 pp.

Theodore, T.G; Blair, W.N; Nash, J.T., 1987, Geology and gold mineralization of the Gold Basin-Lost Basin mining districts, Mohave County, Arizona: U.S. Geological Survey Professional Paper 1361, 167 p.

Thomas, W.M., Clark, S.H., Young, E.D., Orrell, S.E., and Anderson, J.L., 1988, Proterozoic high-grade metamorphism in the Colorado River region, Nevada, Arizona, and California, in Ernst, W.G., ed., Metamorphism and Crustal Evolution of the Western United States, Rubey Volume VII: Prentice-Hall, Englewood Cliffs, J.J., p 526 – 537.

Thompson, K.G., 1985, Stratigraphy and petrology of the Hamblin-Cleopatra Volcano, Clark County, Nevada: University of Texas, Austin, M.S. thesis, 306 p.

Timm, J.J., 1985, Age and significance of Paleozoic sedimentary rocks in the southern River Mountains, Clark County, Nevada: M.S. Thesis, Las Vegas, University of Nevada, 62 p.

Townsend, K.J., Miller, C.F., D'Andrea, J.L., Ayers, J.C., Harrison, T.M., and Coath, C.D., 2000, Low temperature replacement of monazite ein the Ireteba granite, southern Nevada: geochronological implications: Chemical Geology, v. 172, p. 95 – 112.

Umhoefer, P.J., Duebendorfer, E.M., Blythe, N., Swaney, Z.A., Beard, L.S., and McIntosh, W.C., 2010, Development of Gregg Basin and the southwestern Grand Wash trough during late-stage faulting in eastern Lake Mead, Arizona: in Umhoefer, P.J., Beard, L.S., and Lamb, M.A., eds., Miocene Tectonics Of The Lake Mead Region, Central Basin And Range: Geological Society of America Special Paper 463, p. 221 – 242.

U.S. Bureau of Reclamation, 1950, Boulder Canyon Project Final Reports: Part III – Geologic Investigations: Bulletin 1, Denver, Colorado, 232 p.

Varga, R.J., Faulds, J.E., Snee, L.W., Harlan, S.S., and Bettison-Varga, L, 2004, Miocene extension and extensional folding in an anticlinal segment of the Black Mountains accommodation zone, Colorado River extensional corridor, southwestern United States: Tectonics, v. 23, 19 p.

Volborth, A., 1962, Rapakivi-type granites in the Precambrian complex of Gold Butte, Clark County, Nevada: Geological Society of America Bulletin, v. 73, p. 813 – 832.

Volborth, A., 1973, Geology of the granite complex of the Eldorado, Newberry, and northern Dead Mountains, Clark County, Nevada: Nevada Bureau of Mines and Geology Bulletin 80, 40 p.

Walker, B.A., Jr, 2006, Geology and geochronology of the Spirit Mountain batholith, southern Nevada: implications for timescales and physical processes of batholith construction: Master Thesis, Vanderbilt University, Nashville, Tennessee; 72 p.

Wallace, M.A., Faulds, J.E., and Brady, R.J., 2006, Geologic map of the Meadview North quadrangle, Arizona and Nevada: Nevada Bureau of Mines and Geology Map 154, scale 1:24,000.

Wasserburg, G.J., and Lanphere, M.A., 1965, Age determinations in the Precambrian of Arizona and Nevada: Geological Society of America Bulletin, v. 76, p.735 – 758.

Weber, M.E., and Smith, E.I., 1987, Structural and geochemical constraints on the reassembly of disrupted mid-Miocene volcanoes in the Lake Mead – Eldorado Valley area of southern Nevada: Geology, v. 15, p. 553 – 556.

Wenrich, K.J., Billingsley, G.H., and Blackerby, B.A., 1995, Spatial Migration and Compositional Changes of Miocene-Quaternary Magmatism in the Western Grand Canyon: Journal of Geophysical Research, v. 100, no. B7, p. 10,417 – 10,444.

Williams, M. M., 2003, Depositional History of the Black Mountains Conglomerate, Mohave County, Arizona: Sedimentary Response to Miocene Extension: M.S. Thesis, Las Vegas, University of Nevada, 56 p.

Williams, V.S., 1996, Preliminary geologic map of the Mesquite Quadrangle, Clark and Lincoln Counties, Nevada, and Mohave County, Arizona: U.S. Geological Survey Open-File Report 96 – 676.

Williams, V.S., Bohannon, R.G., and Hoover, D.L., 1997, Geologic map of the Riverside quadrangle, Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map 1770, scale 1:24,000.

Wooden, J.L., and DeWitt, E., 1991, Pb isotopic evidence for the boundary between the early Proterozoic Mojave and central Arizona crustal provinces in western Arizona, in Karlstrom, K.E., Proterozoic geology and ore deposits of Arizona: Tucson, Arizona, Arizona Geological Society Digest v. 19, p. 27 – 50.

Young, R.A., 2001, Geomorphic, structural, and stratigraphic evidence for Laramide uplift of the southwestern Colorado Plateau margin in northwestern Arizona, in Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D. (eds.), The geologic transition, High Plateaus to Great Basin – A symposium and field Guide: The Mackin Volume: Utah Geological Association Publication 30, p. 227 – 237.

Extracted from: (Lake Mead NRA).

GRI Digital Data Credits

This document was developed and completed by Greg Mack (NPS PWR Seattle) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory(GRI) Program. Quality control of this document by Stephanie O'Meara (Colorado State University).

The information in this document was compiled from the GRI source map, and intended to accompany the digital geologic-GIS map(s) and other digital data for Lake Mead National Recreation Area, Nevada and Arizona (LAKE) developed by Greg Mack (NPS PWR Seattle) (see the GRI Digital Map and Source Map Citation section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS map(s)). Quality control of GRI digital geologic-GIS data by Stephanie O'Meara.

GRI finalization by Stephanie O'Meara.

GRI program coordination and scoping provided by Bruce Heise and Tim Connors (NPS GRD, Lakewood, Colorado).