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

Grand Canyon National Park

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Grand Canyon National Park

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Geologic Resources Inventory Map Document for Grand Canyon National Park

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Geologic Resources Inventory Map Document

Grand Canyon National Park, Arizona

Document to Accompany Digital Geologic-GIS Data

grca_geology.pdf

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This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Grand Canyon National Park, Arizona (GRCA).

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.

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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:

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GRI Digital Maps and Source Map Citations

Multiple digital geologic-GIS map were produced for this park -- a compiled map clipped to the quadrangles of interest for the park, and eight component maps displaying the geology depicted in the eight 30' x 60' quadrangle maps used for this project.
The GRI digital geologic-GIS maps for Grand Canyon National Park, Arizona (GRCA):

The GRI compiled park extent and vicinity map (source are listed with the individual 30' x 60' quadrangle component maps below),
GRI Digital Geologic Map of Grand Canyon National Park, Arizona *(GRI MapCode GRCA)*

Component 30' x 60' quadrangle maps:
The publications below were used in both the compilation and component maps.

GRI Digital Geologic Map of the Glen Canyon Dam 30' x 60' Quadrangle, Arizona *(GRI MapCode GLCD)*
Billingsley, G.H., and Priest, S.S., 2013, Geologic Map of the Glen Canyon Dam 30' x 60' Quadrangle, Coconino County, Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-3268, 1:100000 scale. (Glen Canyon Dam 30' x 60' Quadrangle). *(GRI Source Map ID 75664).*

GRI Digital Geologic Map of the Tuba City 30' x 60' Quadrangle, Arizona *(GRI MapCode TCTY)*
Billingsley, G.H., Stoffer, P.W., and Priest, S.S., 2012, Geologic Map of the Tuba City 30' x 60' Quadrangle, Coconino County, Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-3227, 1:50000 scale. (Tuba City 30' x 60' Quadrangle). *(GRI Source Map ID 75648).*

GRI Digital Geologic Map of the Fredonia 30' x 60' Quadrangle, Arizona *(GRI MapCode FRDN)*
Billingsley, G.H., Priest, S.S., and Felger, T.J., 2008, Geologic Map of the Fredonia 30' x 60' Quadrangle, Mohave and Coconino Counties, Northern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-3035, 1:100000 scale. (Fredonia 30' x 60' Quadrangle). *(GRI Source Map ID 75234).*

GRI Digital Geologic Map of Wupatki National Monument and Vicinity, Arizona *(GRI MapCode WUPA)*
Billingsley, G.H., Priest, S.S., and Felger, T.J., 2007, Geologic Map of the Cameron 30' x 60' Quadrangle, Coconino County, Northern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-2977, 1:100000 scale. (Cameron 30' x 60' Quadrangle). *(GRI Source Map ID 7454).*

GRI Digital Geologic Map of the Peach Springs 30' x 60' Quadrangle, Arizona *(GRI MapCode PESP)*
Billingsley, G.H., Block, D.L., and Dyer, H.C., 2006, Geologic Map of the Peach Springs 30' x 60' Quadrangle, Mohave and Coconino Counties, Northwestern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-2900, 1:100000 scale. (Peach Springs 30' x 60' Quadrangle). *(GRI Source Map ID 4151).*

GRI Digital Geologic Map of the Valle 30' x 60' Quadrangle, Arizona *(GRI MapCode VLLE)*
Billingsley, G.H., Felger, T.J., and Priest, S.S., 2006, Geologic Map of the Valle 30' x 60' Quadrangle, Coconino County, Northern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-2895, 1:100000 scale. (Valle 30' x 60' Quadrangle). *(GRI Source Map ID 7453).*

GRI Digital Geologic Map of the Mount Trumbull 30' X 60' Quadrangle, Arizona *(GRI MapCode MTRB)*
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, 1:100000 scale. (Mount Trumbull 30' x 60' Quadrangle). *(GRI Source Map ID 4152).*

GRI Digital Geologic Map of the Grand Canyon 30' X 60' Quadrangle, Arizona *(GRI MapCode GRAC)*
Billingsley, G.H., and Hampton, H.M., 2000, Geologic Map of the Grand Canyon 30' X 60' Quadrangle, Coconino and Mohave Counties, Northwestern Arizona, U.S. Geological Survey, Geologic Investigations Series Map I-2688, 1:100000 scale. (Grand Canyon 30' x 60' Quadrangle). *(GRI Source Map ID 1309).*

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

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Grand Canyon National Park, Arizona (GRCA) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qaf - Artificial fill and quarries). Generally, units are listed from youngest to oldest. However, groupings of units (e.g., Volcanic rocks of the San Francisco Volcanic Field) have been preserved in this document, making the unit sorting slightly different than that of the GIS data. Information about each geologic unit is also presented in the GRI Geologic Unit Information (GRCAUNIT) table included with the GRI geology-GIS data.

Cenozoic Era

Quaternary Period

Qaf - Artificial fill and quarries
Qs - Stream-channel deposits
Qf - Floodplain deposits
Qd - Dune sand and sand sheet deposits, undivided
Qes - Sand sheet deposits
Qc - Colluvial deposits
Qdl - Linear dune deposits
Qdp - Parabolic dune deposits
Qdb - Barchan dune deposits
Little Spring Basalt
    Qlsp - Little Spring Basalt, pyroclastic deposits
    Qlsb - Little Spring Basalt, basalt flows
Qdm - Mixed dune deposits
Qdlu - Linear dune and sand sheet deposits, undivided
Qg1 - Young terrace-gravel deposits
Qtgr - Terrace gravel deposits
Qg2 - Intermediate terrace-gravel deposits
Qg3 - Old terrace-gravel deposits
Qa1 - Young alluvial fan deposits
Qa - Alluvial deposits
Qa2 - Intermediate alluvial fan deposits
Qr - Colorado River gravel and silt deposits
Qgy - Young alluvial terrace deposits
Qay - Young alluvial fan deposits
Qa3 - Old alluvial fan deposits
Qps - Ponded sediments
Qae - Mixed alluvium and eolian deposits
Qss - Sand sheet deposits
Qscf - Eolian and fluvial silt deposits
Qv - Valley-fill deposits
Qt - Travertine deposits
Qtr - Talus and rock-fall deposits
Ql - Landslide deposits
Qgo - Older alluvial terrace deposits
Qsd - Silt dune deposits
Qdc - Eolian cinder dune deposits
Qsc - Eolian cinder sand sheet deposits
Qltb - Basalt of Larimore Tank, basalt flows
Little Tanks Basalt
    Qlp - Little Tanks Basalt, pyroclastic deposits
    Qlb - Little Tanks Basalt, basalt flows

Heaton Knolls Basalt
- Qhkp - Heaton Knolls Basalt, pyroclastic deposits
- Qhkb - Heaton Knolls Basalt, basalt flows

Basalt of Graham Ranch
- Qgrp - Basalt of Graham Ranch, pyroclastic deposits
- Qgrb - Basalt of Graham Ranch

Tuckup Canyon Basalt
- Qtid - Tuckup Canyon Basalt, intrusive dikes
- Qtp - Tuckup Canyon Basalt, pyroclastic deposits
- Qtb - Tuckup Canyon Basalt, basalt flow

Basalt of Hancock Knolls
- Qhp - Basalt of Hancock Knolls, pyroclastic deposits
- Qhb - Basalt of Hancock Knolls, basalt flows

Sage Basalt
- Qspd - Sage Basalt, pyroclastic deposits
- Qsb - Sage Basalt, basalt flows

Qidn - Basalt dikes and necks
Qpyr - Pyroclastic deposits
Shadow Mountain Basalt
- Qism - Intrusive dikes of Shadow Mountain
- Qsp - Pyroclastic deposits of Shadow Mountain
- Qsbf - Basalt flows of Shadow Mountain

Qpyd - Pyroclastic deposits
Qbf - Basalt flows
Qbt - Basalt flow of Tappan Wash
Qbfl - Fissure deposits of Lockett Tank
Qbmp - Pyroclastic deposits
Qbmb - Basalt flows
Qsfp - Pumice of San Francisco Mountain
Qmbi - Basalt dike
Qmp - Pyroclastic deposits
Qmb - Basalt flows
Qmlp - Basalt flow of Lava Point
Qslr - Rhyolite dome complex of Slate Mountain
Qbcr - Basalt flows along the Colorado River
Basalt of the Uinkaret Plateau
- Qi - Basalt of the Uinkaret Plateau, intrusive rocks, south of Mount Trumbull
- Qi1 - Basalt of the Uinkaret Plateau, intrusive rocks, north of Mount Trumbull
- Qp - Basalt of the Uinkaret Plateau, pyroclastic deposits, south of Mount Trumbull
- Qp1 - Basalt of the Uinkaret Plateau, pyroclastic deposits, north of Mount Trumbull
- Qb - Basalt of the Uinkaret Plateau, basalt flows, south of Mount Trumbull
- Qb1 - Basalt of the Uinkaret Plateau, basalt flows, north of Mount Trumbull

Basalt of Kenworthy Ranch
- Qkrp - Basalt of Kenworthy Ranch, pyroclastic deposits
- Qkrb - Basalt of Kenworthy Ranch, basalt flows

Basalt of Marshall Ranch
- Qmrp - Basalt of Marshall Ranch, pyroclastic deposits
- Qmrb - Basalt of Marshall Ranch, basalt flows

Basalt of hill 6375
- Qp6375 - Basalt of hill 6375, pyroclastic deposits
- Qb6375 - Basalt of hill 6375, basalt flows

Basalt of hill 6646
- Qp6646 - Basalt of hill 6646, pyroclastic deposits

Qb6646 - Basalt of hill 6646, basalt flows
Basalt of hill 6457
Qp6457 - Basalt of hill 6457, pyroclastic deposits
Qb6457 - Basalt of hill 6457, basalt flows
Qpvp - Basalt of Potato Valley, pyroclastic deposits
Qpvb - Basalt of Potato Valley, basalt flows
Basalt of hill 6588
Qp6588 - Basalt of hill 6588, pyroclastic deposits
Qb6588 - Basalt of hill 6588, basalt flows
Basalt of Craigs Knoll and Berry Knoll
Qcbi - Basalt of Craigs Knoll and Berry Knoll, intrusive dikes or necks
Qcbp - Basalt of Craigs Knoll and Berry Knoll, pyroclastic deposits
Qcbb - Basalt of Craigs Knoll and Berry Knoll, basalt flows
Qg4 - Older terrace-gravel deposits

Quaternary Period and Tertiary Period
QTwb - Basalt flows of Woodhouse Mesa
QTi - Hells Hole dikes
QTd - Old dune deposits, undivided
QTdl - Old linear dune deposits
QTdp - Old parabolic dune deposits
QTes - Old eolian sand sheet and dune deposits
QTg - Terrace-gravel deposits
QTae - Old mixed alluvium and eolian deposits
QTa4 - Older alluvial fan deposits
QTgd - Old gravel deposits
QTg4 - Older terrace-gravel deposits
QTg5 - Youngest old terrace-gravel deposits
Qg5-18 - Oldest terrace-gravel deposits, undivided
QTg6 - Intermediate old terrace-gravel deposits
QTg7 - Oldest old terrace-gravel deposits
Volcanic rocks of the San Francisco Volcanic Field
Qmcb - Basalt flow of Merriam Crater
Qyap - Pyroclastic deposits of S P Mountain
Qyab - Basaltic andesite of S P Mountain
Qyp - Pyroclastic deposits of five young cinder cones
Qyb - Basalt flow of five young cinder cones
QTisf - Volcanic rocks of the San Francisco Volcanic Field, intrusive dike or plug
QTpsf - Volcanic rocks of the San Francisco Volcanic Field, pyroclastic deposits
QTbsf - Volcanic rocks of the San Francisco Volcanic Field, basalt flows
QTai - Volcanic rocks of the San Francisco Volcanic Field, basalt and andesite dikes and necks
QTap - Volcanic rocks of the San Francisco Volcanic Field, basalt and andesite pyroclastic deposits
QTab - Volcanic rocks of the San Francisco Volcanic Field, basalt and andesite flows
Thma - Andesite flows of Howard Mesa
Tyi - Volcanic rocks of the San Francisco Volcanic Field, young intrusive rocks
Typ - Volcanic rocks of the San Francisco Volcanic Field, young pyroclastic deposits
Tyb - Volcanic rocks of the San Francisco Volcanic Field, young basalt flows
Trb - Volcanic rocks of the San Francisco Volcanic Field, basalt flow of Red Butte
Tbi - Dike in ampitheater
Tp - Pyroclastic deposits
Tb - Basalt flows
Basalt north of Mount Emma

Tei - Basalt north of Mount Emma, intrusive rocks
Tep - Basalt north of Mount Emma, pyroclastic deposits
Teb - Basalt north of Mount Emma, basalt flows
Tmlb - Basalt of Mount Logan, basalt flows
Basalt of Bundyville
Tbid - Basalt of Bundyville, intrusive dikes
Tbb - Basalt of Bundyville, basalt flows
Basalt of Mount Trumbull
Tmi - Basalt of Mount Trumbull, intrusive rocks
Tmb - Basalt of Mount Trumbull, basalt flows
Basalt of the Grand Wash Trough
Tigw - Basalt of the Grand Wash Trough, dikes and necks
Tbgw - Basalt of the Grand Wash Trough, basalt flows
Tgs - Gravel and sedimentary deposits
Twi - Whitmore dike swarm, intrusive dikes
Twb - Whitmore dike swarm, basalt flow
Basalt of Poverty Knoll
Tpki - Basalt of Poverty Knoll, intrusive dike
Tpkb - Basalt of Poverty Knoll, basalt flow
Poverty Mountain Basalt
Tpi - Poverty Mountain Basalt, intrusive neck
Tpp - Poverty Mountain Basalt, pyroclastic deposits
Tpb - Poverty Mountain Basalt, basalt flows
Grassy Mountain Basalt
Tgi - Grassy Mountain Basalt, intrusive dikes
Tgp - Grassy Mountain Basalt, basalt flows
Tgb - Grassy Mountain Basalt, pyroclastic deposits
Tay - Alluvium and calcrete soil deposits
Tao - Alluvial deposits
Tgr - Rocks of the Grand Wash Trough, red siltstone, sandstone, and conglomerate facies
Tbpb - Black Point Basalt flows
Tscd - Old stream-channel deposits
Tocb - Basalt flow of Cedar Ranch Mesa
Basalt of the Shiwits Plateau
Tsi - Shiwits basalt, intrusive rocks
Tsp - Basalt of the Shiwits Plateau, pyroclastic deposits
Tsb - Shiwits basalt, basalt flows
T227i - 227-Mile intrusive
Blue Mountain Basalt
Tbmi - Blue Mountain Basalt, dikes and necks
Tbmb - Blue Mountain Basalt, basalt flows
Tp6i - Dikes of Parashant Canyon and Hundred and Ninetysix Mile Creek
T2i - Dikes of Colorado River Mile 202
Snap Point Basalt and Garrett Dikes
Tsgi - Snap Point Basalt and Garrett Dikes, Intrusive dikes
Tsgb - Snap Point Basalt and Garrett Dikes, Basalt flows
Rocks of the Grand Wash Trough
Tgc - Rocks of the Grand Wash Trough, paleozoic-clast conglomerate
Tgl - Rocks of the Grand Wash Trough, limestone and siltstone facies
Tgg - Rocks of the Grand Wash Trough, gypsum and gypsiferous siltstone facies
Tgx - Proterozoic-clast conglomerate facies
Volcanic rocks of the Mount Floyd Volcanic Field
Tri - Volcanic rocks of the Mount Floyd Volcanic Field, rhyolite, rhyodacite, and obsidian dikes,

necks, and vent areas
Tr - Volcanic rocks of the Mount Floyd Volcanic Field, rhyolite, rhyodacite, and obsidian flows
Tiba - Volcanic rocks of the Mount Floyd Volcanic Field, basalt and andesite dikes, plugs, and necks
Tba - Volcanic rocks of the Mount Floyd Volcanic Field, basalt and andesite flows
Tc - Pyroclastic deposits
Volcanic rocks of the Hualapai Plateau
Tv - Volcanic rocks of the Hualapai Plateau, andesite flows and basalt flows, undivided
Ti - Volcanic rocks of the Hualapai Plateau, intrusive dikes
Tbfn - Volcanic rocks of the Hualapai Plateau, basalt flow of Nelson
Ths - Horse Spring Formation, Rainbow Gardens Member
TKs1 - Old gravel and sedimentary deposits
Ts - Sedimentary rocks
TKs2 - Oldest gravel and sedimentary deposits

Mesozoic Era

Cretaceous Period

Kp - Quartz monzonite pluton
Km - Mancos Shale
Kd - Dakota Sandstone

Jurassic Period

Jms - Morrison Formation, Salt Wash Member
San Rafael Group
Jr - Romana Sandstone
Je - Entrada Sandstone
Jc - Carmel Formation, undivided
Jcu - Carmel Formation, Paria River Member and Winsor Member, undivided
Jcj - Carmel Formation, Judd Hollow Tongue and Page Sandstone Tongues, undivided
Jp - Page Sandstone
Glen Canyon Group
Jn - Navajo Sandstone
Jkn - Kayenta Formation and Navajo Sandstone transition zone
Jk - Kayenta Formation, undivided
Jks - Kayenta Formation, Springdale Sandstone Member
Jm - Moenave Formation and Wingate Sandstone, undivided
Jmw - Moenave Formation, Whitmore Point Member
Jmd - Moenave Formation, Dinosaur Canyon Member

Triassic Period

Chinle Formation
TRc - Chinle Formation, undivided
TRco - Chinle Formation, Owl Rock Member
TRcp - Chinle Formation, Petrified Forest Member
TRcs - Chinle Formation, Shinarump Member
Moenkopi Formation
TRm - Moenkopi Formation, undivided
TRmu - Moenkopi Formation, upper red member
TRms - Moenkopi Formation, Shnabkaib Member
TRmw - Moenkopi Formation, Wupatki Member
TRmlm - Moenkopi Formation, lower red member, Virgin Limestone Member, and middle red member, undivided
TRmm - Moenkopi Formation, middle red member

TRmv - Moenkopi Formation, Virgin Limestone Member
TRml - Moenkopi Formation, lower red member
TRmt - Moenkopi Formation, Timpoweap Member

Paleozoic Era

Permian Period, Pennsylvanian Period and Mississippian Period

Kaibab Formation
- Pk - Kaibab Formation, undivided
- Pkh - Kaibab Formation, Harrisburg Member
- Pkf - Kaibab Formation, Fossil Mountain Member

Toroweap Formation
- Pt - Toroweap Formation, undivided
- Ptw - Toroweap Formation, Woods Ranch Member
- Ptb - Toroweap Formation, Brady Canyon and Seligman Members, undivided
- Pts - Toroweap Formation, Seligman Member
- Pc - Coconino Sandstone

Ph - Hermit Formation

Supai Group
- Pe - Esplanade Sandstone
- Pep - Esplanade Sandstone and Pakoon Limestone, undivided
- PNMs - Wescogame Formation, Manakacha Formation, and Watahomigi Formation, undivided

Ms - Surprise Canyon Formation

Mr - Redwall Limestone, undivided

Devonian Period

Dtb - Temple Butte Formation

Cambrian Period

Tonto Group
- Cm - Muav Limestone
- Cba - Bright Angel Shale
- Ct - Tapeats Sandstone

Cs - Sixtymile Formation, undivided

Precambrian Era

Proterozoic Period

Chuar Group
- Kwagunt Formation
  - Zkw - Kwagunt Formation, Walcott Member
  - Zka - Kwagunt Formation, Awatubi Member
  - Zkcb - Kwagunt Formation, Carbon Butte Member
- Galeros Formation
  - Zgd - Galeros Formation, Duppa Member
  - Zgcc - Galeros Formation, Carbon Canyon Member
  - Zgj - Galeros Formation, Jupiter Member
  - Zgt - Galeros Formation, Tanner Member
- Zn - Nankoweap Formation, undivided

Yi - Unnamed diabase sills and dikes

Unkar Group
- Yc - Cardenas Basalt
- Yd - Dox Formation

Ydo - Dox Formation, Ochoa Point Member

Ydc - Dox Formation, Comanche Point Member

Yds - Dox Formation, Solomon Temple Member
Yde - Dox Formation, Escalante Creek Member
Ys - Shinumo Sandstone, undivided
Yh - Hakatai Shale, undivided
Yb - Bass Formation
Ydi - Diabase intrusive rocks
Yg - Young granite and pegmatite
Xg - Granite
Xgr - Granite, granitic pegmatite and aplite
Xgd - Granodiorite-gabbro-diorite and granodiorite complexes
Xum - Ultramafic rocks
Xdg - Diorite, gabbro, and anorthosite
Xs - Schist
Xv - Vishnu Schist
Xr - Rama Schist and Gneiss
Xbr - Brahma Schist
Xm - Mafic metavolcanic rocks
Xo - Orthoamphibole schist
Xc - Carbonate and chert
Xu - Crystalline rocks, undivided
Xec - Elves Chasm pluton

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. Some unit were lumped together in the USGS published map but remained split out in the source GIS data used for this project. As are result, different units might display the same source geologic symbol, name and description. For example, units Qes and Qd from the Fredonia 30 x 60 quadrangle (SIM-3035) were lumped into unit Qd in the published USGS map; both units Qes and Qd in this document will display identical source information.

Qaf - Artificial fill and quarries (Holocene)

Qaf - Artificial fill and quarries (Holocene)
Alluvium and bedrock material removed from borrow pits and trenches to build stock tanks, drainage diversion dams, landfills, roads, railroads, and projects related to the city of Page, Arizona, Glen Canyon Dam, and the Arizona Public Service Power Plant east of Page (not all road and railroad excavations are shown). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qaf - Artificial fill and quarries (Holocene)
Excavated alluvium and bedrock material removed from barrow pits and trenches to build livestock tanks, drainage diversion dams, landfills, roads, and other construction projects (not all road and construction excavations are shown). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qaf - Artificial fill and quarries (Holocene)
Alluvium and bedrock material removed from quarries and trench excavations used to build stock tanks, drainage diversion dams, roads, or other manmade construction projects; not all modern highways cuts are shown. Include uranium and copper mine excavations. No map distinctions between cut or fill excavations. Agricultural fields are not shown. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qaf - Artificial fill and quarries (Holocene)
Excavated alluvium and bedrock material removed from bar-pits and trenches to build livestock tanks, drainage diversion dams, roads, and other construction projects (not all highway road excavations are mapped). Include uranium mine excavations, tailing deposits, and mine restoration sites in the Little Colorado River Valley area. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qaf - Artificial fill and quarries (Holocene)
Alluvium and bedrock material excavated from bar-pits and trenches to build livestock tanks, drainage diversion dams, roads, and other construction projects. Include copper mine excavations and mine dumps southwest of Tusayan and west of State Highway 64. Does not include all highway road cuts and roadbed fill. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qs - Stream-channel deposits (Holocene)

Qs - Stream-channel deposits (Holocene)
Poorly sorted, unconsolidated, interbedded mud, silt, sand, pebbles, and gravel. Intertongue with or inset against young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3), young, intermediate, and old terrace-gravel (Qg1, Qg2, Qg3), and upper part of valley-fill (Qv) deposits in House Rock Valley and Marble Plateau areas. Overlaps and intertongues with floodplain (Qf), ponded sediment (Qps), and mixed alluvium and eolian (Qae) deposits on Paria and Kaibito Plateau areas. Little or no vegetation in stream channels, except for some salt cedar (tamarisk), Russian olive, and cottonwood trees and grass.

Contacts with adjacent alluvial or eolian deposits are approximate. Thickness, 3 to 30 ft (1 to 9 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qs - Stream-channel deposits (Holocene)
Poorly sorted, interbedded mud, silt, sand, pebbles, and gravel. Intertongue with or inset against young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3), young, intermediate, and old terrace-gravel (Qg1, Qg2, Qg3), and upper part of valley alluvial (Qv) deposits; overlaps and intertongues with flood-plain (Qf) and ponded sediment (Qps) deposits. Stream channels subject to high-energy flows and flash floods. Little or no vegetation in stream channels, except for some salt cedar (tamarisk), Russian olive, and cottonwood trees. Contacts with adjacent alluvial or eolian deposits are approximate. Stream-channel deposits of Moenkopi and Hamblin Washes do not necessarily reflect stream-channel deposits of today owing to low-gradient channel changes caused by yearly fluctuations in stream levels and flooding events. Thickness, 3 to 30 ft (1 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qs - Stream-channel deposits (Holocene)
White to light-red interbedded silt, sand, gravel, and pebbles; unconsolidated and poorly sorted. Pebbles and some cobbles are mostly sandstone above the stratigraphic position of the Shinarump Member of the Chinle Formation; below the Chinle, clasts are dominated by black, well-rounded pebbles of quartzite or chert derived from the Shinarump Member of the Chinle Formation. Intertongue with or inset against young alluvial fan (Qay), young terrace-gravel (Qgy), and upper part of valley alluvial (Qv) deposits, overlaps flood-plain (Qf) and ponded sediment (Qps) deposits. Stream channels subject to intermittent high-energy flash floods that produce local sediment accumulation on flood-plain (Qf), young terrace-gravel (Qgy), and young alluvial fan (Qay) deposits. Little or no vegetation in stream channels except for occasional tamarisk trees, willow trees, and grass. About 1 to 4 m (3 to 12 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qs - Stream-channel deposits (Holocene)
Poorly sorted, interlensing silt, sand, pebbles, and gravel. Intertongue with or inset against young alluvial fan (Qay), young terrace-gravel (Qgy), and upper part of valley alluvial (Qv) deposits, overlaps flood-plain (Qf) and ponded sediment (Qps) deposits. Stream channels subject to high-energy flows and flash floods. Little or no vegetation in stream channels, except for salt cedar (tamerisk), Russian olive, and cottonwood trees along Little Colorado River and some of its tributaries. Contact with other alluvial deposits merge laterally and are approximate. Stream-channel deposits of Little Colorado River mapped as shown on 1968 black and white aerial photographs and do not necessarily reflect stream-channel deposits of today due to extensive low-gradient channel changes caused by yearly flooding events. Little Colorado River stream channel meanders within its wide valley from upstream of Cameron to southeast corner of map area where the channel is confined within bedrock strata of Kaibab Formation. Downstream of Cameron, the Little Colorado River is largely confined within alternating hard and soft rocks of the Moenkopi and Kaibab Formations for about 11 km (7 mi), then becomes confined and strikingly meandering within narrow walls of Permian and older Paleozoic strata that form the Little Colorado River Gorge (fig. 1) and is part of the Grand Canyon physiographic area. About 2 to 9 m (6 to 30 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qs - Stream-channel deposits (Holocene)
Light-gray to light-brown and reddish-brown, unconsolidated mud, sand, gravel, pebbles and boulders. Subject to flash flood debris flows. Thickness, 0.5 to 3 m (2 to 10 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene)
Light-brown, pale-red, and gray, poorly sorted fluvial mud, silt, sand, gravel, pebbles, cobbles, and boulders. Composed mainly of subangular to well-rounded Paleozoic sandstone, limestone, and chert clasts of local origin. Include well-rounded clasts of quartzite, quartz, assorted metamorphic crystalline

rocks, and well-rounded volcanic rocks derived from Tertiary sediments (Ts), southwest and southeast part of map area. Interbedded silt, sand, gravel, and pebbles to boulders are partly consolidated by gypsum and calcite cement. Locally overlap young alluvial fan (Qay) and valley-fill (Qv) deposits. Little to moderate vegetation in terrace-gravel deposits; primarily grass and sagebrush. Contact with adjacent alluvial and eolian deposits is approximate. Subject to flash flood and sheet wash erosion. Form fluvial terrace benches about 3 to 40 ft (1 to 12 m) above stream drainages. Deposit intertongues with landslide (Ql) and talus and rock fall (Qtr) deposits in Cataract Canyon. Unit fills erosion channels cut into bedrock and young alluvial fan (Qay) deposits. Support moderate growth of local shrubs, sagebrush, and grass. Thickness, 3 to 40 ft (1 to 12 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qs - Stream-channel alluvium (Holocene)
Light-gray to light-brown and reddish-brown, unconsolidated mud, sand, gravel, pebbles and boulders. Subject to flash flood debris flows. Thickness, 0.5 to 2 m (2 to 6 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qf - Floodplain deposits (Holocene)

Qf - Floodplain deposits (Holocene)
Gray, brown, and light-red interbedded lenses of clay, mud, silt, and sand; include minor lenticular gravel deposits. Intertongue with or overlap stream-channel (Qs), valley-fill (Qv), young terrace-gravel (Qg1), young alluvial fan (Qa1), and mixed alluvium and eolian (Qae) deposits. Subject to stream-channel erosion or overbank flooding in lateral and vertical sense. Similar to valley-fill (Qv) deposits in small tributary drainages and in shallow valleys on Paria and Kaibito Plateaus; subject to widespread and frequent overbank flooding along Colorado River, Paria River, and local drainages in House Rock Valley and in deep tributary drainages to Lake Powell in northeastern half of quadrangle. Subject to temporary ponding; unit is often mixed or intertongues with ponded sediments (Qps) or mixed alluvium and eolian (Qae) deposits in shallow wide drainages on Paria and Kaibito Plateaus. Support moderate growths of sagebrush, grass, tumbleweed, desert shrubs, and tamarisk trees. Thickness, 3 to 30 ft (1 to 9 m) or more. (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qf - Flood-plain deposits (Holocene)
Gray, brown, to light-red interbedded lenses of clay, mud, silt, and sand. Include minor lenticular gravel deposits, partly consolidated by gypsum and calcite cement. Intertongue with or overlap stream-channel (Qs), valley-fill (Qv), young terrace-gravel (Qg1), and young alluvial fan (Qa1) deposits. Subject to stream-channel erosion or overbank flooding in lateral and vertical sense. Similar to valley-fill (Qv) deposits in small tributary drainages; subject to widespread and frequent overbank flooding along Colorado River, Little Colorado River, Moenkopi Wash, and Hamblin Wash areas. Support thick growths of sagebrush and grass, tumble weed, desert shrubs, and tamarisk trees. Subject to temporary ponding and often mixed with ponded sediments (Qps) or mixed alluvium and eolian (Qae) deposits in broad drainages on Moenkopi and Kaibito Plateaus. Thickness, 3 to 30 ft (1 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qf - Flood-plain deposits (Holocene)
Light-red or gray silt, fine- to coarse-grained sand, and gravel lenses; partly consolidated by gypsum or calcite cement. Gravel locally contains yellow, red, black, and white subrounded to subangular chert and quartz, well-rounded red sandstone, and gray-blue rounded limestone fragments and pebbles 0.5 to 1 cm (0.25 to 0.75 in) in diameter. Gradational lateral and vertical contact between stream-channel (Qs), flood-plain (Qf), and young alluvial fan (Qay) deposits. Support thick growths of tamarisk trees and other water-dependent plants where stream bedrock is very shallow, usually less than 3 m (10 ft) below floodplain surface. Dense growths of tamarisk help trap and accumulate sediment that develops flood-plain deposits within and along drainages. Deposits are generally 1 to 2 m (3 to 6 ft) above stream-

channel (Qs) deposits and often grade laterally into stream-channel deposits. About 1 to 6 m (3 to 20 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qf - Flood-plain deposits (Holocene)
Gray, brown, and light-red clay, silt, sand. Include some lenticular gravel. Unit is partly consolidated by gypsum and calcite cement. Intertongue or overlap stream-channel (Qs), valley alluvial (Qv), young terrace-gravel (Qgy), and young alluvial fan (Qay) deposits. Subject to stream-channel erosion or overbank flooding in lateral and vertical sense. Similar to valley alluvial (Qv) deposits in small tributary drainage valleys that form broad, flat, valley floors subject to widespread and frequent overbank flooding along Little Colorado River and in highland valleys west of Gray Mountain. Tamerisk trees in Little Colorado River valley commonly occupy floodplain or low-lying terrace areas. In broad floodplains on Coconino Plateau and northeast of Little Colorado River, minor arroyo development may occur at downstream drainage outlets due to headward erosion of streams. Support thick growths of sagebrush, grass, cliffrose bush, and sagebrush at high elevations over 1,524 m (5,000 ft) that help trap and accumulate fine-grained sediment on floodplains of Coconino Plateau; sagebrush, tumble weed plants, desert shrubs, and grass in and along Little Colorado River area. Subject to temporary ponding and often mixed with ponded sediments (Qps) or young mixed alluvium and eolian (Qae) deposits in broad drainage floodplains on Coconino Plateau. About 2 to 9 m (6 to 30 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qf - Flood-plain deposits (Holocene)
Light-gray to light-brown mud and fine- to coarse-grained, unconsolidated silt and sand and lenses of pebble to cobble gravel; unconsolidated. Intertongue or overlap valley-fill alluvium (Qv) or young alluvial fan (Qay) deposits in Aubrey Valley. Form relatively flat surfaces; support little vegetation except grass. Subject to occasional flooding or ponding of water. Similar deposits in Hualapai Valley are commonly overlapped by or interbedded with valley-fill (Qv) and young alluvial fan (Qay) deposits too thin to show at map scale. Thickness, 1 to 3.5 m (3 to 12 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qf - Flood-plain deposits (Holocene)
Gray, brown, and light-red clay, silt, sand, and some lenticular gravel; partly consolidated by gypsum and calcite cement. Intertongue or overlap young terrace-gravel (Qgy), valley-fill (Qv), and young alluvial fan (Qay) deposits. Subject to lateral stream-channel erosion or overbank flooding. Similar to valley-fill deposits but form broad, flat, valley floors subject to widespread frequent overbank flooding. In broad floodplains, minor arroyo development may occur near downstream drainage outlets. Support thick growths of grass, cliffrose bush, and sagebrush that help to trap and accumulate fine-grained sediment. Subject to temporary ponding in broad drainage floodplains. Thickness, 6 to 20 ft (1.8 to 6 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qf - Floodplain deposits (Holocene)
Light-gray to light-brown mud and fine- to coarse-grained, unconsolidated silt and sand and lenses of pebble to cobble gravel; unconsolidated. Locally includes cinder and basalt fragments. Intertongue or overlap valley-fill alluvium (Qv) or young alluvial fan (Qay) deposits. Form relatively flat surfaces having little or no vegetation. Subject to frequent flooding or ponding. Thickness, 1 to 3 m (3 to 10 ft)Light-gray to light-brown mud and fine- to coarse-grained, unconsolidated silt and sand and lenses of pebble to cobble gravel; unconsolidated. Locally includes cinder and basalt fragments. Intertongue or overlap valley-fill alluvium (Qv) or young alluvial fan (Qay) deposits. Form relatively flat surfaces having little or no vegetation. Subject to frequent flooding or ponding. Thickness, 1 to 3 m (3 to 10 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qd - Dune sand and sand sheet deposits, undivided (Holocene)

Qd - Dune sand and sand sheet deposits, undivided (Holocene)
Echo and Vermilion Cliffs area: White, gray, and light-red, fine- to coarse-grained quartz, feldspar, and chert sand grains locally derived from Paleozoic and Mesozoic sedimentary rocks; especially on or near talus and rock-fall (Qtr) and landslide (Ql) deposits below Vermilion and Echo Cliffs. Unconsolidated stream-channel (Qs) or valley-fill (Qv) deposits are transported by wind to form lumpy, undefined, geometric sand dune or sand sheet deposits over alluvial fan (Qa1, Qa2, Qa3) and young terrace-gravel (Qg1) deposits near washes in southwest quarter of quadrangle. Support moderate growths of grass and sagebrush.

Paria and Kaibito Plateaus areas: White, gray, and light-red, fine- to coarse-grained sand composed mainly of quartz, chert, and minor feldspar derived from nearby Jurassic sedimentary rocks. Include topographically controlled climbing and falling dunes, mixed dune (Qdm) and sand sheet (Qes) deposits that mantle bedrock slopes and shallow valleys on Paria and Kaibito Plateaus. Navajo Sandstone (Jn) is the primary source of sand on Paria and Kaibito Plateaus. Unit has arbitrary and gradational contacts in the lateral and vertical sense with adjacent surficial deposits and bedrock outcrops. Sand is generally transported northeasterly by southwesterly winds. Support moderate growth of grass, Mormon Tea, high desert shrubs, and scattered pinyon and juniper woodlands. Thickness, 3 to 200 ft (1 to 61 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
Grand Canyon, Coconino Plateau, and Marble Plateau areas: White, gray, and light-red, fine- to coarse-grained, windblown sand composed mainly of quartz, feldspar, and chert grains derived from Proterozoic, Paleozoic, and Mesozoic sand and gravel deposits that accumulate in stream-channel (Qs) or valley-fill (Qv) deposits and are transported by wind to form lumpy, undefined geometric sand dunes or sand sheet deposits on flood-plain (Qf) and young terrace-gravel (Qg1) deposits near washes in west half of map. Support moderate growths of grass and sagebrush.

Moenkopi and Kaibito Plateau areas: White, gray to light-red, fine- to coarse-grained sand composed mainly of quartz, chert, and minor feldspar derived from nearby Triassic and Jurassic sedimentary rocks east of U.S. Highway 89. Include topographically controlled climbing and falling dunes, complex dunes, parabolic dunes, barchan dunes, and sand sheets that mantle bedrock slopes north and south of Moenkopi Wash, along the Echo Cliffs, and within drainages on Moenkopi and Kaibito Plateaus. Navajo Sandstone (Jn) is the primary source of sand on Moenkopi and Kaibito Plateaus. Unit has arbitrary and gradational contacts, in the lateral and vertical sense, with adjacent surficial deposits and bedrock outcrops. Sand is generally transported northeast by southwesterly winds that erode local Triassic sandstone units and older sand deposits. Unit distributes a fresh veneer of sand over bedrock and older eolian deposits on Coal Mine Mesa. Support moderate growth of grass, Mormon tea, and high desert shrubs. Wet conditions stabilize all eolian deposits on Moenkopi and Kaibito Plateaus. Thickness, 3 to 200 ft (1 to 61 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
On Moccasin Mountains and Paria Plateau above Vermilion Cliffs; consists of light-red to white silt and fine- to coarse-grained eolian sand derived from the Navajo Sandstone (Jn). Only most extensive and thickest deposits are shown. Gradational contacts between young mixed alluvium and eolian (Qae) deposits based on geomorphologic interpretation on aerial photos. Below Vermilion Cliffs, deposits accumulate along local stream drainages and on gentle slopes of young alluvial fan (Qay) deposits. Deposit often leads to fine-grained climbing dunes or falling dunes of dune sand and sand sheet (Qd) accumulations on steep topography along base of Vermilion Cliffs on west side of Paria Plateau. In Pipe Valley south of State Highway 389 and in House Rock Valley along U.S. Highway 89A, white to light-brown and light-red, fine- to coarse-grained quartz sand partly stabilized by grass and small high-desert shrubs during wet conditions. Support moderate growths of grass, black brush, and other small high-

desert shrubs above Vermilion Cliffs; mostly grass below Vermilion Cliffs. Unit partly stabilized by grassy vegetation or crypto-organic soil growths in local stream drainage areas below Vermilion Cliffs. About 1 to 2 m (0.5 to 6 ft) thick near and below Vermilion Cliffs; about 3 to 11m (9 to 35 ft) thick on Moccasin Mountains and Paria Plateau. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
Coconino Plateau and Gray Mountain area: White, gray, fine- to coarse-grained, wind-blown sand composed mainly of quartz and chert grains derived from Harrisburg Member of the Kaibab Formation west and south of Gray Mountain; accumulates on stream-channel (Qs) or valley alluvial (Qv) deposits. Form lumpy, undefined geometric sand dunes or sand sheet deposits on flood-plain (Qf) and young terrace-gravel (Qgy) deposits of local washes in west and southwest quarter of map area. Small sand sheet and dune deposits are mostly hidden or covered by forest growth in Kaibab National Forest south of Grand Canyon; support moderate growth of grass, sagebrush, pinion pine, juniper, and ponderosa pine woodlands. Little Colorado River and Moenkopi Plateau area: White, gray to light-red, fine- to coarse-grained sand composed mainly of quartz, chert, and minor feldspar grains derived from pre-existing Triassic and Jurassic sedimentary strata east of Little Colorado River. Include topographically controlled climbing and falling dunes and sand sheets that mantle gentle slopes of bedrock at Ward Terrace and Red Rock Cliffs and within tributary drainages northeast and east of Little Colorado River below Moenkopi Plateau. Sand is originally transported by fluvial erosion down tributary drainages from southwestern edge of Moenkopi Plateau to Little Colorado River is re-transported upstream by southwesterly winds onto Triassic and Jurassic bedrock surfaces forming significant deposits on Ward Terrace and against Red Rock Cliffs (Billingsley, 1987a), but does not reach Moenkopi Plateau except in the southeast corner of map area; includes topographically controlled climbing and falling dunes, complex dunes, parabolic dunes, and barchan dunes as mapped by Billingsley (1987a). Arbitrary and gradational lateral and vertical contacts between other alluvial or eolian deposits, especially along southwestern edge of Moenkopi Plateau at Adeii Eechii Cliffs where southwesterly winds actively erode bedrock of Navajo Sandstone and distribute sand as a thin veneer of white quartz sand over red old dune (QTd) and old eolian sand sheet and dune (QTes) deposits. Support moderate growth of grass and high desert shrubs that stabilize extensive sand sheet and dune deposits on Moenkopi Plateau. About 1 to 61 m (3 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
Aubrey Valley area; tan, fine- to coarse-grained, well-sorted wind-blown quartz sand. Sand is derived from erosion of locally old gravel (QTg) and young gravel and sedimentary (Tg) deposits of upper Aubrey Valley. Sand is transported as stream-channel (Qs) deposits and redistributed as wind-blown sand sheet and sand dune (Qd) deposits along drainages. In Hualapai Valley area; southwesterly wind deposits of sand sheet and dune deposits derived from young alluvial fan (Qay) and stream-channel (Qs) deposits near base of Grand Wash Cliffs. All units support thin to moderate grassy vegetation. Only thickest or largest sand sheet and sand dune deposits shown; smaller sand sheet and sand dune deposits are present in the map area but are too small to show at map scale. Thickness, 0.5 to 6 m (2 to 20 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
White to gray, fine- to coarse-grained, wind-blown sand. Composed of quartz and chert sand of the Harrisburg Member of the Kaibab Formation that accumulates from young terrace-gravel (Qgy) or valley-fill (Qv) sources. Form shallow sand dune or thick sand sheet deposits. Commonly occur as lumpy, undefined sand dune shapes or thick to thin sand sheet deposits on floodplain (Qf) and young terrace-gravel (Qgy) deposits along Sandstone Wash, Rodgers Draw, and Farm Dam Draw in west-central part of map area, and minor deposits along Coconino Wash and Red Horse Wash in northeast part of map area. Include climbing and falling dunes or thick sand accumulations on gentle slopes of bedrock outcrops adjacent to large drainages. Sand locally transported northeast by southwesterly winds, especially along Sandstone Wash and Farm Dam Draw where stream channels are wide and sandy. Include sand dune or sand levees along southwest edge of extensive sand sheet (Qss) deposits and

along southwest edge of extensive young mixed alluvium and eolian (Qae) deposits where topography flattens to prairie-like conditions. Sand dune and sand sheet deposits are mostly hidden or covered by forest growths in the forested lands near Tusayan, Arizona, Coconino Wash, and Red Butte areas. Deposits largely absent in southeast third of map area due to volcanic rock outcrops. Support moderate growth of grass in southwest part of map area and sagebrush, pinion pine, juniper, and ponderosa pine woodlands in northeast map area. Thickness, 3 to 20 ft (1 to 6 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qd - Sand sheet and sand dune deposits (Holocene)
Grand Wash Trough area: Light-red and tan, fine- to medium-grained, well-sorted wind-blown quartz sand. Sand material derived from erosion of local red siltstone and sandstone outcrops of Rocks of the Grand Wash Trough (Tgr) and redeposited as stream-channel alluvium (Qs), then redeposited as wind-blown sand sheet and small sand dune deposits along wide drainages in Grand Wash Trough area. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qes - Sand sheet deposits (Holocene)

Qes - Sand sheet deposits (Holocene)
Gray-white to light-red, fine- to coarse-grained, windblown sand composed mainly of quartz and chert grains derived primarily from Jurassic formations. Form extensive cover over gently sloping terrain on Paria and Kaibito Plateaus and upper House Rock Valley. Include thin deposits on alluvial fan slopes below Echo Cliffs and Vermilion Cliffs. Commonly intertongue with mixed alluvial and eolian (Qae) deposits and all eolian sand deposits. (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qes - Sand sheet deposits (Holocene)
White, gray, fine- to coarse-grained, windblown sand composed mainly of quartz and chert grains derived primarily from the Navajo Sandstone and Moenave Formation. Deposits form extensive cover over gently sloping terrain on Moenkopi and Kaibito Plateaus in eastern third of map. Also form thin sand sheets on alluvial fan slopes below the Echo Cliffs parallel to U.S. Highway 89. Commonly intertongue with mixed alluvial and eolian (Qae) deposits that share a gradational lateral and vertical contact. Support moderate growths of grass and small high-desert shrubs that tend to stabilize the deposits. Thickness, 1 to 15 ft (0.3 to 4.5 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
On Moccasin Mountains and Paria Plateau above Vermilion Cliffs; consists of light-red to white silt and fine- to coarse-grained eolian sand derived from the Navajo Sandstone (Jn). Only most extensive and thickest deposits are shown. Gradational contacts between young mixed alluvium and eolian (Qae) deposits based on geomorphologic interpretation on aerial photos. Below Vermilion Cliffs, deposits accumulate along local stream drainages and on gentle slopes of young alluvial fan (Qay) deposits. Deposit often leads to fine-grained climbing dunes or falling dunes of dune sand and sand sheet (Qd) accumulations on steep topography along base of Vermilion Cliffs on west side of Paria Plateau. In Pipe Valley south of State Highway 389 and in House Rock Valley along U.S. Highway 89A, white to light-brown and light-red, fine- to coarse-grained quartz sand partly stabilized by grass and small high-desert shrubs during wet conditions. Support moderate growths of grass, black brush, and other small high-desert shrubs above Vermilion Cliffs; mostly grass below Vermilion Cliffs. Unit partly stabilized by grassy vegetation or crypto-organic soil growths in local stream drainage areas below Vermilion Cliffs. About 1 to 2 m (0.5 to 6 ft) thick near and below Vermilion Cliffs; about 3 to 11m (9 to 35 ft) thick on Moccasin Mountains and Paria Plateau. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
Coconino Plateau and Gray Mountain area: White, gray, fine- to coarse-grained, wind-blown sand

composed mainly of quartz and chert grains derived from Harrisburg Member of the Kaibab Formation west and south of Gray Mountain; accumulates on stream-channel (Qs) or valley alluvial (Qv) deposits. Form lumpy, undefined geometric sand dunes or sand sheet deposits on flood-plain (Qf) and young terrace-gravel (Qgy) deposits of local washes in west and southwest quarter of map area. Small sand sheet and dune deposits are mostly hidden or covered by forest growth in Kaibab National Forest south of Grand Canyon; support moderate growth of grass, sagebrush, pinion pine, juniper, and ponderosa pine woodlands. Little Colorado River and Moenkopi Plateau area: White, gray to light-red, fine- to coarse-grained sand composed mainly of quartz, chert, and minor feldspar grains derived from pre-existing Triassic and Jurassic sedimentary strata east of Little Colorado River. Include topographically controlled climbing and falling dunes and sand sheets that mantle gentle slopes of bedrock at Ward Terrace and Red Rock Cliffs and within tributary drainages northeast and east of Little Colorado River below Moenkopi Plateau. Sand is originally transported by fluvial erosion down tributary drainages from southwestern edge of Moenkopi Plateau to Little Colorado River is re-transported upstream by southwesterly winds onto Triassic and Jurassic bedrock surfaces forming significant deposits on Ward Terrace and against Red Rock Cliffs (Billingsley, 1987a), but does not reach Moenkopi Plateau except in the southeast corner of map area; includes topographically controlled climbing and falling dunes, complex dunes, parabolic dunes, and barchan dunes as mapped by Billingsley (1987a). Arbitrary and gradational lateral and vertical contacts between other alluvial or eolian deposits, especially along southwestern edge of Moenkopi Plateau at Adeii Eechii Cliffs where southwesterly winds actively erode bedrock of Navajo Sandstone and distribute sand as a thin veneer of white quartz sand over red old dune (QTd) and old eolian sand sheet and dune (QTes) deposits. Support moderate growth of grass and high desert shrubs that stabilize extensive sand sheet and dune deposits on Moenkopi Plateau. About 1 to 61 m (3 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qc - Colluvial deposits (Holocene)

Gray to light-brown, poorly sorted, fine- to coarse-grained, slope-forming mixed silt, sand, gravel, and small, well-rounded pebbles. Include angular fragment clasts of petrified wood, sub-rounded sandstone, and small well-rounded black, red, yellow, and brown quartz and chert pebbles derived from Shinarump Member of the Chinle Formation; partly consolidated. Form pediment slopes below Yellowstone Mesa and southwest of Colorado City, west quarter of map area. Small well-rounded pebbles form a partial desert pavement cover on some surfaces. Unit intertongues with young alluvial fan (Qay) deposits and is partly eroded by arroyos as much as 3 m (10 ft) deep. Surfaces are moderately vegetated and stabilized by grasses and small pebble desert pavement. About 3 to 12 m (10 to 40 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qdl - Linear dune deposits (Holocene)

Qdl - Linear dune deposits (Holocene)

Gray-white, light-red, fine- to medium-grained, well-sorted, unconsolidated linear sand accumulations aligned northeasterly across relatively flat terrain on Kaibito Plateau. Unit often merges with sand sheet (Qes), dune sand and sand sheet (Qd), mixed dune (Qdm), and parabolic dune (Qdp) deposits. Linear dunes are generally 40 to 80 ft (12 to 24.5 m) wide and less than 0.5 mi (0.8 km) long but can extend over 1 mi (1.5 km) or more in length. Individual linear dunes are mapped where they form prominent features on Kaibito Plateau. Linear dunes that are not as well defined are mapped as linear dune and sand sheet deposits (Qdlu). Thickness, 6 to 40 ft (2 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qdl - Linear dune deposits (Holocene)

White, gray, light-red, fine- to medium-grained, well-sorted, unconsolidated sand accumulations that are

aligned and generally trend northeast. Often merge with dune sand and sand sheet (Qd), sand sheet (Qes), parabolic dune (Qdp), and barchan dune (Qdb) deposits. Linear dunes are generally 40 to 80 ft (12 to 24.5 m) wide and less than 0.5 mi (0.8 km) long but can reach over 3 mi (5 km) or more in length on Moenkopi and Kaibito Plateaus. Individual linear dunes are mapped where they form prominent landscape features on Moenkopi and Kaibito Plateaus. Groups of linear dunes are mapped as linear dune and sand sheet deposits (Qdlu). Thickness, 6 to 40 ft (2 to 12 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)

Coconino Plateau and Gray Mountain area: White, gray, fine- to coarse-grained, wind-blown sand composed mainly of quartz and chert grains derived from Harrisburg Member of the Kaibab Formation west and south of Gray Mountain; accumulates on stream-channel (Qs) or valley alluvial (Qv) deposits. Form lumpy, undefined geometric sand dunes or sand sheet deposits on flood-plain (Qf) and young terrace-gravel (Qgy) deposits of local washes in west and southwest quarter of map area. Small sand sheet and dune deposits are mostly hidden or covered by forest growth in Kaibab National Forest south of Grand Canyon; support moderate growth of grass, sagebrush, pinion pine, juniper, and ponderosa pine woodlands. Little Colorado River and Moenkopi Plateau area: White, gray to light-red, fine- to coarse-grained sand composed mainly of quartz, chert, and minor feldspar grains derived from pre-existing Triassic and Jurassic sedimentary strata east of Little Colorado River. Include topographically controlled climbing and falling dunes and sand sheets that mantle gentle slopes of bedrock at Ward Terrace and Red Rock Cliffs and within tributary drainages northeast and east of Little Colorado River below Moenkopi Plateau. Sand is originally transported by fluvial erosion down tributary drainages from southwestern edge of Moenkopi Plateau to Little Colorado River is re-transported upstream by southwesterly winds onto Triassic and Jurassic bedrock surfaces forming significant deposits on Ward Terrace and against Red Rock Cliffs (Billingsley, 1987a), but does not reach Moenkopi Plateau except in the southeast corner of map area; includes topographically controlled climbing and falling dunes, complex dunes, parabolic dunes, and barchan dunes as mapped by Billingsley (1987a). Arbitrary and gradational lateral and vertical contacts between other alluvial or eolian deposits, especially along southwestern edge of Moenkopi Plateau at Adeii Eechii Cliffs where southwesterly winds actively erode bedrock of Navajo Sandstone and distribute sand as a thin veneer of white quartz sand over red old dune (QTd) and old eolian sand sheet and dune (QTes) deposits. Support moderate growth of grass and high desert shrubs that stabilize extensive sand sheet and dune deposits on Moenkopi Plateau. About 1 to 61 m (3 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qdp - Parabolic dune deposits (Holocene)

Qdp - Parabolic dune deposits (Holocene)

Gray-white, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand. Ponded sediments (Qps) commonly form on upwind (southwest) side between parabolic dune horns and within parabolic and mixed dune (Qdm) deposits. Bedrock often exposed at southwest interior of parabolic dunes. Contact merges with adjacent dune sand and sand sheet (Qd), sand sheet (Qes), and mixed alluvium and eolian (Qae) deposits. Support little to sparse grassy vegetation. Thickness, 6 to 30 ft (2 to 9 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qdp - Parabolic dune deposits (Holocene)

White, gray, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand arranged most commonly in complex interconnecting parabolic dune deposits or occasionally in individual parabolic dunes. Sandy ponded sediments (Qps) are commonly formed on upwind (southwest) side of dune complex. Bedrock or older sand accumulation is often exposed at southwest side of parabolic dunes. Contact merges with adjacent dune sand and sand sheet (Qd) and sand sheet (Qes) deposits, mixed alluvial and eolian (Qae) deposits, and local Mesozoic bedrock outcrops on Moenkopi and Kaibito

Plateaus. Support little to sparse grassy vegetation. Thickness, 6 to 30 ft (2 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
Coconino Plateau and Gray Mountain area: White, gray, fine- to coarse-grained, wind-blown sand composed mainly of quartz and chert grains derived from Harrisburg Member of the Kaibab Formation west and south of Gray Mountain; accumulates on stream-channel (Qs) or valley alluvial (Qv) deposits. Form lumpy, undefined geometric sand dunes or sand sheet deposits on flood-plain (Qf) and young terrace-gravel (Qgy) deposits of local washes in west and southwest quarter of map area. Small sand sheet and dune deposits are mostly hidden or covered by forest growth in Kaibab National Forest south of Grand Canyon; support moderate growth of grass, sagebrush, pinion pine, juniper, and ponderosa pine woodlands. Little Colorado River and Moenkopi Plateau area: White, gray to light-red, fine- to coarse-grained sand composed mainly of quartz, chert, and minor feldspar grains derived from pre-existing Triassic and Jurassic sedimentary strata east of Little Colorado River. Include topographically controlled climbing and falling dunes and sand sheets that mantle gentle slopes of bedrock at Ward Terrace and Red Rock Cliffs and within tributary drainages northeast and east of Little Colorado River below Moenkopi Plateau. Sand is originally transported by fluvial erosion down tributary drainages from southwestern edge of Moenkopi Plateau to Little Colorado River is re-transported upstream by southwesterly winds onto Triassic and Jurassic bedrock surfaces forming significant deposits on Ward Terrace and against Red Rock Cliffs (Billingsley, 1987a), but does not reach Moenkopi Plateau except in the southeast corner of map area; includes topographically controlled climbing and falling dunes, complex dunes, parabolic dunes, and barchan dunes as mapped by Billingsley (1987a). Arbitrary and gradational lateral and vertical contacts between other alluvial or eolian deposits, especially along southwestern edge of Moenkopi Plateau at Adeii Eechii Cliffs where southwesterly winds actively erode bedrock of Navajo Sandstone and distribute sand as a thin veneer of white quartz sand over red old dune (QTd) and old eolian sand sheet and dune (QTes) deposits. Support moderate growth of grass and high desert shrubs that stabilize extensive sand sheet and dune deposits on Moenkopi Plateau. About 1 to 61 m (3 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qdb - Barchan dune deposits (Holocene)

Qdb - Barchan dune deposits (Holocene)
Light-red, fine- to medium-grained, well-sorted, unconsolidated quartz sand. Form isolated cluster northeast of State Highway 98 northeast of Kaibito on Kaibito Plateau. Dunes are actively forming and expanding as of 2011. Sand is derived mainly from nearby outcrops of Entrada Sandstone (Je) and Carmel Formation (Jc). Subject to changes in extent and shape due to seasonal storms and sand mobility. Support little to no vegetation. Thickness, 6 to 30 ft (2 to 9 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qdb - Barchan dune deposits (Holocene)
White, gray, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand that forms isolated barchan dunes or a cluster of interconnecting barchan dunes mainly northeast of Tuba city, on Kaibito Plateau. Subject to yearly change in extent and shape due to seasonal storms and sand mobility. Support little to sparse grassy vegetation. Thickness, 6 to 40 ft (2 to 12 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qd - Dune sand and sand sheet deposits (Holocene)
Coconino Plateau and Gray Mountain area: White, gray, fine- to coarse-grained, wind-blown sand composed mainly of quartz and chert grains derived from Harrisburg Member of the Kaibab Formation west and south of Gray Mountain; accumulates on stream-channel (Qs) or valley alluvial (Qv) deposits. Form lumpy, undefined geometric sand dunes or sand sheet deposits on flood-plain (Qf) and young

terrace-gravel (Qgy) deposits of local washes in west and southwest quarter of map area. Small sand sheet and dune deposits are mostly hidden or covered by forest growth in Kaibab National Forest south of Grand Canyon; support moderate growth of grass, sagebrush, pinion pine, juniper, and ponderosa pine woodlands. Little Colorado River and Moenkopi Plateau area: White, gray to light-red, fine- to coarse-grained sand composed mainly of quartz, chert, and minor feldspar grains derived from pre-existing Triassic and Jurassic sedimentary strata east of Little Colorado River. Include topographically controlled climbing and falling dunes and sand sheets that mantle gentle slopes of bedrock at Ward Terrace and Red Rock Cliffs and within tributary drainages northeast and east of Little Colorado River below Moenkopi Plateau. Sand is originally transported by fluvial erosion down tributary drainages from southwestern edge of Moenkopi Plateau to Little Colorado River is re-transported upstream by southwesterly winds onto Triassic and Jurassic bedrock surfaces forming significant deposits on Ward Terrace and against Red Rock Cliffs (Billingsley, 1987a), but does not reach Moenkopi Plateau except in the southeast corner of map area; includes topographically controlled climbing and falling dunes, complex dunes, parabolic dunes, and barchan dunes as mapped by Billingsley (1987a). Arbitrary and gradational lateral and vertical contacts between other alluvial or eolian deposits, especially along southwestern edge of Moenkopi Plateau at Adeii Eechii Cliffs where southwesterly winds actively erode bedrock of Navajo Sandstone and distribute sand as a thin veneer of white quartz sand over red old dune (QTd) and old eolian sand sheet and dune (QTes) deposits. Support moderate growth of grass and high desert shrubs that stabilize extensive sand sheet and dune deposits on Moenkopi Plateau. About 1 to 61 m (3 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Little Spring Basalt (Holocene)

Informally named by Billingsley (1997a) and Billingsley and others (2001). Herein formally named for Little Spring (SE1/4 sec. 16, T. 34 N., R. 8 W.) just west of Arkansas Ranch, Uinkaret Plateau, Mohave County, Arizona. The olivine basalt and associated cinder cone represent the youngest volcanic rocks in the Uinkaret Volcanic Field and the map area. Based on cosmogenic 3He dating (Fenton, 1998), the Little Spring Basalt is about 1,000 years old, similar in age to basalt flows at Sunset Crater near Flagstaff, Arizona. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qlsp - Little Spring Basalt, pyroclastic deposits (Holocene)

Red-brown, gray, and reddish-black basaltic scoria, bombs, cinder, and other scoriaceous ejecta deposits. Consist of two deposits that are part of a single pyroclastic cone formed from two closely spaced vent areas. Cone is about 41 m (135 ft) high on basalt flow surface (elev. 2,138 m [7,015 ft]). Only east half and southwest part of cone is preserved; rest of cone has been rafted away on lava flows toward the northwest and southeast, suggesting that the cone is older than the flow. Support growths of a few ponderosa pine trees and oak trees. Thickness, 41 m (135 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qlsb - Little Spring Basalt, basalt flows (Holocene)

Dark-gray, finely crystalline to glassy, alkali-olivine basalt. Groundmass composed of glass, plagioclase, and olivine. Forms clinkery aa surface. Basalt flowed northwest about 1.8 km (1 mi) and southeast about 2.4 km (1.5 mi). Support sparse ponderosa and oak trees. Overlie older Quaternary basalt flows (Qb), pyroclastic deposits (Qp), and young alluvial fan (Qay) deposits. Thickness, 3 to 7 m (10 to 21 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qdm - Mixed dune deposits (Holocene)

Qdm - Mixed dune deposits (Holocene)
Gray-white, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand derived primarily from the Navajo Sandstone (Jn) and Entrada Sandstone (Je). Parabolic and linear dunes are dominant and are often interconnected or associated with extensive sand sheet deposits. On Kaibito Plateau, linear dunes often form on downwind side of parabolic dunes. Parabolic dunes often form adjacent to and as part of linear dunes. Include Navajo Sandstone (Jn) outcrops and ponded sediment (Qps) deposits too small to show at map scale. Frequently reactivated northwest of Kaibito and northeast of Page near Lake Powell. Thickness, 6 to 40 ft (2 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qdm - Mixed dune deposits (Holocene)
White, gray, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand derived primarily from the Navajo Sandstone (Jn). Parabolic and linear dunes are the dominant dune types and are often interconnected and associated with massive sand sheet (Qes) deposits. Linear dunes often form as downwind extension of parabolic dunes on Moenkopi and Kaibito Plateaus and parabolic dunes often attach to or are part of linear dunes. Include quite a few Navajo Sandstone (Jn) and ponded sediment (Qps) deposits too small to show at map scale. Often covered annually by active dune sand and sand sheet (Qd) deposits. Thickness, 6 to 40 ft (2 to 12 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qdlu - Linear dune and sand sheet deposits, undivided (Holocene)

Qdlu - Linear dune and sand sheet deposits, undivided (Holocene)
Gray-white, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand derived primarily from the Navajo Sandstone (Jn) and Entrada Sandstone (Je) on Kaibito Plateau. Unit often forms clusters of closely spaced deposits that often merge and separate as an interconnecting mass of dune forms and abundant sand sheet deposits. Support sparse grassy vegetation and small high desert brush. Thickness, 9 to 40 ft (3 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qdlu - Linear dune and sand sheet deposits (Holocene)
White, gray, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand derived primarily from the Navajo Sandstone (Jn) on Moenkopi and Kaibito Plateaus. Unit is often a cluster or group of closely spaced linear dune and sand sheet deposits. Individual linear dunes often merge and separate as an interconnecting mass of dune forms with abundant sand sheet deposits between. Support little to sparse grassy vegetation. Thickness, 9 to 40 ft (3 to 12 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qg1 - Young terrace-gravel deposits (Holocene and Pleistocene)

Qg1 - Young terrace-gravel deposits (Holocene)
Light-brown, pale-red, and gray, well-sorted, interbedded clay, silt, sand, gravel, pebbles, cobbles, and exotic boulders that came from as far away as Colorado, Utah, and New Mexico along Colorado and Paria Rivers. Include well-rounded clasts of quartzite, quartz, chert, sandstone, and limestone in many large tributaries to the Colorado River throughout the quadrangle. Locally overlap young alluvial fan (Qa1), floodplain (Qf), and valley-fill (Qv) deposits below Vermilion and Echo Cliffs and House Rock Valley and on Marble Plateau. Unit often covered by dune sand and sand sheet (Qd) and sand sheet (Qes) deposits in east half of quadrangle. Form benches about 3 to 12 ft (1 to 3.5 m) above stream-channel (Qs) or floodplain (Qf) deposits along Colorado River, Paria River, Navajo Creek, and Kaibito Creek. Subject to frequent flash-flood erosion and overbank flooding. Support light vegetation, mainly grass, and a few

desert shrubs. Thickness, 6 to 20 ft (2 to 6 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qg1 - Young terrace-gravel deposits (Holocene)
Light-brown, pale-red, and gray, well-sorted, interbedded clay, silt, sand, gravel, pebbles, cobbles, and some boulders. Include well-rounded clasts of quartzite, quartz, chert, sandstone, and limestone. Support light to moderate growths of grass, cactus, and desert shrubs. Subject to flash-flood erosion and overbank flooding. Locally overlap young alluvial fan (Qa1), flood-plain (Qf), and valley-fill (Qv) deposits. Often covered by dune sand and sand sheet (Qd) and sand sheet (Qes) deposits in east half of quadrangle. Support light vegetation, mainly grass, and a few desert shrubs. Form benches about 3 to 12 ft (1 to 3.5 m) above stream-channel (Qs) or flood-plain (Qf) deposits. Subject to frequent flash flood erosion. Thickness, 6 to 20 ft (2 to 6 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene and Pleistocene (?))
Below Vermilion Cliffs; consists of red, white, and gray interbedded fine- to coarse-grained sand and thinly laminated silt; partly consolidated by clay and calcite cement. Include interbedded thin beds of gray or red mud and clay and interbedded lenses of gravel composed of gray subangular chert fragments. Unit cut by modern erosion as much as 9 m (30 ft) deep in Kanab Creek near Fredonia, and other drainages eroded into the Vermilion Cliffs.

On Kanab Plateau, Uinkaret Plateau, and Kanab Canyon areas; consists of gray and light-brown, fine- to coarse-grained silt, sand, and gravel; partly consolidated by gypsum and calcite cement. Include gray-blue subrounded limestone and light-red sandstone clasts, in matrix of mostly white angular and subangular chert gravel. Deposits commonly intertongue with or overlapped by young alluvial fan (Qay) and mixed alluvium and eolian (Qae) deposits and inset against old terrace-gravel (Qgo) deposits. Subject to flash flood erosion or overbank accumulations of flood-plain (Qf) sediments in upper Kanab Creek drainage and its northeastern tributaries in Muggins Flat, north-central part of map area. Terraces are generally 1.2 to 9 m (4 to 30 ft) above local streambeds and as much as 18 m (60 ft) above stream channel in upper reaches of Kanab Creek and some of its tributaries. Unit often cut by arroyo erosion as much as 6 m (20 ft) in south-central part of map and as much as 18 m (60 ft) above stream channels in upper reaches of Kanab Creek and some of its tributaries. Moderately vegetated by sagebrush, grass, cactus, tamarisk trees, willow trees, juniper and pinion pine trees at elevations above 1,525 m (5,000 ft); mostly vegetated by grass, thick growths of cactus, sagebrush, desert shrubs, and some cottonwood trees in lower reaches of Kanab Creek. About 1 to 18 m (3 to 60 ft) thick or more. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene and Pleistocene)
Light-brown, pale-red, and gray, poorly sorted fluvial mud, silt, sand, gravel, pebbles, cobbles, and boulders. Composed primarily of subangular to well-rounded Paleozoic sandstone, limestone, and chert clasts of local origin. Include well-rounded clasts of quartzite, quartz, and assorted metamorphic crystalline rocks derived from terrains far south of the map area. Include well-rounded volcanic rocks that originate from the San Francisco Volcanic Field and may include some quartzite and chert clasts derived from the Shinarump Member of the Chinle Formation. Include flood-plain (Qf) deposits and various terrace-gravel deposits in narrow canyon drainages too small to show at map scale. Clasts are partly consolidated by matrix of mud and sand cemented with calcium and gypsum. Form terraced benches about 1 to 12 m (3 to 40 ft) above stream-channel (Qs) deposits. Deposits are mixed with landslide, talus, and rock fall (Qtr) deposits in Little Colorado River Gorge. Unit fills erosion channels cut into bedrock, young alluvial fan (Qay), and flood-plain (Qf) deposits. Support moderate growth of local high-desert shrubs, sagebrush, and grass. About 1 to 12 m (3 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene)
Light-brown, pale-red, and gray, poorly sorted fluvial mud, silt, sand, gravel, pebbles, cobbles, and

boulders. Composed mainly of subangular to well-rounded Paleozoic sandstone, limestone, and chert clasts of local origin. Include well-rounded clasts of quartzite, quartz, assorted metamorphic crystalline rocks, and well-rounded volcanic rocks derived from Tertiary sediments (Ts), southwest and southeast part of map area. Interbedded silt, sand, gravel, and pebbles to boulders are partly consolidated by gypsum and calcite cement. Locally overlap young alluvial fan (Qay) and valley-fill (Qv) deposits. Little to moderate vegetation in terrace-gravel deposits; primarily grass and sagebrush. Contact with adjacent alluvial and eolian deposits is approximate. Subject to flash flood and sheet wash erosion. Form fluvial terrace benches about 3 to 40 ft (1 to 12 m) above stream drainages. Deposit intertongues with landslide (Ql) and talus and rock fall (Qtr) deposits in Cataract Canyon. Unit fills erosion channels cut into bedrock and young alluvial fan (Qay) deposits. Support moderate growth of local shrubs, sagebrush, and grass. Thickness, 3 to 40 ft (1 to 12 m). (GRI Source Map ID 7453) (Valle 30 x 60).

Qtgr - Terrace gravel deposits (Holocene and Pleistocene)

Qtg - Terrace gravel deposits (Holocene and Pleistocene)
Light-brown, pale-red, and gray, slope-forming, poorly sorted alluvial mud, silt, sand, coarse gravel, pebbles, cobbles, and boulders. Composed mainly of subangular to well-rounded Paleozoic sandstone and limestone clasts of local origin and some rounded clasts of assorted metamorphic rocks locally derived from inner gorge of Grand Canyon, and well-rounded quartzite and volcanic rocks that originated upstream in Utah, Colorado, and New Mexico. Clasts are partly consolidated by matrix of mud and sand cemented with calcium and gypsum. Thick deposits of mud and silt are preserved on south side of Colorado River just downstream of Tapeats Creek (north-central part of map area). Forms terraced benches about 3–300 ft (1–100 m) above post-Glen Canyon Dam high-water line of Colorado River, and above local tributary stream beds. Deposit is mixed with landslide and talus debris near Fossil Canyon and Tapeats Creek areas and may represent deltaic deposits resulting from temporary ponding of Colorado River by the Surprise Valley landslide near Tapeats Creek, or by volcanic dams farther downstream near western edge of map area. Only largest deposits shown. About 3–300 ft (1–100 m) thick. (GRI Source Map ID 1309) (Grand Canyon 30 x 60).

Qg2 - Intermediate terrace-gravel deposits (Holocene and Pleistocene)

Qg2 - Intermediate terrace-gravel deposits (Holocene)
Gray and brown silt, sand, gravel, and lenses of pebbles or conglomerate; partly consolidated. Lithologically similar to young terrace-gravel (Qg1) deposits but stratigraphically higher. Form benches about 15 to 30 ft (4.5 to 9 m) above modern streambeds and about 6 to 25 ft (2 to 7.5 m) above young terrace-gravel (Qg1) deposits in upper reaches of Colorado River tributaries. Locally intertongue with, overlain by, or inset into young and intermediate alluvial fan (Qa1, Qa2), valley-fill (Qv), mixed alluvium and eolian (Qae), talus and rock-fall (Qtr), and landslide (Ql) deposits throughout quadrangle. Subject to severe cut-bank erosion. Support growths of grass and a variety of high desert shrubs, tamarisk, and cottonwood trees. Thickness, 6 to 30 ft (2 to 9 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qg2 - Intermediate terrace-gravel deposits (Holocene)
Gray and brown silt, sand, gravel, and lenses of pebbles or conglomerate; partly consolidated. Lithologically similar to young terrace-gravel (Qg1) deposits. Siltstone and fine-grained sandstone matrix is mixed with subangular to rounded pebbles and boulders derived from nearby bedrock. Form benches about 15 to 30 ft (4.5 to 9 m) above modern streambeds and about 6 to 20 ft (2 to 6 m) above young terrace-gravel (Qg1) deposits in upper reaches of tributary streams. Support growths of grass and a variety of high-desert shrubs. Subject to cutbank erosion. Locally intertongue with, overlain by, or inset into young and intermediate alluvial fan (Qa1, Qa2), valley-fill (Qv), mixed alluvium and eolian (Qae), talus

and rockfall (Qtr), and landslide (Ql) deposits. Thickness, 6 to 25 ft (2 to 7.5 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene and Pleistocene (?))
Below Vermilion Cliffs; consists of red, white, and gray interbedded fine- to coarse-grained sand and thinly laminated silt; partly consolidated by clay and calcite cement. Include interbedded thin beds of gray or red mud and clay and interbedded lenses of gravel composed of gray subangular chert fragments. Unit cut by modern erosion as much as 9 m (30 ft) deep in Kanab Creek near Fredonia, and other drainages eroded into the Vermilion Cliffs.

On Kanab Plateau, Uinkaret Plateau, and Kanab Canyon areas; consists of gray and light-brown, fine- to coarse-grained silt, sand, and gravel; partly consolidated by gypsum and calcite cement. Include gray-blue subrounded limestone and light-red sandstone clasts, in matrix of mostly white angular and subangular chert gravel. Deposits commonly intertongue with or overlapped by young alluvial fan (Qay) and mixed alluvium and eolian (Qae) deposits and inset against old terrace-gravel (Qgo) deposits. Subject to flash flood erosion or overbank accumulations of flood-plain (Qf) sediments in upper Kanab Creek drainage and its northeastern tributaries in Muggins Flat, north-central part of map area. Terraces are generally 1.2 to 9 m (4 to 30 ft) above local streambeds and as much as 18 m (60 ft) above stream channel in upper reaches of Kanab Creek and some of its tributaries. Unit often cut by arroyo erosion as much as 6 m (20 ft) in south-central part of map and as much as 18 m (60 ft) above stream channels in upper reaches of Kanab Creek and some of its tributaries. Moderately vegetated by sagebrush, grass, cactus, tamarisk trees, willow trees, juniper and pinion pine trees at elevations above 1,525 m (5,000 ft); mostly vegetated by grass, thick growths of cactus, sagebrush, desert shrubs, and some cottonwood trees in lower reaches of Kanab Creek. About 1 to 18 m (3 to 60 ft) thick or more. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene and Pleistocene)
Light-brown, pale-red, and gray, poorly sorted fluvial mud, silt, sand, gravel, pebbles, cobbles, and boulders. Composed primarily of subangular to well-rounded Paleozoic sandstone, limestone, and chert clasts of local origin. Include well-rounded clasts of quartzite, quartz, and assorted metamorphic crystalline rocks derived from terrains far south of the map area. Include well-rounded volcanic rocks that originate from the San Francisco Volcanic Field and may include some quartzite and chert clasts derived from the Shinarump Member of the Chinle Formation. Include flood-plain (Qf) deposits and various terrace-gravel deposits in narrow canyon drainages too small to show at map scale. Clasts are partly consolidated by matrix of mud and sand cemented with calcium and gypsum. Form terraced benches about 1 to 12 m (3 to 40 ft) above stream-channel (Qs) deposits. Deposits are mixed with landslide, talus, and rock fall (Qtr) deposits in Little Colorado River Gorge. Unit fills erosion channels cut into bedrock, young alluvial fan (Qay), and flood-plain (Qf) deposits. Support moderate growth of local high-desert shrubs, sagebrush, and grass. About 1 to 12 m (3 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene)
Light-brown, pale-red, and gray, poorly sorted fluvial mud, silt, sand, gravel, pebbles, cobbles, and boulders. Composed mainly of subangular to well-rounded Paleozoic sandstone, limestone, and chert clasts of local origin. Include well-rounded clasts of quartzite, quartz, assorted metamorphic crystalline rocks, and well-rounded volcanic rocks derived from Tertiary sediments (Ts), southwest and southeast part of map area. Interbedded silt, sand, gravel, and pebbles to boulders are partly consolidated by gypsum and calcite cement. Locally overlap young alluvial fan (Qay) and valley-fill (Qv) deposits. Little to moderate vegetation in terrace-gravel deposits; primarily grass and sagebrush. Contact with adjacent alluvial and eolian deposits is approximate. Subject to flash flood and sheet wash erosion. Form fluvial terrace benches about 3 to 40 ft (1 to 12 m) above stream drainages. Deposit intertongues with landslide (Ql) and talus and rock fall (Qtr) deposits in Cataract Canyon. Unit fills erosion channels cut into bedrock and young alluvial fan (Qay) deposits. Support moderate growth of local shrubs, sagebrush, and grass.

Thickness, 3 to 40 ft (1 to 12 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qg3 - Old terrace-gravel deposits (Holocene and Pleistocene)

Qg3 - Old terrace-gravel deposits (Holocene)
Gray and light-brown, clay, silt, sand, gravel, cobbles, and boulders partly consolidated by clay, calcite, and gypsum cement; poorly sorted. Similar to young and intermediate terrace-gravel (Qg1, Qg2) deposits. Form terrace deposits adjacent to and 80 to 100 ft (24 to 30 m) above the Colorado and Paria Rivers and within narrow tributaries of Kaibito and Navajo Creeks. Include abundant rounded and well-rounded clasts of quartzite, quartz, chert, sandstone, and limestone along the Colorado and Paria Rivers. Thickness, 6 to 35 ft (2 to 10 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qg3 - Old terrace-gravel deposits (Holocene)
Gray and light-brown, clay, silt, sand, gravel, cobbles, and boulders partly consolidated by clay, calcite, and gypsum cement; poorly sorted. Include abundant rounded and well-rounded clasts of quartzite, quartz, chert, sandstone, and limestone in Grand Canyon. Form terrace deposits adjacent to and as much as 400 ft (122 m) above the Colorado River. Thickness, 25 to 80 ft (7.5 to 24 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qgo - Old terrace-gravel deposits (Pleistocene)
Gray, light-brown to light-red clay, silt, sand; partly consolidated by calcite and gypsum cement in tributaries of Kanab Creek drainages. Locally contain lenses of small rounded to subrounded pebble gravel and conglomerate composed of white and red sandstone, blue-gray limestone, abundant subrounded or angular white chert, and scattered, well rounded, multicolored quartzite pebbles in fine- to coarse-grained gravel matrix. Down slope of Vermilion Cliffs, include well rounded quartz, chert, or quartzite pebbles of various sizes derived from Shinarump Member of the Chinle Formation. In eastern tributary drainages of Kanab Creek and Muggins Flat west of Kaibab Plateau, include occasional well-rounded pebbles and small cobbles of brown, purple, and gray quartzite clasts derived from old gravel and sedimentary (Ts) deposits. Unit forms terraces about 9 to 37 m (30 to 120 ft) above stream channel (Qs) deposits along Kanab Creek and its tributaries and often covered by thin eolian dune sand and sand sheet deposits or lag gravel deposits too thin to show at map scale. Support sparse growth of sagebrush, black brush, cactus, and grass. About 2 to 6 m (6 to 20 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene and Pleistocene)
Light-brown, pale-red, and gray, poorly sorted fluvial mud, silt, sand, gravel, pebbles, cobbles, and boulders. Composed primarily of subangular to well-rounded Paleozoic sandstone, limestone, and chert clasts of local origin. Include well-rounded clasts of quartzite, quartz, and assorted metamorphic crystalline rocks derived from terrains far south of the map area. Include well-rounded volcanic rocks that originate from the San Francisco Volcanic Field and may include some quartzite and chert clasts derived from the Shinarump Member of the Chinle Formation. Include flood-plain (Qf) deposits and various terrace-gravel deposits in narrow canyon drainages too small to show at map scale. Clasts are partly consolidated by matrix of mud and sand cemented with calcium and gypsum. Form terraced benches about 1 to 12 m (3 to 40 ft) above stream-channel (Qs) deposits. Deposits are mixed with landslide, talus, and rock fall (Qtr) deposits in Little Colorado River Gorge. Unit fills erosion channels cut into bedrock, young alluvial fan (Qay), and flood-plain (Qf) deposits. Support moderate growth of local high-desert shrubs, sagebrush, and grass. About 1 to 12 m (3 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qgy - Young terrace-gravel deposits (Holocene)
Light-brown, pale-red, and gray, poorly sorted fluvial mud, silt, sand, gravel, pebbles, cobbles, and

boulders. Composed mainly of subangular to well-rounded Paleozoic sandstone, limestone, and chert clasts of local origin. Include well-rounded clasts of quartzite, quartz, assorted metamorphic crystalline rocks, and well-rounded volcanic rocks derived from Tertiary sediments (Ts), southwest and southeast part of map area. Interbedded silt, sand, gravel, and pebbles to boulders are partly consolidated by gypsum and calcite cement. Locally overlap young alluvial fan (Qay) and valley-fill (Qv) deposits. Little to moderate vegetation in terrace-gravel deposits; primarily grass and sagebrush. Contact with adjacent alluvial and eolian deposits is approximate. Subject to flash flood and sheet wash erosion. Form fluvial terrace benches about 3 to 40 ft (1 to 12 m) above stream drainages. Deposit intertongues with landslide (Ql) and talus and rock fall (Qtr) deposits in Cataract Canyon. Unit fills erosion channels cut into bedrock and young alluvial fan (Qay) deposits. Support moderate growth of local shrubs, sagebrush, and grass. Thickness, 3 to 40 ft (1 to 12 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qa1 - Young alluvial fan deposits (Holocene and Pleistocene)

Qa1 - Young alluvial fan deposits (Holocene)
Base of Vermilion and Echo Cliffs, House Rock Valley, and Marble Plateau: Reddish gray to light-brown silt, sand, gravel, pebbles, cobbles, and boulders; partly consolidated by calcite and gypsum cement. Pebbles, cobbles, and boulders are subangular to round. Unit is subject to widespread flash-flood debris flows. Subject to temporary cover by dune sand and sand sheet (Qd) and sand sheet (Qes) deposits. Support light growths of sagebrush, cactus, and grass. Thickness 10 to 30 ft (3 to 9 m).

Paria and Kaibito Plateaus: Gray, light-brown, and light-red clay, silt, sand, and minor pebbles of chert, limestone, and sandstone; unconsolidated. Unit often overlapped by stream-channel (Qs), ponded sediments (Qps), floodplain (Qf), dune sand and sand sheet (Qd), sand sheet (Qs), valley-fill (Qv), young terrace-gravel (Qg1), and mixed alluvium and eolian (Qae) deposits. Clay, silt, and sand are primarily derived from local Jurassic and Cretaceous outcrops. Subject to widespread sheet-wash erosion, wind erosion, flash flood debris flows, and arroyo erosion. Thickness, 3 to 30 ft (1 to 9 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qa1 - Young alluvial fan deposits (Holocene)
In Grand Canyon: Reddish-gray to light-brown silt, sand, gravel, pebbles, cobbles, and boulders; partly consolidated by calcite and gypsum cement. All material is derived primarily from Precambrian and Paleozoic rocks and subject to flash-flood debris flows. Pebbles, cobbles, and boulders are subangular to rounded. Little to no vegetation cover. Thickness 10 to 30 ft (3 to 9 m).

On Marble Plateau: Gray-brown to red silt, sand, gravel, pebbles, cobbles, and boulders; partly consolidated by gypsum and calcite cement. Local outcrops of the Kaibab and Moenkopi Formations provide silt and sand and also supply calcite, gypsum, and some salt as cementing agents for most alluvial deposits on Marble Plateau. Support light growths of sagebrush, cactus, and grass. Thickness 3 to 20 ft (1 to 6 m).

In eastern third of map area: Gray, light-brown, and light-red, clay, silt, sand, pebbles, and cobbles of chert, limestone, and sandstone; unconsolidated. Unit often overlapped by stream-channel (Qs), ponded sediments (Qps), flood-plain (Qf), dune sand and sand sheet (Qd), and sand sheet (Qes) deposits. Intertongue with upper part of valley-fill (Qv), young terrace-gravel (Qg1), and mixed alluvium and eolian (Qae) deposits. Clay, silt, and sand are primarily derived from local outcrops of Triassic, Jurassic, and Cretaceous rocks. Subject to extensive sheet-wash erosion, wind erosion, flash flood debris flows, and arroyo erosion. Thickness, 3 to 30 ft (1 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qay - Young alluvial fan deposits (Holocene and Pleistocene(?))
Vermilion Cliffs area; consists of light-red and brown silt and fine- to coarse-grained sand and gravel;

partly consolidated by calcite and clay. Include subangular red and white chert fragments and small red and white sandstone and gray limestone clasts generally less than 5 cm (2 in) in diameter derived locally from nearby Vermilion Cliff outcrops. Include large boulders of the Shinarump Member of the Chinle Formation as much as 2 m (6 ft) in diameter below Yellowstone Mesa area. Clay content greatest below or in outcrops of Petrified Forest Member of the Chinle Formation. Include numerous black, brown, yellow, red, and gray, very well rounded quartzites and chert pebbles 1.5 to 5 cm (0.5 to 2 in) in diameter and occasional rounded, gray-white petrified wood fragments down slope of Vermilion Cliffs areas. Locally covered by thin eolian dune sand and sand sheet (Qd) deposits, young mixed alluvium, and eolian (Qae) deposits at distal ends of alluvial fan deposits.

On Kanab Plateau, Uinkaret Plateau, and in Kanab Creek drainages; gray, light-red, and light-brown silt, sand, and white cherty gravel, partly consolidated by gypsum and calcite. Include lobes of flash flood debris flows of unsorted angular boulders in sandy matrix that often form temporary dams that block principal drainages, primarily in Kanab Creek, Nail Canyon, and Snake Gulch, central part of map area. Surfaces are generally gullied as much as 3 m (10 ft) or partly covered by desert pavement of small gravel or pebbles in northwest quarter of map area; partly consolidated by calcite, clay, and gypsum cement below stratigraphic level of the Chinle Formation; mostly unconsolidated above Chinle below Vermilion Cliffs. Commonly overlapped by or intertongue with stream channel (Qs) deposits in upper Kanab Creek drainages and Muggins Flat area. Intertongue with landslide (Ql) and talus and rock fall (Qtr) deposits at upper reaches of alluvial fans below Vermilion Cliffs where unit is heavily dissected by erosion. Subject to extensive sheet wash erosion or sediment accumulation during heavy storms. Support moderate growths of grass, sagebrush, cactus, juniper, pinion pine, and various small high-desert shrubs. About 2 to 18 m (6 to 60 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qay - Young alluvial fan deposits (Holocene and Pleistocene)
Grayish-brown silt, sand, gravel, and some boulders. Pebbles, cobbles and boulders are subangular to rounded clasts of limestone, chert, and sandstone derived from local Paleozoic and Mesozoic strata of the Moenkopi and Kaibab Formations. Include medium- to coarse-grained sand and scattered well-rounded pebbles of quartzite and quartz and subrounded clasts and fragments of basalt derived from the San Francisco Volcanic Field. Unit is partly consolidated by silt, gypsum, and calcite and partly overlapped by ponded sediments (Qps), flood-plain (Qf), dune sand and sand sheet (Qd) deposits. Intertongue with upper part of valley alluvial (Qv), stream-channel (Qs), and young terrace-gravel (Qgy) deposits. Surfaces are partly eroded and cut by arroyo erosion. Surface has thin calcrete soil development that forms a sandy surface mixed with large cobbles and boulders of basalt near the Dog Knobs area of the San Francisco Volcanic Field. Extensively eroded and cut by arroyos in lowland areas northeast and east of Little Colorado River. Include coarse gravel, subangular to rounded pebbles and cobbles of limestone, chert, and sandstone derived from local Paleozoic and Mesozoic outcrops on Coconino Plateau. Subject to extensive sheetwash erosion and flash flood debris flows. Support moderate growths of sagebrush, cactus, and grass. About 1 to 12 m (3 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qay - Young alluvial fan deposits (Holocene)
Gray-brown silt, sand, gravel, and some boulders. Clasts are subangular to rounded limestone, chert, and sandstone locally derived from Mesozoic and Paleozoic outcrops of the Moenkopi and Kaibab Formations. Include medium- to coarse-grained sand and gravel to well-rounded pebbles of quartzite and quartz derived from Tertiary sediments (Ts); basalt, andesite, rhyolite, and obsidian clasts and fragments from the Mount Floyd Volcanic Field in southwest part of map area and rounded to subrounded clasts and fragments of basalt from the San Francisco Volcanic Field in southeast part of map area. Include subrounded to angular basalt clasts from Red Butte in northeast quarter of map area. Partly consolidated by silt, gypsum, and calcite. Overlapped by ponded sediments (Qps), floodplain (Qf), sand sheet and dune (Qd), and sand sheet (Qss) deposits. Intertongue with upper part of valley-fill (Qv) and young terrace-gravel (Qgy) deposits. Surfaces are partly eroded and cut by small arroyo erosion. Surface has thin sandy calcrete soil mixed with large cobbles and boulders of basalt near Mount Floyd Volcanic

Field. Subject to extensive sheet-wash erosion and flash flood debris flows. Support moderate growth of high desert shrubs, sagebrush, cactus, and grass. Thickness, 3 to 25 ft (1 to 7.5 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qa - Alluvial deposits (Holocene and Pleistocene)

Brown, red, and gray, slope-forming, unsorted mixture of mud, silt, sand, pebbles, cobbles, and boulders. Clasts are mostly angular, some are rounded; locally consolidated by calcite and gypsum cement. Sandstone, limestone, and chert clasts and gravel are locally derived from Paleozoic rocks. Includes alluvial-fan, floodplain, talus, colluvium, and valley-fill deposits. Subject to extensive sheet wash erosion or deposition, flash-flood debris flows, and arroyo erosion. Only largest deposits shown; most talus deposits are not shown to emphasize the bedrock geology, but are common in headward slopes of local tributary drainages and as talus deposits on slopes of Hermit Formation (Ph). About 3–100 ft (1–30 m) thick. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qa2 - Intermediate alluvial fan deposits (Holocene and Pleistocene)

Qa2 - Intermediate alluvial fan deposits (Holocene)

Lithologically similar to young alluvial fan (Qa1) deposits; partly cemented by calcite, gypsum, and clay. Surface of unit is partly eroded by sheet wash erosion with arroyos that have incised as much as 3 to 10 ft (1 to 3 m) below Vermilion and Echo Cliffs. Subject to partial coverage by dune sand and sand sheet (Qd) and sand sheet (Qs) deposits. Unit commonly overlapped by young alluvial fan (Qa1) deposits; intertongues with or overlaps valley-fill (Qv), talus and rock-fall (Qtr), and young and intermediate terrace-gravel (Qg1,Qg2) deposits. Support light to moderate growths of grass, sagebrush, and cactus. Thickness, 6 to 50 ft (2 to 15 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qa2 - Intermediate alluvial fan deposits (Holocene)

Lithologically similar to young alluvial fan (Qa1) deposits; partly cemented by calcite, gypsum, and clay. Surface of unit is partly eroded by sheetwash erosion that incises as much as 3 to 10 ft (1 to 3 m). In eastern third of quadrangle, unit is often covered by dune sand and sand sheet (Qd) and sand sheet (Qes) deposits. Unit is commonly overlapped by young alluvial fan (Qa1) deposits and intertongues or overlaps with valley-fill (Qv), talus and rockfall (Qtr), and young and intermediate terrace-gravel (Qg1, Qg2) deposits. Support light to moderate growths of grass, sagebrush, and cactus. Thickness, 6 to 50 ft (2 to 15 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qay - Young alluvial fan deposits (Holocene and Pleistocene(?))

Vermilion Cliffs area; consists of light-red and brown silt and fine- to coarse-grained sand and gravel; partly consolidated by calcite and clay. Include subangular red and white chert fragments and small red and white sandstone and gray limestone clasts generally less than 5 cm (2 in) in diameter derived locally from nearby Vermilion Cliff outcrops. Include large boulders of the Shinarump Member of the Chinle Formation as much as 2 m (6 ft) in diameter below Yellowstone Mesa area. Clay content greatest below or in outcrops of Petrified Forest Member of the Chinle Formation. Include numerous black, brown, yellow, red, and gray, very well rounded quartzites and chert pebbles 1.5 to 5 cm (0.5 to 2 in) in diameter and occasional rounded, gray-white petrified wood fragments down slope of Vermilion Cliffs areas. Locally covered by thin eolian dune sand and sand sheet (Qd) deposits, young mixed alluvium, and eolian (Qae) deposits at distal ends of alluvial fan deposits.

On Kanab Plateau, Uinkaret Plateau, and in Kanab Creek drainages; gray, light-red, and light-brown silt, sand, and white cherty gravel, partly consolidated by gypsum and calcite. Include lobes of flash flood debris flows of unsorted angular boulders in sandy matrix that often form temporary dams that block

principal drainages, primarily in Kanab Creek, Nail Canyon, and Snake Gulch, central part of map area. Surfaces are generally gullied as much as 3 m (10 ft) or partly covered by desert pavement of small gravel or pebbles in northwest quarter of map area; partly consolidated by calcite, clay, and gypsum cement below stratigraphic level of the Chinle Formation; mostly unconsolidated above Chinle below Vermilion Cliffs. Commonly overlapped by or intertongue with stream channel (Qs) deposits in upper Kanab Creek drainages and Muggins Flat area. Intertongue with landslide (Ql) and talus and rock fall (Qtr) deposits at upper reaches of alluvial fans below Vermilion Cliffs where unit is heavily dissected by erosion. Subject to extensive sheet wash erosion or sediment accumulation during heavy storms. Support moderate growths of grass, sagebrush, cactus, juniper, pinion pine, and various small high-desert shrubs. About 2 to 18 m (6 to 60 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qay - Intermediate alluvial fan deposits (Holocene and Pleistocene)
Grayish-brown silt, sand, gravel, and some boulders. Pebbles, cobbles and boulders are subangular to rounded clasts of limestone, chert, and sandstone derived from local Paleozoic and Mesozoic strata of the Moenkopi and Kaibab Formations. Include medium- to coarse-grained sand and scattered well-rounded pebbles of quartzite and quartz and subrounded clasts and fragments of basalt derived from the San Francisco Volcanic Field. Unit is partly consolidated by silt, gypsum, and calcite and partly overlapped by ponded sediments (Qps), flood-plain (Qf), dune sand and sand sheet (Qd) deposits. Intertongue with upper part of valley alluvial (Qv), stream-channel (Qs), and young terrace-gravel (Qgy) deposits. Surfaces are partly eroded and cut by arroyo erosion. Surface has thin calcrete soil development that forms a sandy surface mixed with large cobbles and boulders of basalt near the Dog Knobs area of the San Francisco Volcanic Field. Extensively eroded and cut by arroyos in lowland areas northeast and east of Little Colorado River. Include coarse gravel, subangular to rounded pebbles and cobbles of limestone, chert, and sandstone derived from local Paleozoic and Mesozoic outcrops on Coconino Plateau. Subject to extensive sheetwash erosion and flash flood debris flows. Support moderate growths of sagebrush, cactus, and grass. About 1 to 12 m (3 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qay - Young alluvial fan deposits (Holocene)
Gray-brown silt, sand, gravel, and some boulders. Clasts are subangular to rounded limestone, chert, and sandstone locally derived from Mesozoic and Paleozoic outcrops of the Moenkopi and Kaibab Formations. Include medium- to coarse-grained sand and gravel to well-rounded pebbles of quartzite and quartz derived from Tertiary sediments (Ts); basalt, andesite, rhyolite, and obsidian clasts and fragments from the Mount Floyd Volcanic Field in southwest part of map area and rounded to subrounded clasts and fragments of basalt from the San Francisco Volcanic Field in southeast part of map area. Include subrounded to angular basalt clasts from Red Butte in northeast quarter of map area. Partly consolidated by silt, gypsum, and calcite. Overlapped by ponded sediments (Qps), floodplain (Qf), sand sheet and dune (Qd), and sand sheet (Qss) deposits. Intertongue with upper part of valley-fill (Qv) and young terrace-gravel (Qgy) deposits. Surfaces are partly eroded and cut by small arroyo erosion. Surface has thin sandy calcrete soil mixed with large cobbles and boulders of basalt near Mount Floyd Volcanic Field. Subject to extensive sheet-wash erosion and flash flood debris flows. Support moderate growth of high desert shrubs, sagebrush, cactus, and grass. Thickness, 3 to 25 ft (1 to 7.5 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qr - Colorado River gravel and silt deposits (Holocene and Pleistocene)

Qr - Colorado River gravel and silt deposits (Holocene and Pleistocene(?))
Mud, silt, and fine- to coarse-grained sand and gravel interbedded with poorly sorted, angular to well-rounded pebbles, cobbles, and boulders adjacent to the Colorado River. Include local alluvial debris fans and flows and eolian sand sheet and small dune deposits. Composed of silt, sand, in a gravelly matrix with small sandstone, limestone, chert, basalt, and well-rounded quartzite rocks and volcanic rocks that

originate from Utah, Colorado, and New Mexico. Unit is mostly mud and fine-grained sand and silt in backwaters of Lake Mead area (Colorado River Mile 237–262). Include older terrace deposits that overlie basalt flows 3 to 30 m (10 to 100 ft) above post Glen Canyon Dam high-water line of Colorado River, partly consolidated by calcium, mud, and gypsum. Deposits often include landslide and talus debris. Thickness, 3 to 30 m (10 to 100 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qr - Colorado River terrace and gravel deposits (Holocene and Pleistocene)
Mud, silt, and fine- to coarse-grained sand and gravel interbedded with poorly sorted, angular- to well-rounded pebbles, cobbles, and boulders adjacent to Colorado River. Overlap and intertongue with local alluvial debris fans and flows. Young (Qgy) and old (Qgo) alluvial terrace-gravel deposits are mapped as one unit (Qr) along Colorado River because map scale is too small to separate them. Include local wind-blown sand sheet and small sand dune deposits. Clasts are primarily comprised of sandstone, limestone, chert, basalt and well-rounded quartzite and volcanic rocks that have originated upstream from distant upper basin uplifts. Terrace gravels underlie and overlie local basalt flows 3 to 122 m (10 to 400 ft) above Colorado River, southeast quarter of map area. Higher terrace-gravel deposits are partly consolidated by calcium and gypsum. Age of terrace deposits commonly between 0.100 to 0.150 Ma (Fenton, 1998). Deposits are interbedded with local landslide and talus debris. Thickest deposits, downstream from the Toroweap and Hurricane Faults, as much as 60 m (200 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qr - Colorado River gravel deposits (Holocene)
Mud, silt, and fine-grained sand transported by the Colorado River; interbedded with poorly sorted, angular to well-rounded, coarse-grained sand, gravel, pebbles, cobbles, and boulders of local alluvial debris fans and flows, partly reworked by the Colorado River. Includes local wind-blown sand sheets and small sand dune deposits derived from local gravel deposits. Only large deposits shown. About 3–80 ft (1–25 m) thick. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qgy - Young alluvial terrace deposits (Holocene and Pleistocene)

In Grand Wash Trough, include lower three terraces along streams as mapped by Billingsley and others (unpub. data). Unit consists of light-brown, pale-red and gray silt, sand, pebbles, cobbles, and boulders, partly consolidated by calcium and gypsum. Composed mostly of well-rounded to sub-angular limestone, sandstone, chert, and basalt clasts as large as 1 m (3 ft) in diameter. Unit is locally inset and overlaps old terrace-gravel (Qgo) deposits and interbedded with young alluvial fan (Qay) deposits. Terraces are 2 to 30 m (6 to 100 ft) above local streambeds. Only thick or large deposits shown. Thickness, 3 to 30 m (6 to 100 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qay - Young alluvial fan deposits (Holocene and Pleistocene)

Qay - Young alluvial fan deposits (Holocene and Pleistocene(?))
On Colorado Plateau, composed of brown, red, and gray, slope-forming, unsorted mix of mud, silt, sand, gravel, pebbles, cobbles, and boulders. Clasts are mostly angular but some are rounded where derived locally from young gravel and sedimentary (Tg) deposits and old gravel (QTg) deposits; locally consolidated by calcite and gypsum cement. Southwest of Grand Wash Cliffs, composed of coarse-grained quartz and feldspar sand and gravel mixed with subangular to rounded pebbles and boulders of Proterozoic schist, gneiss, and granite mixed with Paleozoic clasts of limestone and sandstone and Cenozoic clasts of basalt. Include alluvial fan debris flows, sheet wash alluvium, and fluvial valley-fill (Qv) deposits; partly covered by eolian sand sheet and sand dune (Qd) deposits. Subject to extensive sheet wash erosion, minor arroyo erosion, and flash flood debris flow accumulations. Only largest or thickest deposits shown. Thickness, 1 to 30 m (3 to 100 ft). May be as much as 92 m (300 ft) thick or more in

Hualapai Valley. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qay - Young alluvial fan deposits (Holocene and Pleistocene)
Brown, red, and gray slope-forming, unsorted mix of mud, silt, sand, pebbles, cobbles, and boulders. Clasts are mostly angular but some are rounded; locally consolidated by calcite and gypsum cement. Sandstone, limestone, chert, and gravel are derived locally from Paleozoic and Mesozoic outcrops in Grand Canyon and Grand Wash Trough areas. Include alluvial fan debris flows, sheet wash alluvium, minor eolian sand deposits, and alluvial valley-fill (Qv) deposits. Subject to extensive sheet wash erosion, flash flood debris flows, and arroyo erosion. Only largest or thickest deposits shown. Most talus deposits on canyon slopes are not shown to emphasize bedrock geology. Thickness, 1 to 30 m (3 to 100 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qa3 - Old alluvial fan deposits (Holocene, Pleistocene and Pliocene(?))

Qa3 - Old alluvial fan deposits (Holocene)
Gray and light-brown, unsorted silt, sand, and gravel mixed with angular and subrounded pebbles and cobbles of red and white sandstone, gray limestone, and gray chert; partly consolidated by calcite and gypsum cement. Unit partly overlain by dune sand and sand sheet (Qd) deposits below White Mesa in southeastern quarter of quadrangle. Include large boulders, cobbles, and pebbles of sedimentary rocks derived from nearby talus and rock-fall (Qtr) and landslide (Ql) deposits below Vermilion and Echo Cliffs in southwestern half of quadrangle. Support moderate growths of grass, sagebrush, cactus, and various desert shrubs. Thickness, 5 to 25 ft (1.5 to 7.5 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qa3 - Old alluvial fan deposits (Holocene)
Gray and light-brown, unsorted silt, sand, and gravel mixed with brecciated and subrounded pebbles and cobbles of red sandstone and gray limestone and chert; partly consolidated by calcite and gypsum cement. Unit often overlain by sand sheet (Qes) and mixed alluvium and eolian (Qae) deposits in eastern half of quadrangle. Include large boulders, small cobbles and pebbles of sedimentary rocks derived from nearby talus and rockfall (Qtr) and landslide (Ql) deposits in western half of map. Support moderate growths of grass, sagebrush, cactus, and various desert shrubs. Thickness, 5 to 25 ft (1.5 to 7.5 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qgo - Old terrace-gravel deposits (Pleistocene)
Gray, light-brown to light-red clay, silt, sand; partly consolidated by calcite and gypsum cement in tributaries of Kanab Creek drainages. Locally contain lenses of small rounded to subrounded pebble gravel and conglomerate composed of white and red sandstone, blue-gray limestone, abundant subrounded or angular white chert, and scattered, well rounded, multicolored quartzite pebbles in fine- to coarse-grained gravel matrix. Down slope of Vermilion Cliffs, include well rounded quartz, chert, or quartzite pebbles of various sizes derived from Shinarump Member of the Chinle Formation. In eastern tributary drainages of Kanab Creek and Muggins Flat west of Kaibab Plateau, include occasional well-rounded pebbles and small cobbles of brown, purple, and gray quartzite clasts derived from old gravel and sedimentary (Ts) deposits. Unit forms terraces about 9 to 37 m (30 to 120 ft) above stream channel (Qs) deposits along Kanab Creek and its tributaries and often covered by thin eolian dune sand and sand sheet deposits or lag gravel deposits too thin to show at map scale. Support sparse growth of sagebrush, black brush, cactus, and grass. About 2 to 6 m (6 to 20 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qay - Old alluvial fan deposits (Holocene and Pleistocene)
Grayish-brown silt, sand, gravel, and some boulders. Pebbles, cobbles and boulders are subangular to rounded clasts of limestone, chert, and sandstone derived from local Paleozoic and Mesozoic strata of

the Moenkopi and Kaibab Formations. Include medium- to coarse-grained sand and scattered well-rounded pebbles of quartzite and quartz and subrounded clasts and fragments of basalt derived from the San Francisco Volcanic Field. Unit is partly consolidated by silt, gypsum, and calcite and partly overlapped by ponded sediments (Qps), flood-plain (Qf), dune sand and sand sheet (Qd) deposits. Intertongue with upper part of valley alluvial (Qv), stream-channel (Qs), and young terrace-gravel (Qgy) deposits. Surfaces are partly eroded and cut by arroyo erosion. Surface has thin calcrete soil development that forms a sandy surface mixed with large cobbles and boulders of basalt near the Dog Knobs area of the San Francisco Volcanic Field. Extensively eroded and cut by arroyos in lowland areas northeast and east of Little Colorado River. Include coarse gravel, subangular to rounded pebbles and cobbles of limestone, chert, and sandstone derived from local Paleozoic and Mesozoic outcrops on Coconino Plateau. Subject to extensive sheetwash erosion and flash flood debris flows. Support moderate growths of sagebrush, cactus, and grass. About 1 to 12 m (3 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qao - Old alluvial fan deposits (Holocene(?) and Pleistocene)
Similar to young alluvial fan (Qay) deposits, partly consolidated and commonly covered by calcrete soil 1 to 2 m (3 to 6 ft) thick. On plateaus, composed mostly of gray to brown, fine-grained sand and silt matrix mixed with subangular to rounded pebbles and boulders of basalt, limestone, sandstone, quartzite, and chert. In Aubrey Valley, composed mainly of gray, coarse-grained sand and gravel matrix containing rounded pebbles and small boulders of limestone, sandstone, quartzite, and chert derived from Aubrey Cliffs and upper Aubrey Valley. Support moderate growth of sagebrush, cactus, grass, pinyon pine and juniper trees on Colorado Plateau and sparse cactus and grass in Aubrey Valley. Thickness, 3 to 30 m (9 to 100 ft) or more. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qao - Old alluvial fan deposits (Holocene and Pleistocene)
Lithologically similar to young alluvial fan (Qay) deposits; partly consolidated by calcite and gypsum cement. Surface has thin upper calcrete soil that forms flat rocky and sandy surface near Mount Floyd Volcanic Field outcrops. Include numerous basalt clasts from Mount Floyd Volcanic Field in southwest quarter of map area. Commonly overlapped by or intertongue with talus and rock fall (Qtr), landslide (Ql), and young alluvial fan (Qay) deposits. Support moderate growth of grass, sagebrush, cactus, cliffrose bush, and some scattered pinyon and juniper trees. Thickness, 5 to 25 ft (1.5 to 7.5 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qao - Older alluvial fan deposits (Holocene(?) and Pleistocene)
Similar to young alluvial fan (Qay) deposits, partly consolidated and commonly capped by calcrete soil 1 to 2 m (3 to 6 ft) thick. On plateaus, composed mainly of gray to brown, fine-grained sand and silt matrix mixed with subangular to rounded pebbles and boulders of basalt, limestone, sandstone, and chert. Some basalt boulders are 1 m (3 ft) in diameter. In Grand Wash Trough, composed mainly of gray, coarse-grained sand and gravel matrix containing subangular to rounded pebbles and boulders of limestone, sandstone, and chert derived from Grand Wash Cliffs east of Grand Wash. West of Grand Wash, composed of coarse-grained sand and gravel mixed with subangular to rounded pebbles and boulders of Proterozoic schist, gneiss, and granite mixed with Paleozoic limestone and sandstone clasts. Surfaces are hard and rocky and eroded by arroyos as much as 10 m (30 ft) deep in some areas of the Grand Wash Trough and Colorado Plateau. Support moderate growth of sagebrush, cactus, grass, pinyon pine and juniper trees on Colorado Plateau and sparse growth of cactus, grass, and desert shrubs in Grand Wash Trough. Thickness, 3 to 30 m (9 to 100 ft) or more. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qps - Ponded sediments (Holocene and Pleistocene(?))

Qps - Ponded sediments (Holocene)
House Rock Valley and Marble Plateau: Gray and red-brown clay, silt, sand, and gravel; partly consolidated by calcite and or gypsum cement. Locally include minor lenses of angular to subrounded chert and limestone fragments or pebbles in sandy matrix derived from nearby Permian, Triassic, and Jurassic strata. Similar to floodplain (Qf) deposits but occupy natural internal drainage depressions created by sinkhole development or man-made containment structures in southwestern half of quadrangle.

Paria and Kaibito Plateaus: Gray, brown, and light-red clay, silt, sand, and minor chert gravel. Chert gravel is often locally derived from thin silicified limestone beds within the Navajo Sandstone (Jn). Ponded sediments are commonly formed in depressions caused by sand dune blockage or in small wind deflation hollows within extensive dune sand and sand sheet (Qd), parabolic dune (Qdp), and mixed dune (Qdm) deposits. These deposits are likely temporary but are important as watering places during human and animal migration across the dry sandy areas of the plateaus. Thickness, 5 to 20 ft (1.5 to 6 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qps - Ponded sediments (Holocene)
Gray or red-brown clay, silt, sand, and gravel; partly consolidated by calcite and or gypsum cement. Locally include small lenses of angular to subrounded chert and limestone fragments or pebbles in sandy matrix. Similar to flood-plain (Qf) deposits but occupy man-made ponded areas or natural internal drainage depressions caused by sinkhole development on plateau surfaces in western half of quadrangle. Deposits on Moenkopi and Kaibito Plateaus are commonly formed in depressions created by temporary sand dune dams or in wind deflation hollows of dune sand and sand sheet (Qd) and parabolic dune (Qdp) deposits. Desiccation cracks often develop on hardpan surfaces during dry conditions. Thickness, 5 to 30 ft (1.5 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qps - Ponded sediments (Holocene)
Light-red to white clay, mud, silt, and fine-grained sand. Locally include small angular to subrounded fragments of bedrock clasts from nearby outcrops. Deposits are common sediment in sinkhole depressions. Sediment accumulates in temporary ponded areas on young terrace-gravel (Qgy) deposits due to sand dune accumulations or overbank sand and mud that form levee deposits preventing sediments from eroding back into local drainages for an extended amount of time. Include ponded deposits consisting of sand and silt on Moccasin Mountains and Paria Plateau where widespread sand sheet and sand dunes form temporary dune blockage across local drainages, or as blowout depressions formed within sand dunes. Youngest deposits accumulate in lowland areas where artificial diversion dams, stock tanks, or roads block drainages. Desiccation cracks often form on dry hardpan surfaces. Clay and fine silt content of sediment largely restricts plant growth except in sandy areas above Vermilion Cliffs. About 0.5 to 2 m (1 to 6 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qps - Ponded sediments (Holocene and Pleistocene(?))
Gray or brown clay, silt, sand, and some lenses of gravel; partly consolidated by calcite and or gypsum cement. Locally include small chert and limestone fragments or pebbles. Similar to flood-plain (Qf) deposits but occupy man-made drainage depressions or natural internal drainage depressions caused by sinkhole development, and most commonly caused by sand dune blockages. Larger internal drainage basins, such as Dog Knobs Lake and Babbitt Lake, or smaller sinkhole depressions are common in west half of map area. Eolian blowout depressions, common in dune sand and sand sheet (Qd) deposits on Ward Terrace and below Red Rock Cliffs northeast of Little Colorado River area, and in old eolian sand sheet and dune (QTes) deposits on Moenkopi Plateau, accumulate temporary ponded sediments due to temporary sand-formed dams, many of which are too small to show at map scale. Desiccation cracks often develop in dry conditions on hardpan surfaces of larger accumulations that often restrict plant growth because of excessive clay content. Northeast and east of Little Colorado River and on

Moenkopi Plateau, sandy ponded areas do support growths of seasonal grass and often develop a parabolic dune complex downwind (northeast) of sediment area. About 1.5 to 9 m (5 to 30 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qps - Ponded sediments (Holocene and Pleistocene(?))
Gray to brown clay, silt, sand, and lenses of gravel. Locally include small chert and limestone fragments or pebbles. Similar to floodplain (Qf) deposits but occupy natural internal drainage depressions and man-made stock tank areas. Internal drainage sinkhole ponded sediments are common in northwest quarter of map area. Accumulate in several small areas within sand dune and sand sheet deposits near Farm Dam Draw, many too small to show at map scale. Desiccation cracks common on dry playa-like hardpan surfaces restrict plant growth. Lake beds in the Mount Floyd Volcanic Field area are dry most of the time and are source areas of silt for silt dune (Qsd) deposits. Support little or no vegetation or minor growths of seasonal grass. Thickness, 5 to 35 ft (1.5 to 11 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qae - Mixed alluvium and eolian deposits (Holocene and Pleistocene(?))

Qae - Mixed alluvium and eolian deposits (Holocene)
Gray-white, light-red, fine- to coarse-grained interbedded sand, brown clay and silt, and lenses of subrounded pebbles or angular gravel fragments. Include angular white chert fragments locally derived from Permian and Triassic strata in House Rock Valley and on Marble Plateau. On Paria and Kaibito Plateaus, unit consists of white to gray chert fragments and small black sandstone concretions derived from Navajo Sandstone. Deposits accumulated by alluvial and (or) eolian processes result in an interbedded sequence of mixed mud, silt, sand, and gravel. Deposit subject to sheet wash erosion and arroyo cutting during wet conditions and wind-blown sand accumulation during dry conditions. Support light to moderate growth of grass, cactus, sagebrush, and high desert shrubs. Thickness, 3 to 40 ft (1 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qae - Mixed alluvium and eolian deposits (Holocene)
Gray, light-red, fine- to coarse-grained interbedded sand, brown clay and silt, and lenses of pebbly or brecciated gravel. Include angular white chert fragments locally derived from Permian strata on Kaibab and Marble Plateaus; white, gray, brown, and red chert fragments derived from members of the Chinle Formation in Painted Desert area; and white to gray chert fragments and concretionary sandstone pebbles derived from Navajo Sandstone on Moenkopi and Kaibito Plateaus. Deposits accumulate by combinations of alluvial or eolian processes resulting in an interbedded sequence of mixed mud, silt, sand, and gravel. Deposit subject to sheetwash erosion and arroyo cutting during wet conditions and wind-blown sand accumulations during dry conditions. Sediments commonly accumulate on broad sandy flatlands or on gently sloping alluvial fans. Support light to moderate growth of grass, cactus, sagebrush, and high desert shrubs. Thickness, 3 to 40 ft (1 to 12 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qae - Young mixed alluvium and eolian deposits (Holocene)
Composed of gray, light-red, and white silt and fine- to coarse-grained, eolian and fluvial sand lenses; includes interbedded reddish-brown and gray silt and clay. Include a few coarse-grained gravel lenses composed primarily of angular chert fragments and red to white sub-rounded sandstone pebbles on Moccasin Mountains and Paria Plateau. Below Vermilion Cliffs in House Rock Valley and south and west of Yellowstone Mesa, includes multicolored and black, well-rounded chert pebbles derived from Shinarump Member of the Chinle Formation. Commonly occupies upper slopes of young alluvial fan (Qay) deposits. Below Vermilion Cliffs west of Colorado City, unit mostly composed of white and light-red sand and red silt that intertongues with young alluvial fan (Qay) deposits. Unit often overlapped by dune sand and sand sheet (Qd) deposits. Support thick to moderate growths of grass, cactus, and

sagebrush; thick sagebrush, cliff rose bush, and pinion pine, oak, and juniper trees above Vermilion Cliffs. About 1.5 to 18 m (5 to 60 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qae - Young mixed alluvium and eolian deposits (Holocene and Pleistocene(?))
Gray, light-red, and brown clay, silt, and fine- to coarse-grained sand interbedded with lenses of pebbly gravel. Include white angular chert fragments locally derived from Permian strata on Coconino Plateau and Gray Mountain area; white, gray, brown, and red chert fragments derived from Owl Rock Member of the Chinle Formation east of the Little Colorado River in the Ward Terrace area, and chert fragments derived from the Navajo Sandstone on Moenkopi Plateau. Deposits have accumulated by combinations of alluvial or eolian processes resulting in an interbedded sequence of thin-bedded, mixed mud, silt, sand, and gravel deposits. Deposit subject to sheetwash erosion during wet conditions and wind-blown sand accumulations during dry conditions. Commonly accumulate on broad flatlands or gently sloping alluvial fans downwind (northeast) of local drainage valleys. Often overlapped by dune sand and sand sheet (Qd) deposits. Support light to moderate growth of grass, cactus, and high desert shrubs. About 1 to 12 m (3 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qae - Young mixed alluvium and eolian deposits (Holocene and Pleistocene(?))
Gray, light-red and brown clay, silt, and fine- to coarse-grained sand interbedded with lenses of coarse-grained gravel. Include white angular chert fragments. Formed by wind- and water-transported sediment by fluvial or eolian processes resulting in an interbedded accumulation of alluvial and eolian deposits. Deposit subject to sheet wash erosion in wet conditions, eolian sand accumulation in dry conditions. Commonly occupy broad flatland or gently sloping topography downwind (northeast) of tributary drainages and valleys in northwest two-thirds of map area. Often overlapped by sand sheet (Qss) or sand sheet and dune (Qd) deposits. Support thick to moderate growth of grass, cactus, and local high desert shrubs. Thickness, 1 to 6 ft (0.3 to 1.8 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qss - Sand sheet deposits (Holocene and Pleistocene(?))

White, brown, and gray, fine- to coarse-grained wind-blown sand. Composed primarily of quartz and feldspar grains derived from erosion of Tertiary sediments (Ts) in southwest half of map area. Composed of quartz grains and small chert fragments derived from Harrisburg Member of the Kaibab Formation in central part of map area. Form extensive deposits over gently sloping terrain of flat prairie-land topography downwind (northeast) of sand dune deposits in southwest and central part of map area. Intertongue with young mixed alluvium and eolian (Qae) deposits and old mixed alluvium and eolian (QTae) deposits. Arbitrary and gradational lateral and vertical contact between sand sheet (Qss) and sand sheet and dune (Qd) deposits based on morphologic interpretation of aerial photographs. Only most extensive deposits shown. Support moderate growth of grass and small high-desert shrubs. Thickness, 1 to 10 ft (0.3 to 3 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qscf - Eolian and fluvial silt deposits (Holocene and Pleistocene(?))

Qsc - Eolian and fluvial silt deposits (Holocene and Pleistocene(?))
Brown to medium-gray clay, silt, and fine-grained sand composed of decomposed and weathered volcanic rock. Similar to eolian silt dune (Qsd) deposits except they are thinner, widespread, and restricted to the Mount Floyd Volcanic Field area. Silt and clay matter is primarily derived from weathered volcanic rock that has accumulated as fine-grained silt and sand in young terrace-gravel (Qgy), valley-fill (Qv), ponded sediments (Qps), and silt dune (Qsd) deposits transported downwind (northeasterly) onto nearby slopes of basaltic and andesitic pyroclastic deposits. Gradational and arbitrary contact with adjacent alluvial or eolian deposits. Include unsorted fragments of small pebbles and cobbles derived from local basalt, rhyolite, or obsidian, and pyroclastic deposits. Partly consolidated

by calcite and clay cement. Form extensive thin deposits downwind of young alluvial fan (Qay) deposits. Form thin veneer over most volcanic rocks in the Mount Floyd Volcanic Field area where only thickest and most extensive deposits are shown. Support moderate to thick growth of grass, sagebrush, some cactus, and scattered pinion/juniper woodlands. Thickness, 1 to 25 ft (0.3 to 7.5 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qv - Valley-fill deposits (Holocene and Pleistocene)

Qv - Valley-fill deposits (Holocene and Pleistocene(?))
Gray and light-brown silt, sand, and lenses of gravel; partly consolidated by gypsum and calcite below Vermilion and Echo Cliffs. Include occasional rounded clasts of limestone, sandstone, and subrounded to angular chert derived from nearby outcrops of Kaibab Formation and Shinarump Member of the Chinle Formation in House Rock Valley and on Marble Plateau. Intertongue with or overlain by young and intermediate alluvial fan (Qa1,Qa2) and young and intermediate terrace-gravel (Qg1, Qg2) deposits. Subject to sheet wash flooding or arroyo cutting. Reflects low-gradient, low-energy sediment accumulation in shallow drainages in all areas of quadrangle. Thickness, 3 to 30 ft (1 to 9 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qv - Valley-fill deposits (Holocene)
Gray and light-brown silt, sand, and lenses of gravel; partly consolidated by gypsum and calcite. Include occasional rounded clasts of limestone, sandstone, and subrounded to angular chert derived from nearby bedrock; include abundant rounded chert or quartz pebbles derived from Shinarump Member of the Chinle Formation in Painted Desert area. Intertongue or overlap young and intermediate alluvial fan (Qa1, Qa2) deposits and young terrace-gravel (Qg1) deposits. Commonly reflect low-gradient, low-energy sediment accumulation in shallow drainages in all areas of the map area. Subject to sheetwash flooding and temporary ponding due to grasses at lower elevations; sagebrush, grass, cactus, and some forest trees at elevations above 6,000 ft (1,830 m); sagebrush and temporary blockage by eolian sand accumulation on Moenkopi and Kaibito Plateaus. Thickness, 3 to 30 ft (1 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qv - Valley-fill deposits (Holocene)
Gray to light-red, slope-forming, unsorted mixture of mud, silt, sand, gravel, small pebbles, and cobbles. Partly consolidated by calcite and gypsum cement. Include sandstone, limestone, and chert clasts in sandy matrix locally derived from nearby Paleozoic and Mesozoic sedimentary rock outcrops in northwestern third of map area. On Kaibab Plateau; composed mostly of gray silt, sand, and numerous white to yellow chert fragments. Similar to stream-channel (Qs) deposits but occupies low-gradient drainages that deposit mostly fine-grained sand or silt in flat drainage floors, especially in Nail Canyon and Snake Gulch west of Jacob Lake, Arizona. Similar to or interbedded with flood-plain (Qf) deposits in Pipe Valley area. Subject to extensive sheet wash erosion, deposition, flash flood debris flows, temporary ponding of floods, sheet wash and arroyo erosion. Commonly interbedded with stream-channel (Qs), dune sand and sand sheet (Qd), and ponded sediment (Qps) deposits. About 1 to 6 m (3 to 20 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qv - Valley-fill deposits (Holocene and Pleistocene)
Gray and light-brown silt, sand, and lenses of gravel; partly consolidated by gypsum and calcite cement west and southwest of Little Colorado River; unconsolidated east and northeast of Little Colorado River. Include occasional rounded clasts of limestone, subrounded to angular chert, and subrounded to angular basalt southwest of Little Colorado River. Intertongue or overlap young alluvial fan (Qay) deposits and young terrace-gravel (Qgy) deposits. Commonly reflect low energy, low-gradient, shallow drainages. Subject to sheetwash flooding and temporary ponding due to vegetation growths of grass at lower elevations in central area of map, and sagebrush, grass, cactus, and some juniper trees at higher

elevations above 1,830 m (6,000 ft) in west half of map area. About 1 to 9 m (3 to 30 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qv - Valley-fill deposits (Holocene and Pleistocene)
Brown or reddish-gray, slope-forming, unsorted mixture of mud, silt, sand, pebbles, cobbles and boulders. Clasts are angular to rounded and locally consolidated by calcite and gypsum cement. Sandstone, limestone, and chert clasts in gravelly sandy matrix are derived locally from nearby Paleozoic and Cenozoic outcrops. Unit is similar to stream-channel (Qs) deposits but occupy low gradient, low energy drainages. Subject to extensive sheet wash and arroyo erosion and flash flood debris flows. Most extensive and thickest deposits are in Aubrey and Hualapai Valleys and commonly interbedded with local stream-channel (Qs) and sand sheet and sand dune (Qd) deposits. Thickness, about 60 m (200 ft) in Aubrey Valley; about 60 to 92 m (200 to 300 ft) or more in Hualapai Valley. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qv - Valley-fill deposits (Holocene and Pleistocene)
Gray and light-brown silt, sand, and lenses of gravel; partly consolidated by gypsum and calcite cement. Include occasional rounded clasts of limestone, subrounded to angular chert, and subrounded to angular basalt. Intertongue or overlap young alluvial fan (Qay) deposits and young terrace-gravel (Qgy) deposits. Sediment accumulation is the result of low-energy and low-gradient stream flows. Subject to sheet-wash flooding and temporary ponding where vegetation is thickest. Support moderate growth of grass in lower elevations in central area of map, and heavy sagebrush, grass, cactus, and some juniper trees at higher elevations, generally above 6,000 ft (1,830 m). Thickness, 3 to 12 ft (1 to 3.7 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qv - Valley-fill alluvium (Holocene and Pleistocene)
Gray and light-brown silt, sand, and lenses of pebble to small-boulder gravel; partly consolidated by gypsum cement. Includes well-rounded clasts of limestone, sandstone, subrounded to angular chert fragments, and subrounded to subangular basalt clasts near volcanic outcrops. Arbitrary map contact with young alluvial fan (Qay), young alluvial terrace (Qgy), stream-channel alluvium (Qs), and floodplain (Qf) deposits. Represents less active, low-gradient, alluvial stream-channel or shallow-valley deposits. Alluvial valleys subject to sheetwash flooding or temporary ponding; often cut by arroyos as much as 3 m (10 ft) deep. Supports moderate growth of sagebrush, grass, and cactus on Colorado Plateau and mostly cactus and grass in Grand Wash Trough. Thickness, 1 to 6 m (3 to 20 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qt - Travertine deposits (Holocene and Pleistocene)

Qt - Travertine deposits (Holocene and Pleistocene(?))
Gray and tan, stained light-red, massive, porous, cliff-forming freshwater limestone. Include angular clasts of local talus breccia or stream gravel. Formed by rapid chemical precipitation of calcium carbonate from springwater discharge as encrustations on steep slopes or cliffs. Deposits are primarily near base of Cambrian Muav Limestone along east side of Colorado River and north side of Little Colorado River in Grand Canyon. Include numerous dams in bed of Little Colorado River too small to show at map scale. Include minor deposits at seeps along contact between Kayenta Formation-Navajo Sandstone transition zone (Jkn) and underlying Kayenta Formation (Jk) in Moenkopi Wash area that are too thin to show at map scale. Thickness, 6 to 60 ft (2 to 18 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qt - Travertine deposits (Holocene)
Gray and tan, massive, porous, cliff-forming fresh water limestone. Include angular clasts of local talus breccia or gravel. Formed by rapid chemical precipitation of calcium carbonate of spring water. Form

encrustations on steep slopes or cliffs below active and non-active spring outlets. Thickest deposits are at Slide Spring in Slide Canyon, an eastern tributary to Snake Gulch in upper Kanab Canyon. Thickness, 2 to18 m (6 to 60 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qt - Travertine deposits (Holocene and Pleistocene)
Gray, white, tan, massive, porous, cliff-forming fresh-water limestone. Include angular clasts of local talus breccia or gravel. Formed by rapid chemical precipitation of calcium carbonate of spring water. Form massive, rounded mounds or thick-layered encrustations on steep slopes or cliffs below active and non-active spring outlets in Grand Canyon. Thickest deposits are in Meriwhitica, Spencer, Travertine, and Quartermaster Canyons and form thick "travertine dams" within these canyons. Thickness, 2 to 60 m (6 to 200 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qt - Travertine deposits (Holocene and Pleistocene)
Gray, white, tan, massive, porous, cliff-forming carbonate deposits. Formed by chemical precipitation of calcium carbonate from springs. Form massive, rounded mounds or thick-layered encrustations on steep slopes or cliffs downslope of spring outlets. Several deposits represent spring discharges that were probably active during Pleistocene time but are currently dry. Travertine incorporates angular clasts and boulders of talus and rounded Colorado River gravel. Only thickest deposits shown along Colorado River, southeast and southwest corner of map area. Several minor deposits in Grand Wash Trough area are too small to show at map scale. Thickness, about 1 to 25 m (3 to 80 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qt - Travertine deposits (Holocene and Pleistocene)
Gray, white, and tan, massive, porous, cliff-forming limestone. Includes clasts of talus breccia or stream gravel. Formed as rapid chemical precipitation of calcium carbonate of spring water. Forms massive, rounded mounds or thick, layered encrustations on steep slopes or cliffs at and near active and inactive springs. Forms banded deposits of dripstone, flowstone, and rimstone as porous massive hanging sheets, including stalactites and stalagmites. Thickest deposits are in Havasu Canyon below Supai, and at Royal Arch Creek east of Supai. Forms temporary dams or blockages of Havasu Creek in Havasu Canyon. Only thickest deposits shown. About 3–100 ft (1–30 m) thick. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qtr - Talus and rock-fall deposits (Holocene and Pleistocene)

Qtr - Talus and rock-fall deposits (Holocene and Pleistocene(?))
In Marble Canyon: Gray to yellowish-red silt, sand, and gravel mixed with abundant small to large angular limestone, sandstone, and chert rocks and boulders derived from Paleozoic strata; cemented or partly cemented by calcite and gypsum. Below Vermilion and Echo Cliffs: Red to yellow silt, sand, and gravel mixed with angular rocks and boulders of light-red or white sandstone and red to dark-red siltstone derived from Triassic and Jurassic strata; partly cemented by calcite. Below Cummings Mesa and White Mesa, eastern quarter of quadrangle: Gray siltstone and sandstone derived from Jurassic and Cretaceous strata. Most units are often associated with, adjacent to, or part of landslide (Ql) deposits that commonly grade downslope into young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3) or young, intermediate, or old terrace-gravel (Qg1, Qg2, Qg3) deposits. Thickness, 5 to 80 ft (1.5 to 24 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qtr - Talus and rockfall deposits (Holocene and Pleistocene(?))
In Grand Canyon: Gray to yellowish-red silt, sand, and gravel mixed with abundant angular limestone, sandstone, and chert rocks and boulders derived from steep-walled areas of Proterozoic and Paleozoic strata; partly cemented by calcite and gypsum.
Along Echo Cliffs: Red to yellow, silt and sand mixed with angular rocks and boulders of light-red or

white sandstone and red to dark-red siltstone derived from Mesozoic outcrops along Echo Cliffs and Moenkopi wash; partly cemented by calcite. Unit often associated with or adjacent to landslide (Ql) deposits. Unit commonly grades downslope into young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3) deposits or young and intermediate terrace-gravel (Qg1, Qg2) deposits. Thickness, 5 to 45 ft (1.5 to 14 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qtr - Talus and rock fall deposits (Holocene)
Along Vermilion Cliffs; consists of red to yellow silt and sand mixed with angular rocks and boulders of light-red sandstone and dark-red siltstone; partly cemented by calcite. Form talus debris slopes in steep-walled canyons and on lower slopes of Vermilion Cliffs; often associated with and adjacent to or below landslide (Ql) deposits. Include some boulders of Navajo Sandstone or Shinarump Member of the Chinle Formation larger than 3 m (10 ft) near landslide (Ql) deposits near base of Vermilion Cliffs. In Kanab Creek drainages; consists of gray to yellow silt, sand, gravel mixed with small to large angular rocks and boulders of gray limestone, white chert, and white to tan sandstone derived from the Kaibab and Toroweap Formations and Coconino Sandstone; partly cemented by calcite and gypsum. Form talus debris cover on red slopes of Hermit Formation; associated with and below landslide (Ql) deposits. Unit often grades down slope into young or old alluvial fan (Qay, Qao) deposits or young or old terrace-gravel (Qgy, Qgo) deposits. About 1.5 to 14 m (5 to 45 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qtr - Talus and rock fall deposits (Holocene and Pleistocene)
Along Adeii Eechii Cliffs area; red to yellow, silt and sand mixed with angular rocks and boulders of light-red sandstone and dark-red siltstone; partly cemented by calcite. Form talus debris slopes in steep-walled canyons and lower slopes of Adeii Eechii Cliffs; often associated with, adjacent to, or below landslide (Ql) deposits. In Little Colorado River Gorge and Gray Mountain area; gray to yellow silt, sand, gravel mixed with small to large angular rocks and boulders of gray limestone, white chert, and white to tan sandstone derived from the Kaibab and Toroweap Formations and Coconino Sandstone; partly cemented by calcite and gypsum. Form talus debris cover on slopes below landslide (Ql) deposits. Unit often grades down slope into young alluvial fan (Qay) deposits or young terrace-gravel (Qgy) deposits. About 1.5 to 14 m (5 to 45 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qtr - Talus and rock fall deposits (Holocene and Pleistocene)
Brown, gray, slope-forming, unsorted mixture of mud, silt, sand, pebbles, cobbles, and very large broken boulders. Form talus debris slopes in Cataract Canyon and below volcanic outcrops of the Mount Floyd Volcanic Field and Red Butte. Include individual car- and house-size basalt boulders at Red Butte and Long Point areas. Clasts are mostly angular to subangular. Gradational and arbitrary contact with landslide (Ql), young alluvial fan (Qay), floodplain (Qf), young terrace-gravel (Qgy), and valley-fill (Qv) deposits. Subject to extensive sheet-wash erosion, flash-flood debris flows, and arroyo erosion. Only thick or extensive deposits shown. Thickness, 1 to 25 ft (0.3 to 7.5 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qtr - Talus and rockfall deposits (Holocene and Pleistocene)
No description available. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)

Ql - Landslide deposits (Holocene and Pleistocene)
Unconsolidated to partly consolidated masses of angular unsorted rock debris. Include large slump blocks of rock sediments that have rotated backward against the parent outcrop and slid downslope as a loose mass of rock fragments and deformed strata; often associated with talus and rock-fall (Qtr) deposits. Include individual car- and house-size boulders. Unit partly covered by dune sand and sand

sheet (Qd) and sand sheet (Qes) deposits below Vermilion and Echo Cliffs, White Mesa, and Cummings Mesa. Gradational contact with young, intermediate, and old alluvial fan and young, intermediate, and old terrace-gravel deposits near base of deposits. Subject to extensive sheet wash erosion, flash-flood debris flows, rock fall, and arroyo erosion. Thickness, 10 to 200 ft (3 to 61 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)
Landslides are unconsolidated to partly consolidated masses of angular unsorted rock debris. Include stratified blocks (slumps) that rotated backward against parent outcrop and slid downslope as loose incoherent masses of broken rock fragments and deformed strata; often form talus and rockfall (Qtr) deposits adjacent to and below landslide masses. Include individual car- and house-size boulders. Gradational and arbitrary contact with young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3) and young, intermediate, and old terrace-gravel (Qg1, Qg2, Qg3) deposits. Subject to extensive sheetwash erosion, flash-flood debris flows, and arroyo erosion. Thickness, 10 to 200 ft (3 to 61 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)
Vermilion Cliffs area; consists of unconsolidated masses of unsorted rock debris that include detached blocks of Mesozoic strata that have rotated backward and slid down slope against parent cliff as loose incoherent masses of broken rock and deformed strata, often surrounded by talus and rock fall (Qtr) deposits. Parallel to the Vermilion Cliffs, landslide masses are as large as 3 km (2 mi) in length. Out from the Vermilion Cliffs, landslide masses are 0.8 km (0.5 mi) in width and have slid down slope 153 to 213 m (500 to 700 ft) or more. Unit often partly covered by eolian dune sand and sand sheet (Qd) deposits. Individual landslides may become unstable during wet conditions and creep down slope where unit is underlain by claystone or siltstone bedrock of Kayenta Formation or Petrified Forest Member of the Chinle Formation.

Kanab Creek and tributary canyon drainages; consists of partly consolidated masses of unsorted rock debris that include detached blocks of Permian strata that have either fallen or slide down soft gypsiferous slopes of the Woods Ranch Member of the Toroweap Formation. Support sparse growth of sagebrush, cactus, grass, juniper trees, and pinion trees. About 8 to 60 m (25 to 200 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)
Landslides are unconsolidated to partly consolidated masses of unsorted rock debris. At northeast base of Gray Mountain, includes a horizontally bedded gravity-glide mass of Kaibab Formation that overlies Triassic beds of the Shinarump Member of the Chinle Formation. Include detached stratified blocks that rotated backward against parent outcrop and slid downslope as loose incoherent masses of broken rock fragments and deformed strata; often form talus and rock fall (Qtr) deposits adjacent to and below landslide masses on Gray Mountain, Little Colorado River Gorge, and Black Point areas. Some landslide blocks below edges of basalt flows at Black Point are unstable during wet conditions (fig. 1 on map). Landslide masses at Black Point are commonly associated with soft siltstone and claystone strata of Petrified Forest Member of the Chinle Formation. Include individual car- and house-size basalt boulders near base of Gray Mountain and in Little Colorado River Gorge. Clasts are mostly angular and unsorted; partly cemented by calcium. Gradational and arbitrary contact with young alluvial fan (Qay), flood-plain (Qf), young terrace-gravel (Qgy), and valley alluvial (Qv) deposits. Subject to extensive sheetwash erosion, flash-flood debris flows, and arroyo erosion. About 3 to 61 m (10 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)
Unconsolidated to partly consolidated masses of unsorted rock debris and blocks of sedimentary strata. Detached sedimentary strata has rotated backward against parent outcrop and slid downward as loose

incoherent masses of broken rock and deformed strata, partly surrounded by talus debris (talus not shown). Include local talus debris, rock glacier, and rock-fall debris. Largest landslides are commonly found along either side of Colorado River from Mile 207 to 222, involving as much as 1,067 m (3,500 ft) of vertical Paleozoic strata. Landslide masses are likely associated with earthquake activity along Hurricane and Meriwhitica Faults. Landslide deposits may become unstable in wet climatic conditions. Thickness, 9 to 183 m (30 to 600 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)
Unconsolidated to partly consolidated masses of unsorted rock debris. Include detached blocks that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata. Include talus debris, rock glaciers, and rock-fall debris on lower slopes, adjacent to, and below landslide masses. Some landslide blocks may become unstable in very wet conditions. Only large landslide blocks are shown. Many small landslide masses commonly found below cliffs of volcanic rock of the Mount Floyd Volcanic Field, Red Butte, and around edges of the San Francisco Volcanic Field. Thickness, 10 to 200 ft (3 to 60 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)
In Grand Canyon, form large unconsolidated to partly consolidated masses of Paleozoic rock debris. Include detached blocks of strata that have rotated backward and slid downslope against parent wall as loose incoherent masses of broken rock and deformed strata, partly surrounded by local talus, rock glaciers, and rock-fall debris. Some large landslides in Grand Canyon were likely triggered by earthquakes along the major faults in the area. Landslide masses are common around Tertiary volcanic mountains on the Colorado Plateau and around basalt flows in the Grand Wash Trough area. Landslide masses in Grand Wash Trough are unstable where overlying red siltstone and sandstone of the Grand Wash Trough (Tgr), especially during wet conditions. Only large or significant landslide deposits are shown. Thickness, 10 to 60 m (30 to 200 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Ql - Landslide deposits (Holocene and Pleistocene)
Unconsolidated to partly consolidated masses of unsorted rock debris. Includes detached blocks that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, partly surrounded by talus (talus not shown). Includes local talus, rock glaciers, and rock-fall debris. Landslide blocks may be associated with earthquake activity. Some landslide blocks may become unstable in very wet conditions. Only large landslide blocks shown (fig. 5). Many small landslide masses are commonly found below cliffs of Kaibab Formation (Pk), Coconino Sandstone (Pc), Redwall Limestone (Mr), and Tapeats Sandstone (_t). Variable thickness 10–200 ft (3–60 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qgo - Older alluvial terrace deposits (Holocene(?) and Pleistocene)

Similar to young alluvial terrace (Qgy) deposits and partly consolidated by calcite and gypsum cement. Surface has developed a thin soil that forms a smooth surface texture compared to younger terrace surfaces. Commonly overlapped by or interbedded with talus and landslide (Ql) debris deposits and older alluvial fan (Qao) deposits. Include abundant basaltic clasts that form thin desert pavement near landslide deposits. In Grand Wash Trough, support moderate growth of grass, cactus, and desert shrubs. On Colorado Plateau, support moderate growth of grass, cactus, and sagebrush, juniper trees and pinyon pine trees. Thickness, 2 to 5 m (6 to 15 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qsd - Silt dune deposits (Holocene and Pleistocene)

Brown and medium-gray clay, silt, and fine-grained sand composed of decomposed and weathered volcanic rock. Include subrounded to angular fragments of pebbles and cobbles of local basalt rocks about 4 to 6 inches (9.6 to 14.5 cm) in diameter and as much as 1 ft (0.3 m) in diameter. The basaltic rocks are randomly scattered within and on silt dunes. High winds during wet conditions may have blown basalt rocks across flat slick muddy lake surfaces and up onto slick muddy dune surfaces. Source for silt dunes is locally derived from dry lake surfaces of ponded sediments (Qps), such as Red Lake, Tule Lake, Bishop Lake, Horse Lake, and several unnamed dry lakes and ponds in the Mount Floyd Volcanic Field and transported by southwesterly winds to accumulate on northeast shores of lakes and ponds. Support little to no vegetation due to heavy silt and clay content. Thickness, 6 to 80 ft (1.8 to 25 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qdc - Eolian cinder dune deposits (Holocene and Pleistocene)

Qec - Eolian cinder deposits (Holocene and Pleistocene)
Black, gray, and red, coarse-grained fragments of angular to subangular, glassy, basaltic and andesitic cinders and scoria. Material is derived from nearby pyroclastic volcanic centers; airborne ash and cinders were deposited within a few miles of local volcanic eruptions in the San Francisco Volcanic Field in south part of map area, and from eruptions south and southwest edge of map area. Pyroclastic fragments are commonly vesicular ash fall deposits that have been transported by southwesterly winds and that have accumulated against or downslope of local topographic obstructions such as basalt flows, steep-walled drainages, rock ledges, and local fault scarps, especially in Wupatki National Monument area. Form extensive cover of eolian cinder sheet deposits over all terrain in south-central part of map area; many deposits too thin to show at map scale. Cinder fragments become smaller and more subrounded farther downwind (northeast) of eruptive centers. About 1.5 to 12 m (5 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qsc - Eolian cinder sand sheet deposits (Holocene and Pleistocene)

Qec - Eolian cinder deposits (Holocene and Pleistocene)
Black, gray, and red, coarse-grained fragments of angular to subangular, glassy, basaltic and andesitic cinders and scoria. Material is derived from nearby pyroclastic volcanic centers; airborne ash and cinders were deposited within a few miles of local volcanic eruptions in the San Francisco Volcanic Field in south part of map area, and from eruptions south and southwest edge of map area. Pyroclastic fragments are commonly vesicular ash fall deposits that have been transported by southwesterly winds and that have accumulated against or downslope of local topographic obstructions such as basalt flows, steep-walled drainages, rock ledges, and local fault scarps, especially in Wupatki National Monument area. Form extensive cover of eolian cinder sheet deposits over all terrain in south-central part of map area; many deposits too thin to show at map scale. Cinder fragments become smaller and more subrounded farther downwind (northeast) of eruptive centers. About 1.5 to 12 m (5 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qltb - Basalt of Larimore Tank, basalt flows (Pleistocene)

Informally named for Larimore Tank, a stock tank on U.S. Geological Survey Hat Knoll 7.5´ quadrangle (sec. 16, T. 37 N., R. 7 W.), Uinkaret Volcanic Field, Mohave County, Arizona (Billingsley and others, 2001). Incorrectly named Cave Basalt by Billingsley (1994) and Billingsley and Workman (2000) before it was known the name Cave Basalt was already in use.

Dark-gray to black, finely crystalline, alkali-olivine basalt. Basalt has coalesced from five pyroclastic vent areas just north of map area aligned along northwest-southeast-trending fractures in underlying Permian strata. Contains abundant olivine phenocrysts 0.25 to 1 mm in diameter. Overlain by young alluvial fan (Qay) deposits. Dissolution sinkholes associated with karstification of the Harrisburg Member of the Kaibab Formation have formed under basalt flows allowing basalt to collapse as much as 18 m (60 ft). Sinkholes are partly filled with ponded alluvium. Basalt flowed into upper part of Toroweap Valley but mostly north towards Clayhole Valley north of map area (Billingsley, 1994). Thickness, 1 to 12 m (3 to 40 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Little Tanks Basalt (Pleistocene)

Formally named for a local stock tank labeled “Little Tanks reservoir” in the type area just north of map area, Mohave County, Arizona (sec. 5, T. 36 N., R. 10 W.). Basalt and associated pyroclastic deposits form Cinder Knoll (sec. 29, T. 36 N., R. 10 W.), north-central edge of map. K-Ar age, 1.0±0.4 Ma (Billingsley, 1993; Billingsley and Workman, 2000). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qlp - Little Tanks Basalt, pyroclastic deposits (Pleistocene)

Red-brown and reddish-black basaltic scoria and cinder deposits; partly consolidated. Unit forms Cinder Knoll, a 15-m-high (50-ft-high) pyroclastic cone capped by basalt flow. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qlb - Little Tanks Basalt, basalt flows (Pleistocene)

Dark-gray, finely crystalline to glassy, alkali-olivine basalt. Groundmass composed of plagioclase, olivine, and augite. Unit contains abundant olivine phenocrysts 0.25 to 1 mm in diameter. Unit unconformably overlies Harrisburg Member of the Kaibab Formation (Pk) and Timpoweap Member and lower red member of the Moenkopi Formation. Thickness, 1 to 3 m (3 to 10 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Heaton Knolls Basalt (Pleistocene)

Herein formally defined as the Heaton Knolls Basalt named for Heaton Knolls, the type area that forms a series of linear Pleistocene volcanic cinder cones on U.S. Geological Survey 7.5’ Heaton Knolls quadrangle (sec. 3, T. 36 N., R. 6 W., and sec. 34, T. 37 N., R. 6 W.), Kanab Plateau, Mohave County, Arizona (fig. 1). Heaton Knolls and associated Findlay Knolls volcanoes represent the northeastern extent of the Uinkaret Volcanic Field (Billingsley and others, 2001). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qhkp - Heaton Knolls Basalt, pyroclastic deposits (Pleistocene)

Light-red, grayish-black, and brown olivine basalt fragments of mixed cinder, scoria, volcanic bombs, and volcanic ribbons. Forms 91 m (300 ft) high Heaton Knolls and Findlay Knolls pyroclastic cones that overlies associated basalt flows (Qhkb) that are aligned in north-northwest trend for 2.5 km (1.5 mi)

reflecting the north-northwest trend of bedrock joints and fractures in southwest corner of map area. Unit also partly overlies Harrisburg Member of the Kaibab Formation on northeast flank of Heaton Knolls. About 91 m (300 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qhkb - Heaton Knolls Basalt, basalt flows (Pleistocene)

Dark-gray, finely crystalline, alkali olivine basalt. Include fine-grained groundmass of plagioclase, olivine, augite, and glass of which olivine is most common constituent. Basalt overlies strata of Harrisburg Member of the Kaibab Formation (Pkh) that straddle Toroweap Fault and is overlain by associated pyroclastic (Qhkp) deposits. Lavas flowed out in radial pattern from several eruptive centers along north-northwest fissures southeast of Toroweap Fault and part of basalt flowed northwestward over the Toroweap Fault scarp. Offset of Paleozoic strata along this segment of the Toroweap Fault before eruption of Heaton Knolls was offset about 49 m (160 ft) down-to-the-northwest and subsequent offset of the Heaton Knolls Basalt is about 12 m (40 ft) down-to-the-northwest for total offset of about 60 m (200 ft) near Heaton Knolls. About 2 to 73 m (6 to 240 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Basalt of Graham Ranch (Pleistocene)

Informally named for Graham Ranch in upper Toroweap Valley, the type area (sec. 3, T. 35 N., R. 7 W.), Uinkaret Volcanic Field, Uinkaret Plateau, Mohave County, Arizona (Billingsley and others, 2001). Incorrectly named the Sage Basalt by Billingsley and Workman (2000) and Billingsley and Hampton (2000) before it was know that the name Sage Basalt was already in use. Includes three unnamed pyroclastic cones and associated basalt flows in the upper reaches of Toroweap Valley. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qgrp - Basalt of Graham Ranch, pyroclastic deposits (Pleistocene)

Red-brown and reddish-black scoriaceous basalt fragments, ash, and cinder deposits; partly consolidated. Include three pyroclastic cones aligned along north-south, near vertical bedrock fracture system. Deposits overlie associated basalt flows. Only western part lies within map area. Toroweap Fault offsets north cone 26 m (85 ft). North cone is about 134 m (440 ft) high, central cone about 70 m (230 ft) high, and south cone about 60 m (200 ft) high. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qgrb - Basalt of Graham Ranch (Pleistocene)

Qgrb - Basalt of Graham Ranch (Pleistocene)

Informally named for Graham Ranch in upper Toroweap Valley, the type area (sec. 3, T. 35 N., R. 7 W.), Uinkaret Volcanic Field, Uinkaret Plateau, Mohave County, Arizona (Billingsley and others, 2001). Incorrectly named the Sage Basalt by Billingsley and Workman (2000) and Billingsley (2000) before it was known that the name Sage Basalt was already in use. Includes four unnamed pyroclastic cones and associated basalt flows in upper reaches of Toroweap Valley just southwest of map area. Dark-gray finely crystalline to glassy alkali olivine basalt; vuggy with calcite fillings. Includes altered olivine in glassy groundmass with abundant olivine phenocrysts 0.25 to 1 mm in diameter. K-Ar age, 0.63±0.24 Ma, obtained by Jackson (1990) from basalt of Graham Ranch about 3 km (2 mi) south of southwest corner of map area. Lavas emerged from fissures in bedrock in Harrisburg Member of the Kaibab

Formation and coalesced into radial patterns from each fissure. Much of the basalt flowed north and west into upper reaches of Toroweap Valley and into southwest corner of map area. The basalt and one associated pyroclastic cone is offset by the Toroweap Fault about 26 m (85 ft) down-to-the-west; underlying Kaibab Formation is offset about 67 m (220 ft) down-to-the-west for total offset of 93 m (305 ft) just southwest of map area (Billingsley and others, 2001; Billingsley and Wellmeyer, 2003). Basalt in southwest corner of map area is offset by Toroweap Fault about 26 m (85 ft) down-to-the-west; underlying Kaibab Formation is offset about 74 m (240 ft) down-to-the-west for a total offset of about 99 m (325 ft). About 3 to 60 m (10 to 200 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Qgrb - Basalt flows (Pleistocene)
Dark-gray, finely crystalline to glassy, alkali-olivine basalt. Groundmass contains plagioclase, olivine, and augite laths. Includes abundant olivine phenocrysts 0.25 to 5 mm in diameter composing about 30 percent of basalt in some outcrops. Overlie Harrisburg Member of the Kaibab Formation (Pk). Northern part of basalt of Graham Ranch flow and pyroclastic cone is offset about 26 m (85 ft) down-to-the-west by the Toroweap Fault; southern part is offset about 34 m (110 ft) down-to-the-west, about half of total offset of Toroweap Fault, 67 m (220 ft) in underlying Paleozoic strata. Thickness, 3 to 18 m (10 to 60 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tuckup Canyon Basalt (Pleistocene)

Informally described by Billingsley (1970). Herein formally named for Tuckup Canyon, the type area, central Grand Canyon, northern Mohave County, Arizona (sec. 11, T. 34 N., R. 6 W.). Whole rock K-Ar age is 0.76±0.08 Ma (Wenrich and others, 1995). (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qtid - Tuckup Canyon Basalt, intrusive dikes (Pleistocene)

Qti - Intrusive dikes (Pleistocene)
Dark-gray, finely crystalline alkali-olivine basalt. Contains augite and olivine phenocrysts in glassy groundmass. Occurs as two dikes in unnamed western tributary of upper Tuckup Canyon that align with trend of 10 Hancock Knolls pyroclastic cones (Qhp) on Kanab Plateau. Alignment reflects prominent northwest strike of near-vertical fractures and joints in Paleozoic strata in Tuckup Canyon area. Dikes are 1–3 ft (0.4–1 m) wide. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qtp - Tuckup Canyon Basalt, pyroclastic deposits (Pleistocene)

Red and reddish-gray cinders and scoriaceous glassy fragments of basalt; unconsolidated. Forms small cinder cone overlying associated basalt flow (Qtb) and part of Toroweap and Kaibab Formations (Pt, Pk) and Coconino Sandstone (Pc) in an unnamed western tributary of Tuckup Canyon. Also forms small isolated deposit below Qti dike at Coconino Sandstone (Pc) and Hermit Formation (Ph) contact northwest of unnamed western tributary canyon of Tuckup Canyon. Thickness about 200 ft (60 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qtb - Tuckup Canyon Basalt, basalt flow (Pleistocene)

Dark- to light-gray, finely crystalline alkali-olivine basalt. Most of the basalt came from a fissure-like dike (Qti) and pyroclastic cone (Qtp) vent area in unnamed western tributary of upper Tuckup Canyon (Billingsley, 1970). Basalt flowed into Tuckup Canyon over outcrops of Toroweap and Kaibab Formations,

Coconino Sandstone, Hermit Formation, and Esplanade Sandstone (Pe). The basalt flow merged or coalesced with a basalt flow (Qhb) from the Hancock Knolls area and spread out into upper Tuckup Canyon onto alluvium and Esplanade Sandstone. Tuckup Canyon drainage has been diverted around east side of basalt flow in upper Tuckup Canyon. Remnants of basalt flow cascaded over and cling to steep canyon walls of Esplanade Sandstone and Wescogame Formation, undivided (M_u), indicating that Tuckup Canyon had eroded at least as deep as Manakacha Formation, undivided, prior to the flow about 760,000 years ago. Thickness ranges from 3–25 ft (1–7.5 m). (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Basalt of Hancock Knolls (Pleistocene)

Informally named for Hancock Knolls, the type area, Kanab Plateau, northern Mohave County, Arizona (sec. 20, T. 35 N., R. 6 W.). May be same eruptive phase as Tuckup Canyon Basalt (0.76±0.08 Ma) based on alignment of Hancock Knolls pyroclastic cones (Qhp) to dikes (Qti) and pyroclastic cone (Qtp) in upper Tuckup Canyon, and the coalescing of basalt flows (Qhb, Qtb) from both areas in upper Tuckup Canyon. Divided into units Qhp and Qhb. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qhp - Basalt of Hancock Knolls, pyroclastic deposits (Pleistocene)

Red to reddish-black cinder and scoriaceous basaltic fragments, and black cinders; unconsolidated. Forms 10 pyroclastic cones on the Kanab Plateau that align along a strike of N. 30° W. for about 5 mi (8 km) northwest of Tuckup Canyon. Unit overlies associated basalt flows (Qhb) and Harrisburg Member of Kaibab Formation (Pk). Variable thickness 40–350 ft (12–107 m). (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qhb - Basalt of Hancock Knolls, basalt flows (Pleistocene)

Dark- to light-gray, finely crystalline alkali-olivine basalt. Contains augite and olivine phenocrysts less than 1 mm in diameter in glassy groundmass. Unit overlies Harrisburg Member of Kaibab Formation (Pk). The southernmost basalt flowed about 1 mi (1.5 km) and cascaded down an unnamed western tributary of upper Tuckup Canyon to coalesce with Tuckup Canyon Basalt (Qtb; Billingsley, 1970). Tributary drainage has eroded through this basalt flow. Variable thickness 3–90 ft (1–27 m). (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Sage Basalt (Pleistocene)

Formally named for an unnamed cinder cone with a triangulation survey station on top called “Sage” in upper reaches of Toroweap Valley (sec. 26, T. 36 N., R. 7 W.), the type area, Uinkaret volcanic field, Kanab Plateau, northern Mohave County, Arizona (Billingsley and Workman, 2000). Divided into units Pyroclastic deposits (Qsp) and Basalt flows (Qsb). (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qspd - Sage Basalt, pyroclastic deposits (Pleistocene)

Qsp - Pyroclastic deposits (Pleistocene)

Red-brown and reddish-black scoriaceous basalt fragments, ash, and cinder deposits; partly consolidated. Including deposits outside of map area, forms three pyroclastic cones that align along a

north-south, near vertical bedrock fracture or joint system (Billingsley and Workman, 2000). Deposits overlie associated basalt flows (Qsb). Only eastern part of southernmost pyroclastic cone lies within map area. About 200 ft (60 m) thick. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qsb - Sage Basalt, basalt flows (Pleistocene)

Dark-gray, finely crystalline to glassy alkali-olivine basalt. Groundmass contains plagioclase, olivine, and augite laths. Includes abundant olivine phenocrysts 0.25–5 mm in diameter consisting of about 30 percent basalt in some outcrops. Overlies Harrisburg Member of Kaibab Formation (Pk). Basalt is offset about 110 ft (34 m) by the Toroweap Fault about 2 mi (3 km) west of northwestern corner of map area (Billingsley and Workman, 2000). Thickness ranges from 10 to 60 ft (3 to 18 m). (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qidn - Basalt dikes and necks (Pleistocene)

Qi - Basalt dikes and necks (Pleistocene)

Dark-gray, finely crystalline alkali-olivine basalt with plagioclase laths in glassy groundmass. Intrudes through lower part of Hermit Formation (Ph). Forms small dike in an eastern tributary of Tuckup Canyon, two dikes and a neck just downstream of Havasu Canyon (159-Mile dikes, Wenrick and others, 1995), a dike or neck called “The Cork” on the Esplanade Sandstone just north of the159-Mile dikes, and a neck/ dike combination on the Esplanade Sandstone called “Yumtheska Vent West” and “Yumtheska Vent East” below Yumtheska Point (Wenrich and others, 1995), northwestern part of map area. Whole-rock K-Ar age obtained for The Cork is 0.407±0.07 Ma, and for Yumtheska Vent West 0.78±0.15 Ma. The Cork, the 159-Mile dikes, the Yumtheska Vents East and West , and the small dike in unnamed eastern tributary of Tuckup Canyon are aligned along a northwest-trending (N. 45° W.) near vertical joint and fracture system, suggesting a similar eruptive event between 405,000 and 780,000 years ago. The Cork and the Yumtheska Vents East and West include red pyroclastic deposits and local minor basalt that flowed onto the Esplanade Sandstone surface. The neck associated with the 159-Mile dikes is exposed in upper part of Watahomigi-Manakacha Formations, undivided (M_u), as a neck of welded pyroclastic tuff. All volcanic rocks in this part of map area suggest that the Colorado River had eroded the Grand Canyon almost down to, but not below, Redwall Limestone (Mr) about 405,000–780,000 years ago. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Qpyr - Pyroclastic deposits (Pleistocene)

Qp - Pyroclastic deposits (Pleistocene)

Red and reddish-black, scoriaceous alkali-olivine basalt fragments, cinders, ribbons, and bombs. Thickness about 30 ft (10 m) or more at Yumtheska Vent West; minor accumulations at “The Cork” and Yumtheska Vent West too thin to show at map scale. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Shadow Mountain Basalt

Shadow Mountain is an isolated pyroclastic cone with associated basalt flows and dikes at the south-central edge of the map area. These volcanic rocks are chemically and petrologically similar to rocks of the San Francisco volcanic field, representing the northernmost volcanic rocks of that field, and have a K-Ar age of 0.649±0.23 Ma (Damon and others, 1974; Condit, 1974). Miocene dikes are exposed in

Moenkopi Wash, in Hamblin Wash, at Tuba Butte, and at Wildcat Peak. A recent 40Ar/39Ar age from a dike at Wildcat Peak is 19.05±0.10 Ma (Peters, 2011). (*GRI Source Map ID 75648)* (Tuba City 30 x 60)

Shadow Mountain is an isolated pyroclastic cone with associated basalt flows about 19 km (12 mi) northwest of Cameron, Arizona (fig. 1). These volcanic rocks are chemically and petrographically similar to rocks of the San Francisco Volcanic Field and represent the northern-most volcano of the field. The polarity of these rocks has not been determined. K-Ar age, 0.649±0.23 Ma (Damon and others, 1974; Condit, 1974). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qism - Intrusive dikes of Shadow Mountain (Pleistocene)

Qi - Intrusive dikes of Shadow Mountain (Pleistocene)

Black olivine-labradorite basalt dikes, 1 to 3 ft (0.5 to 1 m) wide. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qsp - Pyroclastic deposits of Shadow Mountain (Pleistocene)

Qsp - Pyroclastic deposits of Shadow Mountain (Pleistocene)

Black and red scoria, cinder, and ash of olivine-labradorite basaltic composition. Overlie associated basalt flows (Qsb) and the Petrified Forest and Shinarump Members of the Chinle Formation. Thickness, 3 to 135 ft (1 to 40 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qsp - Pyroclastic deposits of Shadow Mountain (Pleistocene (Brunhes age))

Black and red scoria, cinder, and ash deposits of olivine-labradorite basaltic composition. Deposits overlie associated basalt flows and strata of Petrified Forest and Shinarump Members of the Chinle Formation. About 183 m (600 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qsbf - Basalt flows of Shadow Mountain (Pleistocene)

Qsb - Basalt flows of Shadow Mountain (Pleistocene)

Black olivine-labradorite basalt largely covered by associated pyroclastic (Qsp) deposits. Basalts flowed into small graben north of main cone, providing evidence that the graben is older than the flow. Flow is offset by a fault suggesting that faulting has occurred within the last 65 k.y. Thickness, 40 ft (12 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Qsb - Basalt flows of Shadow Mountain (Pleistocene (Brunhes age))

Black olivine-labradorite basalt flows that are largely covered by associated pyroclastic (Qsp) deposits. Basalts flowed into one small graben north of main cone making that graben older than the basalt flow. The basalt was down-faulted into another graben 0.8 km (½ mi) east of the main cone suggesting this graben developed after the eruption (within the last half million years). This graben is aligned with the southwest-northeast strike of Mesa Butte Fault southwest of Shadow Mountain and is likely a northern extension of that structural trend. About 3 to 14 m (10 to 45 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qpyd - Pyroclastic deposits (Pleistocene)

Qp - Pyroclastic deposits (Pleistocene (Brunhes age))
Dark-gray, black, and reddish-brown indurated and oxidized pyroclastic deposits. Include ribbon and tear-shaped volcanic bombs in welded tuffaceous scoria and cinder deposits. Contains microscopic crystals of clinopyroxene, olivine, plagioclase, abundant clasts of vesicular basalt with dark-gray or reddish-brown glassy matrix, and occasional sedimentary xenoliths. Includes several eruptive vents that built pyroclastic or splatter cones on associated basalt flows. About 5 to 260 m (15 to 850 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qbf - Basalt flows (Pleistocene)

Qb - Basalt flows (Pleistocene (Brunhes age))
Dark-gray and black porphyritic and aphyric, clinopyroxene-olivine and alkali-olivine basalt. Flows occur locally within present stream drainages, are moderately young in appearance, are locally covered by thin alluvium, eolian sand, or air-borne cinder deposits and have been little dissected. K-Ar age of various flows are 0.22±0.05 Ma, 0.46±0.05 Ma, 0.66±0.11 Ma, 0.74±0.08 Ma, and 0.77±0.04 Ma (Ulrich and Bailey, 1987). About 1 to 20 m (3 to 65 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qbt - Basalt flow of Tappan Wash (Pleistocene)

Dark-gray and black, dense, aphyric, clinopyroxene-olivine and alkali-olivine basalt. Conspicuously rich in black glassy plagioclase groundmass. Flow originated from Crater Lake volcano (N4536 of Wolfe and others, 1987); a vent 9.5 km (6 mi) south of the map area on the east side of Kendrick Mountain and flowed down various tributary drainages to Tappan Wash, then down Tappan Wash to the Little Colorado River, a distance of 88 km (55 mi); then down Little Colorado River another 11 km (7 mi) to the beginning of the Little Colorado River Gorge (see fig. 2 on map). Geomorphology of basalt flow of Tappan Wash is described by Rice (1977) as the Tappan Lava Flow and mapped by Ulrich and Bailey, (1987). K-Ar age, 0.53±0.19 Ma (Damon and others, 1974). The flow averages about 2 m (6 ft) thick for much of its length and accumulated to as much as 40 m (130 ft) in the Little Colorado River where it forms an inverted valley within Little Colorado drainage (fig. 2 on map). Basalt flow is cut by several faults that form grabens north of S P Mountain and at Little Colorado River; fault offset generally less than about 1.5 m (5 ft). About 1 to 40 m (3 to 130 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qbfl - Fissure deposits of Lockett Tank (Pleistocene)

Qbf - Fissure deposits of Lockett Tank (Pleistocene (Brunhes age))
Dark-gray to black linear extrusion of aphyric basalt along fault at Lockett Tank about 14 km (9 mi) north of S P Mountain. About 3 to 6 m (10 to 20 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qbmp - Pyroclastic deposits (Pleistocene)

Dark-gray to red pyroclastic cones and small rounded spatter cones on basalt flows (Qbmb). Weathers yellowish brown and reddish brown. Largest deposit forms Red Mountain (fig. 1). Unit is superficially gullied; consists of bedded cinders, agglutinated spatter with volcanic ribbon and tear-shaped bombs. About 60 to 292 m (200 to 960 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qbmb - Basalt flows (Pleistocene)

Dark-gray to black aphyric alkali basalt composed of plagioclase, clinopyroxene, olivine, and magnetite. Weathers yellowish brown to reddish brown. Surface of flows are relatively smooth, flat and undissected. About 10 to 60 m (30 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qsfp - Pumice of San Francisco Mountain (Pleistocene)

White to light-gray, poorly sorted, mantle bedding of rhyolite pumice fall. Unit is matrix free except for locally reworked zone in upper 1 m (3 ft). Lapilli range from several millimeters to several centimeters in size, are colorless vesicular glass, and lack visible crystals. Contains xenoliths of greenschist and blueish-gray dense rhyolite with feldspar and quartz phenocrysts. Unit overlies older basalt flows (Qmb) near US Highway 89 at south-central edge of map along Deadman Wash and is correlated with lower aphyric pumice deposits on San Francisco Mountain (Dennis, 1981) south of map area because of similarities in petrography, composition, and xenoliths. Fission-track age on zircons is 0.80±0.11 Ma (C. W. Naeser and G.A. Izett, in Ulrich and Bailey, 1987). About 3 to 5 m (10 to 15 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qmbi - Basalt dike (Pleistocene)

Dark-gray to black plagioclase-aphyric basalt with abundant 1- to 3-cm plagioclase laths in groundmass of olivine, clinopyroxene, plagioclase, and magnetite. Contains baked xenoliths of sandstone of the Moenkopi Formation (Ulrich and Bailey, 1987). Includes three dikes just east of US Highway 89 about 16 km (10 mi) north of south-central edge of map area. Dike widths, 0.3 to 0.5 m (1 to 1.5 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qmp - Pyroclastic deposits (Pleistocene)

Dark-gray to reddish-brown plagioclase-aphyric and porphyritic basalt. Consist of intergranular groundmass of plagioclase, clinopyroxene, olivine, and magnetite. Contain scattered olivine and clinopyroxene phenocrysts. Include several cones of Mesa Butte volcano that are aligned with and overlie Mesa Butte Fault (fig. 1). Cones are in early stage of erosion, slightly eroded and gullied. About 25 to 230 m (80 to 750 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qmb - Basalt flows (Pleistocene)

Dark-gray plagioclase-aphyric and porphyritic basalt of similar composition to pyroclastic (Qmp) deposits. Weather yellow or brown. Surfaces are weathered and slightly eroded and gullied. K-Ar age of various flows, 0.83±0.04 Ma, 1.04±0.04 Ma, 1.09±0.03 Ma, 1.20±0.05 Ma, and 1.38±1.01 Ma (Ulrich and Bailey, 1987; Wolfe and others, 1987). Flows generally follow older drainage areas that are above present drainages. About 5 to 45 m (15 to 159 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qmlp - Basalt flow of Lava Point (Pleistocene)

Dark-gray to black plagioclase-aphyric basalt. Similar composition to (Qmb) basalt flows. Mapped as Lava Point flow (Qmb) by Ulrich and Bailey (1987) east of U.S Highway 89 but not mapped separately from other basalt flows of similar composition and age. Mapped herein as separate unit because unit forms an inverted valley for several kilometers north of an unknown source in south part of map area that is similar to an inverted valley formed by adjacent Black Point Basalt flow (Tbpb). K-Ar age, 1.01±0.13 Ma (Ulrich and Bailey, 1987). About 6 to 15 m (20 to 50 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qslr - Rhyolite dome complex of Slate Mountain (Pleistocene)

Light-gray aphanitic rhyolite. Rare microphenocrysts of pale-brown amphibole, biotite, and altered fayalite(?) occur in a felsic cryptocrystalline groundmass (Wolfe and others, 1987). Unit forms the north flank of a 1.5 km (1 mi) diameter cluster of domes that form Slate Mountain; summit of Slate Mountain is south of map area. Uplifted sedimentary rocks of Lower Permian age are exposed adjacent to east and south edge of rhyolite just south of map boundary. K-Ar age, 1.54±0.02 Ma (Wolfe and others, 1987). About 92 m (300 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qbcr - Basalt flows along the Colorado River (Pleistocene)

Qb - Basalt flows along the Colorado River (Pleistocene)
Dark-gray alkali-olivine basalt. Consist of at least one flow known as the Black Ledge flow (Hamblin, 1994). Thickness, 3 to 9 m (10 to 30 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Basalt of the Uinkaret Plateau (Pleistocene)

Informally named and include several pyroclastic cones and associated basalt flows of similar age north and south of Mount Trumbull. Basalts are assumed to have erupted during a similar eruptive phase throughout the map area north and south of Mount Trumbull. Several flows have coalesced from numerous vent areas to form a single massive basalt flow that cascaded into Toroweap Valley and Whitmore Canyon. Basaltic units north of Mount Trumbull are designated with a number (Qi1, Qb1, Qp1) because stratigraphic relations in upper Toroweap Valley suggest that these basalt flows may be slightly older than basalt deposits (Qi, Qp, and Qb) south of Mount Trumbull. Other Quaternary basalt flows and associated pyroclastic deposits that have mappable boundaries are informally designated on the map with an elevation number (Qp6375) representing the highest associated pyroclastic cone or informally named for a nearby ranch shown on U.S. Geological Survey 7.5´ quadrangles. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qi - Basalt of the Uinkaret Plateau, intrusive rocks, south of Mount Trumbull (Pleistocene)

Dark-gray to black alkali-olivine basalt dikes and necks. Form nearly vertical dikes or necks that commonly protrude above surrounding volcanic or bedrock deposits. Variable widths range from 0.5 to 6 m (1 to 18 ft). Neck or plug in Kaibab Formation southeast of Mount Trumbull is partly covered. Best examples are near Paws Pocket, east side of Whitmore Canyon, east-central part of map. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qi1 - Basalt of the Uinkaret Plateau, intrusive rocks, north of Mount Trumbull (Pleistocene)

Dark-gray to black alkali-olivine basalt dikes and necks. Form nearly vertical dikes or necks that commonly protrude above surrounding volcanic or bedrock deposits. Variable widths range from 0.5 to 6 m (1 to 18 ft). Neck or plug in Kaibab Formation southeast of Mount Trumbull is partly covered. Best examples are near Paws Pocket, east side of Whitmore Canyon, east-central part of map. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qp - Basalt of the Uinkaret Plateau, pyroclastic deposits, south of Mount Trumbull (Pleistocene)

Reddish-gray, black, and red to gray tuff, ash, scoriaceous ejecta, bombs, and cinder deposits; partly consolidated. Include about 17 pyroclastic deposits north of Mount Trumbull (Qp1) such as Craigs Knoll and about 36 pyroclastic vents south of Mount Trumbull (Qp) such as Mount Emma, Slide Mountain, and Petty Knoll in the Uinkaret Mountains between Whitmore Canyon and Toroweap Valley. Deposits are associated with coalescing basalt flows that issued from several vents. Locally form fine- to coarse-grained cinder sheet deposits on basalt flows near cones. Map contacts are approximate and show only the thickest deposits, not entire pyroclastic blanket deposit. No K-Ar ages are available, but cosmogenic 3He ages at scattered locations indicate an age of 0.100 to 0.200 Ma (Fenton, 1998). Thickness, 6 to 180 m (18 to 600 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qp1 - Basalt of the Uinkaret Plateau, pyroclastic deposits, north of Mount Trumbull (Pleistocene)

Reddish-gray, black, and red to gray tuff, ash, scoriaceous ejecta, bombs, and cinder deposits; partly consolidated. Include about 17 pyroclastic deposits north of Mount Trumbull (Qp1) such as Craigs Knoll and about 36 pyroclastic vents south of Mount Trumbull (Qp) such as Mount Emma, Slide Mountain, and Petty Knoll in the Uinkaret Mountains between Whitmore Canyon and Toroweap Valley. Deposits are associated with coalescing basalt flows that issued from several vents. Locally form fine- to coarse-grained cinder sheet deposits on basalt flows near cones. Map contacts are approximate and show only the thickest deposits, not entire pyroclastic blanket deposit. No K-Ar ages are available, but cosmogenic 3He ages at scattered locations indicate an age of 0.100 to 0.200 Ma (Fenton, 1998). Thickness, 6 to 180 m (18 to 600 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qb - Basalt of the Uinkaret Plateau, basalt flows, south of Mount Trumbull (Pleistocene)

Qb - Basalt flows (Pleistocene)

Dark-gray to black, finely crystalline, alkali-olivine basalt. Olivine and plagioclase phenocrysts common. Include scoriaceous material from pyroclastic deposits. Basalt flows north of Mount Trumbull originated from several pyroclastic vents and generally flowed east into upper Toroweap Valley. Basalt flows overlie the Moenkopi Formation near pyroclastic cones and the Kaibab Formation farther away from the cones. Flows went down alluviated valleys before reaching Toroweap Valley. Basalt flows in upper Toroweap Valley (Qb1) are mostly covered with young alluvial fan (Qay) deposits and basalt flows (Qb) that originated south of Mount Trumbull. South of Mount Trumbull, basalt cascaded into Whitmore Canyon

and Toroweap Valley from higher terrain of the Uinkaret Mountains. Basalt cascades are steep where they flowed over the Hurricane Fault scarp at Hells Hollow drainage in upper Whitmore Canyon and over cliffs of the Kaibab and Toroweap Formations in Whitmore Canyon and Toroweap Valley. Basalt flowed over the Moenkopi, Kaibab, and Toroweap Formations south of Mount Trumbull. Cosmogenic 3He dating of basalt surfaces in upper Whitmore Canyon indicate an average age of about 0.100 Ma, and flow surfaces in lower Whitmore Canyon and Toroweap Valley have an average age of about 0.150 to 0.200 Ma (Fenton, 1998). Thickness, 6 to 91 m (18 to 300 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qb - Basalt flows along the Colorado River (Pleistocene)
Dark-gray alkali-olivine basalt. Consist of at least one flow known as the Black Ledge flow (Hamblin, 1994). Thickness, 3 to 9 m (10 to 30 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Qb1 - Basalt of the Uinkaret Plateau, basalt flows, north of Mount Trumbull (Pleistocene)

Toroweap Valley from higher terrain of the Uinkaret Mountains. Basalt cascades are steep where they flowed over the Hurricane Fault scarp at Hells Hollow drainage in upper Whitmore Canyon and over cliffs of the Kaibab and Toroweap Formations in Whitmore Canyon and Toroweap Valley. Basalt flowed over the Moenkopi, Kaibab, and Toroweap Formations south of Mount Trumbull. Cosmogenic 3He dating of basalt surfaces in upper Whitmore Canyon indicate an average age of about 0.100 Ma, and flow surfaces in lower Whitmore Canyon and Toroweap Valley have an average age of about 0.150 to 0.200 Ma (Fenton, 1998). Thickness, 6 to 91 m (18 to 300 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of Kenworthy Ranch (Pleistocene)

Informally named for the Kenworthy Ranch in Sink Valley, Uinkaret Plateau, Mohave County, Arizona (sec. 1, T. 35 N., R. 9 W.; Billingsley, 1997b; Billingsley and others, 2001). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qkrp - Basalt of Kenworthy Ranch, pyroclastic deposits (Pleistocene)

Reddish-black and red tuff, ash, scoriaceous ejecta, and cinders overlie associated basalt flows. Map contact is approximate. Include three unnamed cinder cones that align north-south. North pyroclastic cone just west of Kenworthy Ranch is about 49 m (160 ft) high, middle cone is about 24 m (80 ft) high, and south cone about 24 m (80 ft) high. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qkrb - Basalt of Kenworthy Ranch, basalt flows (Pleistocene)

Light- to dark-gray, finely crystalline, alkali-olivine basalt. Include small phenocrysts of augite and olivine in glassy groundmass. Flows radiate from all three pyroclastic cones coalescing to form large elongated north-south oval flow mass. Overlie Harrisburg Member of the Kaibab Formation (Pk). Thickness, 15 m (50 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of Marshall Ranch (Pleistocene)

Informally named for Marshall Ranch about 2.5 km south of Kenworthy Ranch, Uinkaret Plateau, Mohave County, Arizona (sec. 13, T. 35 N., R. 9 W.; Billingsley, 1997b; Billingsley and others, 2001). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qmrp - Basalt of Marshall Ranch, pyroclastic deposits (Pleistocene)

Reddish-black and red tuff, ash, scoriaceous ejecta, and cinders overlie associated basalt flows. Include two unnamed pyroclastic cones and three smaller secondary spatter cones. Secondary cones appear to have erupted from basalt flows that came from south pyroclastic cone. North pyroclastic cone is about 73 m (240 ft) high and south cone is about 85 m (280 ft) high. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qmrb - Basalt of Marshall Ranch, basalt flows (Pleistocene)

Gray-black, finely crystalline, alkali-olivine basalt. Majority of basalt flowed in radial pattern from south pyroclastic cone. Basalt also flowed west about 3 km (2 mi). Partly overlie the basalt of Potato Valley (Qpvb) at south margin and overlie Harrisburg Member of the Kaibab Formation elsewhere. Thickness, 12 to 36 m (40 to 120 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of hill 6375 (Pleistocene)

Informally named for unnamed pyroclastic cone (hill 6375) at the north end of Sink Valley, Uinkaret Plateau, Mohave County, Arizona (sec. 31, T. 35 N., R. 8 W.; Billingsley, 1997b; Billingsley and others, 2001). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qp6375 - Basalt of hill 6375, pyroclastic deposits (Pleistocene)

Reddish-black cinder and scoriaceous ejecta overlie associated basalt flow. Include small cone at the north end of associated basalt flow that may be local splatter cone deposit derived from basalt flow. Main cone deposit, hill 6375, is about 64 m (290 ft) thick. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qb6375 - Basalt of hill 6375, basalt flows (Pleistocene)

Dark-gray alkali-olivine basalt. Basalt flowed west 0.8 km (0.5 mi) and north about 1.5 km (1 mi). Overlies Harrisburg Member of the Kaibab Formation (Pk). Thickness, 1 to 12 m (3 to 40 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of hill 6646 (Pleistocene)

Informally named for unnamed pyroclastic cone (hill 6646) at northwest end of Sink Valley, Uinkaret Plateau, Mohave County, Arizona (sec. 35, T. 36 N., R. 9 W.; Billingsley, 1997b; Billingsley and others, 2001). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qp6646 - Basalt of hill 6646, pyroclastic deposits (Pleistocene)

Red and black cinder and scoriaceous deposits overlie associated basalt flow. Include one large pyroclastic cone and two adjacent small cones. There are three eruptive vent areas that formed the main cone aligned along a north-south strike, similar to north-south strike of basaltic cones in Kenworthy Ranch area. Main pyroclastic cone is about 76 m (250 ft) thick. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qb6646 - Basalt of hill 6646, basalt flows (Pleistocene)

Dark-gray alkali-olivine basalt. Basalt flowed north about 3 km (2 mi). Overlies Harrisburg Member of the Kaibab Formation (Pk). Thickness, 10 to 30 m (30 to 100 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of hill 6457 (Pleistocene)

Informally named for unnamed cinder cone (hill 6457) north of and below Mount Trumbull, Uinkaret Plateau, Mohave County, Arizona (sec. 16, T. 35 N., R. 8 W.; Billingsley and others, 2001). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qp6457 - Basalt of hill 6457, pyroclastic deposits (Pleistocene)

Reddish-black cinder and scoriaceous deposits. Include two smaller cones that partly overlie associated basalt flow from cone 6457. North cone may have erupted from the basalt flow. Pyroclastic cone (hill 6457) is 36 m (120 ft) thick, and north cone about 24 m (80 ft) thick. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qb6457 - Basalt of hill 6457, basalt flows (Pleistocene)

Dark-gray alkali-olivine basalt. Basalt flowed north from hill 6457 about 0.8 km (0.5 mi) onto young alluvial fan (Qay) and floodplain (Qf) deposits. Thickness, 36 m (120 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of Potato Valley (Pleistocene)

Informally named from Potato Valley, Uinkaret Plateau, Mohave County, Arizona (sec. 25, T. 35 N., R. 9 W.; Billingsley, 1997b; Billingsley and others, 2001). Includes several pyroclastic cones and associated basalt flows along north and west edge of Potato Valley. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qpvp - Basalt of Potato Valley, pyroclastic deposits (Pleistocene)

Red and black cinder, tuff, ash, and scoriaceous ejecta. Include two main pyroclastic cones on north and west sides of Potato Valley and five small pyroclastic vents. The two main cones appear to be the main sources for associated basalt flows that ring the north and west side of Potato Valley. Several small cones on basalt flows appear to have erupted from the flow as secondary eruptions. Dikes in Hells Hole (Qti) south of Potato Valley may be associated with Potato Valley cones. Thickness, 106 m (350 ft) on west side of Potato Valley and 85 m (280 ft) on north side. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qpvb - Basalt of Potato Valley, basalt flows (Pleistocene)

Dark-gray alkali-olivine basalt. Flows on north side of Potato Valley erupted from unnamed cinder cone and flowed northwest about 3 km. Flow appears to have merged or coalesced with flows from two cones on west side of Potato Valley forming a basalt dam responsible for the accumulation of alluvial sediments in Potato Valley. Basalt flows on west side of Potato Valley flowed mostly north about 5 km (3 mi). Thickness, 2 to 25 m (6 to 85 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of hill 6588

Informally named for highest of four pyroclastic cones on east flank of Mount Trumbull, the type area, Uinkaret Volcanic Field, Mohave County, Arizona (sec. 36, T. 35 N., R. 8 W.; Billingsley and others, 2001). Includes pyroclastic deposits and associated basalt flows. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qp6588 - Basalt of hill 6588, pyroclastic deposits (Pleistocene)

Reddish-black to mostly black and gray ash, cinder, scoriaceous fragments, and basaltic boulders; partly consolidated. Include four pyroclastic cones aligned in 2-km-long (1-mi-long) northwest-southeast trend. Deposits mostly overlie associated basalt flows and landslide deposits (Ql); often incorporated into basalt flows on steep east slopes of hill 6588. Variable thickness because of steep terrain, 2 to 55 m (6 to 180 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qb6588 - Basalt of hill 6588, basalt flows (Pleistocene)

Dark-gray and light-gray, finely crystalline, alkali-olivine basalt. Include interbedded scoriaceous pyroclastic deposits. Basalt cascaded down steep slope into Toroweap Valley over landslide deposits (Ql) and lower strata of the Moenkopi Formation and Harrisburg Member of the Kaibab Formation (Pk). Flows partly buried by undivided basalt flows (Qb) and young alluvial fan (Qay) deposits in Toroweap Valley. Thickness, 2 to 10 m (6 to 30 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of Craigs Knoll and Berry Knoll (Pleistocene)

Informally named for Craigs Knoll (sec. 4, T. 35 N., R. 8 W.), and Berry Knoll (sec. 24, T. 36 N., R. 9 W.), Uinkaret Plateau, Mohave County, Arizona (Billingsley, 1997b; Billingsley and others, 2001; Billingsley and Workman, 2000). Includes dikes, pyroclastic deposits, and basalt flows that appear to

have erupted simultaneously at Craigs Knoll and Berry Knoll and at unnamed pyroclastic cone between Craigs Knoll and Berry Knoll. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qcbi - Basalt of Craigs Knoll and Berry Knoll, intrusive dikes or necks (Pleistocene)

Greenish-black olivine basalt. Widths of dikes shown on map are approximate. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qcbp - Basalt of Craigs Knoll and Berry Knoll, pyroclastic deposits (Pleistocene)

Gray and reddish-gray to black cinder, tuff, ash, and scoriaceous ejecta; mostly consolidated into welded tuff. Form cliff on east side of Craigs Knoll and steep slope on south and west side. Deposits mostly covered by dark-gray basalt on north flank of Craigs Knoll. Include small secondary pyroclastic deposit on south flank of Craigs Knoll. Deposits overlie associated basal basalt flow exposed on south flank of Craigs Knoll, and an upper associated basalt flow overlies pyroclastic deposits, mostly on north and west flanks of Craigs Knoll. Thickness, 183 m (600 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qcbb - Basalt of Craigs Knoll and Berry Knoll, basalt flows (Pleistocene)

Light-gray and dark-gray alkali-olivine basalt. Include lower and upper basalt flows separated by pyroclastic deposits (Qcbp). No K-Ar age available. Lower basalt accumulated on Harrisburg Member of the Kaibab Formation (Pk) and lower strata of the Moenkopi Formation (TRm). Estimated thickness of lower flow, about 40 m (130 ft). Upper basalt erupted near top of Craigs Knoll and flowed west, north, and east about 8 km (5 mi). Estimated thickness of upper flow, 3 to 20 m (10 to 65 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Qg4 - Older terrace-gravel deposits (Pleistocene)

Gray and light-brown silt, sand, gravel, and well-rounded flat pebbles and cobbles; poorly sorted and partly consolidated by calcrete in top 3 ft (1 m) along Colorado and Paria Rivers. Similar to young, intermediate, and old terrace-gravel deposits. Form isolated deposits 110 to 130 ft (34 to 39 m) above Colorado and Paria Rivers. Support minor growths of grass and low desert shrubs. Thickness, 2 to 15 ft (1 to 4.5 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

QTwb - Basalt flows of Woodhouse Mesa (Pleistocene or Pliocene)

Qwb - Basalt flows of Woodhouse Mesa (Pleistocene or Pliocene (Matuyama age))

Dark-gray alkali olivine basalt and minor alkali-rich-alumina basalt. Contain phenocrysts of olivine, clinopyroxene, and plagioclase in fine- to medium-grained matrix of same minerals. Contain minor gabbro xenoliths. K-Ar age, 0.786±0.14 Ma (Ulrich and Bailey, 1987), and south of map area 0.874±0.13 Ma; 0.897±0.14 Ma; 0.812±0.059 Ma (Reynolds and others, 1986; Damon and others, 1974). About 2 to 15 m (6 to 50 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTi - Hells Hole dikes (Pleistocene or Pliocene(?))

Dark-gray alkali-olivine basalt. Include three dikes in the Kaibab and Moenkopi Formations in Hells Hole. Form nearly vertical walls that stand out in relief in some places as much as 3 to 4 m (10 to 12 ft) high and about 0.5 to 2 m (2 to 6 ft) wide. Dikes are aligned in general north-south trend and appear to connect to pyroclastic vents on west side of Potato Valley (Qpvp); also may be source for basalt of Mount Logan (Tmlb) due to close proximity to Mount Logan. Vertical exposure is nearly 610 m (2,000 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

QTd - Old dune deposits, undivided (Pleistocene and Pliocene(?))

White, light-red to light-brown, coarse- to very fine-grained sand and silt; partly consolidated beneath veneer of active, reworked sand cover. Form base or internal cores of younger, reactivated linear dunes immediately downwind (northeast) of Adeii Eechii Cliffs (shown as active linear dunes by Billingsley, 1987a), on Moenkopi Plateau, Appaloosa Ridge, and Coal Mine Mesa. Contain at least 25% to 35% gray, fine-grained silt and clay content on Coal Mine Mesa from erosion of underlying Dakota Sandstone (Kd) and Mancos Shale (Km). Unit often forms complex linking sets of parabolic dunes along edge of Adeii Eechii Cliffs and Appaloosa Ridge of Moenkopi Plateau. Several individual dunes on Moenkopi Plateau have developed downwind of ponded sediments and are younger than adjacent old eolian sand sheet and dune (QTes) deposits. Bedrock or ponded sediments (Qps) are often exposed within interior of parabolic dunes. Include combinations of parabolic, barchan, dome, and dune-like thick sand sheet deposits that frequently coalesce downwind (northeast) to form old linear dunes (old dune deposits, undivided [QTd]) or old eolian sand sheet and dune (QTes) deposits northeast of Adeii Eechii Cliffs on Moenkopi Plateau. Linear dune traces are often longer than 3 km (2 mi) and as long as 10 km (6 mi). Some linear dunes merge with other linear dunes and form a linear complex of parabolic or barchanoid dune trains within a short length of linear dune (not shown). Include topographically controlled climbing or falling dunes and short linear dunes below Appaloosa Ridge. Unit commonly stabilized by moderate growth of grass and mormon tea bush. Gradational and approximate contact with adjacent surficial deposits. About 2 to 12 m (6 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTdl - Old linear dune deposits (Pleistocene and Pliocene(?))

White, light-red to light-brown, coarse- to very fine-grained sand and silt; partly consolidated beneath veneer of active, reworked sand cover. Form base or internal cores of younger, reactivated linear dunes immediately downwind (northeast) of Adeii Eechii Cliffs (shown as active linear dunes by Billingsley, 1987a), on Moenkopi Plateau, Appaloosa Ridge, and Coal Mine Mesa. Contain at least 25% to 35% gray, fine-grained silt and clay content on Coal Mine Mesa from erosion of underlying Dakota Sandstone (Kd) and Mancos Shale (Km). Unit often forms complex linking sets of parabolic dunes along edge of Adeii Eechii Cliffs and Appaloosa Ridge of Moenkopi Plateau. Several individual dunes on Moenkopi Plateau have developed downwind of ponded sediments and are younger than adjacent old eolian sand sheet and dune (QTes) deposits. Bedrock or ponded sediments (Qps) are often exposed within interior of parabolic dunes. Include combinations of parabolic, barchan, dome, and dune-like thick sand sheet deposits that frequently coalesce downwind (northeast) to form old linear dunes (old dune deposits, undivided [QTd]) or old eolian sand sheet and dune (QTes) deposits northeast of Adeii Eechii Cliffs on Moenkopi Plateau. Linear dune traces are often longer than 3 km (2 mi) and as long as 10 km (6 mi). Some linear dunes merge with other linear dunes and form a linear complex of parabolic or barchanoid dune trains within a short length of linear dune (not shown). Include topographically controlled climbing or falling dunes and short linear dunes below Appaloosa Ridge. Unit commonly stabilized by moderate

growth of grass and mormon tea bush. Gradational and approximate contact with adjacent surficial deposits. About 2 to 12 m (6 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTdp - Old parabolic dune deposits (Pleistocene and Pliocene(?))

White, light-red to light-brown, coarse- to very fine-grained sand and silt; partly consolidated beneath veneer of active, reworked sand cover. Form base or internal cores of younger, reactivated linear dunes immediately downwind (northeast) of Adeii Eechii Cliffs (shown as active linear dunes by Billingsley, 1987a), on Moenkopi Plateau, Appaloosa Ridge, and Coal Mine Mesa. Contain at least 25% to 35% gray, fine-grained silt and clay content on Coal Mine Mesa from erosion of underlying Dakota Sandstone (Kd) and Mancos Shale (Km). Unit often forms complex linking sets of parabolic dunes along edge of Adeii Eechii Cliffs and Appaloosa Ridge of Moenkopi Plateau. Several individual dunes on Moenkopi Plateau have developed downwind of ponded sediments and are younger than adjacent old eolian sand sheet and dune (QTes) deposits. Bedrock or ponded sediments (Qps) are often exposed within interior of parabolic dunes. Include combinations of parabolic, barchan, dome, and dune-like thick sand sheet deposits that frequently coalesce downwind (northeast) to form old linear dunes (old dune deposits, undivided [QTd]) or old eolian sand sheet and dune (QTes) deposits northeast of Adeii Eechii Cliffs on Moenkopi Plateau. Linear dune traces are often longer than 3 km (2 mi) and as long as 10 km (6 mi). Some linear dunes merge with other linear dunes and form a linear complex of parabolic or barchanoid dune trains within a short length of linear dune (not shown). Include topographically controlled climbing or falling dunes and short linear dunes below Appaloosa Ridge. Unit commonly stabilized by moderate growth of grass and mormon tea bush. Gradational and approximate contact with adjacent surficial deposits. About 2 to 12 m (6 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTes - Old eolian sand sheet and dune deposits (Pleistocene and Pliocene(?))

Light-red to light-brown, very fine-grained to medium-grained sand and silt. Form widespread deposits on Moenkopi Plateau that merges with old dune (QTd) and old mixed alluvium and eolian (QTae) deposits. Contacts with other map units are gradational and arbitrary based on morphologic characteristics observed on 1968 aerial photographs. Unit is overlapped by young mixed alluvium and eolian (Qae), stream-channel (Qs), and young alluvial fan (Qay) deposits below Appaloosa Ridge (southwest of ridge) and at Little Hollow Place, northeast corner of map area. Below Appaloosa Ridge, on Coal Mine Mesa, and at Little Hollow Place unit contains abundant gray clay and silt derived from underlying Dakota Sandstone (Kd) and Mancos Shale (Km). Unit is stabilized by thick growth of grass and mormon tea brush. Deposits cover Jurassic and Cretaceous bedrock and form protective cover against wind deflation of bedrock; where not covered, bedrock units are extensively eroded by wind deflation, especially along Adeii Eechii Cliffs. Unit is locally disturbed at stock tanks and windmill watering holes for livestock where fresh sand is actively forming new sand sheet and dune deposits (not mapped). About 1 to 3.6 m (3 to 12 ft) thick. (GRI Source Map ID 7454) (Cameron 30 x 60).

QTg - Terrace-gravel deposits (Pleistocene and Pliocene(?))

Gray and light-brown, mud, silt, sand, gravel, and cobbles; poorly sorted and partly consolidated by calcite, gypsum, and clay cement. Pebbles and boulders are rounded clasts of gray limestone and white chert derived from local outcrops of Kaibab Formation (Pkh and Pkf), scattered brown and purple-brown quartzite cobbles reworked from old stream-channel (Ts) deposits, and multicolored, mostly black well rounded pebbles from Shinarump Member of the Chinle Formation. Form isolated deposits in upper Kanab Creek and in some tributaries as much as 92 m (300 ft) above modern drainages, particularly in upper Jumpup Canyon. Deposits are partially preserved in abandoned cutoff meander loops or in isolated

abandoned point bars in upper Kanab Creek canyon. In Jumpup Canyon, a tributary to Kanab Creek, unit fills 170 m (560 ft) deep ancestral Jumpup Canyon drainage that had previously eroded through Kaibab and Toroweap Formations, Coconino Sandstone, and into upper part of Hermit Formation. About 5 to 8 m (15 to 25 ft) thick; about 170 m (560 ft) thick in Jumpup Canyon. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

QTae - Old mixed alluvium and eolian deposits (Pleistocene and Pliocene(?))

QTae - Old mixed alluvium and eolian deposits (Pleistocene and Pliocene(?))
Lithologically similar to young mixed alluvium and eolian (Qae) deposits but often capped or covered by poorly sorted sand, gravel, and small cobbles and boulders consolidated by calcrete soil development. Form flat mesa-like benches about 9 to 36.5 m (30 to 120 ft) above surrounding plateau surfaces along east-central edge of map area. About 3 to 6 m (10 to 20 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTae - Old mixed alluvium and eolian deposits (Pleistocene and Pliocene (?))
Lithologically similar to young mixed alluvium and eolian (Qae) deposits, but often capped by thin poorly developed calcrete soil; forms thicker deposits than young mixed alluvium and eolian (Qae) deposits. Include small cobbles and boulders. Form flat mesa-like benches about 30 to 120 ft (9 to 37 m) above modern drainage erosion in central part of map area. Unit is overlain in part by sand sheet and dune (Qd) and sand sheet (Qss) deposits in central and west half of map area. Thickness, 10 to 20 ft (3 to 6 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

QTa4 - Older alluvial fan deposits (Pleistocene and Pliocene)

Qa4 - Older alluvial fan deposits (Pleistocene and Pliocene(?))
Gray, sandy and gravelly fluvial debris-flow deposits. Unit is part of a more extensive alluvial fan deposit in House Rock Valley derived from Kaibab Plateau west of map area. Include clasts and boulders eroded from the Hermit Formation, Coconino Sandstone, Toroweap Formation, Kaibab Formation, and Moenkopi Formation from the Kaibab Plateau in House Rock valley. Unit is extensively eroded and gullied; eroded material is redeposited onto adjacent younger alluvial fans. Unit forms protective surface over Moenkopi Formation in western House Rock Valley. Support light to moderate growth of grass, cactus, and various high desert shrubs and bushes. Thickness, 10 to 25 ft (3 to 7.5 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Qa4 - Old alluvial fan deposits (Pleistocene and Pliocene(?))
Red, gray, and brown poorly sorted mixture of mud, silt, sand, and gravel derived from the Kaibab Formation on the west side of Kaibab Plateau, and angular to subrounded fragments of chert, limestone, and sandstone derived from the Hermit Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Formation on east side of Kaibab Plateau. Partly consolidated by calcite and gypsum cement. Include scattered, well rounded, brown, black, gray, and purple quartzite pebbles and cobbles derived from old stream-channel (Ts) deposits. Stony surface where not covered by dune sand and sand sheet (Qd) deposits along base of Vermilion Cliffs; surface often exhibits desert pavement composed mainly of black, well rounded pebbles in northwest. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

QTa - Older alluvial fan deposits (Pleistocene and Pliocene)
Gray and light-brown clay, silt, sand, and gravel, poorly sorted, partly consolidated by calcrete soil in top 1 m (3 ft). Material is mostly reworked older terrace-gravel (QTg4) deposits and erosional debris from Petrified Forest Member and Owl Rock Member of the Chinle Formation, southeast quarter of map area.

Contain angular fragments of petrified wood and well-rounded quartzite and chert pebbles in fluvial and eolian sandy matrix. Form stabilized cover over remaining older terrace-gravel deposits (QTg4). Unit has a gentle surface gradient toward Little Colorado River and is extensively eroded. Support moderate cover of grasses and low desert shrubs. About 1 to 4.5 m (3 to 15 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTa - Old alluvium (Pleistocene and Pliocene)
On Shiwits Plateau, composed of white, gray, and reddish-brown slope-forming siltstone, coarse-gravel, and conglomerate, partly unconsolidated, capped by calcrete soil. Overlies basalt of the Shiwits Plateau (Tsb). White and gray angular chert pebbles are dominant clasts averaging about 5 cm in diameter derived from the Kaibab Formation (Pk). Includes lag gravel of yellow, brown, white, and red, well-rounded, multicolored quartzite pebbles 2.5 to 19 cm (1 to 8 in) in diameter, and small petrified wood fragments derived from the Shinarump Member of the Chinle Formation. Locally includes small basalt fragments derived from underlying basalt of the Shiwits Plateau. Discontinuous calcrete beds form thin, lumpy surface producing white patches of calcrete gravel and alluvium on weathered surface of basalt flows that are easily recognized on aerial photographs. Unconformable contact with underlying basalt of the Shiwits Plateau (Tsb). Unit may have formed an extensive deposit over northern extent of the basalt of the Shiwits Plateau now heavily eroded. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

QTgd - Old gravel deposits (Pleistocene, Pliocene, and middle Miocene)

QTg - Old gravel deposits (Pleistocene, Pliocene, and middle Miocene)
Gray and light-brown silt, sand, gravel, pebbles, and small boulder conglomerate of mixed Paleozoic and Proterozoic lithologies; consolidated to partly consolidated by gypsum and calcite cement. Include calcrete soil deposits in upper 1 to 2 m (3 to 6 ft) of surface on Hualapai Plateau and in Aubrey and Truxton Valleys. Include Coyote Spring Formation of Young (1999). Constituents are reworked from young and old gravel sedimentary (Tg and Ts1) deposits, volcanic units (Tv, Tbmb), and local Paleozoic bedrock outcrops. Clasts are matrix supported and cemented with calcium carbonate as calcrete. Quartzite clasts, eroded from old gravel (QTg) and young gravel and sedimentary (Tg) deposits, form a thin lag gravel cover, too thin to show at map scale, throughout the south and east half of the map area. Unit is present on Coconino Plateau northeast quarter of map area but not mapped because it is difficult to distinguish from old gravel and sedimentary (Ts1) deposits due to lag gravel cover composed of a similar lithology. Unit in Truxton Valley overlies old gravel and sedimentary (Ts1) deposits and is difficult to distinguish from young gravel and sedimentary (Tg) deposits. Thickness, 20 to 200 ft or more. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

QTg4 - Older terrace-gravel deposits (Pleistocene and Pliocene(?))

QTg4 - Older terrace-gravel deposits (Pleistocene and Pliocene(?))
Gray and light-brown silt, sand, gravel and well-rounded flat pebbles and cobbles along higher beveled terraces of Navajo Sandstone (Jn) along Moenkopi Wash. Unit contains mud, silt, and sandy gravel derived from Cretaceous outcrops east of map area. Form terraced benches or ridges on Navajo Sandstone about 30 to 45 ft (9 to 14 m) above Moenkopi Wash. Unit is mainly exposed in cliff areas and commonly covered by thin dune sand and sand sheet (Qd) deposits. Thickness, 2 to 10 ft (0.5 to 3 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

QTg4 - Older terrace-gravel deposits (Pleistocene and Pliocene(?))
Gray and light-brown silt, sand, gravel, cobbles, and boulders up to 30 cm (1 ft) in diameter along Tappan Wash southwest of Cameron; consists mostly of sand and gravel material derived from the

Kaibab and Moenkopi Formations. Includes some volcanic clasts from the San Francisco Volcanic Field that may be older than 1 million years. Form terrace benches or ridges about 9 to 14 m (30 to 45 ft) above Tappan Wash where Tappan Wash meanders over soft strata of lower Moenkopi Formation. Form terrace benches about 45 to 60 m (150 and 200 ft) above modern Little Colorado River between Cameron, Arizona, and Black Point. Unit is extensively eroded and stratigraphically below oldest terrace-gravel (QTg5) deposits. Unit forms Baah Lokaa Ridge east of and lower than Black Point and an unnamed ridge northeast of Little Colorado River below Ward Terrace that fills 3 km (2 mi) wide old Little Colorado River channel with sandy gravely sediment as much as 30.5 m (100 ft) thick. Include calcrete soil horizon in upper 1 m (3 ft) of unit. Supports light vegetation cover, mostly grass and small desert shrubs. Unit is extensively eroded and gullied. About 3 to 55 m (10 to 180 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTg4 - Older terrace-gravel deposits (Pleistocene and Pliocene (?))
Lithologically similar to young terrace-gravel (Qgy) deposits but dominated by well-rounded quartzite pebble and cobble clasts. Form isolated outcrops or small mesas about 30 ft (9 m) above young terrace-gravel (Qgy) deposits and about 120 ft (37 m) above modern drainage of Cataract Canyon near Redlands Ranch. Deposits near Redlands Ranch were once part of thicker and more widespread deposits along Cataract Canyon, now largely removed by modern erosion. Thickness, 10 to 20 ft (3 to 6 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

QTg5 - Youngest old terrace-gravel deposits (Pleistocene, Pliocene and Miocene)

QTg5 - Youngest old terrace-gravel deposits (Pleistocene and Pliocene(?))
Gray and light-brown clay, silt, sand, and gravel, poorly sorted; cemented by calcite on higher terrace levels along Moenkopi Wash. Contain rounded fragments of Cretaceous fossils and well-rounded flat quartzite, chert, sandstone, and limestone pebbles. Fossil fragments are derived from Cretaceous rocks east of the map area. Include iron-rich sandstone concretions probably derived from underlying Navajo Sandstone (Jn). Unit is covered by dune sand and sand sheet (Qd) deposits. Support moderate growths of grass and low desert shrubs. Thickness, 3 to 60 ft (1 to 18 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

QTg5 - Oldest terrace-gravel deposits (Pliocene and Miocene)
Gray to light-brown silt, sand, gravel, pebbles and cobbles. Contain well rounded pebbles and cobbles of gray limestone and chert derived from Kaibab Formation, red sandstone clasts derived from Moenkopi Formation, and dominated by quartzite and a few granite and metamorphic clasts derived from older gravel deposits of the Mogollon Rim southeast of the map area. Unit is 79 m (260 ft) above present Little Colorado River at Cameron, Arizona, (elevation 1,341 m [4,400 ft]). Unit may, in part, be equivalent to old stream-channel (Ts) deposits at Black Point because the Little Colorado River gradient between these high level gravels is 3 m/km (9 ft/mi), comparable to the modern day Little Colorado River gradient between Cameron and Black Point. About 2 to 4.5 m (6 to 15 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTg5 - Oldest terrace-gravel deposits (Pleistocene and Pliocene (?))
Lithologically similar to young terrace-gravel (Qgy) deposits but dominated by well-rounded quartzite pebble and cobble clasts. Form isolated outcrops or small mesas about 30 ft (9 m) above young terrace-gravel (Qgy) deposits and about 120 ft (37 m) above modern drainage of Cataract Canyon near Redlands Ranch. Deposits near Redlands Ranch were once part of thicker and more widespread deposits along Cataract Canyon, now largely removed by modern erosion. Thickness, 10 to 20 ft (3 to 6 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qg5-18 - Oldest terrace-gravel deposits, undivided (Pleistocene and Pliocene(?))

Gray and light-brown clay, silt, sand, and gravel, poorly sorted; partly cemented by calcite. Include numerous subrounded to rounded chert, limestone, and sandstone pebbles locally derived from nearby rock outcrops. Include many well-rounded clasts of quartzite, sandstone, and chert from the Claron Formation transported by an ancestral Paria River in Utah, northwest of the quadrangle, and well-rounded exotic volcanic and metamorphic rocks from Colorado and New Mexico transported by an ancestral Colorado River and its tributaries. The oldest terrace-gravel deposits have been correlated by stratigraphic position above the Colorado River from Marble Canyon to Lake Powell based on aerial photographs and elevations derived from Google Earth images and 7.5' quadrangles (table 1, map sheet 3). Unit is partly covered by eolian sand deposits near Glen Canyon Dam. Support sparse growths of grass and low desert shrubs. Thickness, 6 to 30 ft (2 to 9 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

QTg6 - Intermediate old terrace-gravel deposits (Pleistocene and Pliocene(?))

Gray and light-brown clay, silt, sand, and gravel, poorly sorted; cemented by calcite. Contain angular to subrounded chert, limestone, and sandstone pebbles derived from Cretaceous rocks east of the map area. Form isolated outcrops north of Moenkopi Wash and along U.S Highway 160 east of Tuba City. Unit is mostly covered by extensive eolian sand deposits (Qd, Qes). Thickness, 6 to 30 ft (2 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

QTg7 - Oldest old terrace-gravel deposits (Pleistocene and Pliocene(?))

Gray and light-brown clay, silt, sand, and gravel, poorly sorted; cemented by calcite. Lithology similar to youngest and intermediate old terrace-gravel deposits (QTg5, QTg6) at highest levels north of Moenkopi Wash and east of Tuba City. Unit may represent part of an extensive pediment surface that drained from Black Mesa area east of map and formed before incision of Moenkopi Wash. Thickness, 6 to 18 ft (2 to 6 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Volcanic rocks of the San Francisco Volcanic Field (Pleistocene, Pliocene and Miocene)

Volcanic rocks of the San Francisco Volcanic Field (Pleistocene, Pliocene, and Miocene) are mapped and defined by Moore and Wolfe (1976), Ulrich and Bailey (1987), and Wolfe and others (1987). For a complete history of magnetic polarity determinations, Brunhes, Matuyama, Gauss, and Gilbert age assignments, analytical data, and classification of basalt types in this map area, see Ulrich and Bailey (1987). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Volcanic rocks of the San Francisco Volcanic Field are defined, in part, by Wolfe and others (1987). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Qmcb - Basalt flow of Merriam Crater (Pleistocene)

Dark-gray alkali olivine basalt. Contains scattered phenocrysts of olivine, clinopyroxene, and rare plagioclase in groundmass of the same minerals plus opaque oxides. Basalt flow originated from Merriam Crater 17.5 km (11 mi) southeast of the southeast corner of map area and flowed north to a small 60 m (200 ft) deep canyon of the Little Colorado River and formed a lava dam across the canyon. The lava dam diverted the Little Colorado River stream flow around the north side of the basalt flow and back into 60 m (200 ft) deep canyon downstream of the lava dam that forms Grand Falls (8 km [5 mi]) southeast of map area (Moore and Wolfe, 1976, 1987). Basalt of Merriam Crater flowed downstream of Grand Falls in the Little Colorado River channel into the map area east of Wupatki National Monument. The river overflows the basalt flow and forms rapids known as Black Falls (fig. 1). Downstream of Black Falls, the Little Colorado River flows adjacent to basalt flow, but most of the basalt flow spread out onto abandoned stream-channel (Qs) and low flood-plain (Qf) deposits and terminates just south of Black Point. Optical-luminescence age, 19.6±1.2 ka (Duffield and others, 2004). About 2 to 4 m (6 to 13 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qyap - Pyroclastic deposits of S P Mountain (Pleistocene)

Dark-gray to reddish-gray basaltic andesite. Contain phenocrysts of clinopyroxene, olivine, and intensely corroded plagioclase in hypocrystalline groundmass of the same minerals, plus opaque oxide and glass. Same composition as basaltic andesite flow (Qyab), but less crystalline. Contains abundant large volcanic bombs that help form sharp rims of uneroded crest of cone (Hodges, 1962; Ulrich and Bailey, 1987). Pyroclastic cone partially overlies older cone on west side and has a circular plan view; forms 287-m- (940-ft-) high cone with 60-m- (200-ft-) deep interior crater. About 287 m (940 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qyab - Basaltic andesite of S P Mountain (Pleistocene)

Dark-gray basaltic andesite. Flow is more crystalline than associated basaltic pyroclastic deposits of S P Mountain (Qyap). Flow has rough blocky surface and steep flow fronts. Basalt flowed northward about 6.5 km (4 mi) over Harrisburg Member of the Kaibab Formation and into local graben structures (fig. 4 on map). K-Ar age determined by Baksi (1974) is 0.071±0.004 Ma (Ulrich and Bailey, 1987). About 6 to 40 m (20 to 130 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qyp - Pyroclastic deposits of five young cinder cones (Pleistocene)

Grayish-black porphyritic basalt with abundant 1- to 3-mm phenocrysts of corroded tabular plagioclase, scattered olivine, and sparse clinopyroxene in a hyalophitic groundmass. Forms five young cinder cones overlying older cinder cones; 200 to 800 m (200 to 2,625 ft) in diameter and 25 to 165 m (80 to 540 ft) high at south-central edge of map area. Thickness, 25 to 165 m (80 to 540 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qyb - Basalt flow of five young cinder cones (Pleistocene)

Grayish-black porphyritic basalt flow with same composition as pyroclastic deposits of five young cinder cones (Qyp). Consists of one small flow 700 m (2,297 ft) long and 400 m (1,315 ft) wide. About 5 to 10 m (16 to 33 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTisf - Volcanic rocks of the San Francisco Volcanic Field, intrusive dike or plug (Pleistocene or Pliocene)

Qti - Intrusive dike or plug (Pleistocene(?) or Pliocene (Matuyama age))
Dark-gray aphyric basalt and microporphyritic olivine basalt. Includes pyroclastic fragments. Source for pyroclastic cones (Qtp) and basalt flows (Qtb); Dog Knobs, southwest quarter of map area. Widths, 1.5 to 4.5 m (5 to 15 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qti - Volcanic rocks of the San Francisco Volcanic Field - Intrusive dike or plug (Pleistocene and Pliocene (Matuyama age))
Dark-gray aphyric basalt and microporphyritic olivine basalt. Includes welded pyroclastic fragments. Source for pyroclastic cones (Qtp) and basalt flows (Qtb). Specific dikes or plugs are 5 to 15 ft (1.5 to 4.5 m) wide. (*GRI Source Map ID 7453)* (Valle 30 x 60).

QTpsf - Volcanic rocks of the San Francisco Volcanic Field, pyroclastic deposits (Pleistocene or Pliocene)

Qtp - Pyroclastic deposits (Pleistocene(?) or Pliocene (Matuyama age))
Dark-gray to red cinders, agglutinated spatter, bomb and ribbon fragments; yellowish brown to reddish brown where weathered. Form several rounded, little dissected, superficially gullied pyroclastic cones of Dog Knobs area, southwest quarter of map area. About 60 to 120 m (200 to 400 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qtp - Volcanic rocks of the San Francisco Volcanic Field - Pyroclastic deposits (Pleistocene and Pliocene (Matuyama age))
Dark-gray to red cinders, agglutinated spatter, bomb and ribbon fragments; yellow-brown to red-brown where weathered. Cones rounded, somewhat subdued, little dissected although superficially gullied. Thickness, 200 to 400 ft (60 to 122 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

QTbsf - Volcanic rocks of the San Francisco Volcanic Field, basalt flows (Pleistocene or Pliocene)

Qtb - Basalt flows (Pleistocene(?) or Pliocene (Matuyama age))
Dark-gray, yellowish-brown to brown, aphyric and slightly porphyritic basalt and microporphyritic olivine basalt; surfaces mostly smooth, relatively flat, undissected. Includes thin, interbedded pyroclastic deposits near pyroclastic cones of Dog Knobs area. Unit is thickest near flow margins in some areas. Thickness ranges from about 10 to 60 m (30 to 200 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Qtb - Volcanic rocks of the San Francisco Volcanic Field - Basalt flows (Pleistocene and Pliocene (Matuyama age))
Dark-gray, yellow-brown to brown, aphyric and slightly porphyritic basalt and microporphyritic olivine basalt; surfaces mostly smooth, relatively flat, undissected. Includes thin, interbedded pyroclastic deposits near pyroclastic cone areas. Thickest near flow margins in some areas. Thickness, 30 to 200 ft (9 to 60 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

QTai - Volcanic rocks of the San Francisco Volcanic Field, basalt and andesite dikes and necks (Pleistocene or Pliocene)

Dark-gray intersertal to subophitic basalt with abundant phenocrysts of clinopyroxene, plagioclase, and sparse olivine and hornblende. Source for Quaternary/Tertiary basaltic and andesite flows and pyroclastic deposits. Dikes and necks are 1 to 4 ft (0.5 to 1.3 m) wide. (*GRI Source Map ID 7453)* (Valle 30 x 60).

QTap - Volcanic rocks of the San Francisco Volcanic Field, basalt and andesite pyroclastic deposits (Pleistocene or Pliocene)

QTap - Basalt and andesite pyroclastic deposits (Pleistocene(?) or Pliocene (Matuyama age))
Dark-gray, glassy, basaltic andesite. Weather yellowish brown to brown, locally gullied. Cones composed of cinders, scoria, and spatter, southwest corner of map area. About 25 to 122 m (80 to 400 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTap - Volcanic rocks of the San Francisco Volcanic Field - Basalt and andesite pyroclastic deposits (Pleistocene and Pliocene (Matuyama age))
Dark-gray intersertal to subophitic pyroclastic deposits. Weathers light yellow-brown. Contain abundant phenocrysts of clinopyroxene and plagioclase in glassy groundmass. Form small pyroclastic cones and isolated pyroclastic deposits. Thickness, 20 to 200 ft (6 to 60 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

QTab - Volcanic rocks of the San Francisco Volcanic Field, basalt and andesite flows (Pleistocene or Pliocene)

QTab - Basalt and andesite flows (Pleistocene(?) or Pliocene (Matuyama age))
Dark-gray basaltic andesite; partly blocky, hummocky surfaces, locally gullied. Weather yellowish brown to brown. Contain abundant phenocrysts of clinopyroxene and plagioclase, subordinate phenocrysts of orthopyroxene, sparse phenocrysts of olivine and hornblende and scattered rounded quarts grains with clinopyroxene reaction rims. Groundmass is mostly fine-grained or glassy and contains plagioclase microlites, opaque oxide, and small crystals of clinopyroxene and orthopyroxene. About 18 to 67 m (60 to 220 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

QTab - Volcanic rocks of the San Francisco Volcanic Field - Basalt and andesite flows (Pleistocene and Pliocene (Matuyama age))
Dark-gray intersertal to subophitic basalt, with or without glass; partly blocky, hummocky, locally gullied. Weathers yellow-brown to brown. Contains abundant phenocrysts of clinopyroxene and plagioclase, subordinate phenocrysts of orthopyroxene, sparse phenocrysts of olivine and hornblende and scattered rounded quartz grains with clinopyroxene reaction rims. Groundmass is mostly fine grained or glassy and contain plagioclase microlites, opaque oxide, and small crystals of clinopyroxene. Thickness, 80 to 300 ft (25 to 92 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Thma - Andesite flows of Howard Mesa (Pliocene)

Dark-gray to gray-black andesite; includes two lobes extending into map area from the south. Contains scattered phenocrysts of plagioclase and quartz 1/8 inch in diameter. Plagioclase is intensely corroded; quartz is less abundant, is corroded and has pyroxene reaction rims. Groundmass is hyalocrystalline

consisting of glass, plagioclase microlites, hornblende prisms altered to opaque oxide, and other opaque grains. K/Ar age, 2.06±0.18 Ma, polarity reversed (Wolfe and others, 1987). Thickness, 200 ft (60 m) or more. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tyi - Volcanic rocks of the San Francisco Volcanic Field, young intrusive rocks (Pliocene)

Dark-gray basalt and mixed pyroclastic dikes and necks. Composed of plagioclase, clinopyroxene, olivine, and opaque oxides. Intrusives from 4 to 20 ft (1.2 to 6 m) wide. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Typ - Volcanic rocks of the San Francisco Volcanic Field, young pyroclastic deposits (Pliocene)

Dark-gray to red cinder and spatter fragments; weather yellowish-brown, brown, or reddish-brown. Composed of clinopyroxene and olivine phenocrysts, plagioclase, opaque oxides, and glass. Mass wasting has diminished slope angles of pyroclastic cones; flanks are gullied to extensively eroded. Cones are elongated and aligned along a northwest trend in the Four Hills area indicating the influence of bedrock fractures and bedrock joints on vent position and orientation. Thickness, 30 to 200 ft (9.2 to 60 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tyb - Volcanic rocks of the San Francisco Volcanic Field, young basalt flows (Pliocene)

Medium- to dark-gray basalt; includes plagioclase-phyric, aphyric, and slightly porphyritic basalt. Smooth surfaced, partly dissected. Composed of plagioclase, clinopyroxene, olivine, and opaque oxides. Thickness less than 90 ft (28 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Trb - Volcanic rocks of the San Francisco Volcanic Field, basalt flow of Red Butte (Miocene)

Basalt flow of Red Butte (Miocene)—Dark-gray olivine basalt. Weathers brown; massive flow. K/Ar age, 8.92±0.23 Ma (Wolfe and others, 1987), 9.73±0.91 Ma and 8.78±0.22 Ma (Reynolds and others, 1986). Forms basalt caprock over thin soil deposit 3 to 5 ft (1 to 1.5 m) thick that was baked to a bright red; also partly overlies Shinarump Member of the Chinle Formation where soil is not present. Source of basalt is not present in the immediate vicinity of Red Butte and is assumed to be a dike under the basalt flow or is covered by surrounding landslide (Ql) deposits. Thickness, 165 ft (50 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tbi - Dike in ampitheater (Pliocene)

Dark-gray plagioclase-phyric basalt and mixed pyroclastic dikes and necks. Composed of plagioclase, clinopyroxene, olivine, and opaque oxides. Crystal-rich basalt; occurs in 2.7 km (1.5 mi) wide basalt- and tuff-rimmed depression informally named the “Amphitheater” by Ulrich and Bailey (1987), 10 km (6 mi) east of U.S. Highway 89 and about 8 km (5 mi) northeast of S P Mountain. Dike is 2 to 6 m (4 to 20

ft) wide and 5 to 10 m (15 to 33 ft) in height. K-Ar age, 3.13±0.39 Ma (Ulrich and Bailey, 1987). Coarse pyroclastic debris is scattered on surrounding surface of Wupatki Member of the Moenkopi Formation. Thickness, 5 to 10 m (15 to 33 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Tp - Pyroclastic deposits (Pliocene)

Dark-gray to red cinder and spatter fragments; weathers yellowish brown, brown, or reddish brown. Composed of clinopyroxene and olivine phenocrysts, plagioclase, opaque oxides, and glass; partly decomposed and weathers light red. Mass wasting has diminished slope angles of pyroclastic cones; flanks are gullied to extensively eroded. Cones are elongated and aligned along a northwest trend north in Dog Knobs area indicating the influence of bedrock faults, fractures, and joints on vent positions and orientation. About 1.5 to 12 m (5 to 40 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Tb - Basalt flows (Pliocene)

Medium- to dark-gray plagioclase-phyric, aphyric, and slightly porphyritic basalt. Smooth surfaced, partly dissected north of Dog Knobs area and about 10 km (6 mi) northeast of S P Mountain. Composed of plagioclase, clinopyroxene, olivine, and opaque oxides. Less than 30 m (90 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Basalt north of Mount Emma (Pliocene)

Gray-black alkali-olivine basalt; includes several basalt flows, pyroclastic deposits, and intrusive rocks. Unit largely covered by Quaternary pyroclastic (Qp) deposits at Mount Emma and other north-south-aligned pyroclastic cones and associated basalt flows (Qb). Unit is offset down-to-the-west about 250 m (820 ft) by southern splay of the Hurricane Fault. There are no K-Ar ages available, but age estimated to be about 2.6 to 3.6 Ma based on stratigraphic position, elevation, and flow direction of basalt of Mount Logan (Tmlb) and basalt of Mount Trumbull (Tmb). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tei - Basalt north of Mount Emma, intrusive rocks (Pliocene)

Gray-black alkali-olivine basaltic plug or dike. Unit partly exposed and offset by the Hurricane Fault. Most of unit covered by landslide deposits (Ql). Width of plug is probably in excess of 90 m (300 ft) and appears to be source of Tertiary basalt flows north of and under Mount Emma pyroclastic deposits. Plug does not protrude above ground surface; highly altered and weathered. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tep - Basalt north of Mount Emma, pyroclastic deposits (Pliocene)

Reddish-black cinder, scoria, ash, and other scoriaceous ejecta; deeply eroded. Associated with intrusive plug (Tei) on downthrown side of Hurricane Fault north of Mount Emma. Thickness, 12 m (40 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Teb - Basalt north of Mount Emma, basalt flows (Pliocene)

Near Mount Emma, gray-black alkali-olivine basalt; plagioclase laths common in glassy groundmass. Consist of several basalts that flowed east and south from plug (Tei) area. Underlying strata concealed, but because of similar elevation as basalt of Mount Logan, it is assumed basalt overlies the Chinle Formation or upper Moenkopi Formation. Thickness, 122 m (400 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tmlb - Basalt of Mount Logan, basalt flows (Pliocene)

Informally named Mount Logan basalt for Mount Logan (Reynolds and others, 1986). Forms prominent Mount Logan (elev. 2,398 m [7,866 ft]) on Uinkaret Plateau, Mohave County, Arizona (sec. 12, T. 34 N., R. 9 W.; Billingsley and others, 2000, 2001). K-Ar age, 2.63±0.34 Ma obtained from a basalt flow on Mount Logan, but a specific location was not disclosed. New age determinations are needed to determine the sequence of events between the basalt of Mount Logan and the basalt of Bundyville, which appear to be the same age (3.6 Ma) based on close proximity to each other (about 3.5 km [2 mi] apart), stratigraphic position where both units overlie the same 122-m-thick (400-ft-thick) section of the Chinle Formation, and similar thickness.

Light-gray, finely crystalline, alkali-olivine basalt; contains red and green olivine phenocrysts 1 mm in diameter in glassy groundmass; includes plagioclase laths in glassy groundmass. Plagioclase masses form white spotted blotches in some areas. Basalt flow(s) overlie Petrified Forest Member of the Chinle Formation east side of Hells Hole (sec. 12, T. 34 N., R. 9 W.). Eastern extent of basalt may overlie upper red member and Shnabkaib Member of the Moenkopi Formation. Basalt dikes (Qti) may be source for basalt of Mount Logan below the summit of Mount Logan in Hells Hole. Basalt flowed east about 5.3 km (3 mi) from near the summit of Mount Logan, descending about 335 m (1,100 ft). Average thickness, about 67 m (220 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of Bundyville (Pliocene)

Informally named the Bundyville basalt for the abandoned settlement of Mt. Trumbull (Bundyville; Hamblin and Best, 1970; Hamblin, 1970), Shiwits Plateau, Mohave County, Arizona, (secs. 23, 24, 25, and 26, T. 35 N., R. 10 W.). Exposed on downthrown side of Hurricane Fault in northwest quarter of map area (Billingsley and others, 2000). K-Ar age, 3.6±0.18 Ma (Reynolds and others, 1986). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tbid - Basalt of Bundyville, intrusive dikes (Pliocene)

Tbi - Intrusive dikes (Pliocene)
Dark-gray alkali-olivine basalt. Dikes are nearly vertical and oriented N. 40° W. and nearly parallel to the Hurricane Fault. Widths, 1 to 3 m (2 to 10 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tbb - Basalt of Bundyville, basalt flows (Pliocene)

Dark-gray, finely crystalline, olivine basalt. Groundmass contains olivine. Include one to three basalt flows that form a caprock overlying purple and white mudstone and sandstone beds of the Petrified Forest Member of the Chinle Formation. Flow surfaces locally distorted by landslide and soft sediment deformation of underlying soft mudstone that has been caused by earthquakes related to the Hurricane

Fault. Basalt predates any offset of strata along Hurricane Fault implying that the fault is younger than 3.6 Ma. Flows assumed to have originated from local dikes (Tbi) that are largely covered by basalt, landslide, or talus debris. Thickness, 30 to 55 m (100 to180 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of Mount Trumbull (Pliocene)

First described by Koons (1945), informally named Mount Trumbull basalt for Mount Trumbull by Hamblin and Best (1970) and Hamblin (1970), Uinkaret Plateau, Mohave County, Arizona, (sec. 27, T. 35 N., R. 8 W.; southeast quarter of map area; Billingsley and others, 2001). Forms prominent landmark on Uinkaret Plateau. K-Ar age, 3.6±0.18 and 3.67±0.09 Ma (Reynolds and others, 1986). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tmi - Basalt of Mount Trumbull, intrusive rocks (Pliocene)

Gray-black, finely crystalline, alkali-olivine basalt. Forms highest point on north side of Mount Trumbull (elev. 2,447 m [8,029 ft]). Source for Tertiary basalt flows on Mount Trumbull. Width, 120 m (400 ft) or more. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tmb - Basalt of Mount Trumbull, basalt flows (Pliocene)

Gray-black, finely crystalline, alkali-olivine basalt. Groundmass contains olivine phenocrysts and plagioclase laths. Consist of one or more thin basalt flows that form caprock overlying concealed purple and white mudstone and sandstone beds of the Petrified Forest Member of the Chinle Formation on west side of mountain (exposed in landslide float material) that overlie upper red member and possible Shnabkaib Member of the Moenkopi Formation on east side of mountain (exposed as landslide blocks). Partly covered by Quaternary pyroclastic (Qp) deposits. Thickness, 30 to 60 m (100 to 200 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of the Grand Wash Trough (Pliocene)

Include intrusive dikes and necks (Ti), basalt flows derived from north of map area and from Olaf Knolls (Tb), and interbedded fluvial sediments (not shown on map) between basalt flows (Billingsley and others, unpub. data). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tigw - Basalt of the Grand Wash Trough, dikes and necks (Pliocene)

Ti - Dikes and necks (Pliocene)

At Olaf Knolls, consists of light-gray alkali-olivine basalt dike that intrudes red sandstone and siltstone (Tgr) rocks of the Grand Wash Trough. Form highest part of Olaf Knolls volcanic area (elev. 985 m [3,232 ft]). Hachured symbol on map marks possible small mar or caldera depression on north flank of Olaf Knolls. Age of Olaf Knolls assumed to be about 4 to 4.5 Ma based on relation to nearby basalt flows derived north of the map area (Qb) in Cottonwood and Grand Wash drainages. Include dikes or necks of dark-gray alkali-olivine basalt on east side of Cottonwood Wash, south of Pakoon Springs that intrude gray gypsum, gypsiferous siltstone, and red siltstone and sandstone (Tgr). Pyroclastic deposits not present. Widths, as much as 30 m (100 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tbgw - Basalt of the Grand Wash Trough, basalt flows (Pliocene)

Tb -Basalt flows (Pliocene)
Consist of two or more basalt flows (Damon and others, 1996). Light-gray to medium-gray alkali-olivine basalt. Age of upper flow at Pakoon Springs, 3.99±0.06 to 4.70±0.07 Ma. Age of lower basalt at Grand Wash Bay, Lake Mead, that may have originated from dikes or necks (Ti) along east side of Cottonwood Wash (southwest edge of map area), 3.24±0.05 Ma (Damon and others, 1996). Include interbedded alluvial sediments between basalt flows along Cottonwood, Grand, and Pakoon Wash drainages in upper part. Source of upper basalt flows appears to have originated from pyroclastic vents and dikes in northern part of Grand Wash Trough (north of map area) that occupy Grand, Cottonwood, and Pakoon Wash paleodrainages. Interbedded alluvial sediments are composed of gray and light-brown, poorly sorted, slope-forming, consolidated conglomerate, gravel, sand, and silt. Contain Proterozoic and Paleozoic clasts derived from the Virgin Mountains northwest of map area. Thickness of intrabasaltic sediments are as much as 90 m (300 ft; Lucchitta and others, 1995a, b), but average about 24 m (80 ft) thick in map area and thin southward. Lower basalt flow contains calcite-filled veins and vugs. Basalt at Olaf Knolls (sec. 1, T. 35 N., R. 15 W.) is light- to medium-gray alkali-olivine basalt. Majority of basalt flowed in radial pattern from highest point of Olaf Knolls approximately 2.5 km (1.5 mi) to southwest, 1.5 km (1 mi) to northeast, and 1.5 km (1 mi) to west. Flows occupy Grand Wash paleodrainage and unconformably overlie red siltstone and sandstone (Tgr) deposits. All basalt flows overlain by conglomerate and calcrete (Tay) deposits and partly overlain by young and old alluvial fan (Qay and Qao) deposits. Basalt flows exposed 1.5 km (1 mi) southeast of Olaf Knolls near Grand Wash Cliffs may have originated from another source north of map area or possibly Olaf Knolls. Combined thickness of upper basalt and interbedded sediments, 2 to 140 m (6 to 460 ft). Thickness of lower basalt, 2 to 10 m (6 to 30 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgs - Gravel and sedimentary deposits (Pliocene to lower Paleocene(?))

Tgs - Gravel and sedimentary deposits (Pliocene(?) or Miocene(?))
Gray, brown, and white mudstone, sandstone, siltstone, and minor gravel deposits, poorly sorted and partly consolidated. Unit consists mainly of gray, fine-grained, fluvial silt and sand that contains scattered pebbles and cobbles of well-rounded gray sandstone and limestone clasts derived from Jurassic and Cretaceous rocks of White Mesa east of Kaibito Monocline. Contains numerous rounded and a few well-rounded granite, quartzite, and chert clasts whose origin is not certain (possibly reworked from gravels in the Chuska Mountains of northeastern Arizona). Also well-rounded Cretaceous fossil fragments, sandstone, and limestone pebbles and cobbles locally derived from underlying bedrock. Unit overlies beveled Jurassic rocks of Navajo Sandstone west of Kaibito Monocline and Carmel Formation, Entrada Sandstone, and Dakota Sandstone, east of Kaibito Monocline in southeast corner of quadrangle. Age may be Pliocene(?) as mapped by Billingsley and others (2012) or Miocene(?) as suggested by Lucchitta (2011).
West of Glen Canyon Dam: Poorly sorted and partly consolidated gray clay, silt, sand, and gravel. Includes well-rounded, black, brown, and minor red chert pebbles and small gray limestone pebbles. Pebbles are generally 0.5 to 3 in (1.2 to 7.5 cm) in diameter. Black pebbles make up about 75% of pebble distribution, gray and white about 24%, brown and red less than 1%. Form gray rounded outcrops in channels eroded into underlying Entrada Sandstone about 1 mi (1.6 km) south of U.S. Highway 89, north-central edge of quadrangle. Thickness, 30 to 100 ft (9 to 30 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Tgs - Gravel and sedimentary deposits (Pliocene(?) and Miocene(?))
Gray, brown, and white clay, sand, silt, and gravel, poorly sorted; consolidated. Unit consists mostly of

fine-grained gray silty sand that includes scattered pebbles and cobbles of well-rounded gray sandstone and limestone derived from Jurassic and Cretaceous rocks east and northeast of the map area. Forms extensive thin veneer on Moenkopi Plateau that overlies beveled Jurassic and Cretaceous rocks of the Navajo Sandstone (Jn), Entrada Sandstone (Je), Dakota Sandstone (Kd), and Mancos Shale (Km), in southeast quarter of map. Forms consolidated caprock deposit on Middle Mesa that overlies beveled Jurassic rocks of the Carmel Formation (Jc) and Navajo Sandstone (Jn), east edge of map. Forms partly consolidated mixed sandstone, siltstone, mudstone, and minor pebble sediments on Crooked Ridge in northeast corner of map. Unit at all three localities forms the highest surficial fluvial deposits, have a similar lithology, and are at approximate similar elevations that may be Pliocene (?) age based on relevant elevations above younger fluvial deposits of Moenkopi Wash. Age may be Miocene(?) as suggested by Lucchitta (2011). Thickness, 6 to 100 ft (2 to 30 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Tg - Young gravel and sedimentary deposits (Pliocene to upper Miocene)
Post-volcanic (Tv, Tbmb) deposit of gray and light-brown silt, sand, pebbles, cobbles, and small boulders consisting of either all Proterozoic clasts or mixed Proterozoic and Paleozoic clasts; poorly sorted, partly consolidated to consolidated. Clasts are angular to well rounded in light-red sandy matrix. Poor exposures make it difficult to distinguish from overlying younger deposits of old gravel (QTg) that include some volcanic clasts. Unit may be equivalent, in part, to Paleozoic-clast conglomerate (Tgc) west of and along Grand Wash Cliffs. Weathers to rounded hills. Deposit commonly covered by thin surficial alluvium, lag gravel, or calcrete soil. Thickness, 3 to 80 m (10 to 260 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tg - Undifferentiated gravel deposits of the Hualapai Plateau (Pliocene to lower Paleocene(?))
Dark-gray, finely crystalline, alkali-olivine basalt. Source areas for associated basalt flows and pyroclastic deposits on Grassy Mountain. Dikes are aligned with nearly vertical east-west bedrock joints and fractures of this area. Widths, 0.5 to 2 m (1 to 6 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Twi - Whitmore Dike Swarm, intrusive dikes (Pliocene)

Dark-gray to black alkali-olivine basalt. K-Ar age, 4.56±0.12 Ma (Wenrich and others, 1995). Form nearly vertical dikes eroded down to bedrock surface of Esplanade Sandstone and Pakoon Limestone (Pep) about 2 km (1.3 mi) southwest of Whitmore Canyon and 3 km (1.5 mi) west of Colorado River Mile 188. Dikes parallel joints and nearly vertical fractures in bedrock for about 3.3 km (2 mi) along north-south trend. Dikes exposed in the Esplanade Sandstone and Pakoon Limestone (Pep) and lower part of the Hermit Formation (Ph) 1.6 km (1 mi) west of Colorado River Mile 188 only produced one basalt flow (Twb). Dike widths, 0.5 to 1.2 m (2 to 3.5 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Twb - Whitmore Dike Swarm, basalt flow (Pliocene)

Dark-gray to black alkali-olivine basalt. Includes small olivine phenocrysts and plagioclase laths in glassy groundmass. Basalt emerged from dike (Twi) in lower part of Hermit Formation (Ph) and flowed down steep debris slope descending about 60 m (200 ft) onto upper part of Esplanade Sandstone and Pakoon Limestone (Pep). Basalt preserves soft strata of the Hermit Formation as a basalt-capped hill informally called “Whitmore Hill” (sec. 26, T. 32 N., R. 9 W.; elev. 1,161 m [3,808 ft]). Basalt flow implies that erosion exposed at least the Esplanade Sandstone at this location by 4.5 Ma. Thickness, 18 m (60 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Basalt of Poverty Knoll (Pliocene)

Informally named for Poverty Knoll, a 245-m-high (800-ft-high) mesa or flat-topped knoll on Shiwits Plateau, north-central part of map area (sec. 2, T. 35 N., R. 11 W.; Billingsley and others, 2000). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tpki - Basalt of Poverty Knoll, intrusive dike (Pliocene)

Light-gray, finely crystalline, alkali-olivine basalt. Forms small knoll, center-top of Poverty Knoll. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tpkb - Basalt of Poverty Knoll, basalt flow (Pliocene)

Light-gray, finely crystalline, alkali-olivine basalt containing plagioclase laths and olivine phenocrysts 1 mm in diameter in glassy groundmass; contains about 35 percent olivine phenocrysts. Flow emerged from central dike and flowed in radial pattern over Shnabkaib Member of the Moenkopi Formation. Thickness averages about 37 m (120 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Poverty Mountain Basalt (Pliocene)

Informally named Shiwits basalt by Best and others (1980) and Reynolds and others (1986) in conjunction with the basalt of the Shiwits Plateau flows south of map area. Formally named Poverty Mountain Basalt for Poverty Mountain, the type area, Shiwits Plateau, west-central edge of map area (secs. 29 and 32, T. 35 N., R.11 W.; Billingsley and others, 2000). K-Ar age, 4.75±0.26 Ma (Reynolds and others, 1986). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tpi - Poverty Mountain Basalt, intrusive neck (Pliocene)

Medium-gray, finely crystalline, alkali-olivine basalt. Forms small dike associated with basalt flows and pyroclastic deposits near eastern part of mountain. Dike and nearby small pyroclastic vents are aligned northwest-southeast and are main sources for basalt flows (Tpb) on Poverty Mountain. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tpp - Poverty Mountain Basalt, pyroclastic deposits (Pliocene)

Reddish-black and red fragments of scoria, cinders, and small ribbons overlie basalt flows at and near vent areas. Interbedded with basalt flows near dike (Tpi) and pyroclastic cone areas. Largest cone is about 25 m (80 ft) thick. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tpb - Poverty Mountain Basalt, basalt flows (Pliocene)

Medium-gray to light-gray, finely crystalline, alkali-olivine basalt. Include augite and olivine phenocrysts less than 1 mm in diameter in glassy groundmass. Basalt overlies gently east-northeast-dipping (2° average) upper red member and Shnabkaib Member of the Moenkopi Formation and the Harrisburg Member of the Kaibab Formation. Basalt flowed in radial pattern from three vent areas over upper strata

of the Moenkopi Formation. Basalt flows coalesced and flowed west and down across east-dipping Triassic strata into upper reaches of Hidden Canyon paleodrainage. Thickness, 30 to 92 m (100 to 300 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Grassy Mountain Basalt (Pliocene)

Formally named Grassy Mountain Basalt for Grassy Mountain, the type area, Shiwits Plateau (secs. 3, 4, 9, 10, T. 33 N., R. 11 W.; Billingsley and others, 2000). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgi - Grassy Mountain Basalt, intrusive dikes (Pliocene)

Dark-gray, finely crystalline, alkali-olivine basalt. Source areas for associated basalt flows and pyroclastic deposits on Grassy Mountain. Dikes are aligned with nearly vertical east-west bedrock joints and fractures of this area. Widths, 0.5 to 2 m (1 to 6 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgp - Grassy Mountain Basalt, basalt flows (Pliocene)

Red to reddish-black, angular, scoriaceous cinder fragments and ash deposits; unconsolidated. Spatially associated with intrusive dikes; interbedded with local basalt flows (Tgb). Thickness, 1 to 6 m (3 to 20 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgb - Grassy Mountain Basalt, pyroclastic deposits (Pliocene)

Dark-gray, finely crystalline, alkali-olivine basalt; olivine phenocrysts averaging 1 mm in diameter form about 25 percent of rock sample from interior of basalt flow. One or more flows interbedded with pyroclastic deposits near dikes. Basalts flowed generally west and northwest and overlie upper red member and Shnabkaib Member of the Moenkopi Formation. Thickness, 12 to 60 m (40 to 200 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tay - Alluvium and calcrete soil deposits (Pliocene and Miocene)

Gray and light-brown, slope-forming, silt, sand, coarse gravel in coarse-grained gravely matrix alluvium; includes subangular to well-rounded limestone and dolomite pebbles, cobbles, and boulders up to 1 m (3 ft) in diameter. Include 8 basalt clasts derived from basalt flows (Tb) of the Grand Wash Trough; partly consolidated by calcium and gypsum cement. Form cliffs or weathers to rounded resistant hills. Unit overlain by thin to thick calcrete soil deposits, 1 to 8 m (3 to 25 ft) thick. Unit is poorly sorted to moderately sorted. Calcrete soil deposits that cover basalt flows form thin, rough, and discontinuous beds averaging about 1.2 m (5 ft) thick and contain scattered cobbles of basalt up to 30 cm (12 in) in diameter. Pebble imbrications show southward flow of depositing streams in Grand Wash Trough area. Unit is strongly dissected by modern erosion. East of Grand Wash drainage, unit is composed of gray and light-brown, poorly sorted, consolidated, silt, sand, gravel, cobbles, and boulders derived from Paleozoic rocks in the Grand Wash Cliffs; clasts are composed of about 80 percent limestone and dolomite, and 10 percent chert in gray gypsiferous siltstone and sandstone matrix, all capped by calcrete soil 3 to 4 m (10 to 12 ft) thick; weathers light brown. Rounded and subrounded limestone and

chert clasts are strongly pitted and etched on weathered surfaces and often coated by calcrete rind on underside. Unconformably overlie red siltstone and sandstone (Tgr) and unmapped conglomerate deposits west of Wheeler Fault. Unconformably overlies older gypsum and limestone sediment facies (Tgg and Tgl) between Grand Wash drainage and Grand Wash Cliffs. Support sparse growths of desert vegetation, mainly cactus of various types and creosote bush. Thickness, 15 to 60 m (50 to 200 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tao - Alluvial deposits (Pliocene and Miocene)

Gray to dark-gray, slope-forming schist, granite, gneiss, and amphibole clasts derived from Proterozoic outcrops of the Virgin Mountains about 9 to 11 km (6 to 7 mi) northwest of map area. Include clasts composed of white and gray angular chert, subrounded to rounded gray and dark-gray limestone and dolomite clasts averaging about 5 cm (3 in) in diameter derived from Paleozoic rock outcrops of the Virgin Mountains (Bohannon and Lucchitta, 1991; Beard, 1996). Poorly sorted to moderately sorted. Unconformably overlie red siltstone, sandstone, and conglomerate facies (Tgr) and strata of the Kaibab and Moenkopi Formations. Unit is strongly dissected by modern erosion. Support sparse growth of desert vegetation, mainly cactus of various types and creosote bush. Thickness, 60 m (200 ft) or more. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgr - Rocks of the Grand Wash Trough, red siltstone, sandstone, and conglomerate facies (Pliocene and Miocene)

Dark-red to orange-red, slope-forming, medium- to fine-grained, gypsiferous siltstone and sandstone overlain by cliff-forming, gray to light-orange-brown, coarse- to fine-grained, poorly sorted, consolidated silt, sand, gravel, and conglomerate. Clasts in upper conglomerate consist of about 90 percent limestone and dolomite, 5 percent sandstone, and 5 percent chert in gray gypsiferous siltstone and sandstone gravel matrix. Base of unit not exposed but assumed to unconformably overlie rocks of the Grand Wash Trough (Tgl, Tgg, and Tgx) and Mesozoic and Paleozoic rocks along basin margins. Conglomerate beds contain small subrounded to angular clasts of Proterozoic crystalline rocks along Pakoon Wash, northwest edge of map area. About 130 m (425 ft) of unit exposed along Grand Wash and Pakoon Wash drainages, increasing to about 450 to 470 m (1,475 to 1,550 ft) or more north of map area (Lucchitta and others, 1995a, b; Billingsley and Workman, 2000). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tbpb - Black Point Basalt flows (Pliocene)

Dark-gray to black plagioclase-aphyric basalt; surface weathers smooth and locally dissected. Contain scattered to abundant tabular plagioclase phenocrysts as large as 1 cm in diameter and includes abundant olivine microphenocrysts in feldspathic groundmass with intergranular to ophitic intergrowth of brown pyroxene and plagioclase. K-Ar age, 2.43±0.32 Ma (Ulrich and Bailey, 1987). Basalt flows form two lobes in map area; one extends northeast from south-central edge of map area for 26 km (16 mi) to the Little Colorado River, and the other lobe extends east-northeastward from Wupatki National Monument for 14 km (8.5 mi) referred to as the Citadel flow by Cooley (1962), but is mapped as the Black Point basalt flows (Ulrich and Bailey, 1987) because both lobes emerge from a single flow southwest of Wupatki National Monument. Basalt flows average about 12 m (40 ft) thick at Black Point where basalt filled a low-relief channel of Little Colorado River 1.5 km (1 mi) wide and extended down river about 5 km (3 mi). About 6 to 40 m (20 to 132 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Tscd - Old stream-channel deposits (Pliocene and Miocene)

Ts - Old stream-channel deposits (Pliocene and Miocene(?))

Red, gray, and light-brown, poorly sorted, partly consolidated, matrix-supported pebbles and boulders of well-rounded red, brown, gray, and purple quartzite or chert up to 48 cm (20 in) in diameter. Matrix consists of red, brown, and gray, partly consolidated, coarsely textured arkosic fluvial sandstone and siltstone. Form isolated sediments in early Tertiary paleodrainage of ancestral Kanab Creek system that eroded into the Moenkopi and Kaibab Formations on the Kanab Plateau. Only three deposits are preserved. Two deposits form small reddish hills; Cedar Knoll (sec. 4, T. 39 N., R. 1 W.) and Little Cedar Knoll (secs. 13 and 24, T. 39 N. R. 2 W.) about 17.5 km (11 mi) southeast of Fredonia, Arizona, near Forest Service Highway 212 at about 1,707 m (5,600 ft) elevation. Deposits are about 304 m (1,000 ft) above present level of Kanab Creek 13 km (8 mi) west of Cedar Knoll and Little Cedar Knoll. Unit is currently being mined for road gravel at Little Cedar Knoll. A third deposits fills a paleovalley channel eroded 3 to 5 m (10 to 15 ft) deep into Harrisburg Member of the Kaibab Formation between Jumpup and Sowats Canyons 3 km (2 mi) northeast of The Gooseneck (sec. 29, T. 37 N., R. 2 W.) at elevation 1,828 m (6,000 ft), south-central part of map area. Distance between Little Cedar Knoll south to The Gooseneck locality is about 22 km (14 mi); elevation drops about 183 m (600 ft) suggesting a southward paleogradient of about 13 m/km (43 ft/mi). Quartzite pebbles, cobbles, and boulders commonly form surface pavement or lag gravel in vicinity of Cedar Knoll, Little Cedar Knoll, and near The Gooseneck area. Quartzite pebbles and cobbles from Cedar Knoll and Little Cedar Knoll are commonly reworked into young, and old alluvial fan (Qay, Qao) deposits toward Kanab Creek and into young and old terrace-gravel (Qgy, Qgo) deposits. Quartzite pebbles and cobbles form minor patches of desert pavement or lag gravel surfaces down slope of Cedar Knoll and Little Cedar Knoll on bedrock surfaces. Quartzite gravels are present in old terrace-gravel (Qgo) deposits on southeast side of Muggins Flat area indicating that quartz gravels were derived from other outcrops in southern Utah. A minor quartzite lag gravel deposit is present near U.S. Highway 89A about 8 km (6 mi) northwest of Jacob Lake, Arizona, and does not represent a sedimentary deposit, but is indicated on the map to illustrate highest elevation 2,300 m (7,545 ft) for this type of lag gravel on Kaibab Plateau. Isolated remnants of quartzite lag gravels are scattered on several ridges on east side of Kaibab Plateau near 2,300 m (7,545 ft) elevation in the vicinity of U.S. Highway 89A, but are too thin and widely scattered to show on map. Thickest deposits are at Cedar Knoll, about 14 m (45 ft) thick and at Little Cedar Knoll, about 20 m (65 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Ts - Old stream-channel deposits (Pliocene(?) or Miocene)

Black Point area: Light-red, gray, and brown interbedded siltstone, sandstone, arkosic gravel, and lenticular conglomerate. Sediments are well sorted and consolidated beneath the Black Point Basalt flows (Tbpb) at Black Point, center of map area. Unconsolidated gravel sediments form rounded hill of Little Colorado River terrace and tributary alluvial fan deposit surrounded by the Black Point Basalt flows at Black Point. The Black Point Basalt (Tbpb) flowed northeast and east from the San Francisco Volcanic Field area down tributary drainage eroded into the lower half of the Moenkopi Formation to the Little Colorado River and flowed onto and around a stream delta or river terrace deposit and onto floodplain and channel of the Little Colorado River (fig. 1 on map). Basalt flowed a short distance upstream (south) and across river floodplain (east) about 1.5 km (1 mi) and downstream (north) about 3.5 km (2 mi); 2.43±0.51 Ma (Damon and others, 1974). Unit is the oldest Little Colorado terrace-gravel deposit in the map area. Base of deposit is 174 m (570 ft) above present Little Colorado River bed at Black Point at elevation 1,463 m (4,800 ft). The 207 m (680 ft) river down cutting estimate by Billingsley (1987b) from top the Black Point Basalt flow, not base of map unit. Similar and unconsolidated deposits cover floor of ancient meander channel of Little Colorado River superimposed and eroded into Harrisburg Member of the Kaibab Formation on Black Point Monocline about 1.5 km (1mi) south of Black Point; 174 m (570 ft) above present Little Colorado River. Sediments in small channel are mostly covered by quartzite lag gravel as is small terrace or alluvial fan hill surrounded by the Black Point Basalt flow.

Conglomerate consists primarily of well-rounded quartzite, chert, and minor clasts of granite and metamorphic rocks derived from older gravel deposits of the Mogollon Rim southeast of the map area; and local gray limestone clasts derived from Kaibab Formation; and red sandstone derived from Moenkopi Formation.
East of Gray Mountain area: Light-gray to reddish-gray silt, sand, gravel, pebbles, cobbles, and small boulder detritus derived from erosion of local Kaibab and Moenkopi Formation outcrops; unsorted and partly consolidated. Clasts of gray limestone, white chert, red sandstone, and grayish-black basalt are subrounded to well rounded; pebble imbrications indicating a general flow from southwest to northeast. Meander loops are superimposed into Harrisburg Member of the Kaibab Formation south of Gray Mountain prominence. Includes some well rounded basalt clasts from San Francisco Volcanic Field area that are likely older than basalt flow of Tappan Wash (Qbt) because the basalt of Tappan Wash is stratigraphically below most of the channel fill deposits. Fills old abandoned meander loops of an ancient tributary canyon drainage to the Little Colorado that meandered across the Kaibab and Moenkopi Formations, perhaps as old as Miocene age (Charles Barnes, oral commun., 2005). About 3 to 18 m (10 to 60 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Tocb - Basalt flow of Cedar Ranch Mesa (Miocene)

Dark-gray, massive, olivine-phyric basalt; weathers brown and has a smooth surface. Contains abundant 1- to 3-mm subhedral to euhedral olivine phenocrysts rimmed with iddingsite in a distinctive holocrystalline groundmass of intergranular to subophitic clinopyroxene and plagioclase. K-Ar age, 5.62 ±0.19 Ma (Ulrich and Bailey, 1987). Unit overlies Petrified Forest Member of the Chinle Formation and is susceptible to landslide mass wasting along northern edges of flow near Cedar Ranch. Partly buried by younger basalt flow (Qb). About 20 to 32 m (65 to 110 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Basalt of Shivwits Plateau (Miocene)

Informally named by Best and others (1980) for the Shiwits Plateau, northern Mohave County, Arizona. Includes a widespread mass of basaltic flows and associated pyroclastic vents and dikes at Blue Mountain and Price Point on Shiwits Plateau of this map area. Mount Dellenbaugh is the type section for the Shiwits basalt (sec. 2, T. 31N., R.12 W.), the highest point on Shiwits Plateau (elev. 7,072 ft) that forms a regional landmark 19 km (12 mi) north of the map area. K/Ar ages include 7.06±0.49 Ma and 4.75±0.26 Ma (Best and others, 1980); 6.2±0.30 Ma and 7.64±0.30 Ma (Lucchitta and McKee, 1975); 6.78±0.15 Ma (Reynolds and others, 1986); and 8.2±0.1Ma (Wenrich and others, 1995). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Informally named for Shiwits Plateau, Mohave County, Arizona. Mount Dellenbaugh is highest point (elev. 2,155 m [7,072 ft]) that forms a regional landmark on the southern Shiwits Plateau; type section for basalt of the Shiwits Plateau (sec. 2, T. 31 N., R.12 W.). Includes the 6.2±0.30 Ma and 7.64±0.30 Ma Shiwits basalt of Lucchitta and McKee (1974), 6.78±0.15 Ma Dellenbaugh basalt (Reynolds and others, 1986), 7.06±0.49 Ma Mt. Dellenbaugh basalt of Best and others (1980), 8.2±0.1 Ma Price Point basalt of Wenrich and others (1995). Includes numerous dikes, necks, pyroclastic deposits, and extensive basalt flows. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tsi - Shivwits Basalt, intrusive rocks (Miocene)

Tsi - Shivwits basalt, intrusive rocks (upper Miocene)

Gray-black, finely crystalline, alkali-olivine basalt. Approximate map contact. Source for extensive basalt

flows and pyroclastic deposits on the southern Shiwits Plateau west of Grand Canyon (average elev. 1,829 m [6,000 ft]). Dikes align about N. 30° W., similar to the 202-Mile dikes north of the map area. Average widths of dikes, about 2 m (6 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tsi - Basalt of the Shivwits Plateau, intrusive rocks (Miocene)
Gray-black, finely crystalline, alkali-olivine basalt. Approximate map contacts. Source for extensive basalt flows and minor pyroclastic deposits on Shiwits Plateau (average elev. 1,829 m [6,000 ft]). Dikes trend about N. 30° W., similar to dikes of Colorado River Mile 202 (T2i) east of Shiwits Plateau. Dike widths, 0.1 to 2 m (1 to 6 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tsp - Basalt of the Shivwits Plateau, pyroclastic deposits (Miocene)

Reddish-black scoria and cinder fragments, partly consolidated. Form small pyroclastic cones, heavily eroded and partly covered by basalt flows. Often interbedded with basalt flows near vent areas. Thickness, 12 m (40 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tsb - Shivwits Basalt, basalt flows (Miocene)

Tsb - Shivwits basalt, basalt flows (upper Miocene)
Gray-black, finely crystalline, alkali-olivine basalt. Groundmass contains olivine phenocrysts and plagioclase laths. Consist of one or more thin basalt flows overlying red and white mudstone, siltstone, sandstone, and gypsifereous siltstone beds of the Moenkopi Formation and gray siltstone and limestone of the Kaibab Formation. Form composite volcano of Blue Mountain and Price Point, Shiwits Plateau. Thickness, 2.5 to 122 m (8 to 400 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tsb - Basalt of the Shivwits Plateau, basalt flows (Miocene)
Gray-black, finely crystalline, alkali-olivine basalt. Groundmass contains olivine phenocrysts and plagioclase laths. Consist of one or more thin basalt flows overlying red and white mudstone, siltstone, sandstone, and gypsifereous siltstone beds of the Moenkopi Formation and gray siltstone and limestone of the Kaibab Formation. Form composite volcano of Blue Mountain and Price Point, Shiwits Plateau. Thickness, 2.5 to 122 m (8 to 400 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

T227i - 227-Mile intrusive (Miocene)

Informally named by Wenrich and others (1995). Gray alkali-olivine basalt dikes and sills exposed in Watahomigi Formation of the Supai Group, undivided (*Ms) about 4 km (2.5 mi) north of Colorado River Mile 227. K/Ar age of sill, 13.5±0.3 Ma (Wenrich and others, 1995). Dike and sill thickness, 1 to 3.5 m (3 to 12 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Blue Mountain Basalt (Miocene)

Forms Blue Mountain in Aubrey Valley (not Blue Mountain on Shiwits Plateau), the type locality (secs. 26 and 35, T. 26 N., R. 9 W.) K/Ar age is 14.63±1.10 Ma (Damon, 1968). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tbmi - Blue Mountain Basalt, dikes and necks (Miocene)

Dark-gray alkali-olivine basalt. Forms two small dikes, plugs, or necks southwest of basalt flow on top of unnamed mesa 6.5 km (4 mi) north of Blue Mountain in Aubrey Valley. Highest elevation dike intrudes upper part of the Hermit Formation (Ph); lowest elevation dike intrudes base of the Esplanade Sandstone (Pe). Dike widths, 0.5 to 3.5 m (2 to 12 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tbmb - Blue Mountain Basalt, basalt flows (Miocene)

Dark-gray alkali-olivine basalt. Include small basalt flow on top of unnamed mesa 6.5 km (4 mi) north of Blue Mountain of Aubrey Valley. Overlies old gravel and sedimentary (Ts1) deposits and young gravel and sedimentary (Tg) deposits. Source for basalt on unnamed mesa is likely from one of two dikes (Tbmi) just southwest of mesa. Blue Mountain Basalt is offset by three small normal faults. Thickness, 76 m (250 ft) at Blue Mountain; 6 m (20 ft) thick on top of unnamed mesa. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tp6i - Dikes of Parashant Canyon and Hundred and Ninetysix Mile Creek (Miocene)

Dark-gray, fine-grained to coarsely crystalline, olivine-augite basalt. Dikes commonly form recessive cracks in limestone rocks of canyon walls that appear as open eroded joints. Commonly eroded and chemically altered or decomposed, especially near Colorado River Mile 197 and in Hundred and Ninetysix Mile Creek. Several dikes parallel or occupy faults, but most parallel or occupy northwest-southeast-trending joints and fractures in bedrock for 25 km (15 mi) distance. No associated basalt flows are present. Dikes intrude Cambrian through Permian rocks from Colorado River Mile 197 to north rim of Parashant Canyon on the Shiwits Plateau and southeast of Colorado River into upper reaches of Hundred and Ninetysix Mile Creek. K-Ar age, 6.34±0.1 Ma from dike on Sanup Plateau, north side of Parashant Canyon (Wenrich and others, 1995). Other dikes near Colorado River are too chemically altered or decomposed for K-Ar age dating techniques. Dikes at Colorado River Mile 197 extend upward over 1,050 m (3,450 ft) into Esplanade Sandstone and Pakoon Limestone (Pep) where inner gorge is 3 km (2 mi) wide. Dike widths, 0.3 to 3 m (1 to 10 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

T2i - Dikes of Colorado River Mile 202 (Miocene)

Light-gray, coarsely to finely crystalline, olivine-augite basalt. Include three to four dikes that parallel and occupy northwest-trending joints, fractures, and minor faults in Paleozoic bedrock. Composition is basalt and andesite. K-Ar age is 5.76±0.26 (Wenrich and others, 1995). There appear to be no flows associated with dikes of Colorado River Mile 202, but some basalt flows on the Shiwits Plateau east of Mollies Nipple may be associated with dikes of Colorado River Mile 202. Dikes extend from the Muav Limestone (_m) up almost into the lower Toroweap Formation (Pt) near Mollies Nipple, east edge of Shiwits Plateau. Dikes are aligned to similar northwest-trending dikes at Yellow John Mountain on nearby Shiwits Plateau. Widths, 0.1 to 3 m (1 to 10 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Snap Point Basalt and Garrett Dikes (Miocene)

Includes basalt flow on Snap Point, upper Grand Wash Cliffs, and at Nevershine Mesa, Grand Wash Trough (Billingsley and others, unpub. data). Includes associated dikes (Garrett dikes) in Sanup Plateau

and at Colorado River Mile 264 in Grand Canyon. Informally named Snap Point basalt in Reynolds and others (1986) and Wenrich and others (1995). Because of the isolation and mappable occurrence of basalt flows and associated dikes, the Snap Point Basalt is herein formally named Snap Point Basalt for Snap Point, the type area, Shiwits Plateau, Mohave County, Arizona (sec. 16, T. 32 N., R. 14 W.). K-Ar age is 9.07±0.80 Ma at Snap Point (Reynolds and others, 1986) and 9.2±0.13 Ma for Garrett dikes on Sanup Plateau (Wenrich and others, 1995). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tsgi - Snap Point Basalt and Garrett Dikes, intrusive dikes (Miocene)

Dark-gray, greenish, finely crystalline, alkali-olivine basalt. Contain phenocrysts of augite and olivine less than 1 mm in diameter. Form near-vertical dikes orientated in north-south alignment parallel to local joints and fractures in Paleozoic bedrock units. Include dikes in Pigeon Canyon north of Snap Point that lie on similar north-south trend of Garrett dikes south of Fort Garrett Point. Intrude all Paleozoic rocks in walls of Grand Canyon on both sides of Colorado River Mile 264 and in tributaries of Tincanebitts and Dry Canyons. Exposed dikes in canyon walls reveal that Grand Canyon was not as deep or wide 9 m.y. ago as it is today. Dike widths, 0.5 m (1 to 2 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tsgb - Snap Point Basalt and Garrett Dikes, basalt flows (Miocene)

Dark-gray alkali-olivine basalt. Basalt originates from dike source near highest part of Snap Point. Consists of two separate basalt flows, one flowed east about 2.4 km (1.5 mi) down drainage eroded into Fossil Mountain Member of the Kaibab Formation (Pk) on the Shiwits Plateau and another flowed west down steep erosional escarpment of upper Grand Wash Cliffs into Snap Canyon drainage and into Grand Wash Trough below lower Grand Wash Cliffs. Snap Canyon was filled to a depth of several hundred meters by alluvial deposits (Tgc) at time of Snap Point flow. Alluvial deposit forms large alluvial debris fan at the mouth of Snap Canyon (Billingsley and others, unpub. data). Snap Point Basalt flowed into Grand Wash Trough and was subsequently buried by younger alluvial fan deposits. Modern erosion has removed most of the alluvial deposits (Tgc) from around the Snap Point Basalt to form an inverted topographic feature called Nevershine Mesa. Thickness, 3 to 10 m (10 to 30 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Rocks of the Grand Wash Trough (Miocene)

The Tertiary and Quaternary alluvial rocks in the Grand Wash Trough were collectively called the Muddy Creek Formation by Lucchitta (1979), but recent studies by Bohannon (1984, 1991, 1992), Bohannon and others (1993), and Beard (1996) have determined that these sedimentary rocks are not connected to the Muddy Creek Formation of the Muddy River area farther west but are rocks that have formed in separate basins at about the same time as the Muddy Creek. The Hualapai Limestone of Lucchitta (1979) is equivalent to sediments of gypsum and gypsiferous siltstone facies (Tgg) and limestone and siltstone facies (Tgl) north of Lake Mead. Tertiary sediments, alluvial rocks (Tgx, Tgg, Tgl, Tgc, Tgr, Tao, Tay), and volcanic rocks (Tb) of the Grand Wash Trough unconformably overlie the Horse Spring Formation (Ths; Billingsley and others, unpub. data). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgc - Rocks of the Grand Wash Trough, paleozoic-clast conglomerate (Miocene)

Tgc - Paleozoic-clast conglomerate (Miocene)
Light-gray, brown, ledge- and slope-forming, poorly sorted, poorly bedded alluvial fan debris flows derived from Paleozoic strata in the Grand Wash Cliffs; clasts dominantly limestone and dolomite. Unit thins west and southwest of Grand Wash Cliffs. Thickness, 677 m (2,220 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tgc - Rocks of the Grand Wash Trough - Paleozoic-clast conglomerate facies (Miocene)
Gray, cliff-forming, rounded to subrounded clasts of Paleozoic limestone and sandstone from 1 to 70 cm (1 to 28 in) in diameter mixed with coarse gravel and conglomerate derived from Paleozoic rocks of the Colorado Plateau. Consolidated by calcium and gypsum cement. Forms alluvial debris fans at the mouths of Pigeon, Pearce, and Snap Canyons and several small unnamed drainages from the Grand Wash Cliffs. Lower part of unit includes lenses of reddish and red-brown sandstone gravel and conglomerate, poorly sorted and consolidated by calcite and gypsum cement. Gradational and intertonguing vertical and horizontal contact arbitrarily marked between lithologic change at bottom of conglomeratic facies (Tgc) and top of underlying limestone and siltstone facies (Tgl), and gypsum and gypsiferous siltstone facies (Tgg). Unit gently folded and highly fractured near base of Grand Wash Cliffs. Unit thins rapidly west from Grand Wash Cliffs, thickest near mouths of Snap, Pigeon, and Pearce Canyon drainages. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgl - Rocks of the Grand Wash Trough, limestone and siltstone facies (Miocene)

Gray, silty, crystalline limestone, light-red, gray, and greenish-gray gypsiferous siltstone, gray to reddish-gray calcareous sandstone, and gray to white gypsum. Limestone beds are vuggy, irregularly bedded, 1 to 10 m (3 to 30 ft) thick. Contain abundant plant and algae fossils indicative of freshwater inland basin deposits. Include interbedded gray, greenish-gray, and reddish-gray gypsiferous mudstone and siltstone that grade into underlying gypsum and gypsiferous siltstone facies (Tgg). Siltstone and sandstone beds thin or thicken laterally at expense of equivalent limestone beds. Sandstone beds are conglomeratic in places with small, rounded clasts of chert, quartzite, and carbonate fragments. Gradational and arbitrary vertical and horizontal contact with underlying gypsum and gypsiferous siltstone facies (Tgg). Intertongues laterally into Proterozoic-clast conglomerate facies (Tgx) in lower part of unit and unconformably overlies Proterozoic-clast conglomerate facies (Tgx) in upper part of unit east of Wheeler Fault. Limestone beds are moderately folded as much as 13° in upper part of basin near Grand Wash. Includes one white and one light-brown (0.5 to 1 m [1 to 3 ft]) thick tuff bed between limestone beds. Limestone beds are likely the equivalent of the Hualapai Limestone of Lucchitta (1979) south of Lake Mead. Thickens south to as much as 305 m (1,000 ft) at Lake Mead. Thickness in map area, 60 to 70 m (200 to 230 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgg - Rocks of the Grand Wash Trough, gypsum and gypsiferous siltstone facies (Miocene)

Gray and gray-white gypsum, greenish-gray, light-red, and reddish-gray gypsiferous siltstone and mudstone. Upper 15 to 20 m (50 to 65 ft) consists mostly of multicolored, banded, thin-bedded mudstone and gypsiferous siltstone interbedded with thin-bedded (0.5 to 1 m [1 to 3 ft]), dark-gray limestone beds. Includes beds of pinkish-white to light-gray, cliff-forming tuffaceous limestone and white tuff beds, 0.5 to 1 m (1 to 3 ft) thick in upper part. Forms Gyp Hills badlands area east of Wheeler Fault. Upper siltstone and mudstone beds grade downward into gray silty gypsiferous siltstone and massive

gray gypsum. Unit gently folded except along trace of Wheeler Fault where beds dip west as much as 65°. Base of unit not exposed. Intertongues with Proterozoic-clast conglomerate facies (Tgx). Thickness, 120 m (400 ft) or more. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tgx - Proterozoic-clast conglomerate facies (Miocene)

Dark-gray to reddish-brown, cliff- to resistant slope-forming conglomerate. Includes interbedded lenses of gravel and sandstone, poorly sorted and moderately well bedded; consolidated. Clasts are composed of reddish-brown, brown, red, grayish-green, and light-green, well-rounded rhyolite, black biotite schist, gneiss, gabbro, diorite, red pegmatite, granite, white quartz, gray limestone and dolomite, and red sandstone derived from the Jumbo Peak about 19 km (12 mi) west of map area. Include large boulders as much as 1.5 m (5 ft) in diameter that were probably carried in by large debris flows. Base of unit not exposed. About 675 m (2,275. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Volcanic rocks of the Mount Floyd Volcanic Field (Miocene)

Volcanic rocks in the southwest part of the map area represent the northern part of the Mount Floyd Volcanic Field and have not been studied in detail. Paleomagnetic ages have not been determined. Hand specimens have been identified in the field during the course of this mapping project and are assigned temporary rock unit descriptions that are subject to change pending future investigations. A suggested general 40Ar/39Ar age for the northern part of the Mount Floyd Volcanic Field is 6.76±0.13 Ma and 6.38 ±0.04 Ma (Peters, 2002). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tri - Volcanic rocks of the Mount Floyd Volcanic Field, rhyolite, rhyodacite, and obsidian dikes, necks, and vent areas (upper Miocene)

Red, gray, and black rhyolite and rhyodacite. Rhyolite exhibits convoluted and twisted thin platy flow patterns; weathered outcrops resemble roof shingles. Map contacts are approximate because erosion has not fully exposed extent of these intrusive features. Vent area is source for extensive rhyolite, rhyodacite, and obsidian flows that overlie older basalt flows east of Red Lake. Include dikes and flows of black, gray, and red obsidian within vent areas. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tr - Volcanic rocks of the Mount Floyd Volcanic Field, rhyolite, rhyodacite, and obsidian flows (upper Miocene)

Light gray, dark red, and grayish-black. Obsidian flows are mostly black obsidian but often contain black and gray-banded obsidian or red to red and black obsidian east of Red Lake and southwest of Black Tank Camp (sec. 18, T. 26 N., R. 4 W.). 40Ar/39Ar age, 6.38±0.04 Ma (Peters, 2002). Flows overlie one or more olivine basalt flows (Tba). Thickness, 30 to 200 ft (9.2 to 60 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tiba - Volcanic rocks of the Mount Floyd Volcanic Field, basalt and andesite dikes, plugs, and necks (upper Miocene)

Ti - Volcanic rocks of the Mount Floyd Volcanic Field - Basalt and andesite dikes, plugs, and necks (upper Miocene)
Dark-gray, finely crystalline alkali-olivine basalt. Contains augite and olivine phenocrysts in glassy groundmass. Intrusive units align in north or northwest trend, which parallel local prominent north and northwest strike of near-vertical fractures, joints, and faults in bedrock strata of the Coconino Plateau area. Dikes are 2 to 30 ft (0.6 to 9.2 m) wide; necks are as much as 100 ft (30 m) in diameter. Includes hypothetical laccolithic intrusion beneath Howard Hill as shown on cross section A–A´. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tba - Volcanic rocks of the Mount Floyd Volcanic Field, basalt and andesite flows (upper Miocene)

Dark- to light-gray, finely crystalline alkali-olivine basalt. Most of the basalt came from elongated fissure dikes (Ti) and vent areas beneath pyroclastic cone deposits (Tp). Basalt flowed onto flat, partly eroded Tertiary sedimentary rocks of freshwater limestone, sandstone, and siltstone (Ts). Several basalt flows merge or coalesce into one large flow suggesting an eruptive phase of a similar time; 40Ar/39Ar age, 6.76±0.13 Ma (Peters, 2002) at Duff Brown Tank (sec. 28, T. 26 N., R. 3 W.). Thickness, 25 to 300 ft (7.5 to 92 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Tc - Pyroclastic deposits (Miocene)

Tc - Volcanic rocks of the Hualapai Plateau - Pyroclastic deposits (middle to lower Miocene)
Red basaltic pyroclastic cinder cone deposits at Grapevine Canyon, northwest corner of map area, west edge of Hualapai Plateau. Overlie Devonian and Mississippian strata on rim and within Grapevine Canyon and overlain by thick alkali-olivine basalt flows (Tv). Pyroclastic deposits and basalt flows within Grapevine Canyon indicate that Grapevine Canyon is older then 15.3 Ma. Include deposits on rim of upper Meriwhitica Canyon west of Meriwhitica Monocline. Thickness, 9 to 60 m (30 to 200 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tp - Volcanic rocks of the Mount Floyd Volcanic Field - Pyroclastic deposits (upper Miocene)
Red and reddish-gray cinders, scoria, ash, and glassy fragments of basalt, partly unconsolidated. Form pyroclastic cones that overlie associated basalt and andesite flows (Tba). Cones are extensively eroded and gullied. Thickness, 20 to 400 ft (6 to 122 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Volcanic rocks of the Hualapai Plateau (Miocene)

Deposits include scattered remnants of basalt flows in southwest corner of map area that appear to have originated from the 17.4±0.9 Ma Iron Mountain basalt southwest of the map area and the 15.3±0.3 Ma Grapevine Canyon volcanic rocks south of the map area (Wenrich and others, 1995). Includes the 17.4 ±0.3 Ma plug of The Grand Pipe, a breccia pipe named by Wenrich and others (1996), Sanup Plateau, 3 km (2 mi) north of Colorado River Mile 275. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tv - Volcanic rocks of the Hualapai Plateau, andesite flows and basalt flows, undivided (Miocene)

Tv - Volcanic rocks of the Hualapai Plateau - Andesite flows and basalt flows, undivided (middle to lower Miocene)
Volcanic deposits on the Hualapai Plateau are alkali-olivine basalt and andesitic basalt flows, agglomerate, volcanogenic fluvial sediments, and rhyolite ash flows derived from local and distant sources. Deposits include the Separation Hill basalt near the upper reach of south Separation Canyon on the Hualapai Plateau, K/Ar age, 19.0±0.44 Ma (Wenrich and others, 1995); the Peach Springs basalt at the town of Peach Springs, Arizona, K/Ar age 19.9±0.4 Ma (Wenrich and others, 1995); the Peach Springs Tuff, a gray welded rhyolitic ash-flow tuff that occupies Tertiary paleovalleys in Milkweed and Peach Springs Canyons; K/Ar age 18.5±0.2 Ma (Neilson and others, 1990) average thickness, about 9 m (30 ft); the Iron Mountain basalt, northwest corner of map,K/Ar age 17.4±0.9 Ma (Wenrich and others, 1995); and the Grapevine Canyon volcanics at Grapevine Canyon, northwest corner of map, K/Ar age 15.3±0.3 Ma (Wenrich and others, 1995). Variable thickness, 1 to 73 m (3 to 240 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tv - Volcanic rocks of the Hualapai Plateau, undivided, basalt flows (early to middle Miocene)
Alkali-olivine basalt flows. Scattered remnants of basalt are part of extensive flows that flowed north down drainages from Iron Mountain about 11 km (7 mi) southwest of map area and flows from the Grapevine Canyon volcanic area south of the map. Basalt overlies Tertiary gravel deposits that may be part of the Buck and Doe Conglomerate of Young (1999). No age or chemical studies have been done on these basalts. Thickness, 2 to 4 m (6 to 12 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Ti - Volcanic rocks of the Hualapai Plateau, intrusive dikes (Miocene)

Ti - Intrusive dikes (Miocene)
Dark-gray basalt composed of plagioclase, clinopyroxene, olivine, and opaque oxides. Dikes occur in Moenkopi Wash southwest of Tuba City, in Hamblin Wash south of The Gap, at Tuba Butte northwest of Tuba City, and at Wildcat Peak northeast of Tuba City. Dikes are extensively weathered and are 2 to 6 ft (0.05 to 2 m) wide and 15 to 33 ft (5 to 10 m) in height. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ti - Volcanic rocks of the Hualapai Plateau - Dikes, plugs, and necks (middle to lower Miocene)
Alkali-olivine basalt and andesitic basalt plugs, necks, or dikes in Milkweed and Horse Flat Canyons and on Hualapai Plateau. Includes dikes associated with unnamed dome near Nelson, Arizona (southeast corner of map area). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Tvi - Volcanic rocks of the Hualapai Plateau, undivided, Plug of The Grand Pipe (early to middle Miocene)
Alkali-olivine basalt plug or dike in ring fracture of The Grand Pipe of Wenrich and others (1996) on the Sanup Plateau. K-Ar age, 17.4±0.3 Ma (Wenrich and others, 1996). Plug is about 10 m (30 ft) in diameter and is the source for remnants of eroded basalt flow on small hill on south side of The Grand Pipe. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Tbfn - Volcanic rocks of the Hualapai Plateau, basalt flow of Nelson (middle to lower Miocene)

Tb - Volcanic rocks of the Hualapai Plateau - Basalt flow of Nelson (middle to lower Miocene)
Alkali-olivine basalt associated with intrusive laccolith or dome at Nelson, Arizona, and an unnamed hill

1.5 km (1 mi) northwest of Grand Canyon Caverns, Arizona. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Ths - Horse Spring Formation, Rainbow Gardens Member (Miocene and Oligocene)

Named the Cottonwood Wash Formation by Moore (1972), but these rocks have close lithologic and stratigraphic similarity to the Rainbow Gardens Member of the Horse Spring Formation as proposed by Bohannon (1984) and formally defined by Beard (1996).

Includes basal conglomerate and middle limestone and sandstone unit. Consists of complex intertonguing sequence of clastic and carbonate lithofacies. Upper unit of the Rainbow Gardens Member is not exposed within map area but is assumed to be present in subsurface where it is covered by younger rocks of the Grand Wash Trough. The Thumb Member of the Horse Spring Formation may be present in subsurface. Age of Rainbow Gardens Member of the Horse Spring Formation is bracketed between 26 Ma and 18.8 Ma (Beard, 1996). Only one outcrop is exposed in map area just east of Tassi Spring on upthrown side of Wheeler Fault (southwest corner of map area). Unconformable contact with underlying Kaibab Formation and both units dip 24° to 34° east-southeast. Unconformably overlain by Proterozoic-clast conglomerate facies (Tgx) of rocks of the Grand Wash Trough. Incomplete section, 132 m (435 ft) exposed. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

TKs1 - Old gravel and sedimentary deposits (lower Miocene, Oligocene, Eocene, Paleocene, and Upper Cretaceous)

Ts1 - Old gravel and sedimentary deposits (lower Miocene, Oligocene, Eocene, Paleocene, and Upper Cretaceous)

Include, undivided, the Music Mountain Formation, West Water Formation, Hindu Fanglomerate, Buck and Doe Conglomerate of Young (1999) on the Hualapai Plateau. Include the Frazier Wells gravel of Koons (1964) on Coconino Plateau and upper Aubrey Valley formally renamed the Music Mountain Formation by Young (1999). Composed of poorly sorted, partly consolidated, matrix-supported pebbles and boulders of well-rounded granite, gneiss, schist, and red and white quartzite, as much as 48 cm (20 in) in diameter. Matrix consists of brown to red, partly unconsolidated, coarsely textured arkosic sandstone and siltstone. Form gravely sediments in early Tertiary paleocanyon drainages eroded into Hualapai Plateau, and form widespread alluvial fan deposits in upper Aubrey Valley and on Coconino Plateau. Form rounded hills and slopes where weathered; produce extensive lag gravel deposits. Quartzite pebbles and cobbles commonly reworked into young gravel and sedimentary (Tg) deposits or old gravel (QTg) deposits on Hualapai and Coconino Plateaus and in Aubrey and Truxton Valleys. Quartzite pebbles, cobbles, and boulders commonly form surface pavement or lag gravel making it difficult to distinguish younger sediments from older sediments. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Ts - Sedimentary rocks (lower Eocene and upper Paleocene)

Light-red, gray, and white interbedded siltstone, sandstone, arkosic gravel, lenticular conglomerate, and gray, thin-bedded [1 to 3 ft (0.5 to 1 m)] freshwater limestone. Limestone beds contain long vertical tubular structures generally ½ inch (0.12 cm) in diameter and 2 ft (1.3 m) in length and early Eocene to late Paleocene snail fossils (Young and Hartman, 1984; Young, 2001). Thickest limestone beds are near Black Tank Camp (sec. 3, T. 26 N., R 4 W.) and at Duff Brown Tank (sec. 28, T. 26 N., R. 3 W.).

Conglomerate beds are thickest at the base of sedimentary rocks and are partly consolidated thin units within the sedimentary sequence. Conglomerate clasts consist primarily of quartzite, chert, and minor granite or metamorphic crystalline rocks derived from sources south of map area as far away as Prescott and Kingman, Arizona. Clasts are well rounded and weather out of the general slope deposit and form extensive lag gravel deposits within several miles of outcrop. Several outlying hills are covered by lag gravel conglomerate derived from the erosion of Tertiary sedimentary rocks north of the Mount Floyd Volcanic Field. Extensive conglomerate and sandstone deposits form rounded hills or ridges in the Rose Well Camp vicinity. Rocks of the Mount Floyd Volcanic Field form a protective caprock over these Tertiary sedimentary rocks throughout the southwest quarter of the map area. Thickness, 60 to 180 ft (18 to 55 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

TKs2 - Oldest gravel and sedimentary deposits (Paleocene(?) and Upper Cretaceous)

Ts2 - Oldest gravel and sedimentary deposits (Paleocene(?) and Upper Cretaceous)
Include Robbers Roost gravel of Koons (1948a, b) on Coconino Plateau and upper Aubrey Valley east of Toroweap Fault; composed primarily of sandstone clasts derived from the Coconino Sandstone and limestone and chert clasts derived from the Toroweap and Kaibab Formations as mapped by Billingsley and others (2000b). Unit is well consolidated in cherty, coarse-grained sandy gray matrix cemented by calcium. Clasts are well rounded, well sorted; clast imbrication indicates deposition by north-flowing drainage. Deposit fills ancient drainage valley eroded into Toroweap and Kaibab Formations east of Diamond Creek on Coconino Plateau. Deposit is partly eroded and inset by younger drainage filled with old gravel and sedimentary deposits (Ts1), called Frazier Wells gravel of Koons (1964); renamed Music Mountain Formation by Young (1999). Thickness, 12 to 67 m (40 to 220 ft).
A second and similar deposit occupies a lower elevation north-south paleovalley southeast of Diamond Creek; deposit composed of red-gray silt, sand, gravel, pebbles, and boulders of limestone, sandstone, and chert derived from local Permian outcrops of Esplanade Sandstone, Hermit Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Formation. Unit is well consolidated by calcite and gypsum cement and forms resistant rounded hills or cliffs. Clasts are rounded to angular and include talus debris from local paleovalley walls. Deposit occupies bottom of paleovalley eroded into Hermit Formation; paleovalley is widest at southern extension near Blue Mountain and narrows northward toward Tower of Babylon in upper Diamond Creek. The lower elevation paleovalley is likely younger than the similar Paleozoic higher elevation clastic paleovalley southeast of the Toroweap Fault. Thickness, 60 m (200 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Kp - Quartz monzonite pluton (Upper Cretaceous)

Tp - Quartz monzonite pluton (Upper Cretaceous)
Gray-brown, coarsely crystalline plagioclase-hornblende-biotite-bearing pluton about 0.8 km (½ mi) in diameter. K/Ar age 65.5±3.5 Ma. Pluton intrudes Cambrian sedimentary rocks of Grand Wash Cliffs, near Clay Springs, northwestern Hualapai Plateau (Young, 1979). Unconformably overlain by 19-Ma basalt flows (Tv). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Km - Mancos Shale (Upper Cretaceous)

Km - Mancos Shale (Upper Cretaceous)
The Morrison Formation consists of two members in the Glen Canyon Dam quadrangle. They are, in ascending order, the Salt Wash Member and Brushy Basin Member. The basal Tidwell Member is thin

and interbedded light-gray, fine- to medium-grained sandstone. Includes bentonitic claystone, siltstone, and thin-bedded limestone. Unit is largely covered by dune sand and sand sheet deposits on White Mesa. Locally fossiliferous with cephalopods and other marine fossils that date unit as Late Cretaceous. Deposited on a shallow sea floor that transgressed southwest from the midcontinent. Unit is laterally equivalent to the Tropic Shale of lower part of Mancos Shale in southern Utah (Doelling and others, 2000; Anderson and others, 2000). Gradational contact with underlying Dakota Sandstone. Unit is partially preserved on White Mesa, southeast corner of quadrangle, and mostly removed by Tertiary erosion elsewhere. Thickness, 60 ft (18 m) . (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Km - Mancos Shale (Upper Cretaceous)

Bluish-gray to light-gray, thinly laminated to thin-bedded, slope-forming, carbonaceous claystone, siltstone, and mudstone with interbedded light-gray, fine- to medium-grained sandstone. Includes bentonitic claystone, siltstone, and some thin-bedded limestone. Locally fossiliferous with cephalopods that are laterally equivalent to those in the Tropic Shale in the lower part of Mancos Shale in southern Utah. Age as defined by Doelling and others (2000). Deposited on a shallow sea floor that transgressed southwest from the midcontinent. Gradational and arbitrary contact with underlying Dakota Sandstone (Kd). Deposit is mostly removed by Tertiary erosion on Moenkopi Plateau south of Moenkopi Wash. Erosion channels as deep as 20 ft (6 m) are filled with Tertiary gravel and sedimentary deposits (Tgs) and probably represent widespread alluvial pediment and stream-channel deposition. Largely covered by sand sheet (Qes) and dune sand and sand sheet (Qd) deposits at Coal Mine Mesa on Moenkopi Plateau in southeast corner of map (sheet 2) and on White Mesa in northeast corner of map (sheet 2). Thickness, 140 ft (43 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Km - Mancos Shale (Upper Cretaceous)

Bluish-gray to light-gray, thinly laminated to thin-bedded, slope-forming, carbonaceous claystone, siltstone, and mudstone with interbedded light-gray, fine- to medium-grained sandstone. Includes bentonitic claystone, siltstone, and some thin-bedded limestone. Locally fossiliferous with cephalopod faunas that are laterally equivalent to the Tropic Shale Formation in the lower part of the Mancos Shale in southern Utah. Sediments were deposited on shallow sea floor that transgressed westward from the mid-continent area. Gradational and arbitrary contact with underlying Dakota Sandstone (Kd). Sediments are mostly removed by Cenozoic erosion and largely covered by old eolian sand sheet and dune (QTes) deposits at Coal Mine Mesa on Moenkopi Plateau, northeast corner of map area. About 43 to 60 m (140 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Kd - Dakota Sandstone (Upper Cretaceous)

Kd - Dakota Sandstone (Upper Cretaceous)

Described as Dakota Formation in Utah (Doelling and Davis, 1989), referred to as Dakota Sandstone in Arizona to match nomenclature of the Cameron 30' x 60' quadrangle (Billingsley and others, 2007), the Tuba City 30' x 60' quadrangle (Billingsley and others, 2012), and the Winslow 30' x 60' quadrangle (Billingsley and others, 2013). Medium- to light-gray, slope-forming, laminated to thin-bedded mudstone, siltstone, and sandstone. Locally includes a lower conglomerate to conglomeratic sandstone member, a middle carbonaceous mudstone to coal member, and an upper sandstone member as defined by O'Sullivan and others (1972) in the northeast and southeast corners of quadrangle.
Lower sandstone member: Light-orange to light-gray silty sandstone and conglomeratic sandstone that forms a cliff as much as 20 ft (6 m) thick. Occupies channels eroded into underlying Entrada Sandstone at White Mesa and into Salt Wash Member of the Morrison Formation on Cummings Mesa that marks the regional angular Cretaceous (K-0) unconformity (Pipiringos and O'Sullivan, 1978; Peterson and Turner-Peterson, 1987). Clasts in sandstone are composed of red and gray, well-rounded chert and quartzite typically less than 2 in (5 cm) in diameter. Base of Dakota Sandstone locally overlies younger strata from Cummings Mesa south to White Mesa owing to beveling of underlying Jurassic rocks

southwestward across the quadrangle and younger rocks north of the quadrangle in Utah (Doelling and Willis, 2006; Doelling and Davis, 1989; Doelling and others, 2000; Anderson and others, 2000; Peterson, 1988). Overlies progressively older rocks south and southeast of the quadrangle (Harshbarger and others, 1958; Cooley and others, 1969; Billingsley and others, 2012). Although these relations establish the angularity of the Cretaceous pre-Dakota Sandstone unconformity (K-0), the angularity is so small that it is not apparent at most outcrops within the Glen Canyon quadrangle.
Middle carbonaceous member: Dark-grayish-brown, carbonaceous, flat-bedded mudstone, siltstone, coal, and interbedded brown, conglomeratic, crossbedded lenticular sandstone. Coal beds are generally less than 1 ft (0.3 m) thick on White Mesa. Gypsum is a common constituent in siltstones appearing as thin veins and isolated crystals. The upper sandstone member is not present in the quadrangle. Unit is mostly covered by dune sand and sand sheet deposits at White Mesa and Cummings Mesa.
The upper sandstone member of the Dakota Sandstone may be partly present on White Mesa but was not verified in the field and is included with the middle carbonaceous member. Overall thickness, 10 to 40 ft (3 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Kd - Dakota Sandstone (Upper Cretaceous)
Medium- to light-gray, slope-forming, laminated to thin-bedded mudstone, siltstone, and sandstone. Locally includes lower sandstone, middle carbonaceous, and upper sandstone members as defined by O'Sullivan and others (1972; northeast and southeast corners of map). Age as defined by Doelling and others (2000)
Lower sandstone member: Light-orange to light-gray silty sandstone and conglomeratic sandstone that forms cliffs as much as 20 ft (6 m) thick seen in channels eroded into underlying Entrada Sandstone-Cow Springs Sandstone, undivided (Je). Unit pinches out or thins in short lateral distance within channels. Clasts in sandstone are composed of red and gray, well-rounded chert and quartzite typically less than 2 in (5 cm) in diameter. The regional angular unconformity between the Dakota Sandstone and underlying Jurassic-Cretaceous rocks is based on the Dakota Sandstone overlying younger rocks north of the map area and overlying older rocks south and southeast of the quadrangle. Although these relations establish the angularity of the pre-Dakota Sandstone age unconformity, the dip is so small that it is not apparent at most outcrops within the area (Harshbarger and others, 1958)
Middle carbonaceous member: Dark-grayish-brown, carbonaceous, flat-bedded mudstone, siltstone, and coal and interbedded brown, conglomeratic, crossbedded lenticular sandstone. Coal beds are generally less than 2 ft (0.5 m) thick at east end of Coal Mine Mesa on Moenkopi Plateau (southeast corner of map). Coal was mined from thicker coal beds at the rim of Coal Mine Canyon. Coal-seam fires in the recent past add vibrant red color (baked clay) in upper cliffs of Coal Mine Canyon. Gypsum is a common constituent in the siltstones, appearing as thin veins and isolated crystals. The upper sandstone member is not present in the map area
Unit unconformably overlies Entrada Sandstone-Cow Springs Sandstone, undivided (Je), in eastern part of Coal Mine Mesa where lower sandstone member is not present (J-2 unconformity of Pipiringos and O'Sullivan, 1978). Mostly covered by extensive dune sand and sand sheet (Qd) deposits. Overall thickness, 10 to 40 ft (3 to 12 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Kd - Dakota Sandstone (Upper Cretaceous)
Medium- to light-gray, slope-forming, laminated to thin-bedded mudstone, siltstone, and sandstone. Locally includes the lower sandstone and middle carbonaceous members as defined by O'Sullivan and others (1972). The upper sandstone member is not present in the map area.
Lower sandstone member is light-orange to light-gray silty sandstone and conglomeratic sandstone in lower part. Unit is well cemented and forms a cliff that fills erosional channels as much as 6 m (20 ft) thick and locally pinches out laterally in short distances. Pebble clasts in conglomeratic sandstone lenses are composed of red and gray, well-rounded chert and quartzite typically less than 5 cm (2 in) in diameter. Unit unconformably overlies white sandstone beds of the Entrada Sandstone (Je). The regional unconformity between the Dakota Sandstone and underlying Jurassic-Cretaceous rocks has been established as an angular regional unconformity, based on the Dakota Sandstone overlying younger rocks north of the map area and overlying older rocks south and southeast of the map area. Although

these relationships establish the angularity of the pre-Dakota Sandstone age unconformity, the angularity is so small that it is not apparent at most outcrops within the Navajo Country (Harshbarger and others, 1958).
Middle carbonaceous member is dark-grayish-brown, carbonaceous, flat-bedded mudstone, siltstone, coal, and interbedded brown, conglomeratic, crossbedded lenticular sandstone. Coal beds are generally less than 0.5 m (2 ft) thick and present only at east end of Coal Mine Mesa of map area. Coal was mined from thicker coal beds at the rim of Coal Mine Canyon just north of the northeast corner of map area. Gypsum is common constituent as thin stringers and as isolated crystals. Unit unconformably overlies the Entrada Sandstone in east part of Coal Mine Mesa where lower sandstone member is not present (J-2 unconformity of Pipiringos and O'Sullivan, 1978). Unit is mostly covered by extensive old dune deposits, undivided (QTd). Best exposures are southwest of Coal Mine Mesa at Appaloosa Ridge, northeast corner of map area. Overall thickness, about 3 to 12 m (10 to 40 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Jms - Morrison Formation, Salt Wash Member (Upper Jurassic)

Light-brown to gray, cliff-forming, thick-bedded, fluvial and conglomeratic, coarse-grained sandstone. Forms massive upper sandstone cliffs on Cummings Mesa and most other buttes and mesas farther west. Unit weathers to light-brown or gray cliffs and is unconformably overlain by patches of Dakota Sandstone on Cummings Mesa and at the top of Tse Esgizii Butte and LeChee Rock (K-0 unconformity). The J-5 unconformity marks the basal contact of the Salt Wash Member with the underlying Romana Sandstone. Erosion of the Salt Wash Member beneath the regional K-0 unconformity accounts for the westward thinning of the Salt Wash Member of the Morrison Formation. Thickness, 0 to 380 ft (0 to 116 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

San Rafael Group (Middle Jurassic)

The San Rafael Group includes, in ascending order, the Page Sandstone, the Carmel Formation the Entrada Sandstone, and the Romana Sandstone that overly the Navajo Sandstone at the J-2 unconformity. The eolian Page Sandstone and shallow marine to sabkha Carmel Formation were deposited marginal to a seaway that advanced southward into southwestern Utah and northwestern Arizona (Peterson, 1994). The Carmel Formation and Entrada Sandstone extended to the Moenkopi Plateau south of the quadrangle (Billingsley and others, 2012). Overlying the Carmel, the Entrada and Romana Sandstones were deposited in eolian shoreline and marginal marine environments (Peterson, 1988). The Page Sandstone is included within the San Rafael Group because it intertongues with the Carmel Formation, and both units unconformably overlie the Navajo Sandstone where they are present directly on top of the Navajo Sandstone. (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

The San Rafael Group (Middle Jurassic) includes, in ascending order, the Carmel Formation (Jc) and the Entrada Sandstone (Je) that overlies beveled crossbeds of the Navajo Sandstone (Jn), known as the J-2 unconformity that is recognized primarily on differences in lithology and color change from white sandstone of the Navajo to red siltstone of the Carmel. The Carmel Formation represents a shallow marine environment within a seaway that moved southward from Canada into northern Arizona and extended to and pinches out in the subsurface of Coal Mine Mesa. Overlying the Carmel Formation are white and red sandstone deposits of the Entrada Sandstone-Cow Springs Sandstone, undivided (Je), that represent a coastal beach and marine tidal flat. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Jr - Romana Sandstone (Middle Jurassic)

Brown to gray, cliff-forming, thick-bedded, eolian, flat-bedded, fine- to medium-grained sandstone containing scattered grit and granules; weathers to a shear brown cliff that overlies white and red cliffs of Entrada Sandstone. Contact with Entrada Sandstone is visibly identifiable in several small buttes between Page, Arizona, and Cummings Mesa along northern border of quadrangle based on weathered color differences and local access. Lithologically, the Romana Sandstone is somewhat more coarse grained then the underlying Entrada Sandstone. Unit pinches out southwards, thins northeast and east of Cummings Mesa, and has been removed by Cretaceous erosion south of Cummings Mesa and west of Page, Arizona. Thickness, 0 to 175 ft (0 to 53 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Je - Entrada Sandstone (Middle Jurassic)

Je - San Rafael Group - Entrada Sandstone (Middle Jurassic)

White, light-red, yellow-white, and white cliff-forming, crossbedded, fine-grained sandstone and siltstone in northeast half of quadrangle. Includes, in ascending order, a basal sandy member, a middle silty member, and an upper sandy member as informally defined by Cooley and others (1969). The Entrada Sandstone gradationally overlies the Carmel Formation.

Basal sandy member: Composed of light-red and white steep slope or weak cliff of very fine grained, trough-crossbedded sandstone that partially intertongues with thin, flat-bedded, red siltstone of upper Carmel Formation between White Mesa and Cummings Mesa. Otherwise, forms gradational boundary with underlying Carmel Formation with visible color change from red siltstone of Carmel to light-red and white sandstone of Entrada.

Middle silty member: Consists of prominent light-red, cliff-forming, silty sandstone at White Mesa; undergoes thickness and facies change north and south of White Mesa into red- and white-banded, fine-grained, cliff-forming sandstone that becomes mostly white, low-angle-crossbedded sandstone north and south of White Mesa. Unit forms prominent red and white banded sandstone cliff at Cummings Mesa that is likely equivalent to the middle white and orange-red banded member of Doelling and Davis (1989) in Utah.

Upper sandy member: Composed of white to tan, cliff-forming, low-angle-crossbedded sandstone. Unit forms prominent white sandstone cliff at Cummings Mesa and on several small buttes west of Cummings Mesa capped by brown-weathered Romana Sandstone. Unit is equivalent, in part, to white, fine-grained, crossbedded sandstone of the Cow Springs Sandstone southeast of quadrangle where the Cow Springs Sandstone is considered an upper part of the Entrada Sandstone (Cooley and others, 1969; Peterson, 1988; Billingsley and others, 2013).

Entrada Sandstone forms a sandstone cliff overlain by a thin sheer cliff of the Romana Sandstone that is overlain by a conglomeratic, coarse-grained sandstone cliff of the Salt Wash Member of the Morrison Formation. Conglomerate lenses of Dakota Sandstone locally and unconformably overlie the Salt Wash Member of the Morrison. Unit thins southwest of the quadrangle and thins north into Utah. Maximum thickness is at White Mesa, about 785 ft (240 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Je - San Rafael Group - Entrada Sandstone and Cow Springs Sandstone, undivided (Middle Jurassic)

White, light-gray, and yellowish, very fine grained, trough crossbedded sandstone. Includes interbedded (5 to 7 ft [1.5 to 2 m]) thick beds of red siltstone and sandstone representing southern extent of reddish Entrada Sandstone units just north of quadrangle that thin rapidly southward and pinch out near and just south of Coal Mine Mesa. Interval of uppermost red, flat-bedded siltstone and sandstone is likely equivalent to the Summerville Formation north of map area. Uppermost interval of yellowish-white, fine-grained, crossbedded sandstone is equivalent to the Cow Springs Sandstone northeast and east of quadrangle area. The Summerville Formation and Cow Springs Sandstone are equivalent to lower part of

Morrison Formation north of the map area (Doelling and others, 2000) and east of the map area at Black Mesa (Cooley and others, 1969). Unit as a whole forms a cliff where overlain by resistant conglomeratic, coarse-grained sandstone lenses of Dakota Sandstone (Kd), or Tertiary conglomeratic gravel and sedimentary (Tgs) deposits. Unit thins south and southeast of map area and thickens rapidly north. Thickness, 115 to 250 ft (35 to 76 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Je - Entrada Sandstone and Cow Springs Sandstone, undivided (Middle Jurassic)
Includes a lower interval of white, very fine-grained, trough crossbedded sandstone equivalent to Entrada Sandstone north of map area; a middle interval of interbedded red, flat-bedded siltstone and sandstone equivalent to Summerville Formation north of map area; and an upper interval of white, fine-grained crossbedded sandstone equivalent to Cow Springs Sandstone north of map area. The Summerville Formation and Cow Springs Sandstone are equivalent to the lower Morrison Formation farther north of map area at Black Mesa. Unit as a whole forms a cliff where protected by resistant conglomeratic, coarse-grained sandstone lenses of the overlying Dakota Sandstone. The Carmel Formation is 1.5- to 2-m- (5- to 7-ft-) thick lenses of red siltstone and sandstone near the base of the Entrada Sandstone at the west end of Appaloosa Ridge and is locally absent at the east end of Coal Mine Mesa; Carmel Formation is too thin to show at map scale. Entrada Sandstone-Cow Springs Sandstone, undivided, unconformably overlies the upper beveled surface of Navajo Sandstone known regionally as the J-2 unconformity; erosional relief is generally less than about 4.5 m (15 ft) but is as much as 9 m (30 ft). The unit as a whole thins from 60 m (200 ft) at the west end of Coal Mine Mesa and Appaloosa Ridge to less than 35 m (115 ft) at northeast corner of map area. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Jc - Carmel Formation, undivided (Middle Jurassic)

Jc - San Rafael Group - Carmel Formation, undivided (Middle Jurassic)
Kaibito Plateau area: Red, slope-forming siltstone, claystone, and silty calcareous and gypsiferous sandstone. Includes white, flat-bedded, low-angle-crossbedded calcareous sandstone interbedded with numerous flat-bedded red silty sandstones. Red silty sandstone contains ripple marks and abundant rounded sandy fecal pellets about 0.5 in (1 cm) in diameter. North of Paria River along Utah-Arizona border, unit includes light-gray sandstone beds as much as 3 ft (1 m) thick containing white and red calcite and white barite crystals. Correlative to and intertongues with members of the Page Sandstone in northern half of quadrangle. Unconformably overlies crossbedded Navajo Sandstone in southeast quarter of quadrangle on Kaibito Plateau. Erosional relief at base is generally less than 15 ft (4.5 m). The Carmel Formation pinches out south of the quadrangle in the subsurface of the Moenkopi Plateau (Billingsley and others, 2013). Unit is locally removed from most of the southern Kaibito and Paria Plateaus by Cenozoic erosion. The Carmel Formation gradually thickens west and northwest of the quadrangle (Doelling and others, 2000; Anderson and others, 2000; Doelling and Willis, 2006).
Paria Plateau area: Includes, in ascending order, the Harris Wash Tongue of the Page Sandstone, the Judd Hollow Tongue of the Carmel Formation, and the Thousand Pockets Tongue of the Page Sandstone, undivided, as well as the Paria River Member and Winsor Members, undivided. Members and tongues of the Carmel Formation are described by Doelling and others (2000) and mapped by Peterson (1973), Peterson and Barnum (1973a,b), Doelling and Davis (1989), and Doelling and Willis (2006) along the northern margins of the quadrangle and northward into Utah. Various tongues of the Page Sandstone as described by Peterson (1988) and Blakey and others (1983, 1996) pinch out or intertongue with other members of the Page Sandstone or Carmel Formation along northern margin of Paria Plateau and Cedar Mountain west and northwest of Glen Canyon Dam. Thickness, 165 to 240 ft (48 to 73 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Jc - San Rafael Group - Carmel Formation (Middle Jurassic)
Red and light-gray, slope-forming sandstone, siltstone, claystone, and silty calcareous and gypsiferous sandstone at Middle Mesa (east edge of quadrangle), along Red Lake Monocline (northeast corner of

quadrangle), and as isolated outcrops (northwest quarter of quadrangle). Unit thins southward and pinches out south and east of the Moenkopi Plateau. Present as dark red silty sandstone interval between base of Entrada Sandstone (Je) and top of Navajo Sandstone (Jn) at the east end of Coal Mine Mesa and is locally absent at west end of Coal Mine Mesa. Unconformably overlies upper beveled surface of Navajo Sandstone (Jn), known regionally as the J-2 unconformity; erosional relief is generally less than 15 ft (4.5 m) but can be as much as 30 ft (9 m). Ripple marks and abundant rounded sandy fecal pellets about 0.5 in (1 cm) diameter are found in lenticular, light-gray sandstone beds as much as 3 ft (1 m) thick. Locally contains white and red calcite and white barite crystals. Unit pinches out southward into subsurface of Moenkopi Plateau; locally removed by modern erosion from most of Kaibito Plateau. Unit gradually thickens north and northeast of quadrangle. Thickness, 0 to 30 ft (0 to 9 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Jcu - Carmel Formation, Paria River Member and Winsor Member, undivided (Middle Jurassic)

White, red, and brown, ledge- and cliff-forming, low-angle-crossbedded, thin-bedded, silty sandstone and sandstone in lower part; gray-white, thin-bedded, sandy limestone in upper part. Form white- and red-banded sequence on small mesas and buttes along northern edge of Paria Plateau, Cedar Mountain, and upper reach of Paria River canyon. An unknown thickness of upper part has been removed by modern erosion on the Paria Plateau. Unit thickens northwest of the quadrangle toward the southern end of a shallow seaway in southwestern Utah (Doelling and Willis, 2006). Thickness, 5 to 40 ft (1.5 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Jcj - Carmel Formation, Judd Hollow Tongue and Page Sandstone Tongues, undivided (Middle Jurassic)

Red-brown and yellowish-white, slope- and cliff-forming, thin, interbedded siltstone, crossbedded sandstone, and silty limestone sequence on Paria Plateau, northwestern edge of quadrangle. Thickens north and northwest of Paria Plateau; thins or pinches out rapidly east and south. Sequence includes the Harris Wash Tongue of the Page Sandstone (lower part), the Judd Hollow Tongue of the Carmel Formation (middle part), and the Thousand Pockets Tongue of the Page Sandstone (upper part) collectively mapped as one unit (. Sequence undergoes west to east facies and thickness changes from Paria Plateau to Glen Canyon Dam and intertongues with the Page Sandstone.
Harris Wash Tongue: Yellowish-white, cliff-forming, fine- to medium-grained, crossbedded sandstone. Unconformably overlies similar-appearing Navajo Sandstone.
Judd Hollow Tongue: Dark-brown, slope-forming sandstone and siltstone. Identifiable where red siltstone and sandstone beds intertongue with white sandstone of the Page Sandstone on small buttes and mesas near the Paria River.
Thousand Pockets Tongue: Yellow, white, or brown, massive, cliff-forming, crossbedded sandstone with thin, red siltstone partings. Unconformably overlies Judd Hollow Tongue of Carmel Formation. Forms a thick sandstone bed over the Judd Hollow Tongue where the Judd Hollow is present; pinches out eastward into Page Sandstone southwest of Glen Canyon Dam.
Overall thickness, 10 to 40 ft (3 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Jp - Page Sandstone (Middle Jurassic)

Kaibito Plateau: Light orange-red, cliff-forming, crossbedded, fine- to medium-grained sandstone, locally with thin, dark-red, basal siltstone that unconformably overlies similar-appearing Navajo Sandstone east, south, and southwest of Glen Canyon Dam. Basal unconformity locally contains angular fragments of

white chert at the J-2 unconformity, representing a period of erosion (Pipiringos and O'Sullivan, 1978; Peterson and Pipiringos, 1979). Weathers slightly darker orange than the Navajo Sandstone on the Kaibito Plateau and is locally absent or difficult to identify along southern margins of the quadrangle beneath red siltstone and sandstone of the Carmel Formation.
Paria Plateau: Light-orange-red, cliff-forming, crossbedded, fine- to medium-grained sandstone interbedded with dark-red, thin-bedded silty sandstone. Includes three undifferentiated crossbedded sandstone tongues, in ascending order: the Harris Wash, Thousand Pockets, and Leche-e, as described by Peterson and Pipiringos (1979) and Blakey and others (1983, 1996), and the Judd Hollow Tongue of the Carmel Formation (between the Harris Wash and Thousand Pockets Tongues) as mapped by Doelling and Willis (2006). The Page Sandstone and Carmel Formation intertongue and grade into marine rocks northwest of Paria Plateau. See Peterson and Pipiringos (1979), Doelling and others (2000), and Doelling and Willis (2006) for detailed descriptions, intertonguing relations, and facies relations for the Page Sandstone and Carmel Formation along northern margin of Paria Plateau and north of the quadrangle. The Page Sandstone is present in the upper reaches of Paria Canyon as light-purple-red sandstone but is included as uppermost part of Navajo Sandstone in this quadrangle due to difficulties of access and uncertainties of contact with the Navajo. Thickness, 0 to 300 ft (0 to 92 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Glen Canyon Group

The Glen Canyon Group includes, in ascending order, the Moenave Formation and Wingate Sandstone, undivided; the Springdale Sandstone Member of the Kayenta Formation; the Kayenta Formation, undivided; and the Navajo Sandstone. The red siltstone and sandstone of the Lower Jurassic Moenave Formation and Wingate Sandstone, undivided, unconformably Tr-5; Lucas and Tanner, 2006) overlies the purple and white mudstone, sandstone, and gray limestone of the Upper Triassic Owl Rock Member of the Chinle Formation primarily on the basis of differences in lithology, topography, vertebrate fossils, and color.
The Rock Point Member of the Jurassic Wingate Sandstone, as mapped by Cooley and others (1969), is included within the Moenave Formation and Wingate Sandstone, undivided. The Moenave Formation and Wingate Sandstone are lithologically and stratigraphically equivalent in the Lees Ferry area. Facies changes and thinning of the Wingate Sandstone from the Four Corners area westward along the Arizona/ Utah boundary is attributed to intertonguing within the upper part of the Moenave Formation at Lees Ferry.
In the northern quarter of the quadrangle, the upper boundary of the Glen Canyon Group is marked by the J-2 unconformity between the Navajo Sandstone and Page Sandstone, or the Navajo Sandstone and Carmel Formation where the Page Sandstone is missing (Doelling and others, 2000; Doelling and Willis, 2006; and this report). At the southern edge of the quadrangle, where the Page Sandstone is not present, the J-2 unconformity is between the Navajo Sandstone and Carmel Formation and is easily recognized by color and lithology differences. (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Includes, in ascending order, Moenave Formation (Jm), Springdale Sandstone Member of Kayenta Formation (Jks), Kayenta Formation (Jk), the Kayenta Formation-Navajo Sandstone transition zone (Jkn), and the Navajo Sandstone (Jn). The Moenave Formation unconformably overlies the Triassic Chinle Formation. The unconformity between the Triassic and Jurassic is based primarily on differences in lithology, topography, and color change. The purple and white mudstone, sandstone, and gray limestone of the Owl Rock Member of the Chinle Formation is overlain by red mudstone, siltstone, and sandstone of the Moenave Formation (Jm). The basal light-red sandstone of the Moenave Formation may be a lateral equivalent of the Lukachukai Member of the Wingate Formation as mapped by Cooley and others (1969) but is herein included within the lower part of the Moenave Formation, because it is lithologically the same as the overlying beds of the Moenave Formation and because the Wingate Sandstone thins southward from Utah and does not appear to reach the map area

About 20 mi (32 km) north of the map area, the upper boundary of the Glen Canyon Group is the J-2 unconformity between the Navajo Sandstone (Jn) and Page Sandstone (Doelling and others, 2000). At Middle Mesa, east central edge of the map area, the J-2 unconformity is between the Navajo Sandstone and Carmel Formation (Jc), and in the extreme southeast corner of the map area, it is between the Navajo Sandstone and the Entrada Sandstone-Cow Springs Sandstone, undivided (Je). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

The Glen Canyon Group includes, in ascending order, the Jurassic Moenave Formation (Jm), the Kayenta Formation (Jk), the Kayenta Formation-Navajo Sandstone transition zone (Jkn), and the Navajo Sandstone (Jn). The Moenave Formation unconformably overlies the Triassic Chinle Formation. The boundary between the Triassic and Jurassic units is based on differences in lithology, topography, and color change. The purple and white mudstone, sandstone, and gray limestone of the Owl Rock Member of the Chinle Formation is overlain by the red mudstone, siltstone, and sandstone of the Moenave Formation (Jm). The basal red siltstone of the Moenave Formation may be the lateral equivalent of the Rock Point Member of the Wingate Formation as mapped by Cooley and others (1969), but is likely the lateral equivalent of the Church Rock Member of the Chinle Formation north and northeast of the map area as suggested by Repenning and others (1969); Cooley and others (1969) also mapped an orange-red silty ledge-forming sandstone on Ward Terrace as a tongue of the Lukachukai Member of the Wingate Formation (Sandstone) as did Billingsley (1987a) as suggested by Cooley and others (1969). The basal red siltstone (Rock Point Member of the Wingate Formation) and orange-red sandstone (Lukachukai Member of the Wingate Formation) is herein mapped as the lower part of the Moenave Formation because both units are lithologically the same as several overlying siltstone and sandstone units within the Moenave Formation and because the Wingate Sandstone is stratigraphically above the Moenave Formation at the New Mexico/Arizona State line. Furthermore, the Wingate Sandstone is stratigraphically between the Moenave and Kayenta Formation in the Hopi Buttes about 72 km (45 mi) east of the map area.
North of the map area 80 km (50 mi), the upper boundary of the Glen Canyon Group is an unconformity between the Navajo Sandstone and the Page Sandstone, but in the northeast corner of map area, the upper boundary of the Glen Canyon Group is an unconformity between the Navajo Sandstone (Jn) and Entrada Sandstone (Je) in the map area; old dune (QTd) and old eolian sand sheet and dune (QTes) deposits
obscure the contact. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Jn - Navajo Sandstone (Lower Jurassic)

Jn - Glen Canyon Group - Navajo Sandstone (Lower Jurassic)
Red, white, and light-reddish-brown, cliff-forming, high-angle-crossbedded, fine- to medium-grained, well-sorted sandstone. Includes scattered horizontal thin siliceous limestone and dolomite lenses at various levels between crossbed sets throughout the unit. The sand grains consist of rounded to subrounded, frosted quartz grains, cemented by calcite with some secondary silica and iron oxide. Displays elaborate array of high-angle-crossbed sets as much as 35 ft (11 m) thick. Flat, interbedded, gray- to light-purple, siliceous limestone, dolomite, or dark-red sandy siliceous mudstone form resistant ledges as flat-topped ridges or small mesas on Kaibito Plateau. The limestone and dolomite beds formed in playas or ponds between dunes and are somewhat more abundant southward on the Kaibito Plateau and south of the quadrangle. Sandstone beds contain numerous small, rounded, black and reddish-black, pea-size hematite concretions on the Kaibito Plateau and larger, avocado-shaped, iron-oxide concretions, as much as 3 in (7.5 cm) in diameter on the Paria Plateau. Crossbed dip directions in the map area indicate paleowinds were generally from the northwest (Peterson, 1988). Gradational contact with underlying Kayenta Formation is marked at the lowest white or light-red massive sandstone cliff. Unit thins east and southeast of the quadrangle and thickens north and northwest. Modern erosion of the sandstone provides a rich source of loose sand for eolian transport over much of the Paria and Kaibito Plateaus. Thickness, 1,200 to 1,750 ft (366 to 534 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam

30 x 60).

Jn - Glen Canyon Group - Navajo Sandstone (Lower Jurassic)
Red, white, and tan, cliff-forming, high-angle crossbedded, fine- to medium-grained, well-sorted sandstone. Includes massive horizontal or planar bedding. Quartz grains are frosted. Crossbeds are as much as 35 ft (11 m) thick. Includes many discontinuous thin beds of gray to light-purple siliceous limestone, dolomite, or dark-red sandy siliceous mudstone that form resistant ledges and flat-topped ridges or small mesas on surface of Moenkopi and Kaibito Plateaus. Siliceous beds were formed in playas or ponds between sand dunes and become increasingly common on Moenkopi Plateau. Crossbeds contain numerous small, rounded, black and reddish-black, pea-size hematite concretions as much as 3 in (7.5 cm) in diameter. Crossbed dip direction indicates paleowinds were generally from the north and northwest. Gradational and arbitrary contact with underlying Kayenta Formation-Navajo Sandstone transition zone (Jkn) marked at lowest white or red massive sandstone cliff. Unit rapidly thins east and southeast of map area and thickens north and northwest. Unit is removed by erosion in west half of map. Thickness, 400 to 600 ft (122 to 183 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Jn - Navajo Sandstone (Lower Jurassic)
White, light-red, and yellowish-gray, cliff-forming, medium crossbedded to thickly crossbedded, well-sorted, fine- to coarse-grained eolian quartz sandstone; lower part is interbedded with dark-red, flat-bedded, coarse-grained sandstone and siltstone of Kayenta Formation. Age determination is by Peterson and Pipiringos (1979) and Biek and others (2000). Lower part is commonly red; upper part is commonly white but can be either all red or all white. Includes lenses of interbedded dark purple-gray, thin-bedded, calcareous sandstone or siliceous limestone formed by freshwater deposits within and between sand dunes. High-angle, crossbedded sandstone sets are interbedded with low-angle, crossbedded sandstone sets and thin flat-bedded sandstone sets. Unit commonly covered by thin to thick eolian dune sand and sand sheet (Qd) deposits or young mixed alluvium and eolian (Qae) deposits. Unit is highly fractured by near vertical northeast-, northwest-, and north-oriented bedrock joints and fractures.
Paria Plateau area; unit is highly fractured by near vertical joints and fractures and a few high angle normal faults with northwest strike. Gradational and intertonguing contact with underlying sandstone facies of Kayenta Formation along Vermilion Cliffs, northeast quarter of map area. Unit supports moderate growths of pinion and juniper trees, cliff-rose bush, sagebrush, and various high-mountain shrubs. Incomplete section in map area due to modern erosion of top part of unit. Thickens north of map to as much as 610 m (2,000 ft). About 457 m (1,500 ft) thick in Moccasin Mountains area; about 330 m (1,080 ft) thick in Paria Plateau area. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Jn - Glen Canyon Group - Navajo Sandstone (Lower Jurassic)
Red, white, and tan, cliff-forming, high-angle crossbedded and massive horizontal or planar bedded, fine- to medium-grained, well-sorted, well-rounded frosted quartz sandstone. Crossbedded sets are as much as 11 m (35 ft) thick. Includes several thin lenses or beds of gray siliceous limestone, dolomite, or dark-red sandy siliceous mudstone that weather out as resistant ledges that form flat-topped ridges or hills on eroded surface of Moenkopi Plateau. These siliceous beds were formed in oases, playas, or ponds between eolian sand dunes and become increasingly common in southeast part of Moenkopi Plateau. Sandstone beds contain numerous small rounded black and reddish-black, pea-size hematite concretions in upper part near Appaloosa Ridge on Moenkopi Plateau and are similar to pumpkin-size concretions [25 cm to 1 m (10 in to 3 ft)] in diameter along Adeii Eechii Cliffs. Gradational and arbitrary contact with underlying Kayenta Formation-Navajo Sandstone transition zone (Jkn) at lowest white or red sandstone cliff of Navajo Sandstone. Several springs and seeps issue from the base of the Navajo Sandstone along the Adeii Eechii Cliffs. Unit rapidly thins eastward from Adeii Eechii Cliffs to the subsurface of Moenkopi Plateau. About 48 to 76 m (160 to 250 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Jkn - Kayenta Formation and Navajo Sandstone transition zone (Lower Jurassic)

Jkn - Glen Canyon Group - Kayenta Formation and Navajo Sandstone transition zone (Lower Jurassic)
Light-red and white, fine- to medium-grained, massive to crossbedded, cliff-forming beds of Navajo Sandstone lithology that intertongue with purple and light-red, slope-forming mudstone, siltstone, and sandstone beds of Kayenta Formation lithology. Forms sequence of red and white sandstone cliffs that alternate with purple and light-red mudstone and siltstone slopes resulting in arbitrary map contact. This zone is considered to be the lower "wet part" of the Navajo Sandstone by Marzolf (1983, 1991) and Blakey (1994). Gradually thins northward and becomes basal part of the Navajo Sandstone near Cedar Ridge. Individual red and white sandstone units thin or lens out into purplish siltstones of the Kayenta Formation south of the map area. Several springs and seeps issue from base of Navajo Sandstone along Echo Cliffs from Cedar Ridge to Tuba City and Moenkopi. Thickness, 0 to 240 ft (0 to 73 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Jkn - Glen Canyon Group - Kayenta Formation - Navajo Sandstone transition zone (Lower Jurassic)
Light-red and white, fine- to medium-grained, massive to crossbedded, cliff-forming sandstone beds of Navajo Sandstone lithology that intertongue with purple and light-red, slope-forming mudstone, siltstone, and sandstone beds of underlying Kayenta Formation that forms a sequence of red and white sandstone cliffs that alternate with purple and light-red mudstone and siltstone slopes. This interval is considered to be the lower "wet part" of the Navajo Sandstone by Marzolf (1983) and Blakey (1994). Unit gradually thins southeastward along Adeii Eechii Cliffs and in subsurface of the Moenkopi Plateau based on lithologic map contacts. Individual lower red sandstone units either pinch out or thicken resulting in variable thicknesses of unit and arbitrary contact with the underlying Kayenta Formation. About 37 to 73 m (120 to 240 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Jk - Kayenta Formation, undivided (Lower Jurassic)

Jk - Glen Canyon Group - Kayenta Formation, undivided (Lower Jurassic)
Upper slope- and ledge-forming unit: Light-red, dark-orange, light-purple, and gray, flat-bedded, moderately sorted, subrounded to subangular, fine- to medium-grained, crossbedded sandstone and fine-grained, flat-bedded mudstone, siltstone, and silty sandstone is about 240 to 300 ft (73 to 91 m) thick along the base of the Vermilion and Echo Cliffs to Lees Ferry; about 280 ft (86 m) is exposed in Navajo Canyon in northeastern quarter of quadrangle. Ripple laminations, current ripples, and small-scale trough crossbeds indicate that depositing streams flowed toward the northwest. Upper slope-forming unit undergoes a northward facies change from mostly slope forming siltstone, mudstone, and sandstone to cliff-forming, red sandstone and minor siltstone from the southern part of Echo Cliffs and Vermilion Cliffs to Lees Ferry, southwest half of quadrangle. Unit commonly covered by landslide and talus and rock-fall deposits caused by the erosion of the upper Kayenta Formation undercutting overlying cliffs of Navajo Sandstone, allowing large blocks of both Navajo Sandstone and upper Kayenta Formation to fail as landslide masses, especially where joints and fractures are nearly parallel to Echo and Vermilion Cliffs. Gradational contact with underlying cliff-forming Springdale Sandstone Member. Thickness, 180 to 225 ft (55 to 68 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Jk - Glen Canyon Group - Kayenta Formation (Lower Jurassic)
Includes an upper slope-forming light-purple, siltstone and sandstone and the basal orange-brown, cliff-forming Springdale Sandstone Member. The Springdale Sandstone was originally described as the upper member of the underlying Moenave Formation (Averitt and others, 1955; Stewart and others, 1972; Sargent and Philpott, 1987; Billingsley and others, 2004) but has since been reassigned as the basal part of the Kayenta Formation based on paleontological data and a prominent Jurassic unconformity at

its base (Blakey, 1994; Marzolf, 1991; Lucas and Tanner, 2006; Tanner and Lucas, 2007; Biek and others, 2007)
Upper slope-forming unit: Purple, lavender, and light-red fluvial, crossbedded, fine-grained mudstone, siltstone, and silty sandstone that undergo a northward facies change from mostly slope-forming siltstone, mudstone, and sandstone at Moenkopi Wash to mostly cliff-forming red sandstone and minor siltstone along Echo Cliffs at Cedar Ridge. Age is determined by Peterson and Pipiringoes (1979) and Biek and others (2000). Along Echo Cliffs, often covered by landslide (Ql) and talus and rockfall (Qtr) deposits caused when erosion of underlying Kayenta Formation undercuts overlying Navajo Sandstone cliffs allowing large blocks of both Navajo Sandstone and upper Kayenta Formation to fail as landslide masses; especially prevalent where joints and fractures nearly parallel Echo Cliffs (fig. 1). Unit is unconformable with underlying cliff-forming Springdale Sandstone Member (Jks). Thickness, 300 to 470 ft (92 to 143 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Jk - Kayenta Formation (Lower Jurassic)
Includes an upper slope-forming siltstone, and a basal cliff of the Springdale Sandstone Member. The Springdale Sandstone Member was originally described as the upper member of the underlying Moenave Formation (Averitt and others, 1955; Stewart and others, 1972; Sargent and Philpott, 1987; Billingsley and others, 2004) and has been reassigned to the basal part of the Kayenta Formation on the basis of paleontological data and a prominent Jurassic unconformity at the base of the Springdale (Blakey, 1994; Marzolf, 1994; Lucas and Tanner, 2006; Tanner and Lucas, 2007; Biek and others, 2007). Upper slope-forming unit is dark-red and light reddish-brown, calcareous mudstone, siltstone, and cliff-forming sandstone that undergo a facies change eastward from mostly slope-forming siltstone and mudstone at Moccasin Mountains to a mostly cliff-forming sandstone at Paria Plateau, northeast corner of map area. Age of unit determined by Peterson and Pipiringoes (1979) and Biek and others (2000). Along Vermilion Cliffs, unit often covered by landslide debris (Ql) and talus and rock fall (Qtr) deposits caused by erosion of soft sediments of Kayenta Formation that undercuts resistant overlying cliff of Navajo Sandstone allowing large sections of both Navajo Sandstone and upper Kayenta Formation to fail as landslide masses, especially where the bedrock joints and fractures parallel Vermilion Cliffs. Kayenta Formation is deposited in river floodplains, river channels, playas, and shallow lake environments (Blakey, 1994; Peterson, 1994). Unconformable contact with underlying Moenave Formation (Jm). Thickness increases from 143 m (470 ft) at Ed Lamb Point westward to nearly 183 m (600 ft) in Potter Canyon southwest of Moccasin Mountains and thickness of intertonguing Lamb Point Tongue of Navajo Sandstone decreases in northwest quarter of map area. About 143 to 183 m (470 to 600 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Jk - Glen Canyon Group - Kayenta Formation (Lower Jurassic)
Purple, lavender, and light-red fluvial, crossbedded, fine-grained mudstone, siltstone, and silty sandstone. Weathers to steep slope. Upper part intertongues with Navajo Sandstone north and east of map area, but forms a mappable transition zone of intertonguing units within map area. Unit includes some lenticular, medium-grained sandstone ledges in middle and lower part. Lower part forms resistant ledgy interbedded siltstone and sandstone sequence commonly 6 to 12 m (20 to 40 ft) thick that forms a protective white cliff over Moenave Formation in the Red Rock Cliffs area. This white sandstone gradually thickens eastward and is correlative to the Wingate Sandstone (too thin to show at map scale) of the Hopi Buttes about 72 km (45 mi) east of the map area. Contact with underlying Moenave Formation is unconformable; erosional relief generally less than 2 m (6 ft) in map area and marked by lithology and color changes; the J-sub-K unconformity as defined by Riggs and Blakey (1993) and Blakey (1994). Laterally, the contact is slightly higher or lower in stratigraphic position over several kilometers accounting for variable thickness differences between the Kayenta and Moenave Formations. Overall the unit rapidly thins east and southeast of map area. About 122 m (400 ft) thick in the west to 98 m (320 ft) thick in the east. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Jks - Kayenta Formation, Springdale Sandstone Member (Lower Jurassic)

Jks - Glen Canyon Group - Kayenta Formation, Springdale Sandstone Member (Lower Jurassic)
Light-red to reddish-brown and dark-red, cliff-forming, thin- to thick-bedded sandstone. Includes low-angle trough crossbedding interbedded with fluvial conglomeratic sandstone lenses containing dark-red mudstone, siltstone rip-up clasts, and poorly preserved petrified plant remains north of quadrangle in Utah (Biek and others, 2000). Crossbeds are separated by thin-bedded to laminated, dark-red siltstone and mudstone that locally contain mudstone pellets. Deposited in braided streams and minor floodplains of northward-flowing streams (Biek and others, 2007).
The Springdale Sandstone was originally described as an upper member of the underlying Moenave Formation (Averitt and others, 1955; Stewart and others, 1972; Sargent and Philpott, 1987; Billingsley and others, 2004) but has since been reassigned as the basal part of the Kayenta Formation based on paleontological data and a prominent Jurassic unconformity at its base (Blakey, 1994; Marzolf, 1991; Lucas and Tanner, 2006; Biek and others, 2007; Tanner and Lucas, 2007). This unconformity is the sub-Kayenta unconformity (J-sub-K) as defined by Riggs and Blakey (1993) and Blakey (1994). Erosional relief is generally less than 6 ft (2 m) along the Vermilion and Echo Cliffs but as much as 50 ft (15 m) near Lees Ferry (Nation, 1990). Light-red, fine-grained, crossbedded sandstone at the top of the Springdale Sandstone Member may represent the southern extent of the Wingate Sandstone (not mapped separately). The Early Jurassic age is documented by Peterson and Pipiringos (1979). Unconformable contact with underlying Moenave Formation is known as the J-sub-K unconformity (Blakey, 1994). Thickness, 90 to 220 ft (27 to 67 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Jks - Glen Canyon Group - Kayenta Formation, Springdale Sandstone Member (Lower Jurassic)
Light-red to reddish-brown and dark-red, cliff-forming, thin- to thick-bedded sandstone. Includes low-angle trough crossbed sets with fluvial conglomeratic sandstone lenses containing dark-red mudstone and siltstone rip-up clasts and poorly preserved petrified and carbonized fossil plant remains north of map area by thin-bedded to laminated dark-red siltstone and mudstone that locally contain mudstone pellets. Unconformable contact with underlying Moenave Formation (Jm). Light-red, fine-grained, crossbedded sandstone filling channels eroded into top of Springdale Sandstone may represent southern extent of Wingate Sandstone. Thickness, 100 to 140 ft (30 to 43 m) (Peterson and Pipiringos, 1979; Biek and others, 2000). Crossbeds are separated. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Jks - Kayenta Formation, Springdale Sandstone Member (Lower Jurassic)
Light-red to reddish-brown, cliff-forming, thin- to thick-bedded sandstone and conglomeratic lenses. Includes low-angle trough crossbedded sets of fluvial sandstone that contain dark-red mudstone and siltstone rip-up clasts and poorly preserved petrified and carbonized fossil plant remains within crossbedded sets (Peterson and Pipiringos, 1979; Biek and others, 2000). Crossbeds are separated by thin-bedded to laminated dark-red siltstone and mudstone beds that locally contain mudstone pellets (Wilson, 1967). Unconformable contact with underlying Dinosaur Canyon Member of the Moenave Formation. Unit deposited by northeast to southwest flowing streams based on crossbedding studies by Wilson (1967). Thickens north and east of map area to about 60 m (200 ft) in Utah. Forms light-red sandstone cliffs that weather dark red on east side of House Rock Valley, northeast quarter of map area. Thickness ranges from about 37 to 60 m (120 to 200 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Jm - Moenave Formation and Wingate Sandstone, undivided (Lower Jurassic and Upper Triassic(?))

Jm - Glen Canyon Group - Moenave Formation and Wingate Sandstone, undivided (Lower Jurassic)
Reddish-brown slopes and ledges of thin-bedded, flat-bedded, and crossbedded, fine- to coarse-grained

fluvial siltstone and silty sandstone. Includes the Dinosaur Canyon Member of the Moenave Formation as redefined by Blakey (1994), Marzolf (1991), Lucas and Tanner (2006), Tanner and Lucas (2007), and Biek and others (2007). The age of unit was documented by Peterson and Pipiringos (1979). The unconformable contact with the underlying Owl Rock Member of the Chinle Formation is marked by a distinct lithologic and color change from purple and white calcareous siltstone and sandstone and gray limestone of Owl Rock to dark-red and orange-red, fine- to coarse-grained sandstone of Moenave Formation. Commonly covered by landslide or talus and rock-fall deposits and minor eolian sand deposits along the base of the Echo and Vermilion Cliffs to Lees Ferry. Thickness, 80 to 140 ft (25 to 43 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Jm - Glen Canyon Group - Moenave Formation (Lower Jurassic)
Includes only the Dinosaur Canyon Member as redefined by Blakey (1994), Marzolf (1991), Lucas and Tanner (2006), Tanner and Lucas (2007), and Biek and others (2007) in the map area. Age is after Peterson and Pipiringos (1979) and Biek and others (2000, 2007). Forms reddish-brown slopes and ledges of thin-bedded, flat-bedded, and crossbedded, fine- to coarse-grained fluvial siltstone and silty sandstone. Unconformable contact with underlying Owl Rock Member of the Chinle Formation, known as the J-O unconformity separating Triassic rocks from overlying Jurassic rocks. Commonly covered by landslide (Ql) or talus and rockfall (Qtr) deposits. Thickness, 80 to 140 ft (25 to 43 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Jm - Glen Canyon Group - Moenave Formation (Lower Jurassic and Upper Triassic(?))
Red and light-red, flat-bedded and crossbedded, fine- to coarse-grained fluvial siltstone and silty sandstone. Unit is divided into the Springdale Sandstone Member (upper part) and the Dinosaur Canyon Member (lower part) north of the map area near the town of Moenave, Arizona, the type section. The Springdale Sandstone Member type locality is in Springdale, Utah, and pinches out at the northeast edge of map area. The Dinosaur Canyon Member is informally named from an unnamed tributary (not shown on USGS topographic maps to help protect the fossil dinosaur track ways) to the Little Colorado River below the Adeii Eechii Cliffs. Within the map area the entire sequence of red fluvial sandstones of the Moenave Formation represents the Dinosaur Canyon Member. Formation as a whole generally weathers to form a slope except where overlain by resistant beds of the lower Kayenta Formation that form the Red Rock Cliffs. Unconformable contact with underlying Owl Rock Member of the Chinle Formation is known as the J-O unconformity and separates the Triassic rocks from the overlying Jurassic rocks. About 84 to 98 m (275 to 320 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Jmw - Moenave Formation, Whitmore Point Member (Lower Jurassic)

Moenave Formation (Lower Jurassic)—Includes, in descending order, the Dinosaur Canyon Member and Whitmore Point Member, undivided as redefined by Blakey, 1994; Marzolf, 1994; Lucas and Tanner, 2006; Tanner and Lucas, 2007; Biek and others, 2007. Originally defined as the upper Member of the Moenave Formation by Averitt and others (1955), Stewart and others (1972), and Sargent and Philpott (1987). Age determination after Peterson and Pipiringos (1979) and Biek and others (2000).
Whitmore Point Member (Lower Jurassic)—Type section is near Potter Canyon at southwest point of Moccasin Mountains (elev. 2,013 m [6,603 ft]) at Radio Towers). Named for Whitmore Point by Wilson (1967) 5.6 km (3.5 mi) west of Pipe Spring National Monument, but the name Whitmore Point is not on 1988 USGS 7.5' Moccasin quadrangle. Composed of reddish-brown sandstone and siltstone interbedded with reddish-purple to greenish-gray and blue mudstone and claystone, and thin gray dolomitic limestone. Limestone contains small reddish-brown chert nodules and poorly preserved fossil algal structures and fish scales and bones near Zion National Park north of map area (Biek and others, 2000; 2007). Unconformable contact with underlying Chinle Formation in west half of map area; unit thins eastward to less than 12 m (40 ft) at Vermilion Cliffs on east side of House Rock Valley, northeast quarter of map area. Thickness ranges from about 12 to 24 m (40 to 80 ft) (*GRI Source Map ID 75234)* (

Fredonia 30 x 60).

Jmd - Moenave Formation, Dinosaur Canyon Member (Lower Jurassic)

Moenave Formation (Lower Jurassic)—Includes, in descending order, the Dinosaur Canyon Member and Whitmore Point Member, undivided as redefined by Blakey, 1994; Marzolf, 1994; Lucas and Tanner, 2006; Tanner and Lucas, 2007; Biek and others, 2007. Originally defined as the upper Member of the Moenave Formation by Averitt and others (1955), Stewart and others (1972), and Sargent and Philpott (1987). Age determination after Peterson and Pipiringos (1979) and Biek and others (2000) Dinosaur Canyon Member (Lower Jurassic)—Reddish-brown, slope- and ledge-forming, thin-bedded, very fine-grained sandstone and silty sandstone. Gradational contact with underlying Whitmore Point Member of the Moenave Formation west of Fredonia area, marked by distinct color contrast between blue-green, green, and yellow mudstone and siltstone of Whitmore Point Member to reddish-brown siltstone and sandstone of Dinosaur Canyon Member; unconformable contact with Owl Rock Member of the Chinle Formation in House Rock Valley area where Whitmore Point Member is missing. Unit commonly covered by landslide (Ql) and talus and rock fall (Qtr) deposits. Thickness ranges from about 37 to 60 m (120 to 200 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRc - Chinle Formation, undivided (Upper Triassic)

Includes the Shinarump and Petrified Forest Members. Shinarump Member locally missing or has undergone local facies change to sandstone lithology similar to sandstones in Petrified Forest Member. The Chinle Formation at Hells Hole is 21 km (13 mi) north of Colorado River Mile 188 and is the thickest Chinle Formation deposit nearest to the Colorado River of Grand Canyon other than at Lees Ferry, Arizona. Petrified Forest Member is white, blue-gray, pale-red and purple, slope-forming mudstone, siltstone, and coarse-grained sandstone; contains small, very well rounded pebbles of black, yellow, brown, and red quartzite. Includes white, coarse-grained, ledge-forming sandstone at base that may be equivalent to the Shinarump Member of the Chinle Formation; contains brown, yellow, white, and red petrified wood fragments. Unit contains bentonitic clays derived from decomposition of volcanic ash. Unconformable contact with overlying basalt of Bundyville (Tbb) west of Hurricane Fault and basalt of Mount Logan (Tmlb) east of Hurricane Fault. Erosion has removed an unknown thickness of upper part of the Chinle Formation. Unit is mostly covered by landslide debris (Ql). Unconformable contact with underlying slope-forming upper red member of the Moenkopi Formation; erosional relief less than 2 m (6 ft) at Hells Hole marked by color contrast between red Moenkopi Formation and purple-white Chinle Formation in slope. Thickness, 122 m (400 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Chinle Formation (Upper Triassic)

Includes, in descending order, the Owl Rock Member, Petrified Forest Member, and Shinarump Member (Repenning and others, 1969). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Includes, in descending order, the Owl Rock Member, the Petrified Forest Member, and the Shinarump Member and the sandstone and siltstone member, undivided (Repenning and others, 1969). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Includes the Owl Rock Member; Petrified Forest Member; Shinarump Member and the sandstone and siltstone member, undivided (Repenning and others, 1969). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRco - Chinle Formation, Owl Rock Member (Upper Triassic)

TRco - Chinle Formation, Owl Rock Member (Upper Triassic)
Grayish-red and light-purple, slope- and ledge-forming, nodular siliceous limestone interbedded with purple, light-blue, and light-red calcareous siltstone and sandstone. Limestone beds are gray, cherty, lenticular, silty, irregular bedded, 1 to 5 ft (0.5 to 1.5 m) thick; extend laterally for several miles and form small, resistant benches or ledges along base of Echo and Vermilion Cliffs. Number of limestone beds within unit averages three to four. Contains abundant mud pellets, silicified clay, and concretionary chert nodules. Gradually thins northward from south-central edge of quadrangle along Echo Cliffs to Lee Ferry; thins slightly from Lees Ferry west along base of Vermilion Cliffs; gradually thickens southeast of quadrangle. Gradational contact with underlying Petrified Forest Member placed at lowest laterally continuous nodular limestone bed. Thickness, 100 to 200 ft (30 to 60 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

TRco - Chinle Formation, Owl Rock Member (Upper Triassic)
Grayish-red and light-purple, slope- and ledge-forming, nodular siliceous limestone interbedded with purple, light-blue, and light-red calcareous siltstone and sandstone. Limestone beds are gray, cherty, lenticular, silty, irregular bedded, 1 to 5 ft (0.5 to 1.5 m) thick; extend laterally for several miles and form resistant benches or ledges along Echo Cliffs and Ward Terrace (fig. 1, sheet 3). Number of limestone beds decreases northward from several at Ward Terrace to two at Cedar Ridge. Contains abundant mud pellets and silicified clay and concretionary chert nodules. Gradually thins northward along Echo Cliffs and thickens slightly southeast of map area. Unconformable contact between Owl Rock Member of the Chinle Formation and overlying Moenave Formation commonly marked by a distinct lithologic and color change from purple and white calcareous siltstone and sandstone and gray limestone of Owl Rock to dark-red and orange-red, coarse-grained sandstone of Moenave Formation. Gradational contact with underlying Petrified Forest Member placed at lowest laterally continuous limestone bed or at nodular calcareous grayish-yellow siltstone slope about 10 to 15 ft (3 to 4.5 m) below lowest prominent limestone bed. Thickness, 100 to 200 ft (30 to 60 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

TRco - Chinle Formation, Owl Rock Member (Upper Triassic)
Light-red and blueish-white coarse-grained sandstone, gray, fine-grained sandstone and siltstone interbedded with thin-bedded, 12 cm to 0.5 m (5 in to 2 ft) thick grayish-white siliceous limestone beds. Limestone contains red and white chert nodules and lenses. Gradational contact with underlying Petrified Forest Member. About 9 to 18 m (30 to 60 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRco - Chinle Formation, Owl Rock Member (Upper Triassic)
Grayish-red and light-purple, slope- and ledge-forming nodular limestone interbedded with purple, light-blue, and light-red calcareous siltstone and sandstone. Limestone beds are gray, cherty, lenticular, silty, irregular bedded 0.5 to 1.5 m (1 to 5 ft) thick and extend laterally for several miles to form resistant ledges of Ward Terrace (fig. 1). Black petrified logs form a unique petrified forest on Ward Terrace south of Landmark Wash. Unit contains abundant mud pellets and silicified clay and concretionary chert nodules and generally maintains constant thickness from Cameron to southeast edge of map area. Unconformable contact between Owl Rock Member of the Chinle Formation and overlying Moenave Formation commonly marked by distinct lithology and color change from purple and white calcareous siltstone and sandstone and limestone of the Owl Rock to dark-red or orange-red coarse-grained sandstone of the Moenave. Gradational and arbitrary contact with underlying Petrified Forest Member placed at lowest laterally continuous limestone or nodular calcareous grayish-white siltstone in slope generally about 18 to 25 m (60 to 80 ft) below lowest prominent limestone caprock of Ward Terrace. About 82 m (270 ft) thick in southeast part of map to 60 m (200 ft) thick in northeast part. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRcp - Chinle Formation, Petrified Forest Member (Upper Triassic)

TRcp - Chinle Formation, Petrified Forest Member (Upper Triassic)
Purple, blue, light-red, greenish-gray, and grayish-blue, slope-forming mudstone and siltstone. Includes interbedded white to yellowish-white, coarse-grained, lenticular, low-angle trough crossbeds of siltstone and sandstone in lower part. Petrified logs and wood fragments common in lower part may be within upper part of Shinarump Member. Gradational contact with underlying Shinarump Member approximately marked at change from slope-forming multicolored mudstones of Petrified Forest Member to brown, yellowish-white cliffs and purple slopes of coarse-grained conglomeratic sandstone of Shinarump Member. Weathers into rounded hills or slopes with a rough, puffy, popcorn surface due to swelling of clay when wet. Sandstones are uranium- and copper-bearing in some places and contain traces of gold and mercury in others (Bush, 1983). Thickness, 400 to 500 ft (122 to 153 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

TRcp - Chinle Formation, Petrified Forest Member (Upper Triassic)
Purple, blue, light-red, greenish-gray, and grayish-blue, slope-forming mudstone and siltstone. Includes interbedded white, coarse-grained, lenticular, channel-fill sandstone. Includes three informal units of Akers and others (1958), in descending order: red mudstone and sandstone, gray mudstone and sandstone, and blue mudstone. Includes large lenticular erosion channels and large-scale, low-angle trough crossbeds. Petrified logs and wood fragments common in lower white or yellowish-white sandstone; alternately may be within upper part of Shinarump and sandstone and siltstone member, undivided. Gradational contact with underlying Shinarump Member and sandstone and siltstone member, undivided, at change from slope-forming multicolored mudstones of Petrified Forest Member to tan cliffs and purple slopes of coarse-grained sandstone of Shinarump Member. Weathers into rounded hills or slopes with a rough, puffy, popcorn surface caused by swelling of clay when wet. Thickness, 400 to 500 ft (122 to 153 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

TRcp - Chinle Formation, Petrified Forest Member (Upper Triassic)
Gray, light-purple, blue, to light-red, slope-forming claystone, siltstone, and white, coarse-grained sandstone. Mudstone weathers to frothy popcorn surface. Includes petrified wood and calcite nodules. Unit is mostly covered by eolian sand sheet (Qes), dune sand and sand sheet (Qd), and young mixed alluvium and eolian (Qae) deposits, and young, intermediate, and old alluvial fan (Qay and Qao) deposits. Contact with underlying Shinarump Member is gradational in vertical and lateral extent because of intertonguing and phases changes. Thickness ranges from about 183 to 213 m (600 to 700 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRcp - Chinle Formation, Petrified Forest Member (Upper Triassic)
Purple, blue, light-red, reddish-purple, grayish-blue, slope-forming mudstone and siltstone and interbedded white, coarse-grained lenticular sandstone. Includes three informal units of Akers and others (1958), in ascending order: blue mudstone, gray mudstone and sandstone, and red mudstone and sandstone (not mapped). Includes large lenticular erosional channel structures and large-scale low-angle trough crossbedding. Petrified logs and wood fragments common in white or yellowish-white sandstone in lower part that may be within upper part of sandstone and siltstone member, undivided, of the Chinle Formation. Gradational and arbitrary contact with underlying Shinarump Member and sandstone and siltstone member, undivided, at lithologic and topographic change from sloping multicolored mudstone of Petrified Forest Member to coarse-grained, light-brown sandstone ledges and purple slopes of Shinarump Member. Weathers into rounded hills or slopes with a rough, puffy, popcorn texture surface due to swelling of clay content when wet. Thickness, 122 to 153 m (400 to 500 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRcs - Chinle Formation, Shinarump Member (Upper Triassic)

TRcs - Chinle Formation, Shinarump Member (Upper Triassic)
Brown and (or) tan, cliff- and slope-forming, coarse-grained, low-angle-crossbedded sandstone and conglomeratic sandstone. Includes interbedded slope-forming, poorly sorted, purple, light-red, and blue siltstone and mudstone lenses. Lithology is highly variable locally but regionally homogeneous consisting of about 75% sandstone, 20% conglomerate, and 5% mudstone. Pebbles are well rounded, brown to black, siliceous composition and light-colored, well-rounded quartz. Petrified logs and wood fragments are common and scattered throughout unit. Unconformable contact with underlying red siltstone and sandstone of Moenkopi Formation is known as the Tr-3 unconformity by Pipiringos and O'Sullivan (1978) and as the Tr-3 unconformity by Blakey (1994). Unit is thickest just northeast of Cliff Dwellers Lodge at base of Vermilion Cliffs. Thickness, 60 to 200 ft (18 to 60 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

TRcs - Chinle Formation, Shinarump Member and sandstone and siltstone member, undivided (Upper Triassic)
White, light-brown, tan, and yellowish-pink, cliff-forming, coarse-grained sandstone and conglomeratic sandstone. Includes cliff-forming, low-angle, crossbedded sandstone interbedded with slope-forming, poorly sorted, purple, light-red, and blue siltstone and mudstone. Lithology is highly variable locally but regionally homogeneous, consisting of about 75% sandstone, 20% conglomerate, and 5% mudstone. Pebbles are generally brown, black, or light-colored, well-rounded quartz and siliceous composition. Petrified logs and wood fragments are generally scattered throughout unit but common at some localities. Unconformable contact with underlying red siltstone and sandstone of Moenkopi Formation. Unit is thickest in Painted Desert area; thins north along Echo Cliffs and thins south of map area. Thickness, 60 to 200 ft (18 to 60 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

TRcs - Chinle Formation, Shinarump Member (Upper Triassic)
White to yellowish-brown, cliff-forming, thin- to thick-bedded, coarse-grained, low-angle crossbedded sandstone, gravel, and conglomeratic sandstone. Includes numerous small channel lenses and pockets of small pebble conglomerate composed of well rounded to subrounded, multicolored quartz, quartzite, and black chert pebbles in gravely sandstone matrix. Black chert pebbles are dominant clasts. Pebbles average about 2.4 to 4.8 cm (1 to 2 in) in diameter and include some well-rounded quartzite cobbles as large as 24 cm (10 in) in diameter and numerous angular petrified wood fragments and segments of petrified logs. Black pebbles eroded from Yellowstone Mesa area form desert pavement of lag gravel on all alluvial fan and colluvial surfaces down slope of mesa, southwest quarter of map area. Unit is source area for well rounded, multicolored quartz, quartzite, and chert pebbles in all surficial units below outcrops of the Shinarump Member of the Chinle Formation. Weathered sand from the Shinarump Member provides source for local eolian sand sheet (Qes) and dune sand and sand sheet (Qd) deposits that are transported by southwesterly winds up and over Petrified Forest Member. Unit fills broad channels that are as much as 9 m (30 ft) deep and 0.8 to 1.5 km (0.5 to 1 mi) wide eroded into underlying upper red member of Moenkopi Formation. Thickness ranges from about 6 to 38 m (20 to 125 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRcs - Chinle Formation, Shinarump Member & sandstone and siltstone (Upper Triassic)
White, light-brown, and yellowish-pink, cliff-forming, coarse-grained sandstone and conglomeratic sandstone. Includes cliff-forming, low-angle crossbedded sandstone interbedded with slope-forming, poorly sorted, purple, light-red, and blue siltstone and mudstone. Lithology is highly variable but is relatively homogeneous from a regional viewpoint; consists of about 75% sandstone, 20% conglomerate, and 5% mudstone. Pebbles are generally brown to light-colored, well-rounded quartzite and black siliceous composition. Petrified logs and wood fragments common at some localities but generally scattered throughout unit. Some petrified wood and associated sandstone include uranium mineral

deposits that were mined for uranium along Little Colorado River valley during the 1950's. All open-pit mines (Qaf) are abandoned and most have undergone landscape reclamation. Unconformable erosional contact with underlying red siltstone and sandstone of Moenkopi Formation. Thickest exposures of unit is northwest of Cameron, thinning southeastward along Little Colorado River Valley. About 18 to 60 m (60 to 200 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRcs - Shinarump Member of the Chinle Formation (Upper Triassic)
White, coarse-grained, cliff-forming, low-angle crossbedded sandstone and pebble conglomerate. Unit is overlain by thin soil that is baked brick red by overlying basalt flow at Red Butte. Sandstone and conglomerate is partly baked red by basalt flow where basalt is in direct contact. Disconformable contact with underlying red siltstone and sandstone beds of the Moenkopi Formation. Unit is likely part of a paleovalley filled with fluvial deposits that make up the Shinarump Member of the Chinle Formation. Thickness, 85 ft (26 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Moenkopi Formation (Middle(?) and Lower Triassic)

Includes, in descending order, the upper red member, the Shnabkaib Member, and the lower red member, Virgin Limestone Member, and middle red member, undivided as defined by Stewart and others (1972). The basal Timpoweap Member of the Moenkopi Formation is present in some areas but too thin and limited in extent to show as a separate unit. Where present, it is included within the lower red member.
The Moenkopi Formation forms a continuous outcrop along and near U.S. Highway 89A at base of Vermilion and Echo Cliffs to Lees Ferry. Unit is mostly eroded from House Rock Valley and Marble Plateau and partly covered by large landslides, talus and rock fall, and other surficial deposits. Overall thickness before Cenozoic erosion, about 500 ft (152 m) or more. (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Includes, in descending order, the Holbrook and Moqui Members, undivided, Shnabkaib Member, and Wupatki Member. The basal Timpoweap Member of the Moenkopi Formation is present but too thin and limited in extent to show at map scale so is included in the Wupatki Member. The Moenkopi Formation is mostly eroded in the Grand Canyon area, but remnants form Cedar Mountain, Gold Hill, Yon Dot hills, Shinumo Altar, and several isolated outcrops on Marble and Coconino Plateaus. (*GRI Source Map ID 75648)* (Tuba City 30 x 60)

Includes, in descending order, upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member and Timpoweap Member, as used by Stewart and others (1972). Boundary between Middle(?) and Lower Triassic lies within the upper red member (Morales, 1987). Formation as a whole gradually thickens northwesterly across map area. (Timpoweap Member is partly redefined because of west to east facies change within map area). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRmu - Moenkopi Formation, upper red member (Middle(?) and Lower Triassic)

TRmu - Moenkopi Formation, upper red member (Middle(?) and Lower Triassic)
Reddish-brown and dark-red alternating sequence of slope- and ledge-forming claystone, siltstone, and sandstone. Thin, laminated mudstone and siltstone beds fill minor channels between thin to thick massive sandstone beds (1 to 10 ft [0.3 to 3 m]) thick. Sandstone beds include large- to medium-scale trough crossbedding, abundant cusp-type ripple marks, interbedded thin limestone beds, and lenses of conglomeratic sandstone, chert nodules, and thin veins of gypsum. Gradational contact with underlying

Shnabkaib Member. Unit undergoes rapid facies change southward along Echo Cliffs from red siltstone-sandstone near Lees Ferry to mostly tan and gray-white sandstone at south edge of quadrangle. Includes white-gray, coarse-grained, calcareous sandstone and red siltstone channel lenses similar in lithology and appearance to underlying sandstone and siltstone beds of Shnabkaib Member of the Chinle Formation. Unit is totally removed by Triassic stream-channel erosion at several locations along base of Echo and Vermillion Cliffs to Lees Ferry where channels are instead filled with conglomeratic sandstone of Shinarump Member of the Chinle Formation. Thickness, 0 to 120 ft (0 to 37 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

TRmhm - Moenkopi Formation, Holbrook and Moqui Members, undivided (Middle(?) and Lower Triassic)

Reddish-brown and tan, slope-forming, alternating sequence of claystone, siltstone, and sandstone (McKee, 1954). Unit is equivalent to upper red member of Stewart and others (1972) in northwestern Arizona. Siltstone and sandstone beds include large- to medium-scale trough crossbedding and abundant cusp-type ripple marks, interbedded thin limestone, lenses of conglomeratic sandstone, chert nodules, and thin veins of gypsum. Gradational contact with underlying Shnabkaib Member. Unit undergoes rapid facies change from red siltstone-sandstone sequence in northern part of map area to mostly tan sandstone sequence in the south. Tan sandstone beds increase in thickness north to south across the map and become similar to conglomeratic beds of the overlying Shinarump Member and sandstone and siltstone member, undivided. Include numerous channel lenses that are often confused with the Shinarump. Thus, uncertainties exist in the central part of the map where unconformities between similar sandstones are numerous and difficult to differentiate. Typically, small pebbles within a sandstone lens or bed denotes the Shinarump Member and sandstone and siltstone members, undivided, of the Chinle Formation. Thickness, 80 to 120 ft (25 to 37 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

TRmu - Moenkopi Formation, upper red member (Middle(?) and Lower Triassic)

Light-red and dark-red, slope- and ledge-forming sequence of siltstone, sandstone, and conglomerate interbedded with minor gray gypsum. Includes small dark-red and brown resistant sandstone cliffs in upper part that exhibits minor unconformity at bottom of lowest dark-red sandstone cliff (middle part of unit, not shown on map) that may represent boundary between Early and Middle Triassic age (Moralas, 1987; Billingsley and Workman, 2000). Gradational contact with underlying Shnabkaib Member approximately placed at top of highest thick white siltstone and dolomite bed of Shnabkaib Member. About 49 m (160 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRmhm - Moenkopi Formation, Holbrook and Moqui Members, undivided (Middle(?) and Lower Triassic)

Reddish-brown, slope-forming, alternating sequence of claystone, siltstone, and sandstone (McKee, 1954). Includes large- to medium-scale trough crossbedding and abundant cusp-type ripple marks that testify to fluvial origin. Fossil casts of reptile tracks are often preserved on bottom surfaces of sandstone beds. Include interbedded, thin-bedded limestone and lenses of conglomeratic sandstone, and some lenses, nodules, veins, and thin-bedded gypsum. About 25 to 37 m (80 to 120 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRms - Moenkopi Formation, Shnabkaib Member (Lower Triassic)

TRms - Moenkopi Formation, Shnabkaib Member (Lower Triassic)

Yellowish-white and light-brown, cliff-forming, crossbedded, fine-grained, calcareous and gypsiferous siltstone and dolomite and coarse-grained sandstone. Forms prominent white slope or ledge at south end of Vermilion Cliffs near U.S. Highway 89A south of Cliff Dwellers Lodge and yellow-brown calcareous sandstone ledges or cliff east of U.S. Highway 89A and 89 along Echo Cliffs to south edge of

quadrangle. Shnabkaib Member thins and undergoes a northward facies change to yellow-brown and light-red calcareous sandstone ledges that weather dark red and black. The Shnabkaib Member is locally removed by Middle(?) Triassic channel erosion in several areas below Echo and Vermilion Cliffs to Lees Ferry. Channels are filled with conglomeratic sandstone of Shinarump Member of the Chinle Formation. Unit gradually thickens south of quadrangle (Billingsley and others, 2013) and northwest of quadrangle (Billingsley and others, 2008). Gradational contact with underlying lower red member, Virgin Limestone Member, and middle red member, undivided marked at base of lowest tan or light-red sandstone cliff. Thickness, 0 to 100 ft (0 to 30 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

TRms - Moenkopi Formation, Shnabkaib Member (Lower Triassic)
Yellowish-white and light-brown, cliff-forming, crossbedded, fine-grained, calcareous siltstone and coarse-grained sandstone. Unit is equivalent to lower massive sandstone member of the Moenkopi Formation as defined by McKee (1954) south of the map area (Billingsley and others, 2007). Lowermost ledge-forming sandstone undergoes a facies change from light-red calcareous sandstone south of map area to yellowish-white calcareous gypsiferous sandstone and dolomite north of map area. Gradational contact with underlying Wupatki Member marked at base of lowest tan or light-red sandstone cliff. Thickness, 50 to 100 ft (15 to 30 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

TRms - Moenkopi Formation, Shnabkaib Member (Lower Triassic)
Interbedded and intertonguing, white to light-gray, laminated to thinly bedded, slope-forming, aphanitic dolomite and light-gray, calcareous siltstone and silty gypsum. Includes some light-red, thin-bedded mudstone, siltstone, and sandstone in lower and upper part. Gradational contact with underlying middle red member; map contact placed at lowest thick white or light-gray calcareous siltstone and dolomite bed of the Shnabkaib Member. Unit thickness is variable within map area because of approximate upper and lower contacts; unit thickens northwestward and thins eastward and southeastward. Thickness ranges from about 27 to 114 m (90 to 375 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRmss - Moenkopi Formation, Shnabkaib Member and lower massive sandstone member, undivided (Lower Triassic)
Yellowish-white and light-brown, cliff-forming, crossbedded, fine-grained, calcareous siltstone and sandstone. Shnabkaib Member and lower massive sandstone member is undivided on Marble Plateau north of Little Colorado River Gorge and intertongues or overlaps lower massive sandstone member in the vicinity of the Little Colorado River west of Cameron, Arizona. Unit is the Shnabkaib Member of the Moenkopi Formation on Marble Plateau north of map area. Unit is lower massive sandstone member of the Moenkopi Formation as defined by McKee (1954) from Cameron, Arizona south to southeast edge of map. Unit is thickest at Wupatki National Monument (15 m [50 ft]) consisting of two or more sandstone beds that form prominent isolated mesas or ridges in Wupatki National Monument area. Unit gradually thins in all directions from Wupatki and the lowermost ledge-forming sandstone is the most widespread part of unit. Gradational contact with underlying Wupatki Member marked at base of lowest sandstone cliff. About 3 to 26 m (10 to 53 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRmlm - Moenkopi Formation, lower red member, Virgin Limestone Member, and middle red member, undivided (Lower Triassic)

Red and red-brown, slope-forming, thin-bedded, mudstone, siltstone, and sandstone. Bedding surfaces often contain small-scale ripple marks, salt crystal casts, mudcracks, and rain-drop impressions. Lower and middle red members are separated by thin discontinuous bed of yellowish-white, thin, platy, silty limestone and siltstone of the Virgin Limestone Member less than 2 ft (0.6 m) thick and about 15 to 20 ft (4.5 to 6 m) above Harrisburg Member of the Kaibab Formation. Virgin Limestone pinches out along southern edge of quadrangle and is not present in the Lees Ferry area. Where the Virgin Limestone is

absent, that horizon is marked by color change from light-red siltstone and sandstone of lower red member to a darker red siltstone and sandstone of middle red member. Unit includes basal Timpoweap Member of the Moenkopi Formation composed of subangular to subrounded, small, white, angular chert pebbles and fragments and limestone clasts in calcareous sandstone matrix derived from underlying Harrisburg Member in House Rock Valley and on Marble Plateau, western half of quadrangle. Unconformable erosional contact with underlying Harrisburg Member of the Kaibab Formation in the western half of quadrangle represents regional Permian/Triassic boundary. Thickness, 375 to 400 ft (114 to 122 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

TRmw - Moenkopi Formation, Wupatki Member (Lower Triassic)

TRmw - Moenkopi Formation, Wupatki Member (Lower Triassic)
Red and red-brown, slope-forming, thin-bedded, mudstone, siltstone, and sandstone as defined by McKee (1954). Interbedded sandstones as thick as 1 to 3 ft (0.5 to 1 m) form resistant ledges within crumbly red-brown mudstone/siltstone slopes. Bedding surfaces often contain small-scale ripple marks, salt crystal casts, mud cracks, and rain-drop impressions. Unit is equivalent to lower red member, Virgin Limestone Member, and middle red member of Stewart and others (1972) in northwestern Arizona. Virgin Limestone Member is present at Cedar Ridge and in Yon Dot Mountains on Marble Plateau but is too thin to show at map scale. Virgin Limestone beds consist of yellowish-white, thin, platy, silty limestone and siltstone about 1 to 3 ft (0.3 to 1 m) thick and about 15 to 20 ft (4.5 to 6 m) above Harrisburg Member of the Kaibab Formation (Pkh); represent the regional Permian/Triassic unconformity. Unit includes basal Timpoweap Member of the Moenkopi Formation. Timpoweap Member is composed of subangular to subrounded conglomerate in calcareous sandstone matrix; small, white, angular chert pebbles and fragments derived from Kaibab Formation occupy shallow depressions and channels eroded into underlying Harrisburg Member of the Kaibab Formation in western half of map. Thickness, 30 to 85 ft (9 to 26 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

TRmw - Moenkopi Formation, Wupatki Member (Lower Triassic)
Red and red-brown, slope-forming, thin flat-bedded, siltstone and sandstone and interbedded crumbly red-brown mudstone (McKee, 1954). Thin sandstone beds (0.5 to 1 m [1 to 3 ft]) form resistant ledges. Bedding surfaces often contain small-scale ripple marks, salt crystal casts, or rain drop impressions. Unconformably overlies Kaibab Formation on a regional Permian-Triassic boundary. Unit generally maintains constant thickness from Little Colorado River Gorge to Cameron, Arizona, then gradually thins southwest and southeast of Gray Mountain, Arizona. About 6 to 26 m (20 to 85 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRm - Moenkopi Formation, undivided (Upper(?), Middle(?) and Lower Triassic)

TRm - Moenkopi Formation, undivided (Middle(?) and Lower Triassic)
Light-red and dark-red, slope-forming siltstone and sandstone and minor gray gypsum. Exposed as isolated outcrops in House Rock Valley along lower limb of East Kaibab Monocline and on Little Mountain of the Kaibab Plateau between the west and east segments of the East Kaibab Monocline. Units are likely equivalent to the lower red and middle red members, minus the Virgin Limestone Member of the Moenkopi Formation. Units are often capped by older alluvial sediments except along State Highway 89A near House Rock Valley. Thickness, about 6 to 14 m (20 to 45 ft. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRm - Moenkopi Formation, undivided (Middle(?) and Lower Triassic)
Red, slope-forming, fine-grained, thin-bedded, shaly siltstone and sandstone. Includes, in ascending

order, the Wupatki Member, the Shnabkaib Member and lower massive sandstone member, and the Holbrook and Moqui Members, undivided. White, cliff-forming, coarse-grained, low-angle, crossbedded sandstone in lower part of unit in Dog Knobs area may be equivalent to the lower massive sandstone member of the Moenkopi Formation east of Dog Knobs area. Unit is mostly eroded from southwest part of map area and commonly buried by volcanic rocks of the San Francisco Volcanic Field in Dog Knobs area. The basal Timpoweap Member of the Moenkopi Formation (not mapped) is composed of conglomeratic limestone or calcareous sandstone with small white, angular chert pebbles and fragments that occupy shallow depressions and channels eroded into underlying Harrisburg Member of the Kaibab Formation in western half of map area. Unit is distinguished from underlying red siltstone and sandstone beds of Harrisburg Member of the Kaibab Formation (Pkh) by its darker red color, thin-bedded, platy, coarse-grained, conglomeratic sandstone beds as opposed to massive-bedded, pale-red and gray, undulating, soft siltstone and sandstone beds of Harrisburg Member. Forms unconformable contact with underlying Harrisburg Member of the Kaibab Formation (Pkh) representing the regional Permian/Triassic unconformity. Overall thickness before Cenozoic erosion, about 300 m (1,000 ft) along west edge of map area, thins eastward to about 107 m (350 ft) near Cameron, Arizona, and to about 67 m (220 ft) at Wupatki National Monument area. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

TRm - Moenkopi Formation (Lower Triassic)

Includes only the basal Timpoweap Member (Lower Triassic) as defined by Stewart and others (1972). In general, Moenkopi Formation is mostly eroded from map area except for an isolated outcrop north of Granite Park, northeast edge of map. Unit is likely covered by Shiwits basalt flows on Shiwits Plateau (Billingsley and Wellmeyer, 2003). Timpoweap Member consists of light reddish-gray, cliff-forming conglomerate in lower part and light-gray to light-red, slope-forming calcareous sandstone in upper part. Conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and gray sandstone in matrix of gray to brown, coarse-grained sandstone. Consolidated by calcite and gypsum. All detritus in Timpoweap Member is derived from erosion of the Kaibab Formation. Fills paleovalley about 40 m (130 ft) deep eroded into Kaibab Formation. Imbrication of pebbles in conglomerate shows general northeast flow of depositing stream. Thickness, 0 to 40 m (0 to 130 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

TRm - Moenkopi Formation (Upper(?) and Lower Triassic)

Red, slope-forming, fine-grained, thin-bedded shaley siltstone and sandstone. Includes a white, cliff-forming, coarse-grained, low-angle crossbedded sandstone in lower quarter of unit that may be equivalent to the Moki Member of the Moenkopi Formation east of the map area, or the Shnabkaib Member of the Moenkopi Formation north of the map area. Unit is mostly eroded from map area except for outcrops beneath volcanic rocks in southeast quarter, isolated outcrops in southwest part of map in order, the upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member, and the Timpoweap Member as defined by Stewart and others (1972). In general, Moenkopi Formation is mostly eroded from map area except for isolated outcrops beneath Tertiary volcanic rocks at Mount Trumbull, Mount Logan, Poverty Knoll, Poverty Mountain, Grassy Mountain, and Yellow John Mountain. A complete section of the Moenkopi Formation crops out at Hells Hole 21 km (13 mi) north of Colorado River Mile 188, upper Whitmore Canyon. Total thickness of the Moenkopi Formation at Hells Hole, 365 m (1,200 ft).

Upper red member consists of red, thin-bedded, cliff- and slope-forming siltstone and sandstone. Gradational lower contact placed at uppermost thick white or light-gray calcareous siltstone and dolomite of Shnabkaib Member. Unit thins south and east, thickens north. Thickness, 122 m (400 ft).

Shnabkaib Member is white, laminated to thin-bedded, slope- and ledge-forming, aphanitic dolomite interbedded with light-gray, calcareous, silty gypsum. Gradational lower contact at lowest thick white or light-gray, calcareous, silty dolomite of middle red member. Unit thins south and west, thickens north. Thickness, 135 m (440 ft).

Middle red member consists of red-brown, thin-bedded to laminated, slope-forming siltstone and sandstone. Includes white and gray gypsum beds, minor white platy dolomite, green siltstone, and gray-green to red gypsiferous mudstone. Gradational lower contact about 10 m (30 ft) above gray limestone

bed of Virgin Limestone Member. Unit thins west, south, and east, thickens north. Thickness, 122 m (400 ft).
Virgin Limestone Member consists of one light-gray, thin-bedded to thinly laminated, ledge-forming limestone bed, 0.5 to 2 m (1 to 6 ft) thick, and overlying pale-yellow, red, and bluish-gray, thin-bedded, slope-forming gypsiferous siltstone. Pinches out south and west in map area, thickens north and includes two limestone beds at north edge of map area and as many as four limestone beds near St. George, Utah. Unconformable contact at base of limestone bed with underlying lower red member; erosional relief as much as 2 m (6 ft) just north of map area (Billingsley and Workman, 2000). Thickness, 20 m (65 ft).
Lower red member consists of red, fine-grained, thin-bedded, sandy siltstone; and gray, white, and pale-yellow laminated gypsum and minor sandstone. Lower part contains redeposited gypsum and siltstone of Harrisburg Member of the Kaibab Formation. Gradational contact with underlying conglomerates of the Timpoweap Member; locally, unconformably overlies Harrisburg Member of the Kaibab Formation where Timpoweap is absent. Thickens in paleovalleys and pinches out onto eroded paleohills of underlying Harrisburg Member. Unit distinguished from red siltstone of Harrisburg Member of the Kaibab Formation by dark-red color and thin-bedded, platy beds of the lower red member as opposed to massive-bedded, pale-red, undulating siltstone and gray limestone beds of Harrisburg Member. Thickness, 0 to 20 m (0 to 65 ft).
Timpoweap Member consists of light-gray, slope- and cliff-forming conglomerate in lower part and light-gray to light-red, slope-forming calcareous sandstone in upper part. Conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and gray sandstone in matrix of gray to brown, coarse-grained sandstone. Consolidated by calcite and gypsum. All detritus in Timpoweap Member derived from Kaibab Formation. Fills paleovalleys about 1,500 m (5,000 ft) wide and as much as 70 m (230 ft) deep eroded into Harrisburg Member of the Kaibab Formation. Imbrication of pebbles in conglomerate show general northeastward flow of depositing streams. Thickness, 0 to 70 m (230 ft). (*GRI Source Map ID 7453)* (Valle 30 x 60).

TRm - Moenkopi Formation, undivided (Middle(?) and Lower Triassic)
Includes, in descending order, the upper red member, Shnabkaib Member, middle red member, Virgin Limestone Member, lower red member, and the Timpoweap Member as defined by Stewart and others (1972). In general, Moenkopi Formation is mostly eroded from map area except for isolated outcrops beneath Tertiary volcanic rocks at Mount Trumbull, Mount Logan, Poverty Knoll, Poverty Mountain, Grassy Mountain, and Yellow John Mountain. A complete section of the Moenkopi Formation crops out at Hells Hole 21 km (13 mi) north of Colorado River Mile 188, upper Whitmore Canyon. Total thickness of the Moenkopi Formation at Hells Hole, 365 m (1,200 ft).
Upper red member consists of red, thin-bedded, cliff- and slope-forming siltstone and sandstone. Gradational lower contact placed at uppermost thick white or light-gray calcareous siltstone and dolomite of Shnabkaib Member. Unit thins south and east, thickens north. Thickness, 122 m (400 ft).
Shnabkaib Member is white, laminated to thin-bedded, slope- and ledge-forming, aphanitic dolomite interbedded with light-gray, calcareous, silty gypsum. Gradational lower contact at lowest thick white or light-gray, calcareous, silty dolomite of middle red member. Unit thins south and west, thickens north. Thickness, 135 m (440 ft).
Middle red member consists of red-brown, thin-bedded to laminated, slope-forming siltstone and sandstone. Includes white and gray gypsum beds, minor white platy dolomite, green siltstone, and gray-green to red gypsiferous mudstone. Gradational lower contact about 10 m (30 ft) above gray limestone bed of Virgin Limestone Member. Unit thins west, south, and east, thickens north. Thickness, 122 m (400 ft).
Virgin Limestone Member consists of one light-gray, thin-bedded to thinly laminated, ledge-forming limestone bed, 0.5 to 2 m (1 to 6 ft) thick, and overlying pale-yellow, red, and bluish-gray, thin-bedded, slope-forming gypsiferous siltstone. Pinches out south and west in map area, thickens north and includes two limestone beds at north edge of map area and as many as four limestone beds near St. George, Utah. Unconformable contact at base of limestone bed with underlying lower red member; erosional relief as much as 2 m (6 ft) just north of map area (Billingsley and Workman, 2000).

Thickness, 20 m (65 ft).
Lower red member consists of red, fine-grained, thin-bedded, sandy siltstone; and gray, white, and pale-yellow laminated gypsum and minor sandstone. Lower part contains redeposited gypsum and siltstone of Harrisburg Member of the Kaibab Formation. Gradational contact with underlying conglomerates of the Timpoweap Member; locally, unconformably overlies Harrisburg Member of the Kaibab Formation where Timpoweap is absent. Thickens in paleovalleys and pinches out onto eroded paleohills of underlying Harrisburg Member. Unit distinguished from red siltstone of Harrisburg Member of the Kaibab Formation by dark-red color and thin-bedded, platy beds of the lower red member as opposed to massive-bedded, pale-red, undulating siltstone and gray limestone beds of Harrisburg Member. Thickness, 0 to 20 m (0 to 65 ft).
Timpoweap Member consists of light-gray, slope- and cliff-forming conglomerate in lower part and light-gray to light-red, slope-forming calcareous sandstone in upper part. Conglomerate composed of subangular to rounded pebbles and cobbles of gray and dark-gray limestone, white and brown chert, and gray sandstone in matrix of gray to brown, coarse-grained sandstone. Consolidated by calcite and gypsum. All detritus in Timpoweap Member derived from Kaibab Formation. Fills paleovalleys about 1,500 m (5,000 ft) wide and as much as 70 m (230 ft) deep eroded into Harrisburg Member of the Kaibab Formation. Imbrication of pebbles in conglomerate show general northeastward flow of depositing streams. Thickness, 0 to 70 m (230 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

TRm - Moenkopi Formation (Lower Triassic)
Red, slope-forming, fine-grained, thin-bedded shaley siltstone and sandstone. Unit mostly eroded from map area except for
one small outcrop along Bright Angel Fault southwest of Grand Canyon. Only about 20 ft (6 m) of basal part of Moenkopi Formation is present and most certainly represents Lower Triassic strata only. Unit is distinguished from underlying red siltstone of Harrisburg Member of Kaibab Formation (Pk) by its darker red color and thin-bedded, platy sandstone beds as opposed to the massive-bedded, pale-red, undulating, softer siltstone beds of Harrisburg Member. A complete section of the Moenkopi crops out at the Vermilion Cliffs about 24 mi (38 km) northeast of map area, and at Mount Logan in the Sawmill Mountains about 13 mi (21 km) west of map area. About 20 ft (6 m) exposed. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

TRmm - Moenkopi Formation, middle red member (Lower Triassic)

Reddish-brown, thin-bedded to laminated, slope-forming gypsiferous siltstone and sandstone, white and gray gypsum, minor white platy dolomite, green siltstone, and gray-green to red gypsiferous mudstone. Includes abundant thin veinlets and stringers of gypsum deposited in fractures and cracks throughout unit. Includes minor beds of white laminated dolomite, green siltstone, and gray-green to red gypsiferous mudstone. Mud cracks and ripple marks common throughout. Gradational contact with underlying Virgin Limestone Member at top of highest light-gray limestone bed of Virgin Limestone Member in Fredonia and Muggins Flat, north-central part of map; gradational lower contact with lower red member in House Rock Valley marked by color contrast between dark-red lower red member and light-red middle red member, northeast quarter of map area. Unit gradually thickens northeasterly across map area. Thickness ranges from about 55 to 92 m (180 to 300 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRmv - Moenkopi Formation, Virgin Limestone Member (Lower Triassic)

Includes two light-gray, thin-bedded to laminated, ledge-forming limestone beds [0.3 to 1 m (1 to 3 ft)] thick, separated by pale-yellow, light-red, and blue-gray, thin-bedded slope-forming gypsiferous siltstone that makes up bulk of unit. Lower limestone bed contains star-shaped crinoid plates and poorly preserved Composita brachiopods in upper part 14.5 km (9 mi) east of map area. Lower limestone bed

thickens and thins due to channel fill cut as much as 1.3 m (4 ft) deep into underlying dark-red siltstone and sandstone of lower red member of the Moenkopi Formation south of Fredonia, Arizona, near Kanab Creek. Upper limestone bed contains abundant fossil algae and pinches out a few kilometers east of Fredonia, Arizona; whereas lower limestone bed thins eastward to western edge of Kaibab Plateau and is not present in House Rock Valley east of Kaibab Plateau. Unit as a whole thickens west and north, thins south and east of Fredonia, Arizona. Forms small mesas near Kanab Creek and thin white ledges in Muggins Flat area, north-central part of map. Thickness ranges from 0 to 25 m (0 to 80 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRml - Moenkopi Formation, lower red member (Lower Triassic)

Dark-red, slope-forming, thin-bedded, fine-grained, gypsiferous, sandy siltstone, sandstone, and pale-yellow to gray laminated silty gypsum. Ledge-forming light red sandstone beds become more numerous in upper reaches of Kanab Creek and Fredonia areas. Gypsum, siltstone, and sandstone in lower part are derived from erosion of Harrisburg Member of the Kaibab Formation. Includes prominent ledge-forming, red-gray to light purple-red, coarse-grained to conglomeratic, thin-bedded, low-angle cross-bedded calcareous sandstone marker bed, 2 to 4 m (6 to 13 ft) thick in lower part that forms resistant sandstone surface of Kanab Plateau west of Kanab Creek and south of Pipe Spring National Monument area. Marker bed includes raindrop impressions and rare carbonaceous plant fossils in Short Creek 5 km (3 mi) west of map area (Billingsley and Workman 2000; Billingsley and others, 2002). Interbedded or gradational contact with underlying limestone, sandstone, or conglomerate of the Timpoweap Member, otherwise unconformable contact with Harrisburg Member of the Kaibab Formation. Locally fills paleovalleys eroded into Harrisburg Member of the Kaibab Formation or pinches out onto paleohills of the Kaibab in southwest quarter of map area. Thickness ranges from about 36 to 76 m (120 to 250 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

TRmt - Moenkopi Formation, Timpoweap Member (Lower Triassic)

Includes an upper and lower part: Upper part consists of gray to yellow-gray, cliff-forming, fine-grained, thick-bedded sandy limestone as much as 3 m (10 ft) thick. Locally includes gray, interbedded, coarse-grained, low-angle crossbedded calcareous sandstone containing small, rounded chert pebbles. Gradationally overlies conglomerate or thin-bedded sandy yellowish limestone of lower part except where unit unconformably overlies Harrisburg Member of the Kaibab Formation. Unit is difficult to distinguish from Harrisburg Member of the Kaibab Formation at north edge and is mapped as Harrisburg Member of the Kaibab Formation in that area, whereas adjoining geologic map of Kaibab Plateau in Utah is mapped, in part, as Timpoweap Member of the Moenkopi Formation (Sable and Hereford, 2004).
Lower part consists mainly of cliff- and slope-forming, gray, dark-gray, white and reddish-brown chert conglomerate in gray gravel sandstone matrix. Includes yellow, reddish-brown, interbedded, calcareous, thin-bedded, cross-stratified, sandstone, siltstone, gray gypsiferous siltstone, and yellow to gray, thin-bedded sandy limestone. Conglomerate clasts are subangular to rounded pebbles and cobbles of limestone and chert derived from erosion of nearby and underlying Kaibab Formation. Conglomerate is pebble-supported in most outcrops with pebbles compressed into one another; where matrix-supported, matrix is gray limestone and coarse-grained cherty sandstone. Conglomerate clasts are as much as 30 cm (12 in) in diameter. Imbrication of pebbles in conglomerate indicates northeasterly flow of depositing streams. Unconformable contact with underlying Harrisburg Member of the Kaibab Formation in paleovalleys. Rock Canyon Conglomerate was proposed and abandoned by Gregory (1948, 1952), used by Nielsen and Johnson (1979), and Nielsen (1986, 1991). Timpoweap Member of the Moenkopi Formation is used in this report as used by Stewart and others (1972) and Sable and Hereford (2004). Unit gradually thins west to east across map area and is largely confined to shallow wide paleovalleys in upper reaches of Kanab Creek and Muggins Flat area. Thickness ranges from 0 to 30 m (0 to 100 ft). (

GRI Source Map ID 75234) (Fredonia 30 x 60).

Kaibab Formation (Lower Permian)

Includes, in descending order, the Harrisburg Member and Fossil Mountain Member as defined by Sorauf and Billingsley (1991). Please note that lower Permian is now referred to as Cisuralian. (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Includes, in descending order, the Harrisburg Member and Fossil Mountain Member as defined by Sorauf and Billingsley (1991). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Includes, in descending order, Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Includes, in descending order, Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Includes, in descending order, the Harrisburg Member and Fossil Mountain Member as defined by Sorauf and Billingsley (1991). Please note that lower Permian is now referred to as Cisuralian. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Pk - Kaibab Formation, undivided (Lower Permian)

Pk - Kaibab Formation, undivided (Lower Permian)
Includes, in descending order, Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991). Mapped as Kaibab Formation, undivided, east of Doney Mountain Fault and Wupatki National Monument along the Little Colorado River because of eastward shoreward facies change in both members that collectively forms gray to light-brown, cliff-forming, calcareous sandstone and sandy limestone beds that are indistinguishable from each other. Unit gradually thins southeastward. About 92 m (300 ft) thick in western part of map area, thinning to about 76 m (250 ft) thick in eastern part. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Pk - Kaibab Formation, undivided (Lower Permian)
Includes, in descending order, the Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991), undivided.
Harrisburg Member consists of red-gray, yellow-gray, and blue-gray, slope-forming gypsum, gypsiferous siltstone, sandstone, calcareous sandstone; and gray, ledge-forming limestone, sandy limestone; and capped by yellow-gray, thin-bedded, fossiliferous sandy limestone. Includes silicified fossiliferous chert breccia beds near base of unit, particularly along Aubrey and Toroweap Faults. Forms surface bedrock of Coconino Plateau where not covered by Cenozoic deposits. Unit is partly removed by modern erosion along higher terrain of Aubrey Cliffs and Coconino Plateau. Unit is totally removed by Laramide erosion on Shiwits Plateau of map area. Unit is partly covered by old gravel and sedimentary (Ts1) deposits on Coconino Plateau, northeast quarter of map area. Contact with underlying Fossil Mountain Member is gradational and arbitrary contact is marked at top of cherty limestone cliff of Fossil Mountain Member. Harrisburg Member thickens northeast and east of map area, thins southwest and southeast. Unit is beveled and removed by early Tertiary erosion prior to deposition of the Shiwits basalt (Tsb) on Shiwits Plateau of map area. Thickness, 38 to 50 m (125 to 165 ft).
Fossil Mountain Member consists of light-gray, cliff-forming, fine- to medium-grained, thin- to medium-bedded (0.5 to 2 m [1 to 6 ft]), fossiliferous, sandy, cherty limestone. Weathers dark gray. Unit is characterized by numerous gray to white chert nodules and chert lenses in limestone beds; chert

weathers dark gray to black. Some chert nodules contain spherical black and white bands. Breccia chert beds (1.5 to 3 m [4 to 10 ft] thick) are common in upper part near contact with overlying Harrisburg Member of the Kaibab Formation. Chert composes about 20 percent of unit and limestone beds become sandier east and southeast of map area. Fossil Mountain Member generally forms upper cliff of the Aubrey Cliffs and upper cliff of Shiwits Plateau. Also forms east rim of the Grand Canyon and Coconino Plateau. Most of Fossil Mountain Member is beveled and removed by early Laramide erosion prior to deposition of the Shiwits basalt (Tsb) on Shiwits Plateau in map area. Unconformable contact with underlying Toroweap Formation characterized by dissolution of gypsum and erosion channels with average relief of about 3 m (10 ft). Thickness, 40 to 107 m (130 to 350 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Pk - Kaibab Formation, undivided (Lower Permian)

Includes, in descending order, the Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991). Entire unit is removed by modern erosion from some areas of the north rim of Grand Canyon. Thickness of Kaibab Formation, 0 to 160 m (0 to 530 ft), but as much as 198 m (650 ft) in channel areas.

Harrisburg Member consists of reddish-gray and brownish-gray, slope-forming gypsum, siltstone, sandstone, and limestone. Includes, in descending order, an upper slope, middle cliff, and lower slope unit. Upper slope unit: red and gray, interbedded gypsum, sandstone, siltstone, capped by yellowish-gray, fossiliferous sandy limestone. Middle cliff unit: gray, thin-bedded, cherty limestone that weathers dark gray and yellowish-gray sandy limestone. Lower slope unit: yellowish-gray to pale-red, gypsiferous siltstone and calcareous sandstone; gray, thin-bedded sandy limestone; and gray to white, thick-bedded gypsum. Dissolution within lower gypsum beds has resulted in local warping and bending of middle limestone beds, especially at or near local drainages. Dissolution of gypsum in the Harrisburg Member is responsible for many collapse sinkholes on Shiwits, Uinkaret, and Kanab Plateaus. Gradational contact marked at top of cherty limestone cliff of Fossil Mountain Member. Thickness, 0 to 80 m (0 to 265 ft) in north half of map, beveled and removed by erosion along south edge of the Shiwits Plateau area.

Fossil Mountain Member is light-gray, cliff-forming, fine- to medium-grained, thin- to medium-bedded (0.3 to 2 m [2 to 6 ft]), fossiliferous, sandy, cherty limestone. Unit characterized by gray and white chert nodules and chert lenses parallel to bedding; chert weathers dark gray to black. Unit in general weathers medium gray. Several chert nodules contain concentric black and white bands and or fossil sponges. Brecciated chert beds 1 to 3 m (0.5 to 10 ft) thick common in upper part at contact with overlying Harrisburg Member. Unit generally forms cliff rim of Grand Canyon. Weathers into pinnacles or detached pillars or spires. Unconformable contact with underlying Woods Ranch Member of the Toroweap Formation characterized by channel erosion averaging about 3 m (10 ft) in relief, but in some areas large erosion channels or valleys are as much as 45 m (145 ft) in depth and as much as 2 km (1.3 mi) in width between lower Whitmore and Parashant Canyons and in upper Toroweap Canyon. Thickness of Fossil Mountain Member, 70 to 120 m (240 to 385 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Pk - Kaibab Formation, undivided (Lower Permian)

Includes, in descending order, Harrisburg and Fossil Mountain Members, undivided, as defined by Sorauf and Billingsley (1991). Harrisburg Member—Reddish-gray and brownish-gray, slope-forming gypsum, siltstone, sandstone, and limestone. Informally subdivided, in descending order, into three units forming an upper slope, middle cliff, and lower slope. Upper slope unit is interbedded red and gray gypsum, sandstone, and siltstone, and yellowish-gray fossiliferous sandy limestone. Middle cliff unit is gray, thin-bedded, fossiliferous cherty limestone and sandy limestone. Lower slope unit is (1) yellowish-gray to pale-red gypsifereous siltstone and calcareous sandstone, (2) gray, thin-bedded sandy limestone, and (3) gray to white, thick-bedded gypsum. Upper, middle, and lower units become inseparable on the Kaibab Plateau, northeastern quarter of map area. Solution weathering within gypsum beds of lower slope unit has resulted in warping and bending of limestone of middle cliff unit, especially in or near local drainages on Kanab and Coconino Plateaus where middle cliff unit forms surface bedrock. Gypsum solutioning is responsible for several sinkhole depressions within Harrisburg Member. Contact with

underlying Fossil Mountain Member is gradational and arbitrarily marked at top of cherty limestone cliff of the Fossil Mountain. About 260 ft (80 m) thick in western half of map area, thinning eastward to about 120 ft (36 m) in northeastern quarter of map area. Average thickness about 165 ft (50 m) Fossil Mountain Member—Light-gray, cliff-forming, fine- to medium-grained, thin to medium-bedded [1–6 ft (0.3–2 m)], fossiliferous, sandy, cherty limestone. In general, unit weathers dark gray. Unit characterized by gray to white fossiliferous chert nodules and white chert lenses parallel to bedding; chert weathers dark gray to black. Some chert nodules contain concentric black and white bands. Includes brecciated chert beds 4–10 ft (1–3 m) thick in upper part at contact of thin limestone or gypsiferous siltstone of Harrisburg Member. Chert in central and western parts of map area makes up about 20 percent of unit; unit becomes sandy in northeastern quarter of map area. Generally forms cliff at rim of the Grand Canyon. Weathers into pinnacles or "pillars" detached from cliff in western half of map area. Unconformable contact with underlying Woods Ranch Member of Toroweap Formation (Pt) attributed to solution erosion and channel erosion; average relief about 10 ft (3 m). Some channels have eroded as much as 150 ft (45 m) into the Woods Ranch in western half of map area. Erosion channels were filled with sandy cherty limestone typical of the Fossil Mountain, providing an extra thickness of the Fossil Mountain. Thickness about 230–350 ft (70–107 m) (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Pkh - Kaibab Formation, Harrisburg Member (Lower Permian)

Pkh - Kaibab Formation, Harrisburg Member (Lower Permian (Cisuralian))
Reddish-gray and brownish-gray, ledge- and slope-forming, gypsiferous siltstone, calcareous sandstone, and thin-bedded sandy limestone. Top of unit near south edge of quadrangle includes white, low-angle-crossbedded calcareous sandstone with fossil mollusks; elsewhere, upper part is primarily sandy, cherty limestone beds separated by gray calcareous and gypsiferous siltstone. Forms surface of Marble Plateau and House Rock Valley, southwest part of quadrangle. Contact with underlying Fossil Mountain Member is gradational and marked at topographic break between grayish-white, slope- and ledge-forming sandy limestone, sandstone, and siltstone sequence of Harrisburg Member and underlying gray to light-brown, cliff-forming, thick-bedded cherty limestone and sandy limestone of Fossil Mountain Member. Unit gradually thins west to east across quadrangle and undergoes a shoreward facies change from marine cliff- and slope-forming limestone and siltstone in west half of quadrangle to mostly sandy, cliff-forming calcareous marine sandstone east of Colorado River and Marble Plateau. Thickness, 80 to 120 ft (25 to 37 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Pkh - Kaibab Formation, Harrisburg Member (Lower Permian (Cisuralian))
Reddish-gray and brownish-gray, ledge- and slope-forming, gypsiferous siltstone, calcareous sandstone, and thin-bedded sandy limestone. Top of unit near Little Colorado River Gorge includes white, low-angle, crossbedded, calcareous sandstone with mollusk fossils; elsewhere, upper part is primarily sandy, cherty limestone. Forms surface of Kaibab, Coconino, and Marble Plateaus and House Rock Valley in west half of quadrangle. Contact with underlying Fossil Mountain Member is gradational and marked at topographic break between grayish-white, slope- and ledge-forming sandy limestone and sandstone sequence of Harrisburg Member and underlying cliff-forming, gray to light-brown, thick-bedded, cherty limestone and sandy limestone of Fossil Mountain Member. Unit gradually thins west to east and undergoes shoreward facies change from mostly cliff- and slope-forming limestone and siltstone marine sediments in west half of quadrangle to mostly sandy marine calcareous sandstone east of Grand Canyon. Difficult to distinguish members in subsurface of eastern half of quadrangle. Thickness, 120 to 80 ft (37 to 25 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Pkh - Kaibab Formation, Harrisburg Member (Lower Permian)
Includes an upper, middle, and lower part in the western two-thirds of map area; due to facies changes, all three parts merge into one sandy limestone lithology eastward. In western two-thirds of map area,

upper part consists of slope-forming, red and gray, interbedded gypsiferous siltstone, sandstone, gray gypsum, and thin-bedded gray limestone. Uppermost pale-yellow or light-gray, fossiliferous (mollusks and algae) sandy limestone, 1 to 2 m (2 to 6 ft) thick weathers yellowish-gray, brown, and reddish-gray; forms resistant caprock of Harrisburg Member in south-central half of map area around Kanab Creek drainages. Gradational contact with middle part. Unit is very similar in content, color, and weathering characteristics as limestone of the Timpoweap Member of the Moenkopi Formation. Some Timpoweap Member limestone beds contain small well-rounded chert or quartzite pebbles, whereas Harrisburg Member upper limestone beds contain scattered angular white chert fragments.
Middle part consists of two cliff-forming limestone beds that together gradually increases in thickness eastward across map area from 6 m (20 ft) to as much as 14 m (46 ft). Upper limestone bed is gray, thin-bedded, irregularly bedded cherty limestone that weathers dark brown or black. Lower limestone bed is light-gray, light-brown, and white, thick-bedded, sandy limestone separated from upper cherty limestone by about 3 m (10 ft) of thin-bedded gypsiferous sandstone and siltstone that thins eastward and northeastward to less than 1 m (3 ft). Both limestone beds and intervening gypsiferous sandstone and siltstone beds increase and decrease in thickness at expense of each other. Both limestone beds merge to form ledges and cliffs in small tributary canyons of the northern Kaibab Plateau and is difficult to distinguish from cherty limestone cliffs and ledges of the Fossil Mountain Member of the Kaibab Formation. Erosional unconformity separates middle part of Harrisburg Member from lower part where the lower sandy limestone bed fills erosion channels that are as much as 4 m (14 ft) deep in west half of map area and are less than 1 m (3 ft) deep in east half.
Lower part is slope-forming, light-red, fine- to medium-grained gypsiferous siltstone and sandstone interbedded with gray, medium-grained, thin-bedded limestone and gray to white, massive-bedded gypsum. West of Kaibab Plateau, lower part maintains uniform thickness of about 40 m (130 ft) and thins eastward and southeastward across Kaibab Plateau. Dissolution of gypsum in lower part has locally distorted limestone beds of middle part causing them to slump or bend into local tributary drainages of Kanab Creek area in west half of map area. Gradational contact between slope-forming Harrisburg Member and underlying cliff-forming Fossil Mountain Member of the Kaibab Formation is marked at top of upper cherty limestone bed of Fossil Mountain Member. Harrisburg Member gradually thins eastward across map area and undergoes an eastward facies change to mostly white and gray sandy limestone and calcareous sandstone. Thickness ranges from about 30 to 52 m (100 to 170 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Pkh - Kaibab Formation, Harrisburg Member (Lower Permian)
Reddish-gray and brownish-gray, slope-forming gypsum, siltstone, sandstone, and thin-bedded limestone. Includes yellowish-gray fossiliferous sandy limestone at top of unit that is mostly eroded from much of the map area; forms surface bedrock in west half of map area. Contact with underlying Fossil Mountain Member is gradational and arbitrarily marked at topographic break between the grayish-white, slope and ledge forming sandy limestone and sandstone sequence of Harrisburg Member and the gray, cliff-forming white to light-brown, cherty limestone of Fossil Mountain Member. Unit gradually thins west to east and undergoes shoreward facies change from limestone and sandy limestone to calcareous sandstone. About 25 to 37 m (80 to 120 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Pkh - Kaibab Formation, Harrisburg Member (Lower Permian)
Reddish-gray and brownish-gray, slope-forming gypsum, siltstone, sandstone, and thin-bedded limestone. Includes yellowish-gray fossiliferous sandy limestone at top of unit that is eroded from much of the map area. A gray, thin-bedded, fossiliferous cherty limestone and sandy limestone in middle part of unit form much of the surface bedrock in the central map area. Calcareous sandstone beds west of and near Cataract Canyon have large-scale dessication cracks up to 2 ft (0.6 m) wide filled with reworked calcareous sandstone that form resistant polygon patterns averaging about 14 ft (4.3 m) in diameter; the patterns on aerial photos resemble the surface of a golf-ball. These dessication cracks represent a shallow marine tidal flat subject to extensive dry conditions during the late part of Kaibab Formation deposition. Lower part is yellowish-gray to pale-red gypsiferous siltstone and calcareous sandstone; gray thin-bedded sandy limestone; and gray to white, thick-bedded gypsum in the vicinity of

Cataract Canyon and northwest half of map area. Dissolution weathering of gypsum beds within lower part has resulted in warping and bending of limestone beds in middle part into or near local drainages on the Coconino Plateau. Gypsum dissolution within the Harrisburg Member of the Kaibab Formation is also responsible for the development of several large-scale sinkhole depressions and internal drainage basins such as Hazen Hole Tank, northwest half of map area. Dissolution of gypsum beds in underlying Toroweap Formation may be partly responsible for several internal drainage basin depressions in northwest half of map area, especially in the vicinity of collapse structures. Contact with underlying Fossil Mountain Member of the Kaibab Formation is gradational and arbitrarily marked at top of thick, white, cherty limestone zone near top of limestone cliff in canyon profile. Thickness, 120 ft (37 m) in northeast quarter of map thickening. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Pkf - Kaibab Formation, Fossil Mountain Member (Lower Permian)

Pkf - Kaibab Formation, Fossil Mountain Member (Lower Permian (Cisuralian))
Light-gray, cliff-forming, fine- to medium-grained, thin- to medium-bedded (1 to 6 ft [0.3 to 2 m]), fossiliferous, cherty, sandy limestone and dolomite. Weathers dark gray; cliffs often stained by black magnesium oxide. Includes abundant gray and white chert nodules and white breccia chert beds. Chert makes up about 25% to 30% of Fossil Mountain Member. Some chert nodules exhibit concentric black and white bands or contain fossil sponges. White, cliff-forming, brecciated chert beds, 4 to 10 ft (1 to 3 m) thick in uppermost part, help establish visible contact between Harrisburg and Fossil Mountain members. Unit gradually thins and undergoes a shoreward (eastward) facies change from limestone, dolomite, and sandy limestone to calcareous sandstone and sandy limestone with similar surface texture, composition, and appearance to overlying Harrisburg Member. Unit commonly forms cliff below slopes and ledges of Harrisburg Member along rim of Marble Canyon. Unconformable contact with underlying Toroweap Formation attributed in part to dissolution of gypsiferous siltstone in upper Toroweap but mostly caused by channel erosion; average erosional relief about 10 ft (3 m). Unit gradually thins east and southeast in subsurface of map area, becoming indistinguishable from overlying Harrisburg Member. Thickness, 160 to 230 ft (48 to 70 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Pkf - Kaibab Formation, Fossil Mountain Member (Lower Permian (Cisuralian))
Light-gray, cliff-forming, fine- to medium-grained, thin- to medium-bedded (1 to 6 ft [0.3 to 2 m]), fossiliferous, cherty (25% to 30%), sandy limestone and dolomite. Weathers dark gray; cliff surfaces often stained by black magnesium oxide. Includes abundant gray and white, fossiliferous chert nodules and white chert breccia beds. Chert nodules may contain concentric black and white bands or fossil sponges. White, cliff-forming, chert breccia beds 4 to 10 ft (1 to 3 m) thick commonly present in uppermost part help establish contact between Harrisburg (Pkh) and Fossil Mountain (Pkf) Members. Unit gradually thins eastward and undergoes a shoreward facies change from limestone, dolomite, and sandy limestone to calcareous sandstone and sandy limestone similar in texture, composition, and appearance to overlying Harrisburg Member. Unit commonly forms cliff below slopes and ledges of Harrisburg Member along rim of Grand Canyon, Marble Canyon, and Little Colorado River Gorge. Unconformable contact with underlying Toroweap Formation (Pt) attributed in part to solution and erosion of gypsiferous siltstone in Toroweap but mostly to channel erosion; average erosional relief about 10 ft (3 m). Unit gradually thins east and southeast in subsurface of map area, becoming indistinguishable from upper Harrisburg Member. Thickness, 230 to 180 ft (70 to 55 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Pkf - Kaibab Formation, Fossil Mountain Member (Lower Permian)
Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, cliff-forming, sandy, cherty limestone. Unit characterized by thin bedded, white chert beds and chert nodules in cliff-forming sandy limestone. Weathered chert bands are stained black or dark gray. Unconformable contact with underlying Woods

Ranch Member of the Toroweap Formation is caused by combination of dissolution of gypsum in the Woods Ranch Member and channel erosion with relief as much as 2 to 4.5 m (6 to 15 ft). Thickness ranges from about 61 to 80 m (200 to 265 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Pkf - Kaibab Formation, Fossil Mountain Member (Lower Permian)
Light-gray, cliff-forming, fine- to medium-grained, thin- to medium-bedded (0.3 to 2 m [1 to 6 ft]), fossiliferous, cherty, sandy limestone and dolomite. Weathers dark gray to black. In west half of map area unit characterized by abundance of gray and white, fossiliferous, chert nodules and white chert breccia beds. Some chert nodules contain concentric black and white bands. Breccia chert beds (1 to 3 m [4 to 10 ft]) thick commonly form uppermost part of Fossil Mountain Member in west half of map area that helps establish contact between Harrisburg (Pkh) and Fossil Mountain (Pkf) Members of the Kaibab Formation. Chert makes up about 25% of unit in west half of map area, less than 5% in east half. Unit gradually thins eastward and undergoes a shoreward facies change from sandy marine limestone and limestone to calcareous sandstone similar to texture, composition, and appearance of Harrisburg Member. Generally forms cliff at rim of Grand Canyon and Little Colorado River Gorge overlain by ledges of sandy limestone of Harrisburg Member. Unconformable contact with underlying Toroweap Formation (Pt) attributed partly to solution erosion and mostly channel erosion; average erosional relief, about 3 m (10 ft). Thickness, 60 m (200 ft) in northwest quarter of map area and gradually thins east and southeast in subsurface of map area. About 70 m (230 ft) thick in northwest part of map area, thinning to about 55 m (180 ft) thick in southeast part. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Pkf - Kaibab Formation, Fossil Mountain Member (Lower Permian)
Light-gray, cliff-forming, fine- to medium-grained, thin- to thick-bedded [1 to 6 ft (0.3 to 1.8 m)], fossiliferous, sandy, cherty limestone. Weathers dark gray. Unit characterized by gray to white fossiliferous chert nodules and white chert lenses parallel to limestone bedding; chert weathers dark gray to black. Some chert nodules contain concentric black and white bands. Includes brecciated chert beds 4 to 10 ft (1.2 to 3 m) thick in upper part near contact of overlying Harrisburg Member of the Kaibab Formation. Chert makes up about 20 percent of unit and becomes sandier in northeast quarter of map area. Generally forms cliff at rim of Grand Canyon (Cataract Canyon) overlain by thin cover of gray to red siltstone and sandy limestone beds of Harrisburg Member. Unconformable contact with underlying Woods Ranch Member of the Toroweap Formation (Pt) attributed to solution erosion and channel erosion; average channel relief about 10 ft (3 m). Some channels have eroded as much as 150 ft (46 m) into Woods Ranch Member just north of map area at National and Mohawk Canyons (Billingsley, 2000). Erosion channels are filled with sandy cherty limestone typical of the Fossil Mountain Member strata, which provides an extra thickness of the Fossil Mountain section. Thickness, 230 ft (70 m) in east half of the map, thickening to about 300 ft (92 m) in west half. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Toroweap Formation (Lower Permian)

Includes, in descending order, Woods Ranch Member, Brady Canyon Member, and Seligman Members, undivided as defined by Sorauf and Billingsley (1991). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members, undivided as defined by Sorauf and Billingsley (1991). (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Ptw - Toroweap Formation, Woods Ranch Member (Lower Permian)

Ptw - Toroweap Formation, Woods Ranch Member (Lower Permian (Cisuralian))
Grand Canyon and Marble Canyon areas: gray and light-red, slope-forming gypsiferous siltstone, gray gypsum, and gray sandstone interbedded with gray, thin-bedded limestone. Weathers to reddish-gray

slope. Bedding locally distorted due to dissolution of gypsum and gypsiferous siltstone. Erosional undercutting of overlying Kaibab Formation results in numerous landslides and large open cracks near canyon rims that tend to be accentuated along pre-existing joint and fracture systems. Unit undergoes shoreward (eastward) facies change to mostly brown, cliff-forming, calcareous sandstone and dolomite that weathers dark brown. Contact with underlying Brady Canyon Member is gradational and marked at lithologic and topographic break between slope-forming gypsiferous siltstone and sandstone of Woods Ranch and cliff-forming limestone of Brady Canyon in western two-thirds of Marble Canyon and Grand Canyon area; becomes indistinguishable from underlying Seligman and Brady Canyon Members in eastern third of Marble Canyon, southeastern Grand Canyon, and Little Colorado River Gorge and subsurface of Marble Plateau. Thickness, 100 to 180 ft (30 to 55 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ptw - Toroweap Formation, Woods Ranch Member (Lower Permian)

Gray, slope-forming gypsiferous siltstone and pale-red silty sandstone interbedded with white, laminated gypsum. Beds are locally distorted because of dissolution of gypsum in upper part. At higher elevations of the Kaibab Plateau, dissolution of gypsum produces large sinkholes into overlying Kaibab Formation. Gradational contact with underlying Brady Canyon Member marked at top of limestone cliff of Brady Canyon unit. Variable thickness due to dissolution of gypsum beds, about 49 to 81 m (160 to 265 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Ptb - Toroweap Formation, Brady Canyon and Seligman Members, undivided (Lower Permian)

Ptb - Toroweap Formation, Brady Canyon and Seligman Members, undivided (Lower Permian (Cisuralian))

Brady Canyon Member: Gray to brown, cliff-forming, thin- to medium-bedded (1 to 5 ft [0.05 to 1.4 m]), fine- to coarse-grained, limestone and sandy limestone. Weathers light gray. Contains white and gray chert nodules that make up less than 5% of unit. Gradational contact with underlying Seligman Member marked at base of limestone cliff in western part of quadrangle. Becomes indistinguishable from other Toroweap Members east of Marble Canyon, Grand Canyon, and Little Colorado River Gorge. Thickness, 20 to 30 ft (6 to 9 m)

Seligman Member: Gray, light-purple, and yellowish-red, slope-forming, thin-bedded dolomite, sandstone, gypsum, and calcareous sandstone. Forms slope or recess between overlying Brady Canyon Member and underlying Coconino Sandstone (Pc) in Marble Canyon and Grand Canyon. Undergoes easterly shoreward facies change similar to Brady Canyon and Woods Ranch Members; pinches out before reaching Little Colorado River Gorge. Sharp unconformable contact with underlying white, cliff-forming Coconino Sandstone. Coconino Sandstone intertongues with lower part of Seligman Member west and north of map area (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley and Wellmeyer, 2003; Billingsley and others, 2006). Undergoes gradual shoreward (eastward) facies change along with overlying Brady Canyon and Woods Ranch Members, making all indistinguishable from one another east of Colorado River where they are mapped as Toroweap Formation, undivided (Pt). Thickness, 10 to 20 ft (3 to 6 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ptb - Toroweap Formation, Brady Canyon Member (Lower Permian)

Units are mapped as one because the Seligman Member is too thin to show at map scale in most areas. Brady Canyon Member; gray, cliff-forming, medium-bedded, fine- to coarse-grained, fetid, fossiliferous limestone; weathers dark gray. Includes thin-bedded dolomite in upper and lower parts. Limestone beds average about 0.3 to 1m (1 to 3 ft) thick and contain chert lenses and nodules. Limestone beds undergo eastward facies change from limestone to sandy limestone to calcareous sandstone and become less fossiliferous. Unit is about 55 m (180 ft) thick in Kanab Creek area, thins eastward and northward to about 40 m (130 ft) in House Rock Valley. Gradational contact between cliff-

forming Brady Canyon and slope-forming Seligman Members.
(*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Pt - Toroweap Formation, undivided (Lower Permian)

Pt - Toroweap Formation, undivided (Lower Permian (Cisuralian))
Includes, in descending order, the Woods Ranch, Brady Canyon, and Seligman Members as defined by Sorauf and Billingsley (1991). All three members are present in tributary canyons on western side of Marble Canyon. All three members undergo a rapid shoreward (eastward) facies change from cliff and slope west of Colorado River to all cliffs east of Colorado River. Unit gradually thins east and southeast in subsurface of map area and thickens west (Billingsley, 2000; Billingsley and Wellmeyer, 2003; Billingsley and others, 2007). Eastern extent is unknown but likely extends to or pinches out at eastern margin of quadrangle. Thickness, 180 to 220 ft (65 to 67 m).
Woods Ranch Member, west side of Marble Canyon: Gray and light-red, slope-forming gypsiferous siltstone, gray gypsum, and gray sandstone interbedded with gray, thin-bedded limestone. Weathers to reddish-gray slope. Bedding locally distorted due to dissolution of gypsum and gypsiferous siltstone. Erosional undercutting of overlying Kaibab Formation cliff results in numerous landslides and large open cracks near canyon rims that trend along pre-existing joint and fracture systems. Contact with underlying Brady Canyon Member is gradational and marked at lithologic and topographic break between slope-forming gypsiferous siltstone and sandstone of Woods Ranch Member and cliff-forming limestone of Brady Canyon Member in western two-thirds of Marble Canyon.
Woods Ranch Member, east side of Marble Canyon: Brown, cliff-forming, thin-bedded calcareous sandstone and dolomite. Woods Ranch Member undergoes shoreward (eastward) facies change to cliff-forming sequence that weathers dark brown. Contact with underlying Brady Canyon Member becomes indistinguishable in eastern third of Marble Canyon and subsurface of Marble Plateau. Thickness, 140 to 200 ft (43 to 60 m).
Brady Canyon Member: Yellowish-gray to brown, cliff-forming, thin- to medium-bedded (1 to 5 ft [0.05 to 1.4 m]), fine- to coarse-grained limestone and dolomitic sandy limestone in western half of Marble Canyon area. Becomes sandy dolomite and sandy limestone cliff in eastern half of Marble Canyon area. Weathers light to dark gray. Contains white and gray chert nodules that make up less than 5% of unit. Gradational contact with underlying Seligman Member, marked at base of limestone cliff in western half of Marble Canyon area, becomes indistinguishable from other Toroweap Members east of Marble Canyon. Thickness, 10 to 30 ft (3 to 9 m).
Seligman Member: Gray, light-purple, and yellowish-red, slope-forming, thin-bedded dolomite, sandstone, some gypsum, and calcareous sandstone. Forms slope or recesses between overlying Brady Canyon Member and underlying Coconino Sandstone in western two-thirds of Marble Canyon. Undergoes easterly shoreward facies change similar to Brady Canyon and Woods Ranch Members. Sharp unconformable contact with underlying white to tan, cliff-forming Coconino Sandstone. Coconino Sandstone intertongues with lower part of Seligman Member west and north of quadrangle (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley and Wellmeyer, 2003; Billingsley and others, 2000). Gradual shoreward (eastward) facies change of all three members makes them indistinguishable from one another east of the Colorado River. Thickness, 10 to 20 ft (3 to 6 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Pt - Toroweap Formation, undivided (Lower Permian (Cisuralian))
Includes, in descending order, the Woods Ranch, Brady Canyon, and Seligman Members, undivided, as defined by Sorauf and Billingsley (1991). All three members are present on western side of Marble Canyon and Grand Canyon. All three members undergo a rapid shoreward (eastward) facies change from cliff and slope units west of Colorado River to cliff units east of Colorado River. Unit gradually thins east and southeast in subsurface of map area and thickens west (Billingsley, 2000; Billingsley and Wellmeyer, 2003; Billingsley and others, 2007). Eastern extent is unknown but likely extends to or

pinches out at eastern margin of map. Thickness, 200 to 250 ft (60 to 76 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Pt - Toroweap Formation, undivided (Lower Permian)

Includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members, undivided, as defined by Sorauf and Billingsley (1991). All three members are present in Grand Canyon, northwest corner of map area but too small to show at map scale and are mapped as the Toroweap Formation, undivided. All three members undergo a rapid shoreward facies change eastward from a general slope unit of siltstone, gypsiferous sandstone, and limestone to an indistinguishable cliff unit of calcareous sandstone and sandy limestone in Little Colorado River Gorge and Gray Mountain area. From Little Colorado River Gorge in subsurface of map area to southeast corner of map. Unit gradually thins eastward in subsurface of map from Little Colorado River Gorge and Gray Mountain areas to southeast corner of map where drill holes near Leupp, Arizona (southeast of map area) indicate that only 6 to 9 m (20 to 30 ft) of Toroweap Formation is present in that area (Don Bills, oral commun., July 2005). About 55 m (180 ft) thick in western part of map area, thinning to about 9 m (30 ft) thick in eastern part
Woods Ranch Member—In the Grand Canyon area unit is gray and light-red, slope-forming gypsiferous siltstone and silty sandstone, interbedded with thin, white laminated gypsum and gray thin-bedded limestone. Weathers to reddish-gray slope. Bedding locally distorted due to dissolution of gypsiferous siltstone. Unit undergoes shoreward facies change eastward becoming mostly cliff-forming calcareous sandstone. Contact with underlying Brady Canyon Member at Grand Canyon is gradational and marked at topographic break between slope-forming siltstone of Woods Ranch Member and cliff-forming limestone of Brady Canyon Member. About 20 m thick (65 ft) thick in western part of map area, thinning to about 6 m (20 ft) thick in eastern part
Brady Canyon Member—In the Grand Canyon area unit is gray, cliff-forming, thin- to medium-bedded (0.05 to 1.4 m [1 to 5 ft]), fine- to coarse-grained, sandy limestone. Weathers light-gray. Contains white and gray chert nodules that make up less than 5% of unit. Unit undergoes gradual shoreward facies change eastward along with overlying Woods Ranch Member and underlying Seligman Member making all three units indistinguishable from one another. Contact with underlying Seligman Member is marked at base of limestone cliff in Grand Canyon area. About 6 to 9 m (20 to 30 ft) thick
Seligman Member—In the Grand Canyon area unit is gray, light-purple, and yellowish-red, slope-forming, thin-bedded dolomite, sandstone, gypsum, and calcareous sandstone. Forms slope or recess between overlying cliff-forming Brady Canyon Member and underlying cliff-forming Coconino Sandstone (Pc) in Grand Canyon area. Unit undergoes eastward shoreward facies change similar to overlying Brady Canyon Member and appears to thin and pinch out before reaching Little Colorado River Gorge area. Sharp unconformable contact with underlying Coconino Sandstone where crossbedded sand dunes of Coconino were beveled off by marine wave erosion and sand was redistributed as flat-bedded beach sandstone within Seligman Member of the Toroweap Formation west of map area (Billingsley, 2000; Billingsley and others, 2006). Coconino Sandstone intertongues with lower part of Seligman Member west and north of map area (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; and Billingsley and others, 2003). About 3 to 6 m (10 to 20 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Pt - Toroweap Formation, undivided (Lower Permian)

Includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members as defined by Sorauf and Billingsley (1991).
Woods Ranch Member consists of gray and light-red, slope-forming gypsiferous siltstone, silty sandstone, white laminated gypsum, and gray to dark-gray, thin-bedded, fossiliferous sandy limestone. Gypsum beds are as much as 3 m (10 ft) thick on Coconino Plateau. Unit as a whole weathers red-gray. Bedding locally distorted due to dissolution of gypsum. Contact with underlying Brady Canyon Member is gradational and arbitrarily marked at top of limestone cliff of Brady Canyon Member. Unit thickens north and northwest and thins south and southeast of map area. Variable thickness owing to dissolution of gypsum and channel erosion in upper part; 18 to 30 m (60 to 100 ft) thick.
Brady Canyon Member consists of dark- to light-gray, cliff-forming, thin- to medium-bedded (0.5 to 1.5 m [1 to 5 ft]), fine- to coarse-grained, fetid, fossiliferous limestone; weathers dark gray. Includes thin-

bedded dolomite in upper and lower part; average thickness of limestone beds, 0.5 to 1 m (2 to 3 ft). Contains white and gray chert nodules that make up less than 8 percent of unit. Contact with underlying Seligman Member is gradational and arbitrarily placed at base of limestone cliff of Brady Canyon Member. Unit thickens west and northwest, thins southeast and east of map area. Thickness, 76 m (250 ft) at Coconino Plateau area, 11 0 m (360 ft) at Shiwits Plateau area. Seligman Member consists of gray
, light-purple, and yellow-red, slope-forming, thin-bedded dolomite, sandstone, and gypsum. In Coconino Plateau area, unit is mostly purple, light-red and gray flat-bedded, calcareous sandstone interbedded with gray, thin-bedded limestone. In Shiwits Plateau area, unit is gray to white gypsum and light-red to yellow-red, thin-bedded, calcareous flat-bedded sandstone and thin-bedded gray dolomite. Forms recess between overlying cliff-forming Brady Canyon Member of the Toroweap Formation and underlying cliff-forming Coconino Sandstone. Unit thickens north and northwest, thins east and southeast of map area. Sharp planar and undulate contact with underlying Coconino Sandstone where crossbedded sand dunes of Coconino Sandstone were beveled off and sand was redistributed as planar-bedded sandstone. The Coconino Sandstone (Pc) intertongues within the lower part of the Seligman Member of the Toroweap Formation (Pt) north and west of the map area (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley and others, 2000a; Billingsley and Wellmeyer, 2003). Because the name Coconino Sandstone is well established in the Grand Canyon nomenclature and it forms a significant mappable cliff unit within the walls of Grand Canyon, the term Coconino Sandstone is herein maintained as a separate map unit from the Toroweap Formation. The Coconino Sandstone pinches out in the west half of the map area allowing the Toroweap Formation to overlie the Hermit Formation. Thickness, 4.5 to 12 m (15 to 40 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Pt - Toroweap Formation, undivided (Lower Permian)

Includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members, undivided, as defined by Sorauf and Billingsley (1991).

Woods Ranch Member is gray and light-red, slope-forming gypsiferous siltstone and silty sandstone, interbedded with white laminated gypsum beds and thin-bedded gray limestone. Gypsum beds are as much as 10 ft (3 m) thick. Unit as a whole weathers reddish gray. Bedding locally distorted due to dissolution of gypsum. Contact with underlying Brady Canyon Member is gradational and arbitrarily marked at top of cliff-forming limestone beds of Brady Canyon. Unit commonly thins to less than 20 ft (6 m) thick in vicinity of large collapse structures due to dissolution of gypsum. Variable thickness owing to dissolution of gypsum and channel erosion in upper part; average thickness, 65 ft (20 m) in north-central part of map, thickens to 200 ft (60 m) in west half of map, thins to less than 50 ft (15 m) in southeast quarter of map.

Brady Canyon Member is gray, cliff-forming, thin- to medium-bedded [1 to 5 ft (0.5 to 1.5 m)], fine- to coarse-grained, fetid, fossiliferous limestone. Weathers dark gray. Includes thin-bedded dolomite in upper and lower part. Contains white and gray chert nodules that make up less than 8 percent of unit. Contact with underlying Seligman Member is gradational and arbitrarily placed at base of cliff-forming limestone of Brady Canyon. Thickness, 40 ft (12 m) in northeast half of map area, increasing to about 130 ft (40 m) at northwest edge of map as exposed in Grand Canyon (Billingsley, 2000; Billingsley and Wellmeyer, 2003).

Seligman Member is gray, light-purple, yellowish-red, slope-forming, thin-bedded dolomite, limestone, sandstone, gypsum, and calcareous sandstone. Includes a unit of crossbedded sandstone equivalent to the Coconino Sandstone, which is mapped separately. Includes yellowish-gray to red, thin-bedded sandstone below Coconino Sandstone tongue in the western Grand Canyon area; these beds thin eastward across the map area allowing the Coconino Sandstone to unconformably overlie the Hermit Formation in the central and eastern Grand Canyon areas. Forms slope or recess between cliff-forming Brady Canyon Member and cliff-forming Coconino Sandstone (Pc) in west half of map area, and slight recess at base of Coconino Sandstone at contact of red sandstone and siltstone of the Hermit Formation. Coconino Sandstone intertongues within lower part of Seligman Member (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; and Billingsley and others, 2000a). Thickness, 30 ft (9.2 m) in east half of map, increasing to 55 ft (17 m) in west half. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Pt - Toroweap Formation, undivided (Lower Permian)
Includes, in descending order, Woods Ranch, Brady Canyon, and Seligman Members as defined by Sorauf and Billingsley (1991).
Woods Ranch Member consists of gray and light-red, slope-forming, gypsiferous siltstone and silty sandstone interbedded with white laminated gypsum and gray thin-bedded limestone. Gypsum beds are as much as 3 to 5 m (10 to 15 ft) thick. Unit as a whole weathers as reddish-gray slope. Bedding locally deformed due to subsidence caused by dissolution of gypsum. Contact with underlying Brady Canyon Member is gradational and marked at top of underlying limestone cliff of Brady Canyon Member. Unit in general thins southward and thickens northward. Variable thickness owing to local channel erosion in upper part. Thickness, 18 to 60 m (60 to 200 ft).
Brady Canyon Member is gray, cliff-forming, thin- to medium-bedded (0.05 to 1.4 m [1 to 5 ft]) fine- to coarse-grained, fetid, fossiliferous limestone. Weathers dark gray. Includes thin-bedded dolomite in upper and lower part. Contains white and gray chert nodules that make up less than 8 percent of unit. Contact with underlying Seligman Member is gradational and placed at lithologic break at base of limestone cliff and top of sandstone-gypsum slope. Thickness, 40 m (130 ft) at east edge of map area, increasing to as much as 137 m (450 ft) along upper Grand Wash Cliffs.
Seligman Member consists of light-purple, yellowish-red, and gray, slope-forming, thin-bedded dolomite interbedded with calcareous sandstone and gypsum. In northeastern third of map area, unit is gray to white, light-red gypsum and silty gypsum interbedded with yellowish-red, thin-bedded, calcareous sandstone and gray dolomite. Forms recess between the cliff-forming Brady Canyon Member of the Toroweap Formation and the cliff-forming Coconino Sandstone in southwestern two-thirds of map area. Forms a gypsiferous slope similar to the Woods Ranch Member of the Toroweap Formation in northwestern third of map area. The Coconino Sandstone intertongues with lower part of the Seligman Member of the Toroweap Formation as crossbedded sandstone set between flat-bedded sandstone beds. The near-shore crossbedded sandstone has an upper and lower gradational contact within the flat-bedded marine sandstone of the lower Seligman Member (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley and others, 2000). Where Coconino Sandstone forms a cliff in central and eastern Grand Canyon, flat-bedded sandstone beds of the lower part of the Seligman Member of the Toroweap Formation are present at the base of the cliff in most areas. Upper crossbedded sand dune sets of the Coconino Sandstone were beveled off and redistributed as flat-bedded sandstone of the Seligman Member of the Toroweap Formation. Thickness, about 10 m (30 ft) in southern two-thirds of map area, increasing to about 17 m (55 ft) in northern third. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Pt - Toroweap Formation, undivided (Lower Permian)
Includes, in descending order, Harrisburg and Fossil Mountain Members, undivided, as defined by Sorauf and Billingsley (1991) Harrisburg Member—Reddish-gray and brownish-gray, slope-forming gypsum, siltstone, sandstone, and limestone. Informally subdivided, in descending order, into three units forming an upper slope, middle cliff, and lower slope. Upper slope unit is interbedded red and gray gypsum, sandstone, and siltstone, and yellowish-gray fossiliferous sandy limestone. Middle cliff unit is gray, thin-bedded, fossiliferous cherty limestone and sandy limestone. Lower slope unit is (1) yellowish-gray to pale-red gypsifereous siltstone and calcareous sandstone, (2) gray, thin-bedded sandy limestone, and (3) gray to white, thick-bedded gypsum. Upper, middle, and lower units become inseparable on the Kaibab Plateau, northeastern quarter of map area. Solution weathering within gypsum beds of lower slope unit has resulted in warping and bending of limestone of middle cliff unit, especially in or near local drainages on Kanab and Coconino Plateaus where middle cliff unit forms surface bedrock. Gypsum solutioning is responsible for several sinkhole depressions within Harrisburg Member. Contact with underlying Fossil Mountain Member is gradational and arbitrarily marked at top of cherty limestone cliff of the Fossil Mountain. About 260 ft (80 m) thick in western half of map area, thinning eastward to about 120 ft (36 m) in northeastern quarter of map area. Average thickness about 165 ft (50 m) Fossil Mountain Member—Light-gray, cliff-forming, fine- to medium-grained, thin to medium-bedded [1–6 ft (0.3–2 m)], fossiliferous, sandy, cherty limestone. In general, unit weathers dark

gray. Unit characterized by gray to white fossiliferous chert nodules and white chert lenses parallel to bedding; chert weathers dark gray to black. Some chert nodules contain concentric black and white bands. Includes brecciated chert beds 4–10 ft (1–3 m) thick in upper part at contact of thin limestone or gypsifereous siltstone of Harrisburg Member. Chert in central and western parts of map area makes up about 20 percent of unit; unit becomes sandy in northeastern quarter of map area. Generally forms cliff at rim of the Grand Canyon. Weathers into pinnacles or "pillars" detached from cliff in western half of map area. Unconformable contact with underlying Woods Ranch Member of Toroweap Formation (Pt) attributed to solution erosion and channel erosion; average relief about 10 ft (3 m). Some channels have eroded as much as 150 ft (45 m) into the Woods Ranch in western half of map area. Erosion channels were filled with sandy cherty limestone typical of the Fossil Mountain, providing an extra thickness of the Fossil Mountain. Thickness about 230–350 ft (70–107 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Pts - Toroweap Formation, Seligman Member (Lower Permian)

Seligman Member; gray to purple-red, slope-forming, thin-bedded dolomite and limestone beds interbedded with reddish gypsiferous siltstone and sandstone and gray gypsum. Unconformable contact with underlying Coconino Sandstone in southern two-thirds of map area and with underlying Hermit Formation in northern third; mostly flat plannar contact in most areas; erosional relief less than 1 m (3 ft). Contact mostly covered by talus and alluvial deposits in Kanab Creek drainage area. Seligman Member thins eastward from about 22 m (70 ft) in Kanab Creek area to less than 6 m (20 ft) on east side of Kaibab Plateau. Brady Canyon and Seligman Members combined gradually thin eastward across map area from about 67 to 40 m (220 to 130 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Pc - Coconino Sandstone (Lower Permian)

Pc - Coconino Sandstone (Lower Permian (Cisuralian))

Tan to white, cliff-forming, fine-grained, well-sorted, high-angle-crossbedded quartz sandstone. Large-scale, high-angle-planar crossbeds 6 to 15 ft (3 to 4.5 m) thick. Locally includes large and small amphibian trackways and low-relief wind ripple marks on planar surfaces. Unconformable planar erosional contact with underlying Hermit Formation with relief generally less than 3 ft (1 m) but locally as much as 8 ft (2.5 m). Contact is marked by distinct color and topographic change between overlying white, cliff-forming Coconino Sandstone and underlying dark-red, slope-forming Hermit Formation. Unit is exposed only in walls of Marble Canyon; gradually thickens east and southeast of quadrangle and thins rapidly north and west of quadrangle. Thickness, 30 to 400 ft (9 to 122 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Pc - Coconino Sandstone (Lower Permian (Cisuralian))

Tan to white, cliff-forming, fine-grained, well-sorted, crossbedded quartz sandstone. Thin red sandstone beds at base of Coconino Sandstone in Little Colorado River Gorge are likely the northern edge of the Schnebly Hill Formation as defined by Blakey (1990) in the Verde Valley south of the quadrangle. Contains large-scale, high-angle, planar crossbeds that average about 11 m (35 ft) thick. Locally includes amphibian trackways and low-relief wind ripple marks on crossbed surfaces. Unconformable contact with underlying Hermit Formation (Ph) is sharp and planar with relief generally less than 3 ft (1 m) but locally as much as 8 ft (2.5 m); marked by distinct color and topographic change between white, cliff-forming sandstone of Coconino Sandstone and dark-red, slope-forming siltstone of Hermit Formation. Unit is exposed only in walls of the Grand Canyon but is present in the subsurface of eastern half of map. Unit gradually thickens east and southeast of map area and significantly thins to the north and west. Thickness, 200 to 600 ft (60 to 183 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Pc - Coconino Sandstone (Lower Permian)
Light-brown, yellow-red, and tan, cliff-forming, fine-grained, well-sorted, cross-stratified quartz sandstone. Contains large scale, high-angle, planar crossbedded sandstone sets that average about 6 m (20 ft) thick or less. Lower 1.5 m (5 ft) is thin-bedded, partly calcareous, flat-bedded sandstone of Seligman Member of the Toroweap Formation that forms a sharp planar unconformable contact with underlying Hermit Formation with relief generally less than 1 m (3 ft). Unit gradually thickens from northwest to southeast in southeastern two-thirds of map area; unit pinches out in northwest and north-central part of map where Toroweap Formation (Ptb) overlies the Hermit Formation. Thickness ranges from about 0 to 52 m (0 to 170 ft). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Pc - Coconino Sandstone and Schnebley Hill Formation, undivided (Lower Permian)
Tan to white, cliff-forming, fine-grained, well-sorted, cross-bedded quartz sandstone. Includes the Schnebly Hill Formation of Blakey (1990) in subsurface of map area. Thin red sandstone beds at base of Coconino Sandstone cliff in Little Colorado River Gorge is likely the northern feather edge of the Schnebly Hill Formation (Ronald C. Blakey, oral commun., July 2005). Contains large-scale, high-angle, planar cross-bedded sandstone sets that average about 11 m (35 ft) thick. Locally includes poorly preserved amphibian fossil track ways and low-relief wind ripple marks on crossbedded planar sandstone surfaces. Lower part of Coconino Sandstone intertongues or grades southward into Schnebly Hill Formation in subsurface of southern two-thirds of map area. Type section of Schnebly Hill Formation (Blakey, 1990) is in Verde Valley, 80 km (50 mi) south of map area. Unit intertongues with lower part of Seligman Member of the Toroweap Formation west of map area (Billingsley, 2000; Billingsley and Wellmeyer, 2003; Billingsley and others, 2006). Coconino Sandstone is a well established part of Grand Canyon nomenclature and is retained as a mappable unit because it forms a thick, regional, white sandstone cliff in Grand Canyon and Little Colorado River Gorge that is easily recognized and mappable. Unconformable contact with underlying Hermit Formation (Ph) is sharp, planar, with relief generally less than 1 m (3 ft) but locally as much as 2.5 m (8 ft) marked by distinct color and topographic change between white, cliff-forming Coconino Sandstone, light-red Schnebly Hill Formation, and dark-red, slope-forming Hermit Formation. Unit decreases slightly from west to east in subsurface of the map area. Unit is an important water-bearing sandstone east and south of map area (Don Bills, Water Resources Division of the U.S. Geological Survey, oral commun., 2005). About 183 m (600 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Pc - Coconino Sandstone (Lower Permian)
Light-brown, yellow-red, and light-red, cliff-forming, fine-grained, well-sorted, cross-stratified quartz sandstone. Forms resistant slope along north margin of Aubrey Valley. Contains large scale, high-angle, planar crossbedded sandstone sets that average about 10.5 m (35 ft) thick. Locally includes poorly preserved fossil tracks and low-relief wind ripple marks on crossbedded planar sandstone surfaces. Lower 1.5 to 6 m (5 to 20 ft) is thin-bedded, partly calcareous, flat-bedded sandstone of Seligman Member of the Toroweap Formation that forms a sharp planar unconformable contact with underlying Hermit Formation with relief generally less than 1 m (3 ft), but locally as much as 2.5 m (8 ft). Unit thins west and southwest and pinches out in central part of map area where Toroweap Formation overlies the Hermit Formation; unit thickens southeast, east and northeast of map area. Thickness, 0 to 52 m (0 to 170 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Pc - Coconino Sandstone (Lower Permian)
Tan to white or pale-red, cliff-forming, fine-grained, well-sorted, crossbedded quartz sandstone. Contains large-scale, high-angle, planar crossbedded sandstone sets that average about 35 ft (11 m) thick. Locally includes small and large fossil footprints and low-relief wind ripple marks on crossbedded planar sandstone surfaces. The lower and upper [5 to 20 ft (1.5 to 6 m)] intertongues with thin-bedded, partly calcareous, flat-bedded sandstone beds of Seligman Member of the Toroweap Formation in western Grand Canyon area (Billingsley and others, 2000a; Billingsley, 2000; Billingsley and others, 2001; Billingsley and Wellmeyer, 2003). Coconino Sandstone is mapped separately from Toroweap Formation

because it forms a mappable unit and is an established unit of the Grand Canyon nomenclature. Unconformable contact with underlying Hermit Formation (Ph) in the central and eastern Grand Canyon area as a sharp planar contact with erosional relief less than 3 ft (1 m) but locally as much as 8 ft (2.5 m). Thickness of Coconino increases from 150 (46 m) to over 500 ft (153 m), west to east in subsurface of map area according to exposures in Grand Canyon north of map area and several miles south of map area. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Pc - Coconino Sandstone (Lower Permian)
Tan to white, cliff-forming, fine-grained, well-sorted, crossbedded quartz sandstone. Contains large scale, high-angle, planar crossbedded sandstone sets as large as 11 m (35 ft) thick, and low-angle crossbedded sets less than 2 m (6 ft) thick in upper and lower part of cliff. Locally includes low-relief wind ripple marks on crossbedded planar sandstone surfaces. Unit intertongues with marine sandstone and gypsum beds in lower part of the Seligman Member of the Toroweap Formation in northeastern two-thirds of map area (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley and others, 2000). Crossbedded sets thin and thicken laterally in upper Grand Wash Cliffs and Pakoon Ridge areas. Sharp planar, unconformable contact with underlying Hermit Formation; erosional relief generally less than 1 m (3 ft) but locally as much as 2.5 m (8 ft). Thickness, 47 m (155 ft), eastern third of map area, thins west and pinches out between Parashant Canyon and Snap Point along south edge of Shiwits Plateau. In northwest part of map area, 3 to 9 m (10 to 30 ft) thick. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Pc - Coconino Sandstone (Lower Permian)
Tan to white, cliff-forming, fine-grained, well sorted, cross-bedded quartz sandstone. Contains large-scale, high-angle, planar cross-bedded sandstone sets that average about 35 ft (11 m) thick. Locally includes poorly preserved fossil tracks and low-relief wind ripple marks on crossbedded planar sandstone surfaces. Lower 5–20 ft (2–6 m) is intertongued, thinbedded, partly calcareous, flat-bedded sandstone of Seligman Member of Toroweap Formation (Pt). Unconformable contact with underlying Hermit Formation (Ph) is sharp planar, with relief generally less than 3 ft (1 m) but locally as much as 8 ft (2.5 m). Desiccation cracks in the Hermit, as much as 2 ft (0.05 m) wide and 12 ft (4 m) deep, are filled with tan sandstone of the Toroweap or Coconino, mainly in eastern third of map area. Thickness of the Coconino decreases east to west, whereas Brady Canyon and Seligman Members of Toroweap Formation increase proportionally in thickness. Forms a 500-ft (154- m) thick cliff in southeast corner of map area, thinning northward to about 350 ft (122 m) and westward to about 150 ft (45 m) at western edge of map area. (GRI Source Map ID 1309) (Grand Canyon 30 x 60).

Ph - Hermit Formation (Lower Permian)

Ph - Hermit Formation (Lower Permian (Cisuralian))
Red, slope-forming, fine-grained, thin- to medium-bedded siltstone and sandstone. Siltstone beds throughout unit are dark red and crumbly and fill widespread shallow erosional channels that form recesses between thicker sandstone beds. Ledges of siltstone and sandstone immediately below contact with Coconino Sandstone are often bleached yellowish white by groundwater seepage from Coconino Sandstone. Weathers to dark-red slope. Unconformably overlies Esplanade Sandstone with erosional relief generally less than 10 ft (3 m). Hermit Formation thins southeast of quadrangle and may extend into subsurface of eastern quarter of quadrangle; thickens north and west of quadrangle. Thickness, 520 to 640 ft (158 to 195 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Ph - Hermit Formation (Lower Permian (Cisuralian))
Red, slope-forming, fine-grained, thin- to medium-bedded siltstone and sandstone. In Little Colorado River Gorge, upper part contains red, massive, low-angle, cross-stratified calcareous sandstone and siltstone beds that may be equivalent, in part, to Schnebly Hill Formation in Verde Valley south of map

area (Blakey, 1990). Siltstone beds throughout unit weather dark red and crumbly and fill widespread shallow erosion channels; form recesses between thicker sandstone beds. Contains poorly preserved plant fossils in channel-fill deposits in lower part of unit at Grand Canyon. Red cliffs and ledges of sandstone immediately below contact with Coconino Sandstone (Pc) are often bleached yellowish-white color owing to groundwater seepage from Coconino Sandstone. Unconformably overlies Esplanade Sandstone (Pe) with erosional relief generally less than 10 ft (3 m). Unit thins southeast of Grand Canyon to less than 40 ft (12 m) at Little Colorado River Gorge and may extend into subsurface of eastern part of map area. Unit thickens north and west of map area. Thickness, 40 to 360 ft (12 to 110 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ph - Hermit Formation (Lower Permian)

Red, slope-forming, fine-grained, thin-bedded, siltstone and sandstone. Upper part contains red, massive, low-angle crossbedded calcareous sandstone interbedded with siltstone where sandstone beds gradually thin or pinch out from north to south across map area. Dark-red crumbly siltstone beds fill shallow erosion channels and form recesses between thick, light-red sandstone beds in upper part; lower part contains more siltstone. Unit locally contains poorly preserved plant fossils within channel-fill siltstone deposits in lower part. Sandstone bleaches to yellowish-white in upper 1 to 3.5 m to 12 ft) of contact with overlying Coconino Sandstone or Toroweap Formation. Base of unit unconformably overlies Esplanade Sandstone (Pe) with erosion channels generally less than 3 m (10 ft) deep. Just south of map area, some erosion channels are as much as 40 m (130 ft) wide and 9 m (30 ft) deep (Billingsley, 2000). Unit thins southward and southeastward of map area and thickens westward and northward. In southwest quarter of map area, lower 18 m (60 ft) of unit is equivalent to upper slope unit of Esplanade Sandstone of McKee (1982), (Billingsley, 2000), but is included as part of Hermit Formation in this map area because upper Esplanade Sandstone units thin northward and pinch out along and in south edge of map area making this upper slope unit of the Esplanade Sandstone indistinguishable from the Hermit Formation slope. Hermit Formation gradually thins eastward and southward, thickens westward and northward across subsurface of map area. Approximate map contact between the Hermit Formation and Esplanade Sandstone at lowest red siltstone bed of Hermit Formation on surface of light-red, thick bedded sandstone of Esplanade Sandstone. Thickness ranges from about 150 to 340 m (500 to 800 ft) (3. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Ph - Hermit Formation (Lower Permian)

Red, slope-forming, fine-grained, thin-bedded siltstone and sandstone. Upper part contains red massive, low-angle crossbedded calcareous sandstone and siltstone beds in Little Colorado River Gorge that may be equivalent, in part, to Schnebly Hill Formation. Siltstone beds are dark red and crumbly and fill widespread, shallow erosion channels. Siltstone beds form recesses between thicker sandstone beds; locally contains poorly preserved plant fossils in channel fill deposits in lower part of unit in Grand Canyon area. Sandstone is partly bleached to yellowish-white at upper contact with Coconino Sandstone (Pc). Unconformably overlies Esplanade Sandstone (Pe). Dark-red, platy, thin-bedded siltstone of Hermit Formation fills erosional channels as much as 9 m (30 ft) deep eroded into underlying Esplanade Sandstone in Grand Canyon area (Billingsley, 2000). Otherwise, erosional relief is generally less than 3 m (10 ft). Unit thins south and east of Grand Canyon to less than 12 m (40 ft) in Little Colorado River Gorge; may thicken southward in subsurface of map based on exposures in Verde Valley 80 km (50 mi) south of map area (Blakey, 1990). About 25 m (80 ft) thick in northwestern part of map area, thins to 12 m (40 ft) thick in southeast part. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Ph - Hermit Formation (Lower Permian)

Red to red-brown, slope-forming, fine-grained, thin-bedded siltstone and sandstone; mostly covered by surficial deposits in Aubrey Cliffs area. Includes red, thick-bedded, massive to low-angle crossbedded, calcareous sandstone beds in upper part below Shiwits Plateau area. Siltstone beds are dark red, crumbly, and fill erosional channels or form widespread flat-bedded units that form recesses between thicker sandstone beds throughout unit. Sandstone beds thicken and thin laterally either as channel fill or low-angle crossbedded sandstone sets. Sandstone beds often bleach to white in or near vicinity of

breccia pipes and at upper contact with the Coconino Sandstone (Pc) in east half of map area. Locally contains poorly preserved plant fossils in channel fill siltstone beds eroded into underlying Esplanade Sandstone and Pakoon Limestone, undivided (Pep). Unconformable contact with underlying Esplanade Sandstone and Pakoon Limestone, undivided (Pep) and Esplanade Sandstone (Pe), erosional relief generally less than 3 m (10 ft) deep. West of Hurricane Fault, channels have eroded into light-red, cliff-forming sandstone beds of the Esplanade Sandstone and Pakoon Limestone, undivided. This sandstone cliff overlies 60 m (200 ft) of red, thin-bedded slope-forming siltstone beds that visually resembles strata of the Hermit Formation on Sanup Plateau north of Colorado River. Erosional unconformity is difficult to locate in some areas due to low relief. Unit thickens northwest, north, and northeast; thins east, southeast, and south of map area. Thickness, 30 to 213 m (100 to 700 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Ph - Hermit Formation (Lower Permian)

Red, slope-forming, fine-grained, thin-bedded siltstone and sandstone. Upper part contains red, massive, low-angle crossbedded calcareous sandstone and siltstone beds. Dark-red crumbly siltstone beds fill shallow erosion channels. Siltstone beds form recesses between thicker light-red sandstone beds. Unit locally contains poorly preserved plant fossils within channel fill deposits in lower part of formation. Sandstone beds thicken and thin laterally either as channel fill or low-angle crossbedded sand dune or stream channel accumulations. Sandstone bleaches to yellowish-white at upper contact with Coconino Sandstone (Pc). Unconformably overlies Esplanade Sandstone (Pe) with erosion channels generally less than 10 ft (3 m) in depth. Some channels are as much as 130 ft (40 m) and commonly 30 ft (9.2 m) deep in lower Cataract Canyon area just north of map area (Billingsley, 2000). Otherwise, erosional relief is generally less than 10 ft (3 m) between channel areas. Unit thins south and east of Cataract Canyon to less than 260 ft (80 m) in southeast part of map based on thinning of unit in Grand Canyon (Billingsley, 2000); thickens west and north of Cataract Canyon to 850 ft (260 m); Billingsley and others, 2000b; Billingsley and Wellmeyer, 2003). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Ph - Hermit Formation (Lower Permian)

Red, slope-forming, fine-grained, thin-bedded siltstone and sandstone. Includes red and white, massive to low-angle crossbedded, calcareous sandstone ledges in upper part, northwest quarter of map area. Majority of unit is interbedded, slope-forming sandstone and siltstone. Unit often bleached white or yellow near breccia pipes and at upper contact with the Coconino Sandstone due to reducing effect of ground water in the Coconino Sandstone. Base of unit unconformably overlies massive-bedded, red and white sandstone of Esplanade Sandstone (Pe and Pep) throughout map area. The deep erosion channels as much as 16 m (50 ft) deep at the unconformity are most pronounced in northeastern part of map area. Depth of channels decreases westward to generally less than 3 m (10 ft) deep along the Grand Wash Cliffs, and the contact between the Hermit Formation and Esplanade Sandstone/Pakoon Limestone is difficult to determine in the field. Along the Grand Wash Cliffs, contact between the Hermit Formation and Esplanade Sandstone/Pakoon Limestone is marked at the top of the first red or white cliff-forming, massive, sandstone bed. Dark-red, crumbly, thin-bedded siltstone that contains poorly preserved plant fossils forms recesses between thicker sandstone beds in lower 60 m (200 ft) of unit along the Grand Wash Cliffs. Similar plant fossils are also present in dark-red siltstone deposits within deep erosion channels cut into the Esplanade Sandstone (Pe) in eastern part of map area. Thickens from 213 m (700 ft), east edge of map area, to 244 to 260 m (800 to 860 ft) along the Grand Wash Cliffs. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Ph - Hermit Formation (Lower Permian)

Red, slope-forming, fine-grained, thin-bedded siltstone and sandstone. Upper part contains red and white, massive, low-angle cross-bedded calcareous sandstone and siltstone beds in western one-quarter of map area. Siltstone beds are dark red and crumbly, and fill shallow erosion channels that are widespread. Siltstone beds form recesses between thicker sandstone beds; locally contains poorly preserved plant fossils in channel fills in lower part of formation. Sandstone beds thicken and thin laterally either as channel fill or low sand dune accumulations. Sandstone bleaches to yellow-white color

in vicinity of breccia pipes throughout map area, and at upper contact with Coconino Sandstone (Pc) or Toroweap Formation (Pt) in western half of map area. Unconformably overlies Esplanade Sandstone (Pe). Dark-red, platy, thin-bedded siltstone of Hermit Formation fills channels as much as 60 ft (16 m) deep eroded into the underlying Esplanade in eastern part of map area, and as much as 130 ft (40 m) deep in Havasu Canyon area, south-central part of map area. Erosional relief is generally less than 10 ft (3 m) in northeastern part of map area. About 260 ft (80 m) thick along eastern edge of map area, increasing to about 850 ft (260 m) at western edge of map area. (GRI Source Map ID 1309) (Grand Canyon 30 x 60).

Supai Group (Lower Permian, Pennsylvanian, Upper Mississippian)

Includes, in descending order, the Esplanade Sandstone and Wescogame, Manakacha, and Watahomigi formations, undivided as defined by McKee (1982). Overall thickness of Supai Group, 825 ft (252 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Includes in descending order, the Esplanade Sandstone and Wescogame, Manakacha, and Watahomigi Formations, undivided. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Includes, in descending order, Esplanade Sandstone (Lower Permian); and Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided, as defined by McKee (1975; 1982). Upper Mississippian and Lower Pennsylvanian age for Watahomigi Formation is defined by Martin and Barrick (1999). (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Includes in descending order, the Esplanade Sandstone; Wescogame Formation, Manakacha Formation, and Watahomigi Formation, undivided. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Includes, in descending order, Esplanade Sandstone, east of the Hurricane Fault (Lower Permian, Pe); Esplanade Sandstone and Pakoon Limestone, undivided, west of the Hurricane Fault (Lower Permian; Pep); Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian (PNMs), undivided as defined by McKee (1975; 1982). Upper Mississippian age for Watahomigi Formation is defined by Martin and Barrick (1999). Pakoon Limestone as defined by McNair (1951). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Only the Esplanade Sandstone of the Supai Group is exposed in map area. Units beneath the Esplanade Sandstone are exposed in Grand Canyon north of the map area. The Supai Group includes, in descending order, Esplanade Sandstone (Lower Permian), Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian) as defined by McKee (1975, 1982). Age of Watahomigi Formation is defined by Martin and Barrick (1999). Divided into Esplanade Sandstone; and Wescogame, Manakacha, and Watahomigi Formations, undivided. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Includes, in descending order, the Esplanade Sandstone east of Hurricane Fault (Pe), the Esplanade Sandstone and Pakoon Limestone west of Hurricane Fault (Pep), and the Wescogame, Manakacha, and Watahomigi Formations, undivided (M*s) as defined by McKee (1975, 1982). Age of the Watahomigi Formation is Lower Pennsylvanian and Upper Mississippian by Martin and Barrick (1999). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Includes, in descending order, Esplanade Sandstone (Lower Permian), Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower

Pennsylvanian and Upper Mississippian) as defined by McKee (1975, 1982). Age of Watahomigi redefined by Martin and Barrick (1999). Divided into Esplanade Sandstone and Wescogame, Manakacha, and Watahomigi Formations, undivided. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Pe - Esplanade Sandstone (Lower Permian)

Pe - Supai Group - Esplanade Sandstone (Lower Permian (Cisuralian))
Light-red and pinkish-gray, cliff-forming, fine- to medium-grained, medium- to thick-bedded (3 to 10 ft [1 to 3 m]), well-sorted calcareous sandstone. Includes interbedded, dark-red, thin-bedded, crumbly, recessive and slope-forming siltstone beds in upper and lower part. Crossbeds are small- to medium-scale, low- and high-angle sets. Unconformable contact with underlying Pennsylvanian and Upper Mississippian rocks marked by erosion channels as much as 15 ft (4.5 m) deep filled with conglomerate that is well displayed in Marble Canyon. Thickness, 350 to 400 ft (107 to 122 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Pe - Supai Group - Esplanade Sandstone (Lower Permian (Cisuralian))
Light-red and pinkish-gray, cliff-forming, fine- to medium-grained, medium- to thick-bedded (3 to 10 ft [1 to 3 m]), well-sorted calcareous sandstone. Includes interbedded dark-red, thin-bedded, crumbly, recessive and slope-forming siltstone beds in upper and lower part. Crossbeds are small to medium scale, low- and high-angle planar. Unconformable contact with underlying Pennsylvanian and Upper Mississippian rocks (*Ms) marked by erosion channels as much as 30 ft (9 m) deep in Grand Canyon and Little Colorado River Gorge area. Thickness, 350 to 400 ft (107 to 122 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Pe - Supai Group - Esplanade Sandstone (Lower Permian)
Light-red, white, and pinkish-gray, cliff-forming, fine- to medium-grained, medium- to thick-bedded [1 to 3 m (3 to 10 ft)], well sorted calcareous sandstone. Includes interbedded dark-red, thin-bedded, crumbly recesses of slope-forming siltstone between sandstone beds in upper and lower part. Crossbeds are small- to medium-scale, planar low-angle and high-angle sets 3 to 12 m (10 to 40 ft) thick. Unconformable contact with underlying Wescogame Formation is marked by erosion channels as deep as 15 m (50 ft) filled with calcareous sandstone and limestone conglomerate; average channel depth about 11 m (35 ft) in lower reaches of Kanab Creek area. About 122 to 137 m (400 to 450 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Pe - Supai Group - Supai Group, Esplanade Sandstone (Lower Permian)
Light-red and pinkish-gray, cliff-forming, fine- to medium-grained, medium- to thick-bedded (1 to 3 m [3 to 10 ft]), well-sorted calcareous sandstone. Includes intrabedded dark-red, thin-bedded, crumbly, recessive and slope-forming siltstone beds in upper and lower part. Crossbeds are small- to medium-scale, planar low-angle and high-angle sets. Unit gradually thins eastward and southeastward in subsurface of map area based on limited exposures in northwest quarter of map. Unconformable contact with underlying rocks (*Ms) is marked by erosion channels as much as 9 m (30 ft) deep in Grand Canyon and Little Colorado River Gorge area. Variable thickness, about 122 to 107 m (400 to 350 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Pe - Supai Group - Esplanade Sandstone (Lower Permian)
Consists of an upper cliff and slope, a middle cliff, and lower slope unit.
Upper cliff and slope unit is composed of an upper, light-red or white sandstone cliff and a lower, dark-red siltstone, sandstone and gypsum slope. The lower siltstone and sandstone slope visually resembles strata of overlying Hermit Formation. Erosional unconformity separates Esplanade Sandstone from overlying Hermit Formation as shallow channels eroded into sandstone cliff of upper cliff and slope unit

(Pe). Maximum thickness of upper cliff and slope unit, about 67 m (220 ft), thins westward.
Middle cliff unit is composed of light-red, cliff-forming, fine- to medium-grained, low-angle, crossbedded, well-sorted, calcareous sandstone beds 1 to 3 m (3 to 10 ft) thick. Includes a few interbedded gray, thin-bedded sandy limestone units of the Pakoon Limestone in lower half of middle cliff unit that pinch out east and southeast of the Hurricane Fault area, but thicken west and northwest of the Hurricane Fault toward the Shiwits Plateau, northwest corner of map where Esplanade Sandstone (McKee, 1963) and Pakoon Limestone (McNair, 1951) are undivided (Pep). Middle cliff unit averages about 76 m (250 ft) thick at east edge of map area.
Lower slope unit is composed of a basal limestone pebble conglomerate that grades upward into slope-forming, interbedded dark-red siltstone, light-red sandstone, and gray, thin-bedded limestone that fills channels eroded as much as 9 m (30 ft) into underlying Wescogame Formation of the Supai Group, undivided (*Ms). Forms unconformable contact between Permian and Pennsylvanian strata in northeastern two-thirds of map area. Thickness of lower slope unit, about 24.5 m (80 ft) at east edge of map area, thins northwest and pinches out beneath Shiwits Plateau and northwest corner of map area. Thickness, about 152 m (500 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Pe - Supai Group - Esplanade Sandstone (Lower Permian)
Light-red and pinkish-gray, cliff-forming, fine- to medium-grained, medium- to thick-bedded [3 to 10 ft (1 to 3 m)], well sorted calcareous sandstone. Includes interbedded dark-red, thin-bedded, crumbly recesses of slope-forming siltstone between sandstone beds in upper and lower part. Crossbeds are small- to medium-scale, planar low-angle and high-angle sets. Unconformable contact with underlying Wescogame Formation marked by erosion channels as much as 50 ft (15 m) deep filled with calcareous sandstone and limestone conglomerate; average channel depth about 35 ft (11 m) in Cataract Canyon, north of map area. Erosion of Cataract Canyon has not extended completely through Esplanade Sandstone. Total thickness in Cataract Canyon north of map area is 400 to 450 ft (122 to 137 m); Billingsley, 2000). Incomplete exposure in map area; thickness, 120 ft (37 m). (*GRI Source Map ID 7453)* (Valle 30 x 60).

Pe - Supai Group - Esplanade Sandstone east of Hurricane Fault (Lower Permian)
Includes, in descending order, an upper cliff and slope, a middle cliff, and lower slope unit. Upper cliff and slope unit includes an upper, light-red or white sandstone cliff and a lower, dark-red siltstone, sandstone, and gypsum slope that visually resemble that of the Hermit Formation in eastern third of map area (Hurricane Fault and east of Hurricane Fault). In western two thirds of map area, the upper cliff and slope undergoes a gradual facies change west of the Hurricane Fault to a light-red and white, low-angle crossbedded and massive calcareous sandstone along Grand Wash Cliffs and at Pakoon Ridge, which forms the upper part of the Esplanade Sandstone and Pakoon Limestone west of the Hurricane Fault (Pep) unit. Maximum thickness of upper unit, about 67 m (220 ft) along east edge of map area, thinning westward to about 15 m (50 ft) in Grand Wash Cliffs area. Middle cliff unit is composed of light-red, cliff-forming, fine- to medium-grained, medium-bedded 1 to 3 m (3 to 10 ft) thick, well-sorted, calcareous sandstone east of Hurricane Fault. Includes gray, thin-bedded sandy limestone of the Pakoon Limestone interbedded in lower half of Esplanade cliff west of Hurricane Fault. Pakoon Limestone pinches out eastward about the Hurricane Fault area, but thickens rapidly westward towards Grand Wash Cliffs and Pakoon Ridge where the Esplanade Sandstone and Pakoon Limestone of McNair (1951) are undivided (Pep). Middle cliff unit averages about 75 m (250 ft) thick at east edge of map area, thickening to about 91 m (300 ft) along Grand Wash Cliffs area. Lower slope unit is composed of a basal limestone pebble conglomerate that grades upward into slope-forming, interbedded dark-red siltstone, light-red sandstone, and gray, thin-bedded limestone that fills channels eroded as much as 10 m (30 ft) into underlying Wescogamie Formation of the undivided Supai Group (M*s). Unconformable contact between the Permian and Pennsylvanian strata in east two-thirds of map area and a disconformity between the Permian and Pennsylvanian strata along the Grand Wash Cliffs and in the Pakoon Ridge area. Thickness of lower slope unit, about 25 m (80 ft) at east edge of map area, thins westward and pinches out near Grand Wash Cliffs. Overall, Esplanade Sandstone (Pe) and Esplanade Sandstone and Pakoon Limestone (Pep) are about 167 m (550 ft) thick in east half of map area, decreasing to about 107 m (350

ft) in west half. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Pe - Supai Group - Esplanade Sandstone (Lower Permian)
Light-red and pinkish-gray, cliff-forming, fine- to medium-grained, medium-bedded [3–10 ft (1–3 m)], well-sorted calcareous sandstone. Includes intrabedded dark-red, thin-bedded, crumbly, slope-forming siltstone in upper and lower parts. Consists of an upper cliff and slope unit in western two-thirds of map area, and a middle cliff unit and a lower slope unit throughout map area. In western two-thirds of map area, the upper cliff and slope unit contains thin-bedded slope-forming sandstone and siltstone similar to Hermit Formation (Ph) capped by cliff of thick-bedded, low-angle cross-bedded, red and white sandstone; entire unit thins and pinches out eastward in eastern third of map area. Maximum thickness of upper cliff and slope unit about 220 ft (67 m), western edge of map. Middle cliff unit forms a prominent cliff whose upper surface forms the “Esplanade Bench” in western two-thirds of map area, and a prominent cliff in eastern third of map area. Unit consists of light-red, medium-grained, medium- to thick-bedded sandstone and calcareous sandstone in upper half, and mostly flat, massive, low-angle cross-bedded sandstone sets and calcareous sandstone beds in lower half. Cross beds are small- to medium-scale, planar low-angle and high angle sets. Cross-bedded calcareous sandstone is most common in western half of map area, lesser calcite in eastern half. Middle cliff unit averages about 250 ft (75 m) thick in western half of map area, thinning to about 200 ft (60 m) in eastern half. Lower slope unit consists of alternating layers of light-red, flat-bedded sandstone interbedded with dark-red siltstone and mudstone and gray, thinbedded limestone. Lower slope unit averages about 80 ft (25 m) thick in western half of map area, thickening to about 100 ft (30 m) in eastern half. Unconformable contact with underlying Wescogame Formation marked by erosion channels as much as 50 ft (15 m) deep filled with limestone conglomerate; average channel depth about 35 ft (11 m). Overall, the Esplanade averages about 550 ft (167 m) thick in western half of map area, thinning to less than 300 ft (90 m) in eastern half. (GRI Source Map ID 1309) (Grand Canyon 30 x 60).

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

Pep - Supai Group - Esplanade Sandstone and Pakoon Limestone, undivided (Lower Permian)
Light-red and red-gray, cliff-forming, fine- to medium-grained, medium-bedded (1 to 3 m [3 to 10 ft]), well-sorted calcareous sandstone; interbedded, dark-red, slope-forming siltstone, and light-gray sandy limestone and limestone. Includes an upper cliff and slope unit, middle cliff unit, and lower slope unit. Upper cliff and slope unit consists of thin-bedded, slope-forming, sandstone and siltstone about 60 m (200 ft) thick capped by 6 to 12 m (20 to 40 ft) cliff of light-red, thick-bedded, low-angle, crossbedded sandstone; forms upper cliff and lower slope at base of Hermit Formation often mistaken for strata of Hermit Formation on Sanup Plateau; unit gradually thins west and northwest of map area. Thickness, 73 m (240 ft).
Middle cliff unit forms “Esplanade Bench” of Sanup Plateau north of Colorado River, a prominent cliff throughout map area. Consists of light-red to white, fine- to medium-grained, thick-bedded, crossbedded sandstone and calcareous sandstone in upper half, and flat, massive, low-angle crossbedded sandstone and calcareous sandstone in the lower half separated by sandy limestone and limestone beds of intertonguing Pakoon Limestone. Some calcareous sandstone beds have small- to medium-scale, planar, mixed low-angle and high-angle crossbedded sets throughout. Beds of Pakoon Limestone intertongue within sandstone lower half of middle cliff unit; limestone beds increase in thickness toward western half of map area and form nearly half of the Esplanade Sandstone and Pakoon Limestone undivided cliff in western Grand Canyon. Pakoon Limestone beds thin and pinch out eastward near Hurricane Fault vicinity, but some thin limestone beds of the Pakoon Limestone extend into the Aubrey Valley southeast of the map area.
Pakoon Limestone is gray to pinkish-gray, fine-to medium-grained, thin- to medium-bedded limestone, oolitic limestone, and sandy limestone in northwest quarter of map area, becoming increasingly sandy

and silty toward southeast and east part of map area. Pakoon Limestone contains numerous Lower Permian marine fossils in western half of map area, which establishes the Lower Permian age for the Esplanade Sandstone (Pe) east and north of map area. Thickness of middle cliff unit, 107 to 137 m (350 to 450 ft).
Lower slope unit is composed of alternating light-red sandstone, dark-red siltstone, dark-red mudstone, and gray thin-bedded limestone. Unconformable contact with underlying Wescogame Formation of Supai Group, undivided (*Ms) is marked by erosional channels as much as 15 m (50 ft) deep. Most erosion channels average about 10.5 m (35 ft) in depth and often contain limestone pebble conglomerate in light-purple calcareous sandstone matrix. Thickness, 24.5 to 30 m (80 to 100 ft).
Overall, Esplanade Sandstone and Pakoon Limestone, undivided, thickens northwest and north of map area, thins east and southeast. Thickness, 167 to 183 m (550 to 600 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Pep - Supai Group - Esplanade Sandstone and Pakoon Limestone west of Hurricane Fault (Lower Permian)

Esplanade Sandstone defined by McKee (1975, 1982); Pakoon Limestone defined by McNair (1951). Light-red and pinkish-gray, cliff-forming, fine- to medium-grained, medium-bedded (1 to 3 m [3 to 10 ft]), well-sorted, calcareous sandstone and interbedded, dark-red, slope-forming siltstone. Includes an upper cliff and slope unit, a middle cliff unit, and a lower slope unit as described for Esplanade Sandstone (Pe). In western two-thirds of map area, the upper cliff and slope undergoes a gradual facies change west of the Hurricane Fault to a light-red and white, low-angle crossbedded and massive calcareous sandstone along Grand Wash Cliffs and at The Cockscomb, southwest corner of map area, which forms the upper part of the Esplanade Sandstone and Pakoon Limestone west of the Hurricane Fault (Pep) unit. Maximum thickness of upper unit, about 67 m (220 ft) along east edge of map area at Lake Mead, thinning westward to about 15 m (50 ft) in Grand Wash Cliffs area.
Middle cliff unit is composed of an upper, light-red to white, fine- to medium-grained, thick-bedded calcareous sandstone and flat, massive, low-angle crossbedded sandstone and calcareous sandstone in lower half that intertongue with gray limestone beds of the Pakoon Limestone. Small- to medium-scale, planar low-angle, calcareous sandstone crossbeds that include some high-angle sets throughout compose nearly half of the Esplanade Sandstone and Pakoon Limestone cliff along the Grand Wash Cliffs. Pakoon Limestone beds are gray to pinkish-gray, fine-to medium-grained, thin- to medium-bedded limestone and oolitic limestone along Grand Wash Cliffs and The Cockscomb areas. Pakoon Limestone contains numerous Early Permian marine fossils throughout unit in west half of map area, which establish Early Permian age (McNair, 1951) for Esplanade Sandstone east of Hurricane Fault (Pe), and Esplanade Sandstone and Pakoon Limestone west of Hurricane Fault (Pep). Pakoon Limestone thins eastward and pinches out in the vicinity of the Hurricane Fault in eastern part of map area. Pakoon Limestone beds form topographic bench of Sanup Plateau along Grand Wash Cliffs area. Thickness of middle cliff unit averages about 91 m (300 ft) in west half of map area and thins to about 76 m (250 ft) in east half.
Lower slope unit consists of alternating layers of light-red sandstone, dark-red siltstone and mudstone, and gray thin-bedded limestone of the Esplanade Sandstone (Pe). Unconformable contact with underlying Wescogame Formation of the Supai Group undivided (M*s) marked by erosion channels of as much as 10 m (30 ft) deep; channels contain limestone pebble conglomerate. Lower slope unit, about 25 m (80 ft) thick in eastern part of map area, thins and pinches out near Grand Wash Cliffs area. Overall thickness of Esplanade Sandstone and Pakoon Limestone west of Hurricane Fault, about 107 m (350 ft) along Grand Wash Cliffs. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

PNMs - Wescogame Formation, Manakacha Formation, and Watahomigi Formation, undivided (Pennsylvanian and Upper Mississippian)

PNMs - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided (Pennsylvanian and Upper Mississippian)

Includes, in descending order, the Wescogame, Manakacha, and Watahomigi formations as defined by McKee (1982). Individual formations are difficult to identify because of similar lithology and topographic expression; unconformable contacts between them are shallow and difficult to find.

Wescogame Formation (Upper Pennsylvanian): Light-red, pale-yellow, and light-gray upper slope unit and lower cliff unit. Upper slope unit consists mainly of dark-red, fine-grained siltstone and mudstone interbedded with light-red, coarse-grained, calcareous sandstone, dolomitic sandstone, siltstone, mudstone, and conglomerate. Lower cliff unit consists mainly of light-red to gray, high-angle, large- and medium-scale, tabular- to planar-crossbedded sandstone and calcareous sandstone as much as 20 ft (6 m) thick. Unconformable contact with underlying Manakacha Formation marked by erosion channels 3 ft (1 m) deep in Marble Canyon. Channels commonly filled with limestone/chert conglomerate. Thickness, 110 to 130 ft (34 to 40 m).

Manakacha Formation (Middle Pennsylvanian): Light-red, white, and gray upper slopes and ledges of sandstone, calcareous sandstone, dark-red siltstone, and thin gray limestone. Upper slope consists mainly of shaley siltstone and mudstone with minor interbedded, thin-bedded limestone and sandstone. Carbonate content increases southwest of map area forming numerous ledge-forming, thin- to medium-bedded limestone beds. Lower cliff is dominated by reddish-gray, medium- to thick-bedded, crossbedded, calcareous sandstone and sandy limestone. Carbonate content increases west of quadrangle forming numerous gray limestone ledges (McKee, 1982). Unconformable contact between Manakacha Formation and underlying Watahomigi Formation marked at base of lower red sandstone cliff of Manakacha; erosional relief generally less than 3 ft (1 m). Thickness, 175 ft (53 m).

Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian): Gray and purple, slope-forming limestone, siltstone, mudstone, and some conglomerate. Lower limestone beds contain red chert lenses and nodules. Includes alternating gray, thin-bedded cherty limestone ledges interbedded with purplish-gray siltstone and mudstone in upper part. Lower slope consists mainly of purplish-red mudstone and siltstone interbedded with thin-bedded, aphanitic to granular limestone with red chert veins and nodules. Fossil conodonts in lower limestone beds west of quadrangle indicate Upper Mississippian age (Martin and Barrick, 1999). Includes purple siltstone and gray limestone interbedded with reddish conglomeratic sandstone that fill small erosion channels cut into underlying Surprise Canyon Formation or into Redwall Limestone. Supai Group gradually thins eastward and gradually thickens west of quadrangle. Thickness, 100 to 120 ft (30 to 37 m). Overall thickness of Supai Group, 825 ft (252 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

PNMs - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Moscovian), and Watahomigi Formation (Bashkirien and Serpukhovian), undivided

Includes, in descending order, the Wescogame, Manakacha, and Watahomigi Formations as defined by McKee (1982). Individual formations are difficult to identify because of similar lithology and topographic expression; unconformable contacts are shallow, difficult-to-find erosion channels. Herein, the three formations are shown as one map unit.

Wescogame Formation: Light-red, pale-yellow, and light-gray upper slope unit and lower cliff unit. Upper slope unit consists mainly of dark-red, fine-grained siltstone and mudstone interbedded with light-red, coarse-grained, calcareous sandstone, dolomitic sandstone, siltstone, mudstone, and conglomerate. Lower cliff unit consists mainly of light-red to gray, high-angle, large- and medium-scale, tabular-planar, crossbedded sandstone and calcareous sandstone as much as 40 ft (12 m) thick. Unconformable contact with underlying Manakacha Formation marked by erosion channels 3 to 6 ft (1 to 2 m) deep in Grand Canyon area. Channels commonly filled with limestone/chert conglomerate west of map area. Thickness, 130 to 150 ft (40 to 45 m).

Manakacha Formation: Light-red, white, and gray upper slopes and ledges of sandstone, calcareous sandstone, dark-red siltstone, and thin gray limestone. Upper slope consists mainly of shaley siltstone and mudstone with minor interbedded, thin-bedded limestone and sandstone. Carbonate content increases west of map area forming numerous ledge-forming, thin and medium limestone beds at west edge of map. Upper slope is about 75 to 100 ft (23 to 30 m) thick in Grand Canyon. Lower cliff is dominated by reddish-gray, medium- to thick-bedded, crossbedded, calcareous sandstone and sandy limestone. Lower cliff is about 60 ft (18 m) thick. Carbonate content increases west of map area, forming numerous gray limestone ledges (McKee, 1982). Unconformable contact between Manakacha Formation and underlying Watahomigi Formation marked at base of lower red sandstone cliff; erosional relief nearly flat, generally less than 3 ft (1 m). Thickness, 200 ft (60 m).
Watahomigi Formation: Gray and purple, slope-forming limestone, siltstone, mudstone, and minor conglomerate. Minor red chert lenses and nodules in lower limestone beds. Includes alternating gray, thin-bedded cherty limestone ledges interbedded with purplish-gray siltstone and mudstone in upper part. Upper ledge/slope averages about 70 ft (21 m) thick. Lower slope consists mainly of purplish-red mudstone and siltstone, interbedded with thin-bedded, aphanitic to granular limestone with red chert veins and nodules. Fossil conodonts in lower thin limestone beds west of map area are Late Mississippian age (Martin and Barrick, 1999). Unit includes purple siltstone and gray limestone interbedded with reddish conglomeratic sandstone that fills small erosion channels cut into underlying Surprise Canyon Formation (Ms) or into Redwall Limestone (Mr). Lower Supai Group gradually thins eastward and gradually thickens westward in west half of map. Thickness, 100 to 120 ft (30 to 37 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

PNMs - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided

As defined by McKee (1982). Watahomigi Formation is Upper Mississippian and Lower Pennsylvanian age as defined by Martin and Barrick (1999).
Wescogame Formation is light-red, pale-yellow, and light-gray upper slope and lower cliff unit composed of fine- to coarse-grained gray sandstone, dolomitic sandstone, siltstone, mudstone, and conglomerate. Upper slope is composed mostly of light-red, fine-grained siltstone, mudstone, and interbedded light-red sandstone. Lower cliff is composed mainly of light-red to gray, high-angle, large- and medium-scale, tabular-planar, crossbedded sandstone sets as much as 12 m (40 ft) thick. Includes interbedded dark-red, thin-bedded siltstone in upper part. Unconformable contact with underlying Manakacha Formation marked by erosion channels as deep as 9 m (30 ft). Erosional channels commonly filled with limestone/ chert pebble conglomerate. About 40 m (130 ft) thick.
Manakacha Formation consists of light-red, white, and gray upper slope and lower cliff of sandstone, calcareous sandstone, dark-red siltstone, and gray limestone. Upper slope is composed mainly of shaly siltstone and mudstone with minor amounts of interbedded, thin-bedded limestone and sandstone. Carbonate content in upper slope increases westward to form numerous ledge-forming, thin- and medium-bedded sandy limestone beds west of map area. Upper slope is about 18 m (60 ft) thick. Lower cliff unit is predominantly a crossbedded, calcareous sandstone, dolomite, and sandy limestone, about 30 m (100 ft) thick. Unconformable erosional contact between Manakacha and underlying Watahomigi Formations marked at base of lower sandstone cliff of Manakacha Formation. Erosional relief is generally less than 1 m (3 ft), and contact is mostly a wavy unconformable surface. About 55 m (180 ft) thick.
Watahomigi Formation consists of gray and purplish-red, slope-forming limestone, siltstone, mudstone, and conglomerate. Forms an upper ledge and slope unit and lower cliff unit. Upper ledge and slope unit is sequence of alternating gray, thin-bedded cherty limestone ledges and purplish-gray siltstone and mudstone slopes; limestone beds contain Early Pennsylvanian conodont fossils (Martin and Barrick, 1999); red chert lenses and nodules are common in limestone beds. Includes limestone chert pebble conglomerate at base; upper ledge and slope unit locally contains Pennsylvanian fossils and averages about 21 m (70 ft) thick. Lower cliff unit consists of a basal, purplish-red mudstone and siltstone overlain by thin-bedded aphanitic to granular limestone cliff with red chert nodules and chert veins. About 30 to

40 m (100 to 130 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

PNMs - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided

Includes, in descending order, Wescogame, Manakacha, and Watahomigi Formations as defined by McKee (1982). Separate formations are difficult to identify in the field and due to limited exposures in northwest corner of map area and in the Little Colorado River Gorge

Wescogame Formation (Upper Pennsylvanian)—Light-red, pale-yellow, and light-gray upper slope unit and lower cliff unit. Upper slope unit consists mainly of dark-red, fine-grained siltstone and mudstone interbedded with light-red, coarse-grained, calcareous sandstone and dolomitic sandstone, siltstone, mudstone, and conglomerate. Lower cliff unit consists mainly of light-red to gray, high-angle, large- and medium-scale, tabular-planar, crossbedded sandstone and calcareous sandstone sets as much as 12 m (40 ft) thick. Unconformable contact with underlying Manakacha Formation marked by erosion channels as much as 4.5 m (15 ft) deep in Grand Canyon part of map area. Channels commonly filled with limestone/chert conglomerate. About 45 m (150 ft) thick.

Manakacha Formation (Middle Pennsylvanian)—Light-red, white, and gray upper slope and lower cliff of sandstone, calcareous sandstone, dark-red siltstone, and gray limestone. Upper slope consists mainly of shaly siltstone and mudstone with minor interbedded, thin-bedded limestone and sandstone. Carbonate content of upper slope increases westward to form numerous ledge-forming, thin- and medium-bedded limestone beds. Upper slope is about 30 m (100 ft) thick in Grand Canyon area of map. Lower cliff is dominated by grayish-red, medium- to thick-bedded, crossbedded calcareous sandstone, dolomite, and sandy limestone. Lower cliff is about 18 m (60 ft) thick. Carbonate content increases west of map area forming numerous gray limestone ledges. Unconformable contact between the Manakacha Formation and underlying Watahomigi Formation marked at base of lower red sandstone cliff of Manakacha; erosional relief generally less than 1 m (3 ft) as wavy unconformable surface. About, about 60 m (200 ft) thick.

Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian)—Gray and purplish-red, slope-forming limestone, siltstone, mudstone, and conglomerate. Forms an upper ledge/slope and lower slope. Upper ledge/slope consists of alternating gray, thin-bedded cherty limestone ledges interbedded with purplish-gray siltstone and mudstone; limestone beds contain Lower Pennsylvanian conodont fossils in western Grand Canyon area (Martin and Barrick, 1999); red chert lenses and nodules common. Includes limestone chert-pebble conglomerate at base, locally containing Lower Pennsylvanian fossils. Upper ledge/slope averages about 21 m (70 ft) thick throughout Grand Canyon area. Lower slope consists mainly of purplish-red mudstone and siltstone, interbedded with thin-bedded, aphanitic to granular limestone in upper part with red chert veins and nodules. Conodonts in lower thin limestone beds are Upper Mississippian (Martin and Barrick, 1999). Unit includes purple siltstone and gray limestone interbedded with conglomerate that fills small erosion channels cut into either the Surprise Canyon Formation (Ms) north and west of map area or into Redwall Limestone (Mr). Purple shale and mudstone of lower slope unconformably overlies gray Redwall Limestone in Grand Canyon and Little Colorado River Gorge area. Surprise Canyon Formation (Ms) is not present within map area but is present just north of map in Grand Canyon (Billingsley, 2000) and may be present in subsurface of map area. About 30 m (100 ft) thick. Supai Group gradually thins eastward in subsurface of map area. Overall thickness of Supai Group ranges from about 244 to 274 m (800 to 900 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

PNMs - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided

Supai Group as defined by McKee (1982). Watahomigi Formation is Upper Mississippian and Lower Pennsylvanian age as defined by Martin and Barrick (1999).

Wescogame Formation consists of light-red, pale-yellow, and light-gray upper slope and lower cliff,

composed of fine- to coarse-grained gray sandstone, dolomitic sandstone, siltstone, mudstone, and conglomerate. Upper slope is composed mostly of light-red, fine-grained siltstone, mudstone, and interbedded light-red sandstone. Lower cliff is composed mainly of light-red to gray, high-angle, large and medium-scale, tabular-planar, crossbedded sandstone sets as much as 12 m (40 ft) thick. Includes interbedded dark-red, thin-bedded siltstone in upper part. Unconformable contact with underlying Manakacha Formation marked by erosion channels as much as 24.5 m (80 ft) deep in western part of map area; less than 9 m (30 ft) deep in eastern part. Erosional channels commonly filled with limestone/ chert pebble conglomerate. Uniform thickness, 40 m (130 ft).
Manakacha Formation consists of light-red, white, and gray upper slope and lower cliff of sandstone, calcareous sandstone, dark-red siltstone, and gray limestone. Upper slope is composed mainly of shaley siltstone and mudstone with minor amounts of interbedded, thin-bedded limestone and sandstone. Carbonate content in upper slope increases westward to form numerous ledge-forming, thin- and medium-bedded sandy limestone beds. Thickness of upper slope is about 18 m (60 ft). Lower cliff unit is dominantly a crossbedded, calcareous sandstone, dolomite, and sandy limestone, about 30 m (100 ft) thick. Carbonate content increases westward across map area forming numerous gray limestone ledges. Unconformable erosional contact between Manakacha and underlying Watahomigi Formations marked at base of lower sandstone cliff of Manakacha Formation. Erosional relief is generally less than 1 m (3 ft), and is mostly a wavy unconformable surface. Thickness, 55 m (180 ft).
Watahomigi Formation consists of gray and purplish-red, slope-forming limestone, siltstone, mudstone, and conglomerate. Forms an upper ledge and slope unit and lower cliff unit. Upper ledge and slope unit is sequence of alternating gray, thin-bedded cherty limestone ledges and purplish-gray siltstone and mudstone slopes; limestone beds contain Early Pennsylvanian conodont fossils (Martin and Barrick, 1999); red chert lenses and nodules are common in limestone beds. Includes limestone chert pebble conglomerate at base of upper ledge and slope unit that locally contain Pennsylvanian fossils. Upper ledge and slope unit average about 21 m (70 ft) thick. Lower cliff unit consists of a basal, purplish-red mudstone and siltstone overlain by thin-bedded aphanitic to granular limestone cliff with red chert nodules and chert veins. Conodonts in lower thin limestone beds are Late Mississippian (Martin and Barrick, 1999). Include purple siltstone and gray limestone interbedded with conglomerate that fill small erosion channels eroded into either the Surprise Canyon Formation (Ms) or Redwall Limestone (Mr). In majority of map area, purple shale and mudstone of the Watahomigi Formation unconformably overlies gray limestone beds of the Redwall Limestone. Contact with the Surprise Canyon Formation is often based on color change from purple mudstone of the Watahomigi Formation to dark-red mudstone of Surprise Canyon Formation. Unit averages about 30 m (100 ft) thick along east edge of map area thickening to about 60 m (200 ft) along Grand Wash Cliffs. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

PNMs - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided

Wescogame Formation is light-red, pale-yellow, and light-gray upper slope unit and lower cliff unit. Upper slope consists mainly of dark-red, fine-grained siltstone and mudstone interbedded with light-red, coarse-grained calcareous sandstone and dolomitic sandstone and conglomerate. Lower cliff consists mainly of light-red to gray, high-angle, large- and medium-scale, tabular-planar crossbedded sandstone and calcareous sandstone sets as much as 40 ft (12 m) thick. Includes interbedded dark-red, thin-bedded siltstone in upper part of cliff. Unconformable contact with underlying Manakacha Formation marked by unconformity of erosion channels as much as 80 ft (25 m) deep in western part of map area and less than 30 ft (9 m) deep in eastern part of map area. Channels commonly filled with limestone/chert conglomerate. The Wescogame Formation thickens slightly from west to east, averaging about 130 ft (40 m) thick in west part of map area to about 150 ft 46 m) in east part.
Manakacha Formation is light-red, white, and gray upper slope and lower cliff of sandstone, calcareous sandstone, dark-red siltstone, and gray limestone. Upper slope consists mainly of shaley siltstone and mudstone with minor interbedded, thin-bedded limestone and calcareous sandstone. Carbonate content of upper slope increases westerly to form numerous ledge-forming, thin- and medium-bedded

limestones. Upper slope is about 100 ft (30 m) thick in east half of map area, decreasing to less than 60 ft (18 m) thick in west half. Lower cliff is dominated by grayish-red, medium- to thick-bedded, crossbedded calcareous sandstone, dolomite, and sandy limestone. Lower cliff is about 60 ft (18 m) thick in east part of map area, thickening to about 100 ft (30 m) in west part. Carbonate content increases westward across map area forming numerous gray limestone ledges. Unconformable contact between the Manakacha and underlying Watahomigi Formations marked at base of lower sandstone cliff of Manakacha Formation; erosional relief is generally less than 3 (1 m) ft as a wavy unconformable surface. Overall thickness, 200 ft (60 m) throughout map area.
Watahomigi Formation is gray and purplish-red, slope-forming limestone, siltstone, mudstone, and conglomerate. Forms an upper ledge/slope and a lower slope. Upper ledge/slope consists of alternating gray, thin-bedded cherty limestone ledges interbedded with purplish-gray siltstone and mudstone. Limestone beds contain Early Pennsylvanian conodont fossils (Martin and Barrick, 1999); red chert lenses and nodules are common in limestone beds. Includes limestone chert-pebble conglomerate at base, locally containing Early Pennsylvanian fossils. Upper ledge and slope averages about 70 ft (22 m) thick throughout map area. Lower slope consists of purplish-red mudstone and siltstone interbedded with thin-bedded, aphanitic to granular limestone in upper part with red chert veins and nodules. Conodonts in lower thin limestone beds are Late Mississippian (Martin and Barrick, 1999). Unit includes purple siltstone and gray limestone interbedded with conglomerate that fills small erosion channels cut into either the Surprise Canyon Formation (Ms) or Redwall Limestone (Mr). Purple shale and mudstone of lower slope unconformably overlies gray Redwall Limestone in majority of map area and unconformably overlies the Surprise Canyon Formation where present. Contact with the Surprise Canyon Formation is often based on color change from purple mudstone of Watahomigi Formation to dark-red mudstone of Surprise Canyon Formation. Unit averages about 100 ft (30 m) thick along east edge of map area thickening to 200 ft (60 m) along west edge. In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

PNMs - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided

Supai Group as defined by McKee (1975, 1982). Age of the Watahomigi Formation is Lower Pennsylvanian and Upper Mississippian as defined by Martin and Barrick (1999). All three formations are equivalent to the Callville Limestone (not exposed in map area) of the Basin and Range west of the Grand Wash Cliffs.
Wescogame Formation forms an upper slope and lower cliff. Upper slope is composed of dark-red, fine-grained siltstone, mudstone, and interbedded light-red sandstone. Lower cliff is composed of light-red to gray, high-angle, large- and medium-scale, tabular-planar, crossbedded sandstone sets as much as 10 m (30 ft) thick. Includes interbedded dark-red, thin-bedded siltstone beds in upper part of cliff. Unconformable contact with underlying Manakacha Formation marked by erosion channels as much as 24 m (80 ft) deep in western part of map area, less than 10 m (30 ft) deep in eastern part of map area. Channel deposits commonly composed of limestone chert conglomerate. Thickness, 40 to 64 m (130 to 210 ft).
Manakacha Formation consists of light-red, white, and gray upper slope and lower cliff of sandstone, calcareous sandstone, dark-red siltstone, and gray limestone. Upper slope unit consists of shaley siltstone and mudstone with minor amounts of interbedded, thin-bedded limestone and sandstone. Carbonate content increases westward to form numerous ledge-forming, thin- and medium-bedded limestone beds. Thickness of upper slope unit, about 18 m (60 ft). Lower cliff unit is dominantly a crossbedded, calcareous sandstone, dolomite, and sandy limestone. Carbonate content increases westward across map area forming numerous gray limestone ledges. Unconformable contact between Manakacha and underlying Watahomigi Formations at base of lower sandstone cliff of Manakacha Formation. Erosional relief is generally less than 1 m (3 ft). Thickness of lower cliff, 30 m (100 ft). Average thickness, 55 m (180 ft).
Watahomigi Formation consists of gray and purplish-red, slope-forming limestone, siltstone, mudstone, and conglomerate. Forms an upper ledge and slope unit and a lower cliff unit. Upper ledge and slope unit

is composed of a sequence of alternating gray, thin-bedded cherty limestone ledges and purplish-gray siltstone and mudstone slopes; limestone beds contain Early Pennsylvanian conodont fossils (Martin and Barrick, 1999); red chert lenses and nodules are common. Includes limestone chert pebble conglomerate at base of upper ledge and slope unit, which locally contains Pennsylvanian fossils. Upper ledge and slope unit averages 21 m (70 ft) thick throughout map area. Lower cliff unit consists of a basal, purplish-red mudstone and siltstone overlain by thin-bedded aphanitic to granular limestone with red chert nodules and chert veins. Conodonts in lower thin limestone beds are Late Mississippian age (Martin and Barrick, 1999). Includes purple siltstone and gray limestone interbedded with conglomerate that fill small channels eroded into either the Surprise Canyon Formation (Ms) or Redwall Limestone (Mr) at the basal erosional unconformity. In majority of map area, purple shale and mudstone of Watahomigi Formation unconformably overlie gray limestone of Redwall Limestone. Contact with laterally discontinuous Surprise Canyon Formation is often based on color change from purple mudstone of the Watahomigi Formation to dark-red mudstone of the Surprise Canyon Formation. Unit averages 30 m (100 ft) thick along east edge of map area thickening to 60 m (200 ft) along Grand Wash Cliffs. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

MPNu - Supai Group - Wescogame Formation (Upper Pennsylvanian), Manakacha Formation (Middle Pennsylvanian), and Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian), undivided

Light-red, pale-yellow, and light-gray upper slope unit and lower cliff unit. Upper slope unit consists mainly of dark-red, fine-grained siltstone and mudstone interbedded with light-red, coarse-grained, calcareous sandstone and dolomitic sandstone, siltstone, mudstone, and conglomerate. Lower cliff unit consists mainly of light-red to gray, high-angle, large- and medium-scale, tabular-planar, cross-bedded sandstone and calcareous sandstone sets as much as 40 ft (12 m) thick. Includes interbedded dark-red, thin-bedded siltstone in upper part of cliff. Cross-bed sets contain large footprints of four-footed vertebrate animals in eastern part of map area. Unconformable contact with underlying Manakacha Formation marked by unconformity of erosion channels as much as 80 ft (24 m) deep in western part of map area, and less than 30 ft (10 m) deep in eastern part of map area. Channels commonly filled with limestone/ chert conglomerate. The Wescogame thickens slightly from west to east, averaging about 130 ft (40 m) in western part of map area and about 150 ft (45 m) in eastern part.

Manakacha Formation—Light-red, white, and gray upper slope unit and lower cliff unit of sandstone, calcareous sandstone, dark-red siltstone, and gray limestone. Upper slope unit consists mainly of shaley siltstone and mudstone with minor interbedded, thin-bedded limestone and sandstone. Carbonate content of upper slope unit increases westward to form numerous ledge-forming, thin- and medium-bedded limestone beds. Upper slope unit is about 100 ft (30 m) thick in eastern half of map area, decreasing to less than 60 ft (18 m) thick in western half. Lower cliff unit is dominated by grayish-red, medium- to thick-bedded, crossbedded calcareous sandstone, dolomite, and sandy limestone. Lower cliff unit is about 60 ft (18 m) thick in eastern part of map area, thickening to about 100 ft (30 m) in western part. Carbonate content of lower cliff unit increases westward across map area, forming numerous gray limestone ledges. Unconformable erosional contact between the Manakacha and underlying Watahomigi Formation approximately marked at base of lower sandstone cliff of the Manakacha; erosional relief generally less than 3 ft (1 m) and wavy unconformable surface. Overall thickness averages about 200 ft (60 m) throughout map area.

Watahomigi Formation—Gray and purplish-red, slope-forming limestone, siltstone, mudstone, and conglomerate. Forms an upper ledge/slope unit and a lower slope unit. Upper ledge/slope unit consists of alternating gray, thin-bedded cherty limestone ledges interbedded with purplish-gray siltstone and mudstone; limestone beds contain Lower Pennsylvanian conodont fossils (Martin and Barrick, 1999); red chert lenses and nodules common. Includes limestone chertpebble conglomerate at base, locally containing Lower Pennsylvanian fossils. Upper ledge/slope unit averages about 70 ft (21 m) thick throughout map area. Lower slope unit consists mainly of purplish-red mudstone and siltstone, interbedded with thin-bedded, aphanitic to granular limestone in upper part with red chert veins and nodules. Conodonts in lower thin limestone beds are Upper Mississippian (Martin and Barrick, 1999). Unit includes purple siltstone and gray limestone interbedded with conglomerate that fill small erosion

channels cut into either Surprise Canyon Formation (Ms) or Redwall Limestone (Mr). Purple shale and mudstone of lower slope unit unconformably overlies the gray Redwall in majority of map area. Contact with the Surprise Canyon is often based on color change from purple mudstone of the Watahomigi to dark-red mudstone of the Surprise Canyon. Unit averages about 100 ft (30 m) thick along eastern edge of map area, thickening to about 200 ft (60 m) along western edge . (GRI Source Map ID 1309) (Grand Canyon 30 x 60).

Ms - Surprise Canyon Formation (Upper Mississippian)

Ms - Surprise Canyon Formation (Upper Mississippian)
Dark-reddish-brown, massive to thin-bedded, poorly sorted siltstone, sandstone, thin-bedded gray limestone, and dolomite, and a basal conglomerate containing gray and white, subrounded chert clasts derived from Redwall Limestone in dark-red or black sandstone matrix. Unit is limited to deposits within paleovalleys and karst caves eroded into top half of underlying Redwall Limestone (Billingsley and Beus, 1999). Unit is likely present in subsurface of eastern part of quadrangle. Sandstone and siltstone beds contain plant and bone fossils, mudcracks, and ripple marks. Thickness, 0 to 40 ft (0 to 12 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Ms - Surprise Canyon Formation (Upper Mississippian)
Dark-reddish-brown, massive to thin-bedded, poorly sorted siltstone, sandstone, thin-bedded gray limestone, dolomite, and a basal gray and white conglomerate of subrounded chert clasts derived from Redwall Limestone in dark-red or black sandstone matrix. Unit is locally absent throughout map area and limited to deposits within paleovalley and karst caves eroded into top half of underlying Redwall Limestone (Billingsley and Beus, 1999). Unit is likely present in subsurface of eastern part of map area. Sandstone and siltstone beds contain plant and bone fossils, mud cracks, and ripple marks. Thickness, 0 to 100 ft (0 to 30 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ms - Surprise Canyon Formation (Upper Mississippian)
Dark reddish-brown cliff and slope-forming siltstone, sandstone, gray limestone, dolomite, and white conglomerate in dark-red or black sandstone matrix as defined by Billingsley and Beus (1999). Formation is locally absent throughout map area and present only as sediment accumulations in paleovalleys and karst caves eroded into top part of the Redwall Limestone (Mr). The Surprise Canyon Formation is the most fossiliferous rock strata in Grand Canyon. Deepest channel deposits are in northwest quarter of map area (up to 122 m [400 ft] deep), unit gradually thins east and south across map area. Forms an upper slope, middle cliff, and lower slope, undivided.
Upper slope includes red-brown, thin-bedded siltstone, calcareous sandstone, and reddish-gray, thin-bedded sandy limestone. Contains numerous ripple marks and tidal flat to shallow water marine fossils. Thickness, 14 to 23 m (50 to 75 ft). Middle cliff consists of reddish-gray, thin-bedded, coarsely-grained silty/sandy limestone. Contains numerous shallow water marine fossils. Thickness, 14 to 60 m (50 to 200 ft). Lower slope consists of dark red-brown to black, iron-stained, thin-bedded, coarse- to medium-grained fluvial and marine siltstone, sandstone, limestone, and conglomerate. Sandstone and siltstone beds contain numerous plant fossils, bone fossils, mudcracks, ripplemarks, and thin low-angle crossbedded sandstone sets. Conglomerate consists of white and gray chert clasts supported in a coarse-grained chert sandstone or gravel matrix all derived from the Redwall Limestone. Conglomerate beds average about 7.5 m (25 ft) thick. Includes local coal beds about 1 m (3) ft thick in black shale beds, northwest corner of map area. Thickness of lower slope, 23 to 38 m (75 to 125 ft). Overall thickness, 0 to 122 m (0 to 400 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Ms - Surprise Canyon Formation (Upper Mississippian)
Dark reddish-brown siltstone and sandstone, gray limestone and dolomite, and grayish-white chert conglomerate in dark-red or black sandstone matrix. Formation locally absent throughout map area and

present only in paleovalleys and karst caves eroded into top half of the Redwall Limestone (Mr). Consists of an upper slope, a middle cliff, and lower slope in west half of map area; forms slope in east half of map area.
Upper slope consists of reddish-brown, thin-bedded siltstone, calcareous sandstone, and reddish-gray, thin-bedded sandy limestone. Contains numerous ripple marks and marine fossils. Thickness ranges from about 50 to 75 ft (15 to 23 m). Middle cliff consists of a reddish-gray, thin-bedded, coarse-grained silty and sandy limestone containing numerous marine fossils. Average thickness about 50 ft in (15 m) west third of map area, thins and pinches out in east two-thirds of map area based on exposures in Grand Canyon north of map area (Billingsley, 2000). Lower slope consists of dark reddish-brown to black, iron-stained, thin-bedded, coarse- to medium-grained siltstone, sandstone, limestone, and conglomerate. Sandstone and siltstone beds contain numerous plant fossils and bone fossils, mudcracks, and ripplemarks. Sandstone is coarse grained and thin bedded with some low-angle, crossbedded sets. Conglomerate beds consist of white and gray chert clasts supported in dark-red to black, coarse-grained chert sandstone or gravel matrix, all derived from erosion of the Redwall Limestone. Thickness of lower slope, about 3 to 60 ft (1 to 18 m), averages about 25 ft (7.5 m). In east half of map area, the Surprise Canyon Formation consists mainly of dark reddish-brown, slope-forming, massive to thin-bedded, poorly sorted siltstone and sandstone containing plant fossils.
The Surprise Canyon Formation is the most fossiliferous rock unit in the Grand Canyon. Overall, thickness averages about 145 ft (44 m) in west half of map area, thinning to less than 50 ft (15 m) in east half. In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Ms - Surprise Canyon Formation (Upper Mississippian)
Dark reddish-brown cliff- and slope-forming siltstone and sandstone; gray limestone and dolomite; and white conglomerate in dark-red or black sandstone matrix (Billingsley and Beus, 1999). Formation is present only as sedimentary deposits in erosion channels and infillings of karst features dissolved from the upper part of Redwall Limestone (Mr). Includes an upper slope, middle cliff, and lower slope unit.
Upper slope unit includes red-brown, thin-bedded siltstone, calcareous sandstone, and reddish-gray, thin-bedded, sandy limestone. Contains numerous ripple marks and marine fossils. Thickness, about 15 to 23 m (50 to 75 ft).
Middle cliff unit consists of reddish-gray, thin-bedded, coarse-grained, silty sandy limestone. Contains numerous marine fossils distinguishing it as the most fossiliferous rock unit in Grand Canyon. Thickness, 15 to 60 m (50 to 200 ft).
Lower slope unit consists of dark red-brown to black, iron-stained, thin-bedded, coarse- to medium-grained siltstone, sandstone, limestone, and conglomerate; includes minor coal beds. Thin, low-angle crossbedded sandstone sets and siltstone beds contain numerous plant and bone fossils, mudcracks, and ripple marks. Conglomerate beds consist of white and gray chert clasts supported in coarse-grained chert sandstone or gravel matrix, all derived from Redwall Limestone (Mr). Conglomerate beds average about 8 m (25 ft) thick. Includes local coal beds 1 m (3 ft) thick in black shale slope in southwest corner of map area. The Redwall Limestone surface was a tropical sinkhole plain drained by west-trending, low-gradient channels. The channels developed into major drainage valleys with depths reaching up to 122 m (400 ft) cutting out 2/3 of the thickness of the Redwall Limestone. The depth of karstification exceeded that of nearby channels. This environment was drowned by a marine transgression from the west that deposited carbonate sediments of the Surprise Canyon Formation in the channels, valleys, and karst, but did not cover the entire Redwall Limestone surface. Maximum thickness, 122 m (400 ft), unit thins eastward. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Ms - Surprise Canyon Formation (Upper Mississippian)
Dark-reddish-brown siltstone and sandstone, gray limestone and dolomite, and grayish-white chert conglomerate in dark-red or black sandstone matrix. Formation locally absent throughout map area; present only in paleovalleys and karst caves eroded into top half of Redwall Limestone (Mr). Consists of an upper slope unit, a middle cliff unit, and a lower slope unit in western half of map area; forms slope in eastern half of map area. Upper slope unit consists of red-brown, thin-bedded siltstone, calcareous sandstone, and reddish-gray, thin-bedded sandy limestone. Contains numerous ripple marks and marine

fossils. Thickness ranges from about 50 to 75 ft (15 to 23 m). Middle cliff unit consists of a reddish-gray, thin-bedded, coarse-grained silty and sandy limestone containing numerous marine fossils. Average thickness about 50 ft (15 m) in western third of map area, thinning and pinching out eastward in eastern two-thirds of map area. Lower slope unit consists of dark-red brown to black, iron-stained, thin-bedded, coarse- to medium-grained siltstone, sandstone, limestone, and conglomerate. Sandstone and siltstone beds contain numerous plant fossils, bone fossils, mudcracks, and ripplemarks. Sandstone is coarse grained and thin bedded with some low-angle, cross-beds. Conglomerate beds consists of white and gray chert clasts supported in dark-red to black, coarse-grained chert sandstone or gravel matrix, all derived from the Redwall. Thickness of lower unit about 3–60 ft (1–18 m), averaging about 25 ft (8 m). In eastern half of map area, the Surprise Canyon consists mainly of dark-red-brown, slope-forming, massive to thin-bedded, poorly sorted siltstone and sandstone, containing localized plant fossils. The Surprise Canyon is the most fossiliferous rock unit in the Grand Canyon. Overall, thickness averages about 145 ft (45 m) in western half of map area, thinning to less than 50 ft (15 m) in eastern half . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Mr - Redwall Limestone, undivided (Mississippian)

Mr - Redwall Limestone, undivided (Upper and Lower Mississippian)
Includes, in descending order, Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members, as defined by McKee (1963) and McKee and Gutschick (1969). Members are not shown at map scale because of sheer cliff topography in Marble Canyon. Unit overall is light- to dark-gray, cliff-forming, thin- to thick-bedded, fine- to coarse-grained, fossiliferous limestone and dolomite. Includes gray and white thin-bedded chert beds, lenses, and nodules. Unit gradually thins eastward and thickens westward in subsurface of quadrangle. Solution-eroded caverns and caves along joint and fracture systems make it an important groundwater transporting aquifer. Thickness, 500 to 550 ft (152 to 167 m).

Horseshoe Mesa Member: Light-olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Includes distinctive ripple-laminated limestone, oolitic limestone, and some bedded chert lenses. Fossils are locally common. Weathers to receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded platy limestone beds that form receding ledges near top of Mooney Falls Member cliff. Unit locally absent where removed by Late Mississippian paleovalley erosion. Thickness, 50 to 100 ft (15 to 30 m).

Mooney Falls Member: Light-gray, cliff-forming, fine- to coarse-grained, thick-bedded (4 to 20 ft [1 to 6 m]), fossiliferous limestone. Limestone weathers dark gray; chert beds weather black. Upper part includes dark-gray dolomite beds, oolitic limestone, and chert beds. In Marble Canyon, karst caves in upper part contain red sandstone and siltstone deposits of Surprise Canyon Formation. Disconformable contact with underlying Thunder Springs Member marked by lithology change between massive gray limestone of the Mooney Falls Member and thin-bedded, dark-gray to brown dolomite and white chert beds of Thunder Springs Member. Thickness, 300 ft (75 m).

Thunder Springs Member: Beds of gray, cliff-forming, thin-bedded, fossiliferous limestone and brownish-gray, cliff-forming, thin-bedded (1 to 5 in [2 to 12 cm]), finely crystalline dolomite and fine- to coarse-grained limestone interbedded with thin beds of white chert. Weathers dark gray with bands of white chert. Locally includes large-scale crossbedding and irregular gently folded beds. Nautiloid (Mollusca: Cephalopoda) fossils are common in upper 10 ft (3 m) of unit. Disconformable planar contact with underlying Whitmore Wash Member distinguished by a distinct lack of chert beds in Whitmore Wash Member. Thickness, 100 ft (30 m).

Whitmore Wash Member: Not exposed in quadrangle but lies beneath the Colorado River at southern edge of quadrangle. Consists of yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-

grained dolomite. Unit mostly overlies flat ledges of light-gray to greenish-gray, thick-bedded limestone and dolomite of Muav Limestone, or locally overlies reddish-purple mudstone and dark-gray contorted limestone of Temple Butte Formation that fills channels eroded into Muav Limestone in Marble Canyon just south of quadrangle. Unconformable contact with underlying Devonian Temple Butte Formation or Cambrian Muav Limestone marked by low-relief (5 to 10 ft [2 to 3 m]) erosion channels just south of quadrangle along Colorado River. Thickness, 80 ft (25 m). (*GRI Source Map ID 75664)* (Glen Canyon Dam 30 x 60).

Mr - Redwall Limestone, undivided (Mississippian)
Includes, in descending order, Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members, with no middle Mississippian as defined by McKee (1963) and McKee and Gutschick (1969). Members are too small to show at map scale because of steep topography in Grand Canyon. Unit overall is light- to dark-gray, cliff-forming, thin- to thick-bedded, fine- to coarse-grained, fossiliferous limestone and dolomite. Includes thin-bedded gray and white chert beds, lenses, and nodules. Exposed mainly as sheer cliff in Grand Canyon; gradually thins eastward in subsurface. Is an important aquifer because of solution caverns and joint and fracture systems. Thickness, 400 to 450 ft (122 to 137 m).

Horseshoe Mesa Member: Light olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Weathers to receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin, platy limestone beds that form recess about 3 to 9 ft (1 to 3 m) thick near top of Mooney Falls Member cliff. Fossils locally common. Includes distinctive ripple-laminated limestone, oolitic limestone, and some chert lenses. Unit locally absent in Paleozoic section where removed by Late Mississippian paleovalley erosion. Thickness, 50 to 100 ft (15 to 30 m).

Mooney Falls Member: Light-gray, cliff-forming, fine- to coarse-grained, thick-bedded to very thick bedded (4 to 20 ft [1 to 6 m]), fossiliferous limestone. Limestone weathers dark gray; chert beds weather black. Upper part includes dark-gray dolomite beds, oolitic limestone, and chert beds. Karst caves in upper part contain red sandstone and siltstone deposits of Surprise Canyon Formation (Ms) in Marble Canyon. Disconformable contact with underlying Thunder Springs Member is distinguished by lithology; massive-bedded, gray limestone of the Mooney Falls Member overlies thin-bedded, dark-gray to brown dolomite and white chert beds of Thunder Springs Member. Thickness, 300 ft (75 m).

Thunder Springs Member: Roughly half of member is gray, cliff-forming, fossiliferous, thin-bedded limestone and half is brownish-gray, cliff-forming, thin-bedded (1 to 5 in [2 to 12 cm]), finely crystalline dolomite and fine- to coarse-grained limestone interbedded with thin beds of white chert. Locally includes large-scale crossbedding and irregular gently folded beds. Nautiloid fossils are common in upper 10 ft (3 m) of unit. The disconformable planar contact with the underlying Whitmore Wash Member is distinguished by a distinct lack of chert in Whitmore Wash Member. Thickness, 100 ft (30 m).
Whitmore Wash Member: Yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained dolomite. Weathers dark gray. Unconformable contact with underlying Temple Butte Formation (Dtb) or Muav Limestone (_m) marked by low-relief erosion channels about 5 to 10 ft (2 to 3 m) deep. Contact generally recognized where major cliff of light-gray Redwall Limestone overlies stair-step ledges of dark-gray Devonian Temple Butte Formation in Grand Canyon, Little Colorado River Gorge, and Marble Canyon; locally overlies channel filled with reddish-purple mudstone and dark-gray contorted limestone beds of Temple Butte Formation within Marble Canyon. Otherwise unit most commonly overlies flat ledges of light-gray to greenish-gray, thin-bedded limestone of Cambrian Muav Limestone in Marble Canyon area. Thickness, 80 to 100 ft (25 to 30 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Mr - Redwall Limestone (Upper and Lower Mississippian)
Includes, in descending order, the Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members as defined by McKee (1963), and McKee and Gutschick (1969).

Horseshoe Mesa Member consists of light olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained

limestone. Weathers to receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded, platy limestone beds that form 1 to 3 m (3 to 10 ft) thick recess at base of member near top of Redwall Limestone cliff. Fossils are not common except locally. Includes distinctive ripple laminated limestone beds and oolitic limestone and some chert. Thickness ranges from about 14 to 30 m (50 to 100 ft).

Mooney Falls Member consists of light-gray, cliff-forming, fine- to coarse-grained, thick-bedded to very thick bedded (1.5 to 6 m [4 to 20 ft]) fossiliferous limestone. Includes dark-gray dolomite beds in lower part; oolitic limestone and chert beds are restricted to the upper part. Contains large-scale, tabular and planar, low-angle cross-stratified limestone beds in upper third of unit. Limestone weathers dark gray, chert beds weather black. Disconformable contact with underlying Thunder Springs Member distinguished mainly by lithology; massive bedded gray limestone of Mooney Falls Member overlies thin-bedded dark-gray to brown dolomite and chert beds of Thunder Springs Member. About 122 m (400 ft) thick.

Thunder Springs Member consists of about 50 percent white, cliff-forming, fossiliferous, thin-bedded, alternating bands of white chert, and about 50 percent brownish-gray, thin-bedded (2.4 to 12 cm [1 to 5 in]), finely crystalline dolomite and fine- to coarse-grained limestone. Weathers into distinctive prominent band of black and light-brown bands on cliff face. Disconformable planar contact with underlying Whitmore Wash Member distinguished by distinct lack of chert in Whitmore Wash Member. About 30 to 46 m (100 to 150 ft) thick.

Whitmore Wash Member consists of yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained dolomite that is partly exposed within map area in lower reach of Kanab Creek. Weathers dark gray. West and north of map area, unit is mostly limestone. Unconformable contact with underlying Temple Butte Formation marked by erosional channels of low relief, about 1.5 to 3 m (5 to 10 ft) deep just south of map area (Billingsley, 2000). About 24.5 m (80 ft) thick. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Mr - Redwall Limestone, undivided (Upper and Lower Mississippian)
Includes, in descending order, Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members, as defined by McKee (1963) and McKee and Gutschick (1969), but these members are too small to show at map scale because of the sheer cliff outcrops of the Redwall Limestone in general. Unit overall is light-gray to dark-gray, cliff-forming, thin- to thick-bedded, fine- to coarse-grained, fossiliferous limestone and dolomite. Includes thin-bedded gray and white chert lenses and nodules. Unit is exposed as sheer cliff in Grand Canyon, and just the top part of the Redwall Limestone is exposed in Little Colorado River Gorge but is too thin to show at map scale. Unit gradually thins eastward in subsurface of map area and is an important subsurface aquifer because of solution-eroded caverns and bedrock joint systems. Variable thickness, about 137 to 122 m (450 to 400 ft). (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Mr - Redwall Limestone, undivided (Upper and Lower Mississippian)
Includes, in descending order, the Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members as defined by McKee (1963), and McKee and Gutschick (1969).

Horseshoe Mesa Member consists of light olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Weathers to receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded, platy limestone beds 12 that forms recess about 1to 3 m (3 to 9 ft) thick at base of member near top of Redwall Limestone cliff. Fossils not common except locally. Include distinctive ripple laminated limestone beds and oolitic limestone and some chert. Member thickens slightly from east to west across map area, locally absent where removed by Late Mississippian paleovalley erosion. Thickness, 14 to 30 m (50 to 100 ft).

Mooney Falls Member consists of light-gray, cliff-forming, fine- to coarse-grained, thick to very thick bedded (1.5 to 6 m [4 to 20 ft]) fossiliferous limestone. Includes dark-gray dolomite beds in lower part; oolitic limestone and chert beds are restricted to the upper part. Contains large-scale, tabular and planar, low-angle cross-stratified limestone beds in upper third of unit in western half of map area. Limestone weathers dark gray, chert beds weather black. Disconformable contact with underlying Thunder Springs Member distinguished mainly by lithology; massive bedded gray limestone of Mooney Falls Member overlies thin-bedded dark-gray to brown dolomite and chert beds of Thunder Springs Member. Unit thickens from about 92 m (300 ft) in southeast corner of map area to about 122 m (400 ft) in northwest corner.

Thunder Springs Member consists of about 50 percent white, cliff-forming, fossiliferous, thin-bedded, alternating bands of white chert, and about 50 percent brownish-gray, thin-bedded (2.4 to 12 cm [1to 5 in]), finely crystalline dolomite and fine- to coarse-grained limestone. Limestone is most common in northwest half of map area, dolomite more common in southeast half. Weathers into distinctive prominent band of black and light-brown bands on cliff face. Disconformable planar contact with underlying Whitmore Wash Member distinguished by distinct lack of chert in Whitmore Wash Member. Unit increases in thickness from east to west across map area. Thickness, 30 to 46 m (100 to 150 ft).

Whitmore Wash Member consists of yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained dolomite. Weathers dark gray. Fossiliferous in northwestern quarter of map area. Unit is mostly a limestone west and north of map area. Unconformable contact with underlying Temple Butte Formation marked by erosional channels of low relief, about 1.5 to 3 m (5 to 10 ft) in depth. Contact generally recognized where major cliff of light-gray Redwall Limestone overlies dark-gray stair-step ledges of Temple Butte Formation. Thickness, 24.5 m (80 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Mr - Redwall Limestone, undivided (Upper and Lower Mississippian)
Includes, in descending order, Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members, as defined by McKee (1963) and McKee and Gutschick (1969).

Horseshoe Mesa Member is light-olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Weathers to form receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded platy limestone beds of Horseshoe Mesa Member that form recess about 3 to 9 ft (1 to 3 m) thick near top of Mooney Falls cliff. Fossils are locally common. Includes distinctive ripple-laminated limestone and oolitic limestone beds and some chert lenses. Member thickens slightly from east to west across map area; locally absent where removed by Late Mississippian paleovalley erosion. Thickness, 50 to 100 ft (15 to 30 m).

Mooney Falls Member is light-gray, cliff-forming, fine- to coarse-grained, thick-bedded to very thick bedded [4 to 20 ft (1.2 to 6 m)] fossiliferous limestone. Limestone weathers dark gray; chert beds weather black. Includes dark-gray dolomite beds in lower part in western quarter of map area; oolitic limestone and chert beds restricted to upper part throughout map area. Contains large-scale, tabular and planar, low-angle cross-stratified limestone beds in upper third of unit in western half of map area. Disconformable contact with underlying Thunder Springs Member distinguished by lithology; massive-bedded, gray limestone of the Mooney Falls overlies thin-bedded, dark-gray to brown dolomite and white chert beds of the Thunder Springs Member. Unit thickens from about 250 ft (76 m) in southeast quarter of map to about 400 ft (122 m) in northwest quarter.

Thunder Springs Member; about half of member is gray, cliff-forming, fossiliferous, thin-bedded limestone and about half is brownish-gray, cliff-forming, thin-bedded [1 to 5 in (2.4 to 12 cm)], finely crystalline dolomite and fine- to coarse-grained limestone interbedded with white chert beds. Limestone common in north half of map area; dolomite is common in south half. Locally includes large-scale crossbedding and irregularly folded beds in north half of map area. Fossil content increases from east to west across map area. Disconformable planar contact with underlying Whitmore Wash Member is distinguished by

distinct lack of chert in the Whitmore Wash. Member is about 100 ft (30 m) thick in south half of map area, increasing to about 150 ft (46 m) thick in north half.

Whitmore Wash Member is yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained dolomite. Unit is mostly limestone in western and northern part of map area. Unconformable contact with underlying Temple Butte Formation (Dtb) marked by erosion channels of low relief about 5 to 20 ft (1.5 to 6 m) in depth. Contact generally recognized where major cliff of the Redwall Limestone overlies stair-step ledges of the Temple Butte Formation in Grand Canyon. Uniform thickness throughout map area, about 80 ft (25 m). In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Mr - Redwall Limestone, undivided (Upper and Lower Mississippian)
Includes, in descending order, the Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members as defined by McKee (1963), and McKee and Gutschick (1969).

Horseshoe Mesa Member is light olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Weathers to form receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded, platy limestone beds that form recess about 1 to 3 m (3 to 10 ft) deep at base of unit near top of Redwall Limestone cliff. Fossils not common except locally. Includes distinctive ripple-laminated limestone beds, oolitic limestone, and some chert. Member thickens slightly from east to west across map area, highly karstified with laterally extensive karst breccia, locally absent where removed by Late Mississippian paleovalley erosion. Thickness, 15 to 30 m (50 to 100 ft).

Mooney Falls Member is light-gray, cliff-forming, fine- to coarse-grained, thick to very thick bedded (3 to 6 m [10 to 20 ft]), fossiliferous limestone. Highly karstified with laterally extensive karst breccias in upper part. Includes dark-gray dolomite beds in lower part, west quarter of map area; oolitic limestone and chert beds are restricted to upper part. Contains large-scale, tabular and planar, low-angle cross-stratified limestone beds in upper third of unit. Limestone weathers dark gray. Disconformable contact with underlying Thunder Springs Member distinguished by weathered color change and lithology; massive bedded, gray limestone of Mooney Falls Member overlies thin-bedded, dark-gray to brown dolomite and chert beds of Thunder Springs Member. Thickness, 158 m (520 ft).

Thunder Springs Member consists of about 50 percent white, cliff-forming, fossiliferous, thin-bedded, alternating bands of white chert and about 50 percent brownish-gray, thin-bedded (2 to 12 cm [1 to 7 in]) finely crystalline dolomite and fine- to coarse-grained limestone. Limestone is most common lithology in north half of map area, dolomite more common in south half. Weathers into distinctive prominent black and light-brown bands on cliff face. Locally, includes large-scale crossbedding and irregularly folded beds in north half of map area. Fossil content increases from east to west across map area. Disconformable planar contact with underlying Whitmore Wash Member distinguished by distinct lack of chert in Whitmore Wash Member. Thickness, 30 m (100 ft) in south half of map area, increasing to 45 m (150 ft) in north half.

Whitmore Wash Member is yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained limestone. Weathers dark gray. Fossiliferous in northwest quarter of map area. Unit is mostly dolomite east and northeast of map area. Unconformable contact with underlying Temple Butte Formation (Dtb) at erosion channels of low relief, about 2 to 3 m (6 to 10 ft) in depth. Contact generally recognized where major cliff of gray Redwall Limestone overlies stair-step ledges of dark-gray Temple Butte Formation. Uniform thickness throughout map area, 25 m (80 ft). Overall, Redwall Limestone increases in thickness east to west from about 183 m (600 ft) to 243 m (800 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Mr - Redwall Limestone, undivided (Upper and Lower Mississippian)
Includes, in descending order, Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash

Members as defined by McKee (1963) and McKee and Gutschick (1969).

Horseshoe Mesa Member- Light-olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Weathers to receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded, platy limestone beds of the Horseshoe Mesa that form recess about 3–9 ft (1–3 m) thick near top of cliff formed by the Mooney Falls. Fossils are locally common. Includes distinctive ripple-laminated limestone and oolitic limestone beds and some chert lenses. Member thickens slightly from east to west across map area; locally absent where removed by Late Mississippian paleovalley erosion. Thickness 50–100 ft (15–30 m).

Mooney Falls Member- Light-gray, cliff-forming, fine- to coarse-grained, thick-bedded to very thick bedded [4–20 ft (1–6 m)], fossiliferous limestone. Limestone weathers dark gray; chert beds weather black. Includes dark-gray dolomite beds in lower part in western quarter of map area; oolitic limestone and chert beds restricted to upper part throughout map area. Contains large-scale, tabular and planar, low-angle cross-stratified limestone beds in upper third of unit in western half of map area. Disconformable contact with the underlying Thunder Springs distinguished by lithology; massive-bedded, gray limestone of the Mooney Falls overlies thin-bedded, dark-gray to brown dolomite and white chert beds of the Thunder Springs. Member thickens from about 250 ft (75 m) in southeast quarter of map area to about 400 ft (122 m) in northwest quarter.

Thunder Springs Member- About half of member is gray, cliff-forming, fossiliferous, thin-bedded limestone and about half is brownish-gray, cliff-forming, thin-bedded [1–5 in. (2–12 cm)], finely crystalline dolomite and fine- to coarse-grained limestone interbedded with white beds of chert lenses. Limestone is common in northern half of map area, dolomite is more common in southern half. Weathers into distinctive prominent band of black and light-brown bands on cliff face. Locally includes large-scale cross-bedding and irregularly folded beds in northern half of map area. Fossil content increases from east to west across map area. Disconformable planar contact with underlying Whitmore Wash Member distinguished by distinct lack of chert in the Whitmore Wash. Member is about 100 ft (30 m) thick in south half of map area, increasing to about 150 ft (45 m) thick in north half.

Whitmore Wash Member- Yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained dolomite. Weathers dark gray. Fossiliferous in northwestern quarter of map area. Unit is mostly limestone in western and northern part of map area. Unconformable contact with underlying Temple Butte Formation (Dtb) marked by erosion channels of low relief about 5–10 ft (2–3 m) in depth. Contact generally recognized where major cliff of the Redwall overlies stair-step ledges of the Temple Butte. Uniform thickness throughout map area, about 80 ft (25 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Dtb - Temple Butte Formation (Upper and Middle Devonian)

Dtb - Temple Butte Formation (Upper and Middle Devonian)

Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone, as defined by Beus (2003). Purple and light-gray, fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate-fill channels eroded into the underlying Cambrian Muav Limestone; channels are as much as 40 to 120 ft (12 to 37 m) deep in Marble Canyon. Carbonate ledges weather to dark gray. Unconformity at base represents major stratigraphic break spanning about 100 m.y. in the Grand Canyon that includes part of Late Cambrian, all of Ordovician and Silurian, and most of Early and Middle Devonian. Unit thins east and north of the map area, thickens west and south, and is likely intermittent or discontinuous in the subsurface of the northeastern two-thirds of the map. Thickness, 0 to 120 ft (0 to 37 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Dtb - Temples Butte Formation (Upper and Middle Devonian)
Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone as defined by Beus (2003). The unconformity at base of Temple Butte Formation represents a major stratigraphic break in Paleozoic rock record in Grand Canyon that includes part of the Late Cambrian, all of the Ordovician and Silurian, and most of the Early and Middle Devonian, representing about 100 m.y. Dark-gray Devonian strata are distinguished from underlying light-gray Cambrian rocks by color contrast. Unit thickens westward, thins southward. Thickness ranges from about 24 to 106 m (80 to 350 ft). In cross section only. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Dtb - Temple Butte Formation (Upper and Middle Devonian)
Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone, as defined by Beus (2003). Purple and light-gray, fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate fill channels eroded into underlying Cambrian Muav Limestone; channels are as much as 12 m (40 ft) deep in Grand Canyon area in northwest corner of map. Channel deposits are overlain by dark-gray to olive-gray, medium- to thick-bedded dolomite, sandy dolomite, limestone, and sandstone. Ledges weather to dark gray. Unconformity at base represents major stratigraphic break spanning about 100 million years in Grand Canyon that includes part of the Late Cambrian, all of the Ordovician and Silurian, and most of Early and Middle Devonian time. Dark-gray Devonian rocks are distinguished from underlying light-gray Cambrian rocks by color contrast. Unit thins eastward from Grand Canyon and is likely intermittent or discontinuous in the subsurface of the eastern two-thirds of map area. About 0 to 30 m (0 to 100 ft) thick. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Dtb - Temple Butte Formation (Upper and Middle Devonian)
Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone as defined by Beus (2003). Purple, reddish-purple, and light-gray, fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate fills channels eroded into the underlying Cambrian strata as much as 30 m (100 ft). Channel deposits are overlain by dark olive-gray, medium- and thick-bedded dolomite, sandy dolomite, limestone, and sandstone forming a sequence of dark-gray ledges. Unconformity at base of Temple Butte Formation represents major stratigraphic break in Paleozoic rock record in Grand Canyon that includes part of the Late Cambrian, all of the Ordovician and Silurian, and most of the Early and Middle Devonian time, representing about 100 m.y. Dark-gray Devonian strata are distinguished from underlying light-gray Cambrian rocks by color contrast. Unit thickens east to west, thins south. Thickness, 122 to 140 m (400 to 460 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Dtb - Temple Butte Formation (Upper and Middle Devonian)
Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone, as defined by Beus (2003). Purple, reddish-purple, and light-gray, fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate fill channels eroded into the underlying Cambrian strata; channels are as much as 100 ft (30 m) deep in east half of map area, and about 40 ft (12 m) deep in west half of map area. Channel deposits are overlain by dark-gray to olive-gray, medium- to thick-bedded dolomite, sandy dolomite, limestone, and sandstone. Unit weathers to dark-gray sequence of ledges. Unconformity at base represents major stratigraphic break in the Paleozoic rock record in Grand Canyon, spanning part of the Late Cambrian, all of the Ordovician and Silurian, and most of Early and Middle Devonian time, about 100 million years. Dark-gray Devonian rocks are distinguished from underlying light-gray Cambrian rocks by color contrast. Unit thickens from about 50 ft (15 m) in east half of map area to as much as 275 ft (84 m) in west half of map area, excluding extra channel fill thickness. In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Dtb - Temple Butte Formation (Upper and Middle Devonian)
Purple, reddish-purple, dark-gray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone as defined by Beus (1990). Purple, reddish-purple, and light-gray, fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate fills channels eroded as much as 15 m (50 ft) into the underlying Cambrian strata in east half of map area. Channel deposits are overlain by dark to olive-gray, medium- and thick-bedded dolomite, sandy dolomite, limestone, and sandstone that form a sequence of dark-gray ledges. Unconformity at base of Temple Butte represents major stratigraphic break in the Paleozoic record in Grand Canyon that represents erosion or non-deposition during part of the Late Cambrian, all of the Ordovician and Silurian, and most of the Early and Middle Devonian, representing a hiatus of about 100 m.y. Dark-gray rocks of the Temple Butte Formation are distinguished from underlying, light-gray rocks of Cambrian age by color contrast. Unit thickens from 84 m (275 ft) in eastern part of map area to as much as 140 m (460 ft) in western part. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Dtb - Temple Butte Formation (Upper and Middle Devonian)
Purple, reddish-purple, darkgray, and light-gray, ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone as defined by Beus (1990). Purple, reddish-purple, and lightgray, fine- to coarse-grained, thin- to medium-bedded, ripple-laminated ledges of mudstone, sandstone, dolomite, and conglomerate fill channels eroded into the underlying Cambrian strata; channels are as much as 100 ft (30 m) deep in eastern half of map area, and about 40 ft (12 m) deep in western half of map area. Channel deposits are overlain by dark-gray to olive-gray, medium- to thick-bedded dolomite, sandy dolomite, limestone, and sandstone. Unit as a whole forms sequence of dark-gray ledges. Unconformity at base of unit represents major stratigraphic break in Paleozoic rock record in the Grand Canyon, spanning part of Late Cambrian, all of Ordovician and Silurian, and most of Early and Middle Devonian time, about 100 million years. Dark-gray Devonian rocks are distinguished from underlying light-gray Cambrian rocks by color contrast. Unit thickens from about 50 ft (15 m) in eastern half of map area to as much as 275 ft (84 m) in western half of map area, excluding local channel deposit thickness . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Tonto Group (Middle and Lower Cambrian)

Includes, in descending order, the Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922) and modified by McKee and Resser (1945). The age and depositional history of Cambrian rocks in Grand Canyon are explained by Rose (2003). Tonto Group overlies tilted strata of the Grand Canyon Supergroup of Mesoproterozoic age (1.4 to 1.1 Ma). Grand Canyon Supergroup rocks may be present only in the western part of the map. Otherwise, Tonto Group overlies igneous and metamorphic rocks of Paleoproterozoic age (1.7 to 1.6 Ma). This hiatus is known regionally as the Great Unconformity. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Includes, in descending order, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922), modified by McKee and Resser (1945); recognized on the basis of distinct lithology. All limestone and dolomite in the Cambrian sequence belong to the Muav Limestone; shale and siltstone belong to the Bright Angel Shale; and sandstone and conglomerate belong to the Tapeats Sandstone. The Tonto Group strata unconformably overlie Statherian Paleoproterozoic (1.7 to 1.6 billion years) igneous and metamorphic rocks; this hiatus is known as the Great Unconformity. See Rose (2003) for a revised age and depositional history of Cambrian rocks in the Grand Canyon. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Includes in descending order, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922) and modified by McKee and Resser (1945). Only the Muav Limestone is exposed in the northwest corner of the map in Grand Canyon; the other Cambrian units are present in the subsurface of

the map area. The age and depositional history of the Cambrian rocks in Grand Canyon are revised by Rose (2003). Tonto Group may overlie tilted strata of Grand Canyon Supergroup of Mesoproterozoic (1.4 to 1.1 billion years) age in subsurface of west and central part of map area and igneous and metamorphic rocks of Paleoproterozoic (1.7 to 1.6 billion years) elsewhere within the map area; this hiatus is known regionally as the Great Unconformity. (*GRI Source Map ID 7454)* (Cameron 30 x 60)

Includes, in descending order, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922), modified by McKee and Resser (1945); recognized on the basis of distinct lithologies. All limestone and dolomite in the Cambrian sequence belong to the Muav Limestone; shale and siltstone belong to the Bright Angel Shale; and sandstone and conglomerate belong to the Tapeats Sandstone. The Tonto Group strata unconformably overlie Lower Proterozoic (1.7 to 1.6 billion years) igneous and metamorphic rocks; this hiatus is known as the Great Unconformity. See Rose (2003) for a revised age and depositional history of Cambrian rocks in the Grand Canyon. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Includes in descending order, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922) and modified by McKee and Resser (1945). These Cambrian units are recognized on basis of distinct rock types: limestone and dolomite lithologies belong to the Muav Limestone; shale and siltstone lithologies belong to the Bright Angel Shale; and sandstone and conglomerate lithologies belong to the Tapeats Sandstone (Rose, 2003). Tonto Group may overlie tilted strata of Grand Canyon Supergroup of Middle Late Proterozoic (1.4 to 1.1 billion years) age in east part of map area and igneous and metamorphic rocks of Early Proterozoic (1.7 to 1.6 billion years) age in central and west part of map area; this hiatus is known regionally as the Great Unconformity. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Includes in descending order, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922), modified by McKee and Resser (1945). For this map, all limestone and dolomite lithologies in the Cambrian sequence are assigned to the Muav Limestone; all shale and siltstone lithologies to the Bright Angel Shale; and all sandstone and conglomerate lithologies to the Tapeats Sandstone in the lateral and vertical sense. However, the Muav Limestone map unit includes tongues of Bright Angel Shale, the Bright Angel Shale map unit contains tongues of the Muav Limestone and Tapeats Sandstone, and the Tapeats Sandstone map unit contains tongues of Bright Angel Shale. The Tonto Group overlies Early Proterozoic (1.7 to 1.6 Ma) igneous and metamorphic rocks above what is regionally known as the Great Unconformity. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Includes, in descending order, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone as defined by Noble (1922) and modified by McKee and Resser (1945). These Cambrian units are recognized on the basis of distinct rock types: limestone and dolomite lithologies belong to the Muav; shale and siltstone lithologies belong to the Bright Angel; and sandstone and conglomerate lithologies belong to the Tapeats. Tonto Group overlies tilted strata of Grand Canyon Supergroup of Middle to Late Proterozoic (1.4–1.1 billion years) age in eastern and central parts of map area, and igneous and metamorphic rocks of Early Proterozoic (1.7–1.6 billion years) age in western part of map area. This hiatus is known regionally as the Great Unconformity. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Cm - Muav Limestone (Middle Cambrian)

Cm - Tonto Group - Muav Limestone (Middle Cambrian)
Dark-gray to light-greenish-gray, brown, and orange-red, cliff-forming, fine- to medium-grained, thin- to thick-bedded, mottled, fossiliferous, silty limestone, limestone, dolomite, and calcareous mudstone. Includes unnamed siltstone and shale beds of green and purplish-red, micaceous siltstone, mudstone, and thin beds of brown sandstone. Contact with underlying Bright Angel Shale is gradational and

lithology dependent; marked at base of lowest prominent limestone cliff. Unit gradually thins west to east, thinning to an unknown thickness in subsurface of eastern two-thirds of quadrangle. Thickness, 320 to 380 ft (97 to 115 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Cm - Tonto Group - Muav Limestone (Middle Cambrian)
Dark-gray, light-gray, brown, and orange-red, cliff-forming limestone, dolomite, and calcareous mudstone. Contact with underlying Bright Angel Shale is gradational and lithology dependent and marked at base of lowest prominent cliff-forming limestone. Muav Limestone generally thins from west to east in subsurface of map area. Intertonguing and facies change relations between Muav Limestone and Bright Angel Shale produce variable thickness trends. Thickness ranges from about 24 to 213 m (80 to 700 ft). In cross section only. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Cm - Tonto Group - Muav Limestone (Middle Cambrian)
Dark-gray, light-gray, brown, and orange-red, cliff-forming, fine- to medium-grained, thin- to thick-bedded, mottled, fossiliferous, silty limestone, limestone, dolomite, and calcareous mudstone. Includes unnamed siltstone and shale beds of green and purplish-red, micaceous siltstone, mudstone, and thin beds of brown sandstone. Contact with the underlying Bright Angel Shale is gradational and lithology dependent, arbitrarily marked at base of lowest prominent limestone of Muav Limestone in Grand Canyon just north of map area. Muav Limestone gradually thins from 107 m (360 ft) in west part of map area to an unknown thickness in subsurface of eastern two-thirds of map area. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Cm - Tonto Group - Muav Limestone (Middle Cambrian)
Dark-gray, light-gray, brown, and orange-red, cliff-forming limestone, dolomite, and calcareous mudstone. Includes, in descending order, unclassified dolomites, the carbonate units Havasu, Gateway Canyon, Kanab Canyon, Peach Springs, Spencer Canyon, and Rampart Cave Members (McKee and Resser, 1945), and three unnamed, slope-forming siltstone and shale of Bright Angel shale type lithologic units between carbonate members. Carbonate members are fine- to medium-grained, thin- to thick-bedded, mottled, fossiliferous, silty limestone, limestone, and dolomite. Unnamed shale and siltstone units are green and purplish-red, micaceous siltstone, mudstone, shale, and thin brown sandstone beds. Contact with underlying Bright Angel Shale is gradational and lithology dependent and marked at base of lowest prominent cliff-forming limestone, the Rampart Cave Member. Muav Limestone Members thicken from east to west across the map area, but the Spencer Canyon and Rampart Cave Members change facies to a purple-red and green siltstone/shale of Bright Angel Shale lithology in northeast half of map area where they are included as part of Bright Angel Shale. Intertonguing and facies change relations between Muav Limestone and Bright Angel Shale produce variable thickness trends. Thickness, 365 to 427 m (1,200 to 1,400 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Cm - Tonto Group - Muav Limestone (Middle Cambrian)
Dark-gray, light-gray, brown, and orange-red, cliff-forming limestone, dolomite, and calcareous mudstone. Includes, in descending order, unclassified dolomites, Havasu, Gateway Canyon, Kanab Canyon, Peach Springs, Spencer Canyon, and Rampart Cave Members of McKee and Resser (1945). These members consist of fine- to medium-grained, thin- to thick-bedded, mottled, fossiliferous, silty limestone, limestone, and dolomite. Three unnamed slope-forming siltstone and shale units of Bright Angel Shale lithology are positioned between cliff-forming members of Muav Limestone. These unnamed siltstone and shale units are green and purplish-red, micaceous siltstone, mudstone, and shale, and thin brown sandstone. Contact with the underlying Bright Angel Shale is gradational and lithology dependent. Contact is arbitrarily marked at base of lowest prominent limestone of Rampart Cave Member of the Muav Limestone in west quarter of map area, and at base of limestone of Peach Springs-Kanab Canyon Members of the Muav Limestone in east three-quarters of map area. All members of the Muav Limestone thicken from east to west across map area and thin south to the south edge of map area. However, the Peach Springs, Spencer Canyon, and Rampart Cave Members change to purplish-red and green

siltstone/shale facies of the Bright Angel Shale in east quarter of map area where they are included as part of the Bright Angel Shale map unit. Intertonguing and facies change relations between the Muav Limestone and Bright Angel Shale produce variable thickness trends. Overall, the Muav Limestone thickens from about 359 ft (107 m) in east part of map area to about 600 ft (183 m) in west part. In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Cm - Tonto Group - Muav Limestone (Middle Cambrian)
Dark-gray, light-gray, brown, and orange-red, cliff-forming limestone, dolomite, and interbedded thin calcareous mudstone. Includes, in descending order, the unclassified dolomite member, the Havasu Member, Gateway Canyon Member, Kanab Canyon Member, Peach Springs Member, Spencer Canyon Member, and Rampart Cave Member as defined by McKee and Resser (1945) and three unnamed Bright Angel Shale lithologic units between limestone members. Carbonate beds are composed of fine- to medium-grained, thin- to thick-bedded, mottled, fossiliferous, silty limestone, limestone, and dolomite. Unnamed Bright Angel Shale beds are composed of green and purplish-red, micaceous, siltstone, mudstone, shale, and thin brown sandstone beds. Contact between Muav Limestone and underlying Bright Angel Shale is lithology dependent and placed at the base of lowest prominent cliff-forming limestone of the Rampart Cave Member of the Muav Limestone. Intertonguing relations between Muav Limestone and Bright Angel Shale produce variable thicknesses of limestone and shale units. Limestone units thicken from east to west across the map area. Overall, the Muav Limestone thickens from 185 m (600 ft) in eastern part of map area to 425 m (1,400 ft) in western part. (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Cm - Tonto Group - Muav Limestone (Middle Cambrian)
Dark-gray, light-gray, brown, and orange red, cliff-forming limestone, dolomite, and calcareous mudstone. Includes, in descending order, unclassified dolomites, and Havasu, Gateway Canyon, Kanab Canyon, Peach Springs, Spencer Canyon, and Rampart Cave Members of McKee and Resser (1945). These members consist of fine- to medium-grained, thin to thick-bedded, mottled, fossiliferous, silty limestone, limestone, and dolomite. Three unnamed slope-forming siltstone and shale units of Bright Angel Shale lithology are intertongued between cliff-forming members of Muav Limestone. These unnamed siltstone and shale units are green and purplish-red, micaceous siltstone, mudstone, and shale, and thin brown sandstone. Contact with the underlying Bright Angel is gradational and lithology dependent. Contact is arbitrarily marked at base of lowest prominent cliff-forming limestone of Rampart Cave Member of the Muav in western half of map area, and of Peach Springs– Kanab Canyon Members of the Muav in eastern half of map area. All members of the Muav thicken from east to west across map area. However, the Peach Springs, Spencer Canyon, and Rampart Cave change to purple-red and green siltstone/shale facies of the Bright Angel in eastern half of map area, where they are included as part of the Bright Angel . Intertonguing and facies change relationships between the Muav and Bright Angel produce variable thickness trends. Overall, the Muav thickens from about 350 ft (107 m) in eastern part of map area to about 600 ft (183 m) in western part . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Cba - Bright Angel Shale (Middle Cambrian)

Cba - Tonto Group - Bright Angel Shale (Middle Cambrian)
Green and purple-red, slope-forming siltstone, shale, and red-brown to brown sandstone. Includes abundant green and purple-red, fine-grained, micaceous, ripple-laminated, fossiliferous shale and siltstone; dark-green, medium- to coarse-grained, thin-bedded, glauconitic sandstone; and interbedded purplish-red and brown, thin-bedded, fine- to coarse-grained, ripple-laminated sandstone. Contact with underlying Tapeats Sandstone is gradational and marked at top of transition from dominantly green siltstone slopes to dominantly brown sandstone ledges above Tapeats Sandstone cliff. Unit generally maintains a uniform thickness across western part of map area based on exposures in Grand Canyon; gradually thins eastward in subsurface. Thickness, 200 to 300 ft (60 to 90 m). (*GRI Source Map ID*

75648) (Tuba City 30 x 60).

Cba - Tonto Group - Bright Angel Shale (Middle Cambrian)
Green and purple-red, slope-forming siltstone, shale, and reddish-brown to brown sandstone. Includes the ledge-forming reddish-brown sandstone member of McKee and Resser (1945). Consists of green and purplish-red, fine-grained, micaceous, ripple-laminated, fossiliferous shale and siltstone; dark-green, medium- to coarse-grained, thin-bedded, glauconitic sandstone; and interbedded purplish-red and brown, thin-bedded, fine- to coarse-grained, ripple laminated sandstone. Contact with Tapeats Sandstone is approximately marked at top of vertical transition zone from predominantly green shale and siltstone to predominantly brown sandstone above Tapeats Sandstone cliff. About 60 to 90 m (200 to 300 ft) thick. In cross section only. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Cba - Tonto Group - Bright Angel Shale (Middle Cambrian)
Green and purple-red, slope-forming siltstone, shale, and red-brown to brown sandstone. Consists of green and purple-red, fine-grained, micaceous, ripple-laminated, fossiliferous shale and siltstone; dark-green, medium- to coarse-grained, thin-bedded, glauconitic sandstone; and interbedded purplish-red and brown, thin-bedded, fine- to coarse-grained, ripple laminated sandstone. Contact with underlying Tapeats Sandstone is gradational and arbitrarily marked at top of vertical transition zone from dominantly green siltstone to dominantly brown sandstone above Tapeats Sandstone cliff. About 60 to 90 m (200 to 300 ft) thick. In cross section only. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Cba - Tonto Group - Bright Angel Shale (Middle Cambrian)
Green and purple-red, slope-forming siltstone, shale, and red-brown to brown sandstone. Includes the ledge-forming red-brown sandstone member of McKee and Resser (1945). Consists of green and purple-red, fine-grained, micaceous, ripple-laminated, fossiliferous shale and siltstone; dark-green, medium- to coarse-grained, thin-bedded, glauconitic sandstone; and interbedded purplish-red and brown, thin-bedded, fine- to coarse-grained, ripple laminated sandstone. Includes gray, thin-bedded, fine-grained, micaceous silty dolomite in the upper part of west quarter of map area. Intertonguing and facies change relations produce variable thickness trends. Contact with Tapeats Sandstone is arbitrarily marked at top of vertical transition zone from dominantly green shale and siltstone to dominantly brown sandstone in slope above Tapeats Sandstone cliff. Thickness, 92 to 107 m (300 to 350 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Cba - Tonto Group - Bright Angel Shale (Middle and Lower(?) Cambrian)
Green and purple-red, slope-forming siltstone and shale, and interbeds of reddish-brown to brown sandstone of Tapeats Sandstone lithology. Includes ledge-forming red-brown sandstone member of McKee and Resser (1945). Consists of green and purplish-red, fine-grained, micaceous, ripple-laminated, fossiliferous siltstone and shale; dark-green, medium- to coarse-grained, thin-bedded, glauconitic sandstone; and interbedded purplish-red and brown, thin-bedded, fine- to coarse-grained, ripple-laminated sandstone. Includes gray, thin-bedded, fine-grained, micaceous silty dolomite in upper part in western quarter of map area. Intertonguing and facies change relations with the underlying Tapeats Sandstone produce variable thickness trends. Contact with Tapeats Sandstone is arbitrarily marked at lithologic vertical and lateral transition from predominantly green siltstone and shale to predominantly brown sandstone above Tapeats Sandstone cliff. About 350 ft (107 m) thick in east quarter of map area, thickening to about 500 ft 153 m) in northwestern quarter, thinning to about 150 ft (46 m) in southwest quarter. In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Cba - Tonto Group - Bright Angel Shale (Middle Cambrian)
Green and purple-red, slope-forming siltstone and shale and red-brown to brown sandstone. Includes interbedded limestone of the Flour Sack Member of McKee and Resser (1945) in upper part and ledge-forming, red-brown sandstone member in middle part. Includes interbedded, dark-green, medium- to coarse-grained, thin-bedded glauconitic sandstone; and purplish-red and brown, thin-bedded, fine- to

coarse-grained, ripple-laminated sandstone in lower part. Intertonguing relations produce variable thicknesses and lithologies. Contact with Tapeats Sandstone is arbitrarily marked at lithologic change from dominantly green shale and siltstone of the Bright Angel Shale to dominantly brown sandstone of the Tapeats Sandstone, generally about 10 m (30 ft) above Tapeats Sandstone cliff. Thickness, 150 m (500 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Cba - Tonto Group - Bright Angel Shale (Middle Cambrian)
Green and purple-red, slope-forming siltstone and shale, and interbeds of red-brown to brown sandstone of Tapeats Sandstone lithology. Includes ledge-forming red-brown sandstone member of McKee and Resser (1945). Consists of green and purple-red, fine-grained, micaceous, ripple-laminated, fossiliferous siltstone and shale; dark-green, medium- to coarse-grained, thin-bedded, glauconitic sandstone; and interbedded purplish-red and brown, thin-bedded, fine- to coarse-grained, ripple-laminated sandstone. Includes gray, thin-bedded, fine-grained, micaceous silty dolomite in upper part of unit in western quarter of map area. Intertonguing and facies change relationships with the underlying Tapeats produce variable thickness trends. Contact with the Tapeats is arbitrarily marked at lithologic vertical and lateral transition from predominantly green siltstone and shale to predominantly brown sandstone in slope above the Tapeats cliff. Thickness is about 350 ft (107 m) in eastern quarter of map area, thickening to about 500 ft (150 m) in western quarter . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Ct - Tapeats Sandstone (Middle and Lower(?) Cambrian)

Ct - Tonto Group - Tapeats Sandstone (Middle and Lower(?) Cambrian)
Brown and red-brown, cliff-forming, coarse-grained sandstone and conglomerate. Unconformable contact with the underlying Proterozoic surface is called the Great Unconformity. Tapeats Sandstone fills lowland areas between Proterozoic highlands and is locally absent on Proterozoic highlands. Variable thickness, 0 to 300 ft (0 to 91 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ct - Tonto Group - Tapeats Sandstone (Middle and Lower(?) Cambrian)
Brown and reddish-brown, cliff-forming, coarse-grained sandstone and conglomerate. Unconformable contact with underlying Statherian Paleoproterozoic surface forms the Great Unconformity. Tapeats Sandstone fills lowland areas and thins across or pinches out against Proterozoic highlands. Variable thickness from 0 to 60 m (0 to 200 ft). In cross section only. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Ct - Tonto Group - Tapeats Sandstone (Middle and Lower(?) Cambrian)
Brown and red-brown, cliff-forming, coarse-grained sandstone and conglomerate. Unconformable contact with underlying Lower Proterozoic surface forms the Great Unconformity. Tapeats Sandstone fills lowland areas and thins across or pinches out against Proterozoic highlands. Variable thickness, 0 to 60 m (0 to 200 ft). In cross section only. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Ct - Tonto Group - Tapeats Sandstone (Middle and Lower(?) Cambrian)
Brown and red-brown, cliff-forming, coarse-grained sandstone and conglomerate. Includes an upper slope-forming transition zone of nearly equal distribution of brown sandstone and green shale, and a lower cliff-forming sandstone and conglomeratic sandstone. Lower cliff unit consists mainly of a medium- to coarse-grained, thin-bedded, low-angle planar and trough crossbedded sandstone and conglomeratic sandstone; sandstone beds 14 to 57 cm (6 to 24 in) thick. Unconformable contact with underlying Lower Proterozoic surface forming the Great Unconformity. Tapeats Sandstone fills in lowland areas, and thins across or pinches out against Proterozoic highlands between Colorado River Mile 230 and 235. Variable thickness, 0 to 60 m (0 to 200 ft). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Ct - Tonto Group - Tapeats Sandstone (Middle and Lower(?) Cambrian)

Brown and reddish-brown, cliff-forming sandstone and conglomerate. Includes an upper slope-forming transition zone of nearly equal distribution of brown sandstone of Tapeats Sandstone lithology and green siltstone and shale of Bright Angel Shale lithology, and a lower sandstone and conglomeratic sandstone. Lower cliff consists mainly of medium- to coarse-grained, thin-bedded, low-angle planar and trough crossbedded sandstone and conglomeratic sandstone; sandstone beds are 6 to 24 in (14 to 58 cm) thick. Unconformable contact with underlying Early Proterozoic rocks that form the Great Unconformity. The Tapeats Sandstone fills lowland areas and thins across or pinches out against Proterozoic highlands. Variable thickness, 0 to 400 ft (0 to 122 m). In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Ct - Tonto Group - Tapeats Sandstone (Middle and Lower(?) Cambrian)
Brown and red-brown, cliff-forming sandstone and conglomerate. Includes an upper slope-forming transition zone of nearly equal distribution of brown sandstone and green shale beds and lower cliff-forming sandstone and conglomeratic sandstone. Lower cliff is composed mostly of medium- to coarse-grained, thin-bedded, low-angle planar and trough crossbedded sandstone and conglomeratic sandstone beds 15 to 60 cm (6 to 24 in) thick. Silica cement gives appearance of quartzite. Unconformable contact with underlying Early Proterozoic surface forms the Great Unconformity. Tapeats fills lowland areas and thins across or pinches out against Proterozoic highlands. Thickness, 0 to 122 m (0 to 400 ft). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Ct - Tonto Group - Tapeats Sandstone (Middle and Lower Cambrian)
Brown and red-brown, cliff forming sandstone and conglomerate. Includes an upper slope-forming transition zone of nearly equal distribution of brown sandstone of Tapeats Sandstone lithology and green siltstone and shale of Bright Angel Shale lithology, and a lower unit of cliff-forming sandstone and conglomeratic sandstone. Lower cliff unit consists mainly of medium- to coarse-grained, thin-bedded, low-angle planar and trough cross-bedded sandstone and conglomeratic sandstone; sandstone beds 6–24 in. (15–60 cm) thick. Unconformable contact with underlying Middle and Late Proterozoic surface that forms the Great Unconformity. The Tapeats fills in lowland areas and thins across or pinches out against young Proterozoic highlands. Variable thickness 0–400 ft (0–122 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Cs - Sixtymile Formation, undivided (Middle and Lower Cambrian)

Zs - Sixtymile Formation, undivided (Neoproterozoic) Informally divided into, in descending order, the lower, middle, and upper members (Elston, 1979). Lower member is composed of slumped blocks of dolomite surrounded by black shale exposed mainly in Sixtymile Canyon in eastern Grand Canyon. Middle member is thick sequence of white to red, laminated and thinly bedded siltstone, locally disrupted by intraformational brecciation and folding. Upper member contains intraformational breccias and red fluvial sandstones derived from the middle siltstone member. Unit unconformably overlain by Tapeats Sandstone. Thickness, 196 ft (60 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

> *Note: This unit is now considered to be Middle and Lower Cambrian in age. The symbol and age of this unit, in the GRI data, has been changed to reflect this current stratigraphic understanding. The age and symbol, as shown on the original map source, are listed above in line with the source unit description.*

Chuar Group (Neoproterozoic)

Includes, in descending order, the Kwagunt Formation and Galeros Formation as defined by Ford and Dehler (2003), modified by Timmons and others (2007). A correlation by long-distance lithologic comparison, micropaleontologic assemblages, paleomagnetism, and very limited isotopic dating suggests the Nankoweap Formation, Chuar Group, and Sixtymile Formation were deposited within the

1,000 to 700 m.y. period. The Cambrian Tonto Group overlies these tilted strata in the subsurface west and east of Grand Canyon in the Tuba City quadrangle (sheet 1); this hiatus is known regionally as the Great Unconformity. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Kwagunt Formation (Neoproterozoic)

Includes, in descending order, the Walcott, Awatubi, and Carbon Butte Members as mapped by Timmons and others (2007). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zkw - Kwagunt Formation, Walcott Member (Neoproterozoic)

Black to gray mudstone, gray dolomitic sandstone (12 to 31 ft [4 to 9.5 m] thick), brecciated dolomite and sandstone. A thin tephra deposit yielded a U-Pb zircon age of 742±6 Ma, providing an upper age limit for the Chuar Group (Karlstrom and others, 2000). Thickness, 838 ft (255 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zka - Kwagunt Formation, Awatubi Member (Neoproterozoic)

Red, green, blue, and light-brown mudstone, siltstone, and sandstone. A basal tan to light-brown stromatolite carbonate bed contains fossil biohermal dome features. Thin-bedded sandstone and siltstone contain ripple foreset beds and mud-crack casts. Near top of member, organic shale preserves the macroalgal fossil, Chuaria circularis, first described by Ford and Breed (1973). Thickness, 823 to 1,128 ft (252 to 344 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zkcb - Kwagunt Formation, Carbon Butte Member (Neoproterozoic)

Interbedded sandstone and siltstone. Basal sandstone is brown, medium- to fine-grained, thick sandstone, forming a distinctive marker bed approximately 252 ft (76 m) thick, and includes abundant soft-sediment deformation features, interference ripple marks, and mud-crack casts (Ford and Breed, 1973). Above basal sandstone unit are thin, interbedded, multicolored, mudstone, siltstone, and sandstone. Thickness, 112 to 223 ft (34 to 68 m). Galeros Formation (Neoproterozoic)—Includes, in descending order, the Duppa, Carbon Canyon, Jupiter, and Tanner Members as mapped by Timmons and others (2007) (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Galeros Formation (Neoproterozoic)

Includes, in descending order, the Duppa, Carbon Canyon, Jupiter, and Tanner Members as mapped by Timmons and others (2007). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zgd - Galeros Formation, Duppa Member (Neoproterozoic)

Fine-grained siliciclastic unit dominated by shale and interbedded thin-bedded siltstone. Includes interbedded calcareous siltstone beds about 3 ft (1 m) thick. Variable thickness, 571 to 2,050 ft (174 to 625 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zgcc - Galeros Formation, Carbon Canyon Member (Neoproterozoic)

Fine-grained, interbedded siliciclastic mudstone, siltstone, and sandstone. Includes several thin dolomite and sandstone marker beds, 3 to 6 ft (1 to 2 m) thick. Sandstone beds contain symmetric and interference ripple marks, low-angle crossbeds, and mud-crack casts. Stromatolite fossils become more common toward top of unit. Thickness, 1,546 ft (471 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zgj - Galeros Formation, Jupiter Member (Neoproterozoic)

Fine-grained, interbedded siliciclastic mudstone, siltstone, sandstone, and dolomite. Dolomite and some sandstone beds form several marker beds throughout unit. Base of unit is stromatolitic dolomite, 40 ft (912 m) thick. Interbedded sandstone beds contain symmetric ripple marks, mud-crack casts, and raindrop impressions. Thickness, 868 to 1,516 ft (264 to 462 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zgt - Galeros Formation, Tanner Member (Neoproterozoic)

Very fine grained siliciclastic siltstone, sandstone, and thin dolomite. Include dark-brown dolomite at base of unit that unconformably overlies sandstone beds of the Nankoweap Formation. Thickness, 20 to 80 ft (6 to 24 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Zn - Nankoweap Formation, undivided (Neoproterozoic)

YZh - Nankoweap Formation (latest Mesoproterozoic to Neoproterozoic) Unconformity-bounded Nankoweap Formation separates rocks of the Neoproterozoic Chuar Group and Late Mesoproterozoic Unkar Group. Includes an upper and lower member, undivided (Gebel, 1978). Upper member is composed of siltstone and thick-bedded, fine-grained, red sandstone at base and more massive 3-ft-thick (1-m-thick) sandstone bed toward top of section, capped by white, fine-grained quartz sandstone. Unit contains trough crossbeds, ripple marks, mud cracks, soft-sediment deformation, and rare salt casts. Lower member is dominated by hematite-cemented quartzite sandstone and siltstone with lenses of lithic sandstone derived from underlying Cardenas Basalt. Thickness, 330 ft (100 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

> *Note: This unit is now considered to be a part of the Chuar Group and to be entirely Neoproterozoic. The symbol and age of this unit, in the GRI data, has been changed to reflect this current stratigraphic understanding. The age and symbol, as shown on the original map source, are listed above in line with the source unit description.*

Unkar Group (Mesoproterozoic)

Includes, in descending order, Cardenas Basalt and the Dox Formation as defined by Hendricks and Stevenson (2003) and modified by Timmons and others (2007). Unkar Group rocks have been correlated to mafic intrusions of similar age and type in the southwestern United States (Howard, 1991). Cambrian Tonto Group overlies these tilted strata in the subsurface west and east of eastern Grand Canyon. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Includes, in descending order, unnamed diabase sills and dikes, Cardenas Basalt, Dox Formation, Shinumo Quartzite, Hakatai Shale, and Bass Formation. The Cardenas and upper part of the Dox are not exposed in map area, but complete sections are present about 6 mi (9.5 km) east of map area. There, the Cardenas is about 900 ft (300 m) thick and the Dox is about 1,280 ft (390 m) thick. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Yc - Cardenas Basalt (Mesoproterozoic)

Includes informal members, in descending order: the lapillite, fan-jointed, and bottle-green members (Lucchitta and Hendricks, 1983). Lapillite member is composed of scoriaceous fragments of volcanic bombs and ash matrix interbedded in massive basalt flows a few meters to several tens of meters thick (Lucchitta and Hendricks, 1983). Includes diabase intrusions that intrude both the Unkar Group and crystalline basement rocks as dikes and sills from a few tens of meters to 981 ft (300 m); dikes are thinner and locally utilize fault planes; similar in texture, mineralogy, and chemistry to Cardenas Basalt, suggesting a shared and common source. Thickness, 163 to 294 ft (50 to 90 m). Fan-jointed member is composed of porphyritic and vesicular basaltic andesite, approximately 163 ft (50 m) thick (Hendricks and Lucchitta, 1974). The bottle-green member consists of thin, discontinuous sequences of interbedded basalt flows and sandstone beds, highly altered, and contains secondary chlorite, epidote, talc, and zeolites; approximately 294 ft (90 m) thick. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Yi - Unnamed diabase sills and dikes (Mesoproterozoic)

Black, medium- to coarse-grained, olivine-rich diabase. Contains plagioclase, olivine, clinopyroxene, magnetite-ilmenite, and biotite. Diabase sills and dikes intrude all rocks within Unkar Group below Cardenas Basalt. Chemical variation diagrams indicate a potential common parentage between dikes and sills and the overlying Cardenas, but direct physical connection has not been observed, although isochron ages are basically identical at 1,070±70 Ma (Hendricks and Stevenson, 1990). Sills range in thickness from about 65 ft (20 m) in Clear Creek at eastern edge of map area to more than 655 ft (200 m) near Bass Rapids in central part of map area. Dike widths range from 3 to 12 ft (1 to 4 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Dox Formation (Mesoproterozoic)

Includes, in descending order, the Ochoa Point, Comanche Point, Solomon Temple, and Escalante Creek Members as mapped by Timmons and others (2007) and described by Hendricks and Stevenson (2003). Contacts between members of Dox Formation are gradational and based mainly on topographic expression, depositional environments, and color change. (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Yd - Dox Formation (Mesoproterozoic)

Includes, in descending order, Ochoa Point, Comanche Point, Solomon Temple, and Escalante Creek Members as defined by Stevenson and Beus (1982). Of these, only part of the Escalante Creek is exposed in map area. Upper two-thirds or more of the Dox is removed by erosion and subsequently covered by Paleozoic rocks. The Escalante Creek is exposed in upper Bright Angel Creek and Shinumo Creek, eastern quarter of map area Escalante Creek Member—Gray, light-brown to dark-brown, cliff-forming, fine- to medium-grained sandstone and interbedded dark-brown to green, slope forming shale

and mudstone. Includes gray contorted sandstone beds in lower part similar to those in underlying Shinumo Quartzite and small-scale, tabular planar cross-bedded and graded-bedding sets. Conformable contact with the underlying Shinumo marked at lowest shaley slope of the Dox. Incomplete exposure due to erosion of upper part. Exposed thickness about 200 ft (60 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Ydo - Dox Formation, Ochoa Point Member (Mesoproterozoic)

Red slope- and cliff-forming micaceous mudstone that grades upward into red quartz sandstone and silty sandstone. Includes salt-crystal casts in mudstone and asymmetrical ripple marks and small-scale crossbeds in sandstone. Thickness, 250 to 300 ft (976 to 91 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ydc - Dox Formation, Comanche Point Member (Mesoproterozoic)

Light-red, pale-green to white, slope-forming, mudstone and siltstone and minor thin-bedded sandstone. Includes mud cracks, ripple marks, salt casts, wavy to irregular bedding, and stromatolitic dolomite beds within or adjacent to white siltstone beds. Thickness, 508 ft (155 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Yds - Dox Formation, Solomon Temple Member (Mesoproterozoic)

Cyclical sequence of red mudstone, siltstone, and quartz sandstone. Includes thin beds of argillaceous dolomite or calcareous siltstone. Mud cracks and ripple marks are common. Thickness, 920 ft (280 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Yde - Dox Formation, Escalante Creek Member (Mesoproterozoic)

Light-brown to greenish-brown sandstone, calcareous sandstone, and arkosic sandstone. Includes an upper dark-brown to green shale and mudstone. Thickness, 1,278 ft (390 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ys - Shinumo Sandstone, undivided (Mesoproterozoic)

Ys - Shinumo Sandstone, undivided (Mesoproterozoic)
Includes five informal members, in descending order: the Seventy Five Mile Rapid, Cottonwood Camp, Papago Creek, Ribbon Falls, and Surprise Valley Members, undivided (Timmons and others, 2007). Consists of red, brown, purple and white, cliff-forming, fine- to coarse-grained, well-sorted quartz arenite and subarkose sandstone with siliceous cement. Upper massive sandstone shows dramatic contorted bedding. Unconformable contact with underlying Hakatai Shale truncates crossbeds and alluvial channel deposits. Thickness, 1,132 ft (345 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Ys - Unkar Group - Shinumo Quartzite (Middle Proterozoic)
Red-brown, purple, and gray, cliff-forming sandstone. Includes four undivided informal members as defined by Daneker (1975). In descending order, they are upper, upper middle, lower middle, and lower sandstone members. Upper member consists of red-brown and purple, fine- to coarse-grained, well-

sorted, highly contorted, gnarly bedded sandstone capped by nondisrupted, flat-bedded, gray sandstone. Upper middle member consists of rusty-red, fine- to coarse-grained, highly contorted, gnarly bedded sandstone. Lower middle member consists of purple “freckled” (reduction spots), fine-grained, well-sorted, lowangle cross-bedded sandstone with local contorted beds in upper part. Lower member consists of purplish-red, coarse-grained, flat-bedded, arkosic conglomeratic sandstone. All members cemented with silica, making sandstone as hard as metamorphic quartzite, but unit is not metamorphosed. Angular unconformity separates cliff of red-brown Shinumo Quartzite from underlying slope of red Hakatai Shale, marked at truncated beds of the Hakatai. The Shinumo increases in thickness from 1,132 ft (345 m) at eastern edge of map area to 1,540 ft (470 m) at Shinumo Creek, central part of map area . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Yh - Hakatai Shale, undivided (Mesoproterozoic)

Yh - Hakatai Shale, undivided (Mesoproterozoic)
Includes three informal members, in descending order: the Stone Creek, Cheops Pyramid, and Hance Rapids members based on lithology of Beus and others (1974) and Reed (1976). The Cheops and Hance Rapids members are red to bright-red, slope-forming, highly fractured, argillaceous mudstones and shale. Upper Hance Rapids member is purple and red, cliff-forming, medium-grained sandstone. Unit contains mud cracks, ripple marks, and tabular-planar crossbed structures. Gradational contact with underlying Bass Formation. Thickness, 448 to 981 ft (137 to 300 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Yh - Unkar Group - Hakatai Shale (Middle Proterozoic)
Orange-red, purple, and red mudstone, shale, and sandstone. Forms an upper cliff unit, a middle slope unit, and a lower slope unit. Upper cliff unit consists of pale-purple or lavender, fine- to coarse-grained, thin- to mediumbedded, cross-bedded sandstone. Forms gradational contact with underlying middle slope unit at distinct color change from purple to bright red. Middle slope unit is the most distinctive red-bed unit in the Grand Canyon, consisting of reddish- orange, thin-bedded, fine-grained mudstone, siltstone and sandy siltstone; includes non-red, spherical reduction spots (“freckles”) less than 10 cm in diameter. Gradational contact with underlying lower slope unit arbitrarily placed at red to purple color change. Lower slope unit consists of purple to reddish-purple, thin-bedded to laminated, fine-grained mudstone, siltstone, and sandy siltstone. Mudcracks, ripple marks, and tabular-planar cross-bedding are common in all units. Gradational contact with underlying Bass Formation in eastern part of map area; sharp but conformable contact in central part of map area. Overall thickness varies from about 445 ft (135 m) in eastern part of map area to nearly 985 ft (300 m) in Hakatai Canyon, central part of map area . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Yb - Bass Formation (Mesoproterozoic)

Yb - Bass Formation (Mesoproterozoic)
Gray and reddish-gray dolomite interbedded with arkose and sandy dolomite and siltstone interbedded with intraformational breccias and conglomerates throughout sequence. Interbedded with dolomite and mudstone beds. Beds of white, very fine grained tephra deposits with a U-Pb zircon age of 1254±2 Ma (Timmons and others, 2007) toward base of section. The basal Hotauta Conglomerate Member (Noble, 1922) consists of rounded, gravel-sized clasts of chert, granite, quartz, plagioclase crystals, and micropegmatites in quartz sand matrix (Dalton, 1972). Contains biscuit-form and biohermal stromatolite beds (Nitecki, 1971). Unconformable contact with underlying Paleoproterozoic granites and schists. Thickness, 196 to 327 ft (60 to 100 m). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Yb - Unkar Group - Bass Formation* (Middle Proterozoic)

Red-brown and reddish-gray, ledge-forming dolomite, silty sandstone, and conglomerate. Includes basal Hotauta Conglomerate Member as defined by Dalton (1972). Consists of fine- to coarse-grained, thin- to medium bedded dolomite, fine- to coarse-grained, thin-bedded sandstone, silty sandstone, conglomerate, and breccia. Dolomite is most common lithology in Shinumo Creek area (central part of map area), becoming mostly sandstone, siltstone, and conglomerate in Bright Angel Canyon and eastern part of map area. Dolomite beds contain biscuit-shaped biohermal stromatolite fossils and red chert; sandstone beds contain ripple marks, desiccation cracks, and intraformational breccia and conglomerate. The Hotauta is considered part of the Bass in most map areas because of its lensing characteristics. The Bass, including the Hotauta, gradually thickens from southeast to northwest across map area from about 260 to 300 ft (80 to 91 m) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Ydi - Diabase intrusive rocks (Proterozoic)

Yd - Diabase intrusive rocks (Proterozoic)
Black sills and dikes intruded into granitic rocks. Unit is shown as dark line with hatchers on map, Colorado River Mile 237 to 239. About 1.1 Ga (billion years old). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Yg - Young granite and pegmatite (Proterozoic)

Granite plutons, stocks, dikes, and pegmatite. About 1.4 Ga (billion years old). (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xg - Granite (Paleoproterozoic)

Xg - Granite (Paleoproterozoic)
Unfolded to weakly foliated, medium- to fine-grained muscovite-biotite, granitic pegmatite and aplite dikes, sills, and small plutons. U-Pb zircon ages range from 1,685 to 1,680±1 Ma (Hawkins and others, 1996). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Xg - Young granite and pegmatite (Early Proterozoic)
Granite plutons, stocks, dikes, and pegmatite. About 1.4 Ga (billion years old) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xgr - Granite, granitic pegmatite and aplite (Proterozoic)

Xgr - Granite, granitic pegmatite and aplite (Proterozoic)
Granite plutons, stocks, and pegmatite and aplite dikes emplaced synchronously with peak metamorphism. Contains abundant biotite, muscovite, and garnet. About 1.7 to 1.68 Ga. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xgr - Granite, granitic pegmatite, and aplites (Early Proterozoic)
Granite plutons and stocks and pegmatite and aplite dikes emplaced synchronously with peak metamorphism. One small outcrop in map area is at Colorado River Mile 190 just south of Whitmore Canyon junction with Colorado River. About 1.7–1.66 Ma (Ilg and others, 1996; Hawkins and others, 1996). (*GRI Source Map ID 4152)* (Mount Trumbull 30 x 60).

Xgr - Granite, granitic pegmatite, and aplite (Early Proterozoic)
Granite plutons, stocks, and pegmatite and aplite dikes emplaced synchronously with peak metamorphism. About 1.7–1.66 Ga . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xgd - Granodiorite-gabbro-diorite and granodiorite complexes (Proterozoic)

Xgd - Granodiorite-gabbro-diorite and granodiorite complexes (Paleoproterozoic)
Weakly to well-foliated, medium- to coarse-grained quartz-plagioclase and diorite-hornblende-bearing granitoids of probable volcanic arc origin (1.74 to 1.71 Ga). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Xgd - Granodiorite complexes (Proterozoic)
Gabbro-diorite-graniodiorite complexes of probable volcanic arc origin. Includes hornblende-biotite granodiorite, and tonalite. About 1.74 to 1.72 Ga. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xgd - Granodiorite complexes (Early Proterozoic)
Gabbro-diorite-granodiorite complexes of probable volcanic arc origin. About 1.74–1.71 Ga . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xum - Ultramafic rocks (Paleoproterozoic)

Probable cumulate origin as supracrustal rocks. (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xdg - Diorite, gabbro, and anorthosite (Proterozoic)

About 1.74 to 1.72 Ga. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xs - Schist (Proterozoic)

Quartz-mica, schist, and pelitic schist. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xv - Vishnu Schist (Proterozoic)

Xv - Granite Gorge Metamorphic Suite - Vishnu Schist (Paleoproterozoic)
Quartz-mica schist, pelitic schist, and meta-arenites of probable volcanic arc basin origin. Locally contains graded bedding and turbidite layering. Strongly foliated with multiple generations of folds and foliations (Ilg and others, 1996). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Xv - Intermediate metavolcanic rocks (Proterozoic)
Massive, fine-grained quartzo-feldspatic schist and gneiss of probable felsic metavolcanic rocks. Equivalent to the Rama Schist of eastern Grand Canyon as defined by Ilg and others (1996). About 1.75 Ga. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xv - Vishnu Schist (Early Proterozoic)

Quartz-mica schist, pelitic schist, and meta-arenites of metamorphosed, arc-basin, submarine sedimentary rocks. About 1.75 Ga. Locally interlayered with Brahma Schist (Xbr) and Rama Schist (Xr) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xr - Rama Schist and Gneiss (Paleoproterozoic)

Xr - Granite Gorge Metamorphic Suite - Rama Schist and Gneiss (Paleoproterozoic)
Quartzofeldspathic schist and gneiss of probable felsic to intermediate metavolcanic origin; strongly foliated; yields a U-Pb zircon age of 1,741±1 Ma (Hawkins and others, 1996). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Xr - Rama Schist (Early Proterozoic)
Massive, fine-grained quartzofeldspathic schist and gneiss of probable felsic metavolcanic rocks. About 1.75 Ga. Locally interlayered with Brahma Schist (Xbr) and Vishnu Schist (Xv) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xbr - Brahma Schist (Paleoproterozoic)

Xbr - Granite Gorge Metamorphic Suite - Brahma Schist (Paleoproterozoic)
Amphibolites, biotite-hornblende schist and biotite schist of probable mafic volcanic origin. Local metafelsite interbeds contain phenocrysts of quartz and feldspar; beds yield a U-Pb zircon age of 1,750 ±2 Ma (Hawkins and others, 1996). (*GRI Source Map ID 75648)* (Tuba City 30 x 60).

Xbr - Brahma Schist (Early Proterozoic)
Consists of amphibolite, hornblende-biotite-plagioclase schist, biotite-plagioclase schist, orthoamphibole-bearing schist and gneiss, and metamorphosed sulfide deposits. Mafic to intermediate-composition metavolcanic rocks. About 1.75 Ga. Locally interlayered with Rama Schist (Xr) and Vishnu Schist (Xv) . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xm - Mafic metavolcanic rocks (Proterozoic)

Biotite hornblende schist and amphibolite. Contains abundant biotite and garnet. Equivalent to Brahma Schist of eastern Grand Canyon. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xo - Orthoamphibole schist (Proterozoic)

Xo - Orthoamphibole schist (Proterozoic)
Regolith. An interval several meters thick of weathered detritus eroded from older plutonic rock. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xo - Orthoamphibole-bearing gneiss (Early Proterozoic)
Regolith. An interval several meters thick of weathered detritus eroded from older plutonic rocks. Metamorphic monazite from pelitic schist containing garnet, kyanite, gedrite, sillimanite, and cordierite. Very small outcrops along Colorado River within Granite Gorge . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Xc - Carbonate and chert (Proterozoic)

A few meters thick interval of carbonate rock and chert nodules within an orthoamphibole schist, one location only, below Colorado River Mile 237. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xu - Crystalline rocks, undivided (Proterozoic)

Xu - Crystalline rocks, undivided (Paleoproterozoic (Statherian))

The intrusive and metamorphic rocks are as defined by Ilg and others (1996), Hawkins and others (1996), and Karlstrom and others (2003). There is at least a 50 percent chance that younger Proterozoic sedimentary rocks of the Grand Canyon Supergroup exposed in the eastern Grand Canyon area (Huntoon and others, 1996) may be present in the eastern subsurface of this map area.
Undivided intrusive and metamorphic rocks. Includes granite plutons, stocks, and pegmatite and aplite dikes, gabbro-diorite, and granodiorite rocks, garnet schist, hornblende-biotite schist, orthoamphibole-bearing schist and gneiss, and probable felsic metavolcanic rocks. In cross section only. (*GRI Source Map ID 75234)* (Fredonia 30 x 60).

Xu - Crystalline rocks, undivided (Paleoproterozoic)

Intrusive and metamorphic rocks as defined by Ilg and others (1996), Hawkins and others (1996), and Karlstrom and others (2003). There is at least a 50 to 75 percent chance that younger Proterozoic sedimentary rocks of the Grand Canyon Supergroup exposed in the eastern Grand Canyon area (Huntoon and others, 1996) may be present in the southern and eastern subsurface of this map area.
Undivided intrusive and metamorphic rocks. Includes granite plutons, stocks, and pegmatite and aplite dikes, gabbro-diorite, and granodiorite rocks, garnet schist, hornblende-biotite schist, orthoamphibole-bearing schist and gneiss, and probable felsic metavolcanic rocks. In cross section only. (*GRI Source Map ID 7454)* (Cameron 30 x 60).

Xu - Crystalline rocks, undifferentiated (Proterozoic)

Undivided intrusive and metamorphic rocks. Includes granite plutons, stocks, and pegmatite and aplite dikes, gabbro-diorite, and granodiorite rocks, garnet schist, hornblende-biotite schist, orthoamphibole-bearing schist and gneiss, and probable felsic metavolcanic rocks. Unit is not mapped in detail and needs future study. Probably same age range as similar rocks along Colorado River. (*GRI Source Map ID 4151)* (Peach Springs 30 x 60).

Xu - Crystalline rocks, undifferentiated (Early Proterozoic)

Includes various types of igneous and metamorphic granite, and crystalline schist and gneiss. Thickness unknown. In cross section only. (*GRI Source Map ID 7453)* (Valle 30 x 60).

Xec - Elves Chasm pluton (Paleoproterozoic)

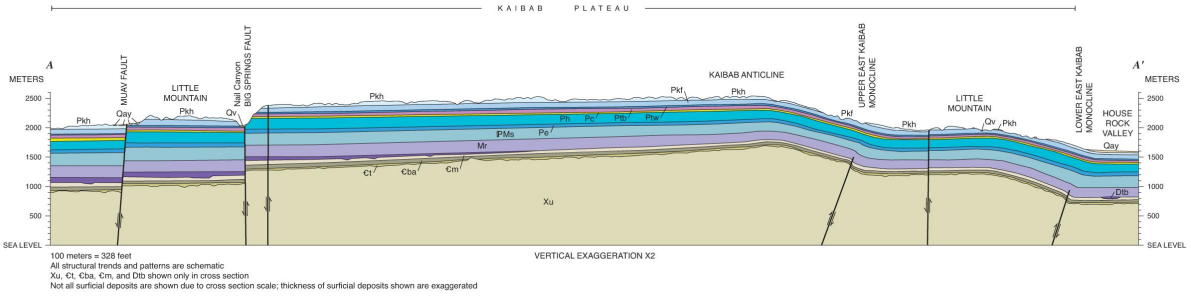
Oldest plutonic rocks, possible “basement” substrate. Contains mafic (hornblende-biotite tonalite) and intermediate-composition plutonic units (quartz diorite), including tabular amphibolite bodies that may be dikes. About 1.84 Ga . (*GRI Source Map ID 1309)* (Grand Canyon 30 x 60).

Geologic Cross Sections

The geologic cross sections present in the GRI digital geologic-GIS data produced for Grand Canyon National Park, Arizona (GRCA) are presented below. Note that some cross section abbreviations (e.g., A - A') may have been changed from their source map abbreviation in the GRI data so that each cross section abbreviation in the GRI data is unique. Cross section graphics were scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document).

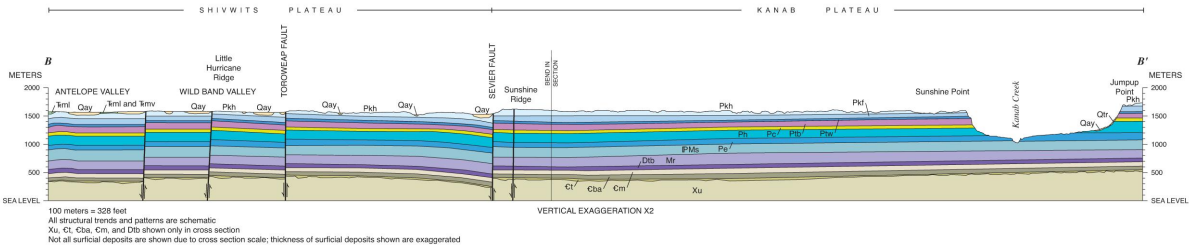
Fredonia Cross Sections

Fredonia Cross Section A-A'



Displayed as compiled cross section A-A' in GIS data.
Extracted from: (Fredonia 30' x 60' Quadrangle).

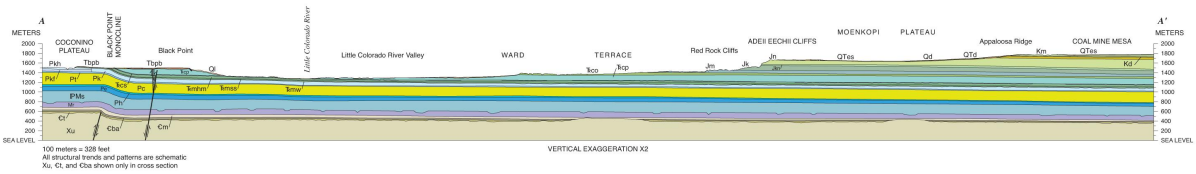
Fredonia Cross Section B-B'



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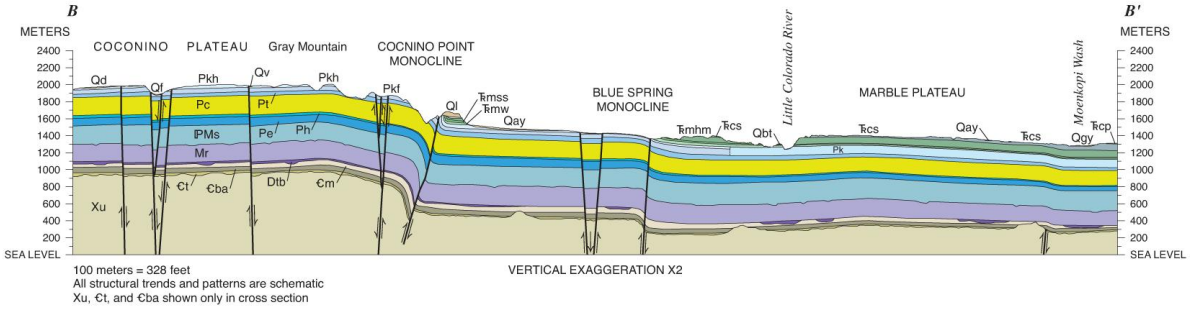
Cameron Cross Sections

Cameron Cross Section A-A'



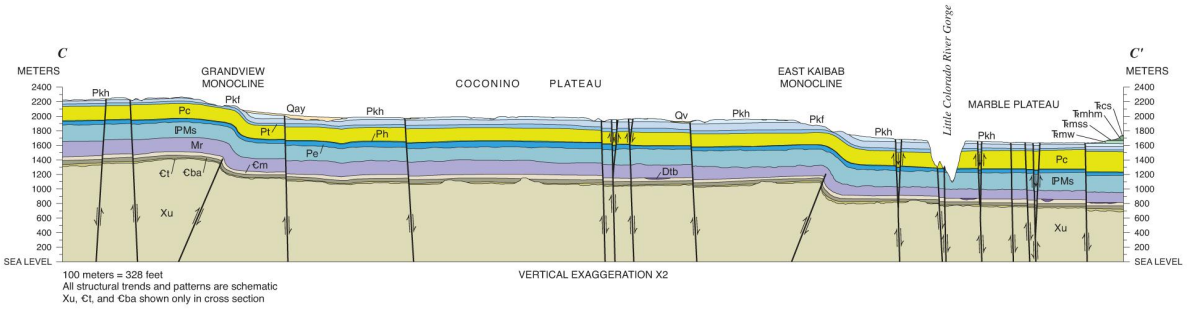
Displayed as compiled cross section P-P' in GIS data.
Extracted from: (Cameron 30' x 60' Quadrangle).

Cameron Cross Section B-B'



Displayed as compiled cross section O-O' in GIS data.
Extracted from: (Cameron 30' x 60' Quadrangle).

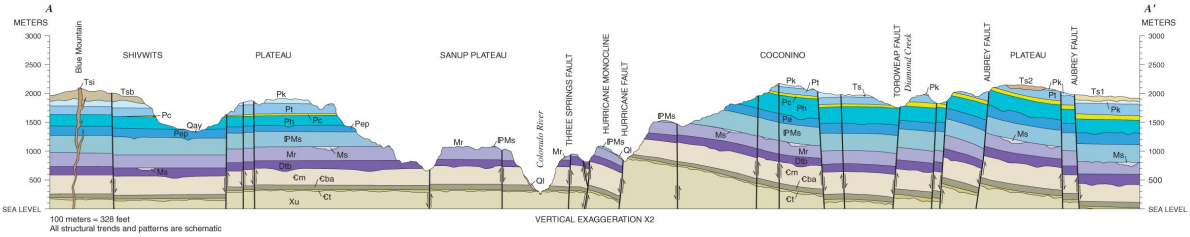
Cameron Cross Section C-C'



Displayed as compiled cross section N-N' in GIS data.
Extracted from: (Cameron 30' x 60' Quadrangle).

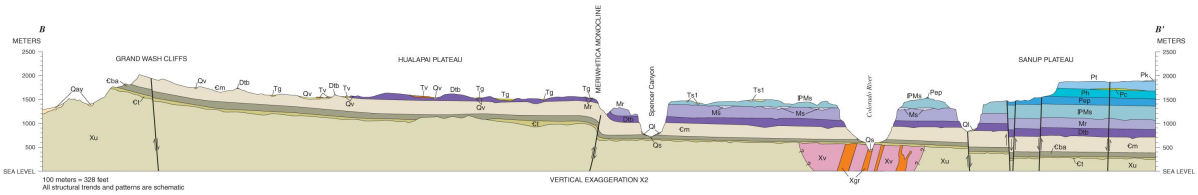
Peach Springs Cross Sections

Peach Springs Cross Section A-A'



Displayed as compiled cross section J-J' in GIS data.
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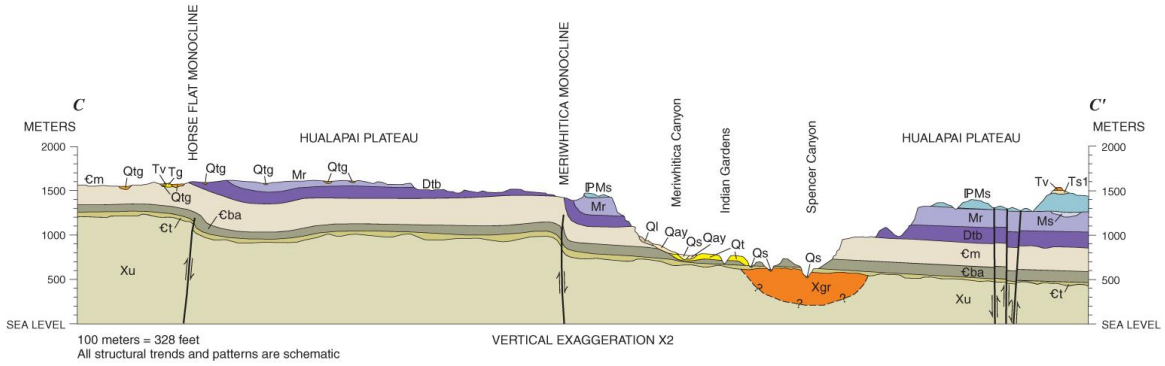
Peach Springs Cross Section B-B'



Displayed as compiled cross section I-I' in GIS data.

Extracted from: (Peach Springs 30' x 60' Quadrangle).

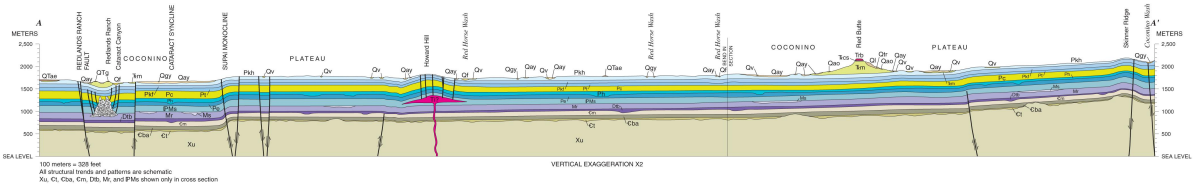
Peach Springs Cross Section C-C'



Displayed as compiled cross section Q-Q' in GIS data.
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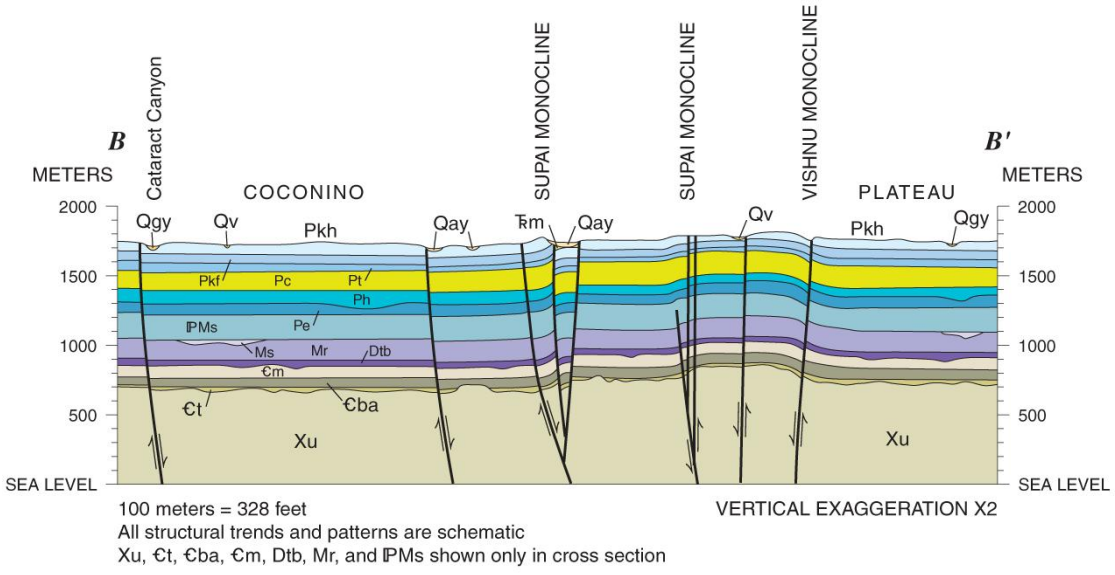
Valle Cross Sections

Valle Cross Section A-A'



Displayed as compiled cross section K-K' in GIS data.
Extracted from: (Valle 30' x 60' Quadrangle).

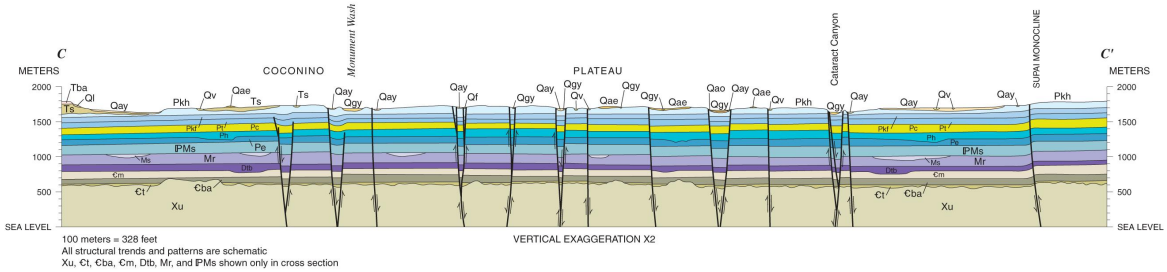
Valle Cross Section B-B'



Displayed as compiled cross section M-M' in GIS data.

Extracted from: (Valle 30' x 60' Quadrangle).

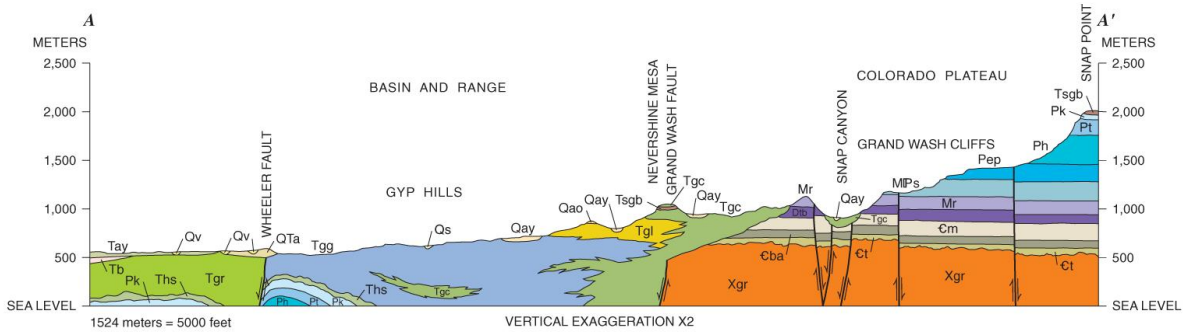
Valle Cross Section C-C'



Displayed as compiled cross section L-L' in GIS data.
Extracted from: (Valle 30' x 60' Quadrangle).

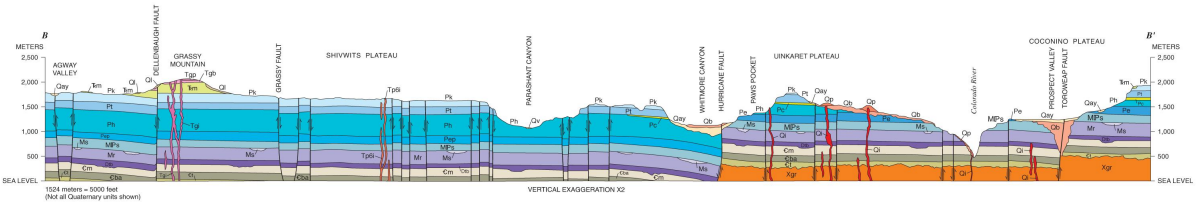
Mount Trumbull Cross Sections

Mount Trumbull Cross Section A-A'



Displayed as compiled cross section C-C' in GIS data.
Extracted from: (Mount Trumbull 30' x 60' Quadrangle).

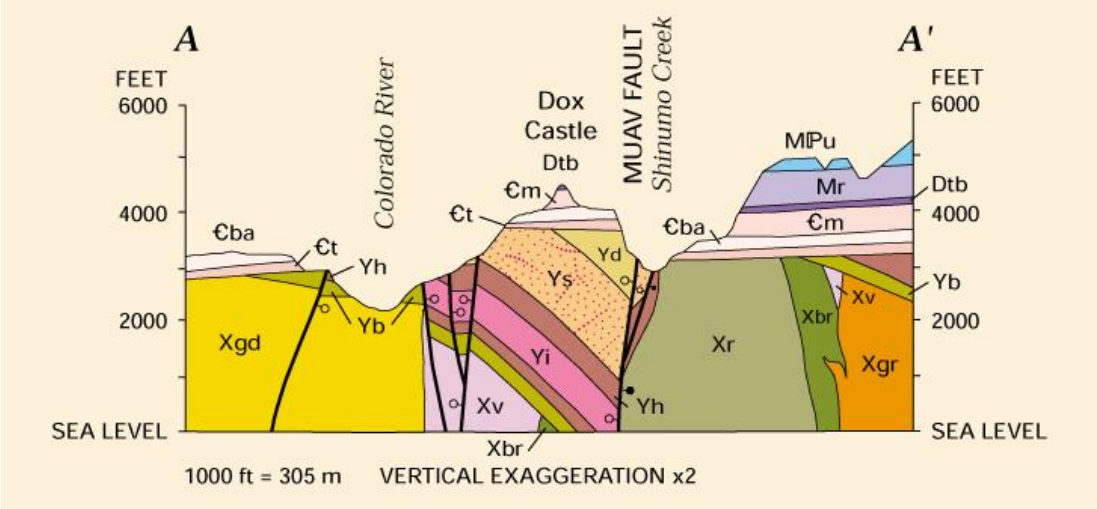
Mount Trumbull Cross Section B-B'



Displayed as compiled cross section D-D' in GIS data.
Extracted from: (Mount Trumbull 30' x 60' Quadrangle).

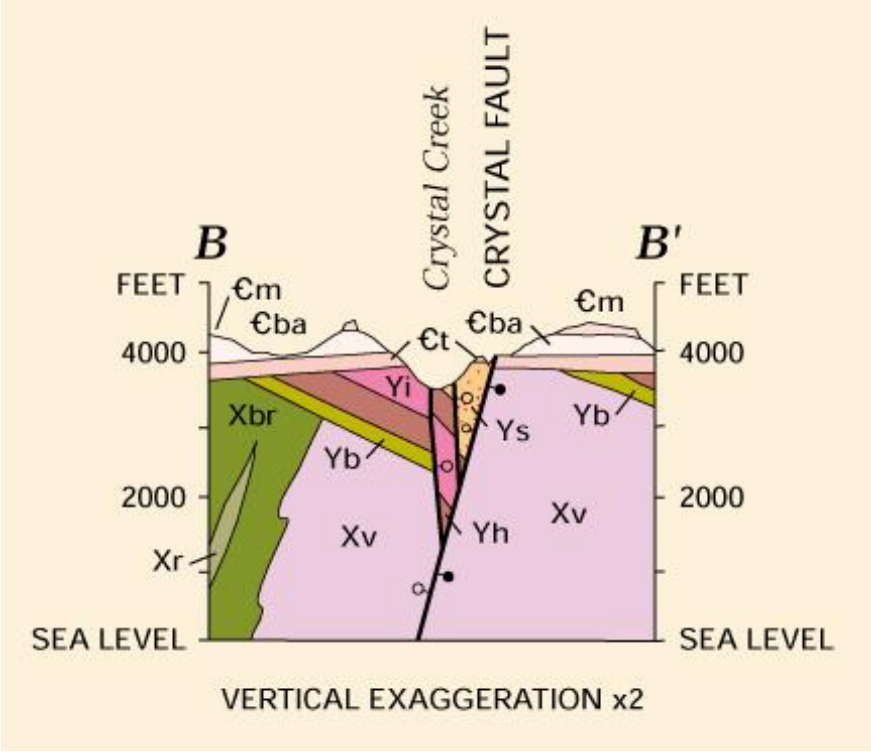
Grand Canyon Cross Sections

Grand Canyon Cross Section A-A'



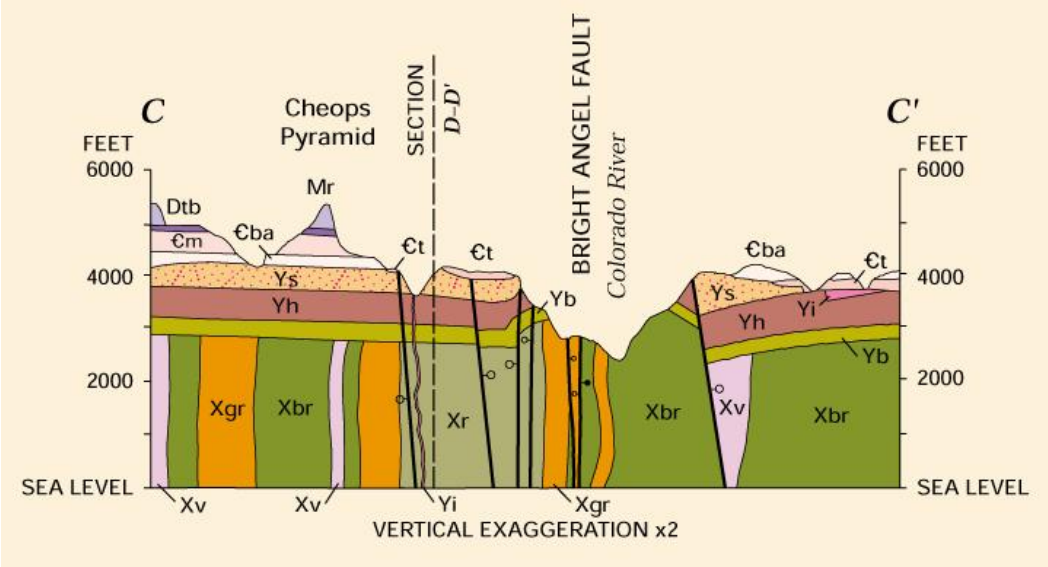
Displayed as compiled cross section E-E' in GIS data.
Extracted from: (Grand Canyon 30' x 60' Quadrangle).

Grand Canyon Cross Section B-B'



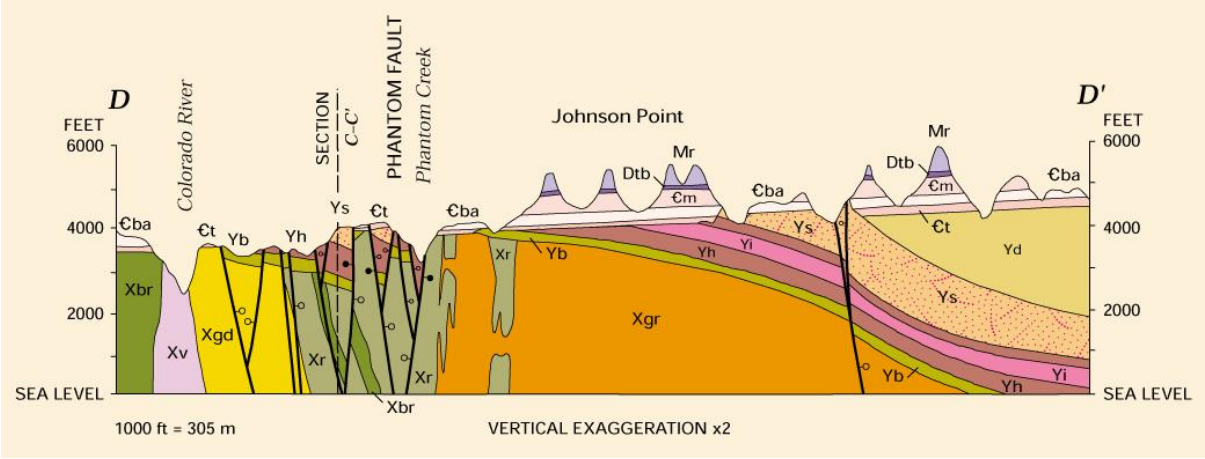
Displayed as compiled cross section F-F' in GIS data.
Extracted from: (Grand Canyon 30' x 60' Quadrangle).

Grand Canyon Cross Section C-C'



Displayed as compiled cross section G-G' in GIS data.
Extracted from: (Grand Canyon 30' x 60' Quadrangle).

Grand Canyon Cross Section D-D'



Displayed as compiled cross section H-H' in GIS data.
Extracted from: (Grand Canyon 30' x 60' Quadrangle).

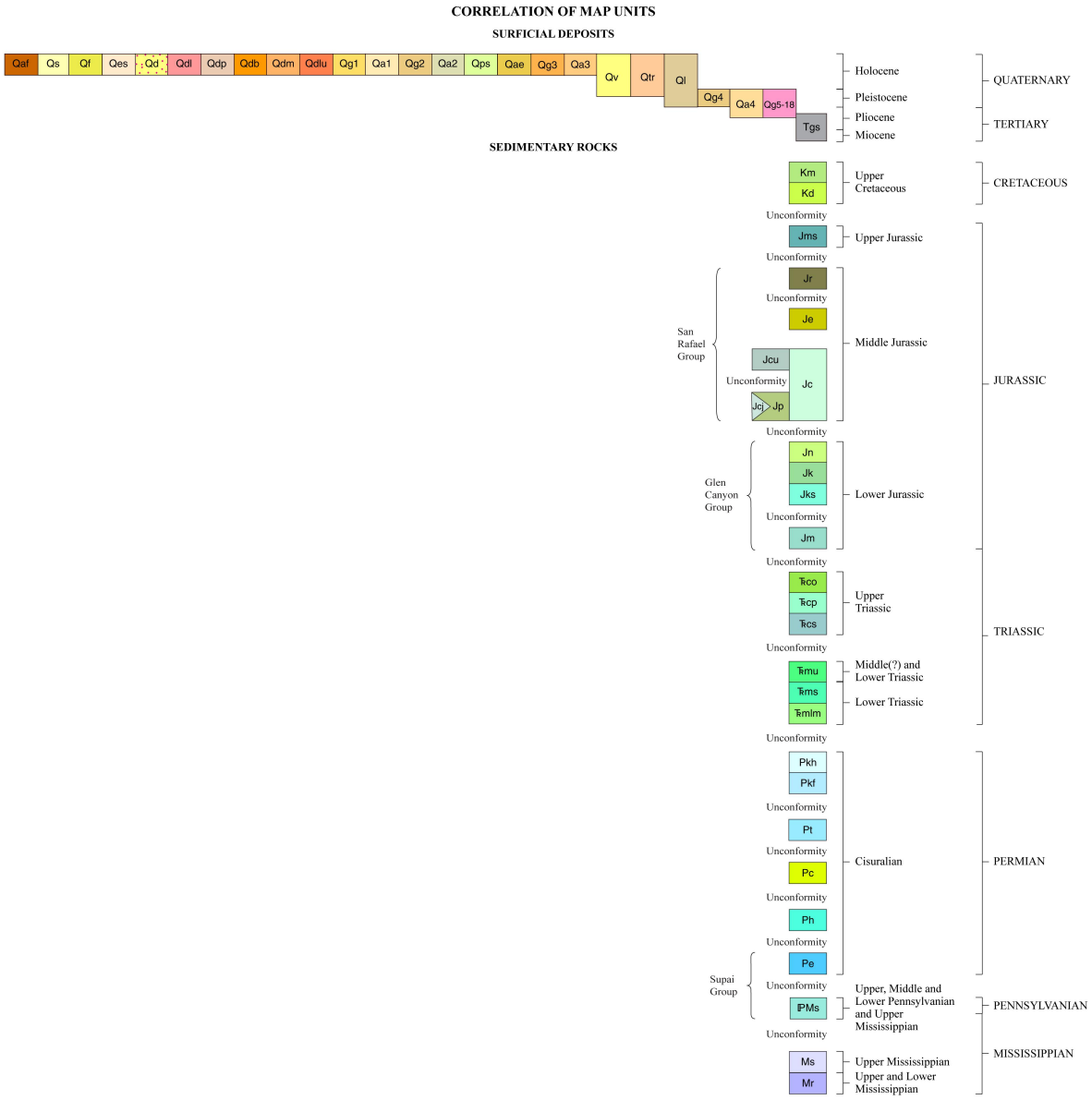
GRI Source Map Information

Glen Canyon Dam 30' x 60' Quadrangle

Billingsley, G.H., and Priest, S.S., 2013, Geologic Map of the Glen Canyon Dam 30' x 60' Quadrangle, Coconino County, Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-3268, 1:100000 scale. (GRI Source Map ID 7454)

Note: Data for this project was derived from an updated GIS database provided by the USGS that is based on and closely resembles this publication. Although this publication has a scale of 1:100,000, the source GIS database contained 1:24,000 scale data that was utilized for this project. To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/sim/3268/

Correlation of Mapped Units



Extracted from: (Glen Canyon Dam 30 x 60).

Legend

EXPLANATION OF MAP SYMBOLS

Contact—Contacts between all alluvial and eolian units are approximate and arbitrary

35

Fault—Dashed where inferred; dotted where concealed; bar and ball on down-thrown side. Showing fault offset in feet

Folds—Showing trace of axial surface and direction of plunge; dotted where location is concealed

Anticline

Plunging anticline

Syncline

Plunging syncline

Monocline

Strike and dip of beds

35 **Inclined**—Showing dip measured in the field

Implied—Interpreted from aerial photographs; dip not determined

Strike of vertical and subvertical joints—Interpreted from aerial photographs; symbol placed where joints are most visible on aerial photographs

Collapse structure—Black dot shows circular collapse structure characterized by strata dipping inward toward a central point. Magenta dot shows circular collapse structure characterized by strata dipping inward toward a central point and brecciated rock

Sinkhole

Mine or prospect

Fracture—Open fracture (0.5 to 3.5 m wide) without offset

Offset fracture—Open fracture (0.5 to 3.5 m wide) with offset (generally less than 1.5 m

Extracted from: (Glen Canyon Dam 30 x 60).

Overview Map of the Glen Canyon Dam 30' x 60' Quadrangle

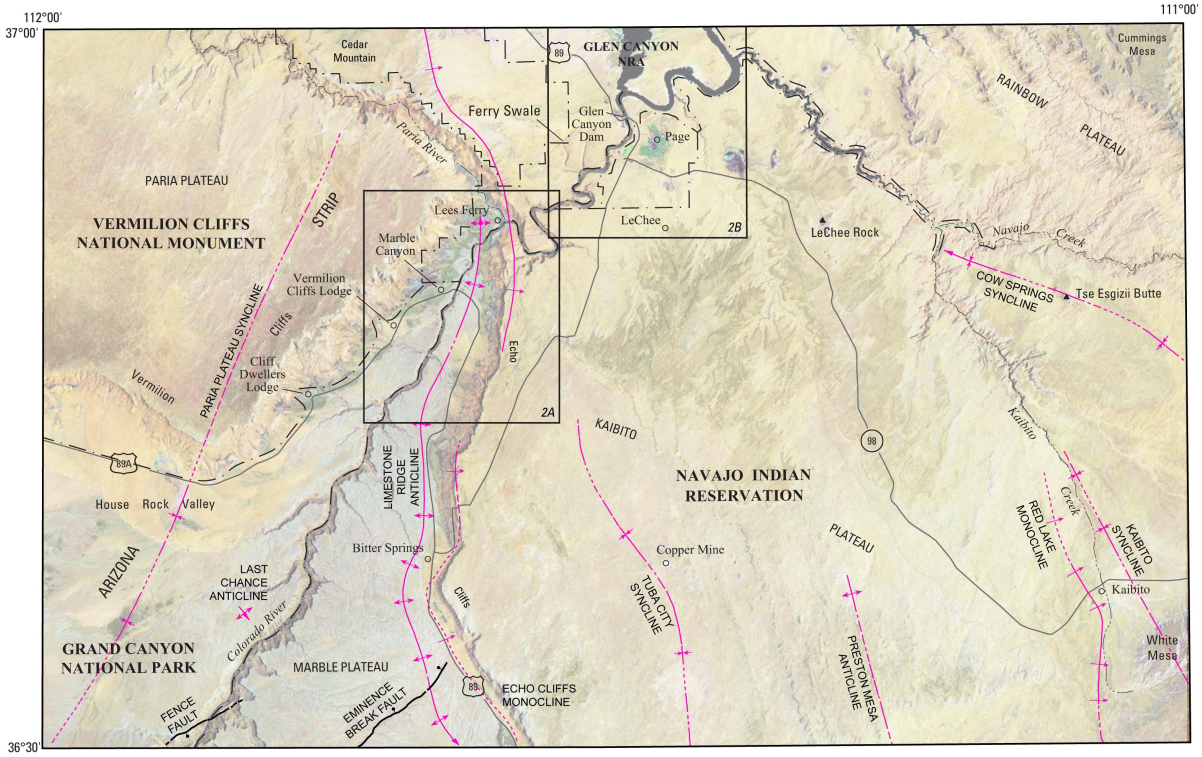


Figure 1. Map of the Glen Canyon Dam 30′ x 60′ quadrangle showing cultural and physiographic features as well as major geologic structures. Boxes define area of maps in figure 2.

Extracted from: (Glen Canyon Dam 30 x 60).

Figure 1 - Map of Terrace Gravels

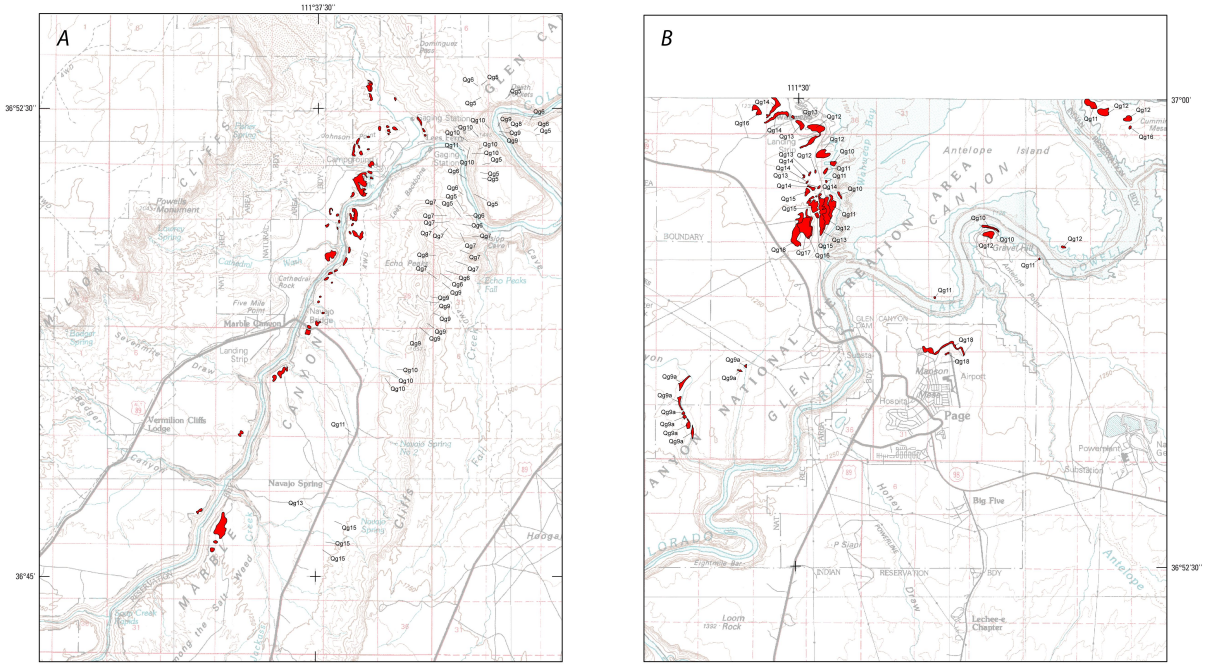


Figure 2. Maps showing detail of terrace gravels (units Qg5-Qg18) along the Colorado River. *A*. Gravels from Lees Ferry south to River Mile 9 below Badger Rapid. Colorado River elevation at Lee's Ferry is 3,133 ft (955 m). *B*. Gravels from northeast of Lees Ferry north to lower Lake Powell. Colorado River elevation at base of Glen Canyon Dam is 3,146 ft (959 m). River gradient between Glen Canyon Dam and River Mile 9 is 3.5 ft/mi. See table 1 for additional unit information. See figure 1 for map locations.

Extracted from: (Glen Canyon Dam 30 x 60).

Table 1 - Floodplain and Terrace Gravel Deposits

Table 1. Age and elevation of floodplain and terrace-gravel deposits along the Colorado River from Glen Canyon Dam to Badger Rapids, a 25 mile (40 km) section of the river. Refer to locations of separate older terrace-gravel deposits in figure 2.

Map unit	*Age*	*Elevation above Colorado River*
	Floodplain deposits	
Qf	Holocene	0–45 ft (0–14 m)
	Young and intermediate terrace-gravel deposits	
Qg1	Holocene	7–17 ft (2–5 m)
Qg2	Holocene	27–47 ft (8–14 m)
Qg3	Holocene	47–77 ft (14–23 m)
Qg4	Holocene and Pleistocene(?)	87–127 ft (27–39 m)
	Older terrace-gravel deposits	
Qg5	Holocene and Pleistocene(?)	107–127 ft (33–39 m)
Qg6	Holocene(?) and Pleistocene	147–207 ft (45–63 m)
Qg7	Pleistocene	275–300 ft (84–91 m)
Qg8	Pleistocene	290–390 ft (88–119 m)
Qg9	Pleistocene	495–555 ft (151–169 m)
Qg9a	Pleistocene	620–635 ft (189–194 m)
Qg10	Pleistocene	600–620 ft (183–189 m)
Qg11	Pleistocene	620–630 ft (189–192 m)
Qg12	Pleistocene	760–800 ft (232–244 m)
Qg13	Pleistocene	800–860 ft (244–262 m)
Qg14	Pleistocene	900–920 ft (274–280 m)
Qg15	Pleistocene	960–980 ft (293–299 m)
Qg16	Pleistocene and Pliocene(?)	990–1,000 ft (302–305 m)
Qg17	Pleistocene and Pliocene(?)	1,060–1,085 ft (323–331 m)
Qg18	Pleistocene and Pliocene(?)	1,140–1,190 ft (347–363 m)

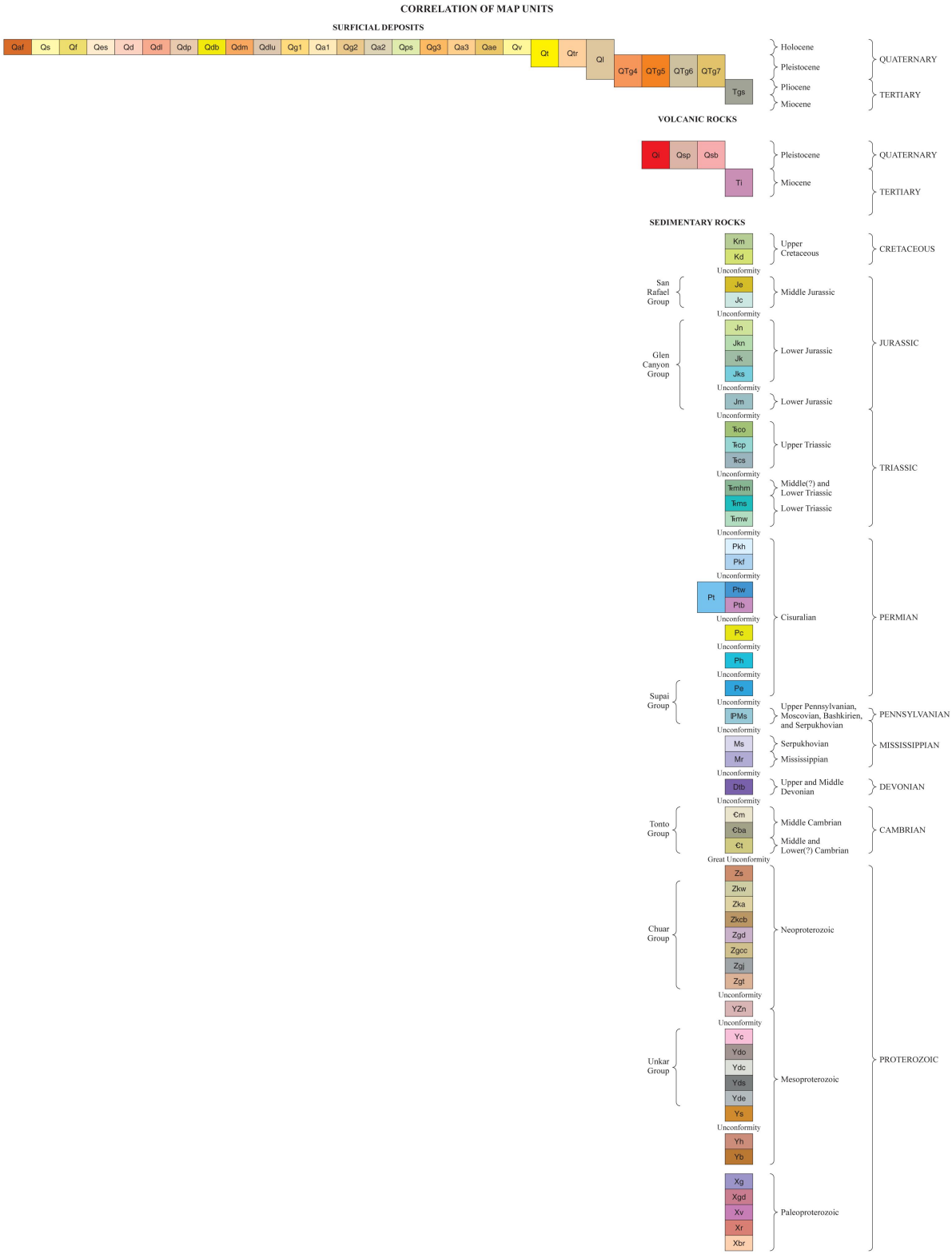
Extracted from: (Glen Canyon Dam 30 x 60).

Tuba City 30' x 60' Quadrangle

Billingsley, G.H., Stoffer, P.W., and Priest, S.S., 2012, Geologic Map of the Tuba City 30' x 60' Quadrangle, Coconino County, Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-3227, 1:50000 scale. (GRI Source Map ID 75648)

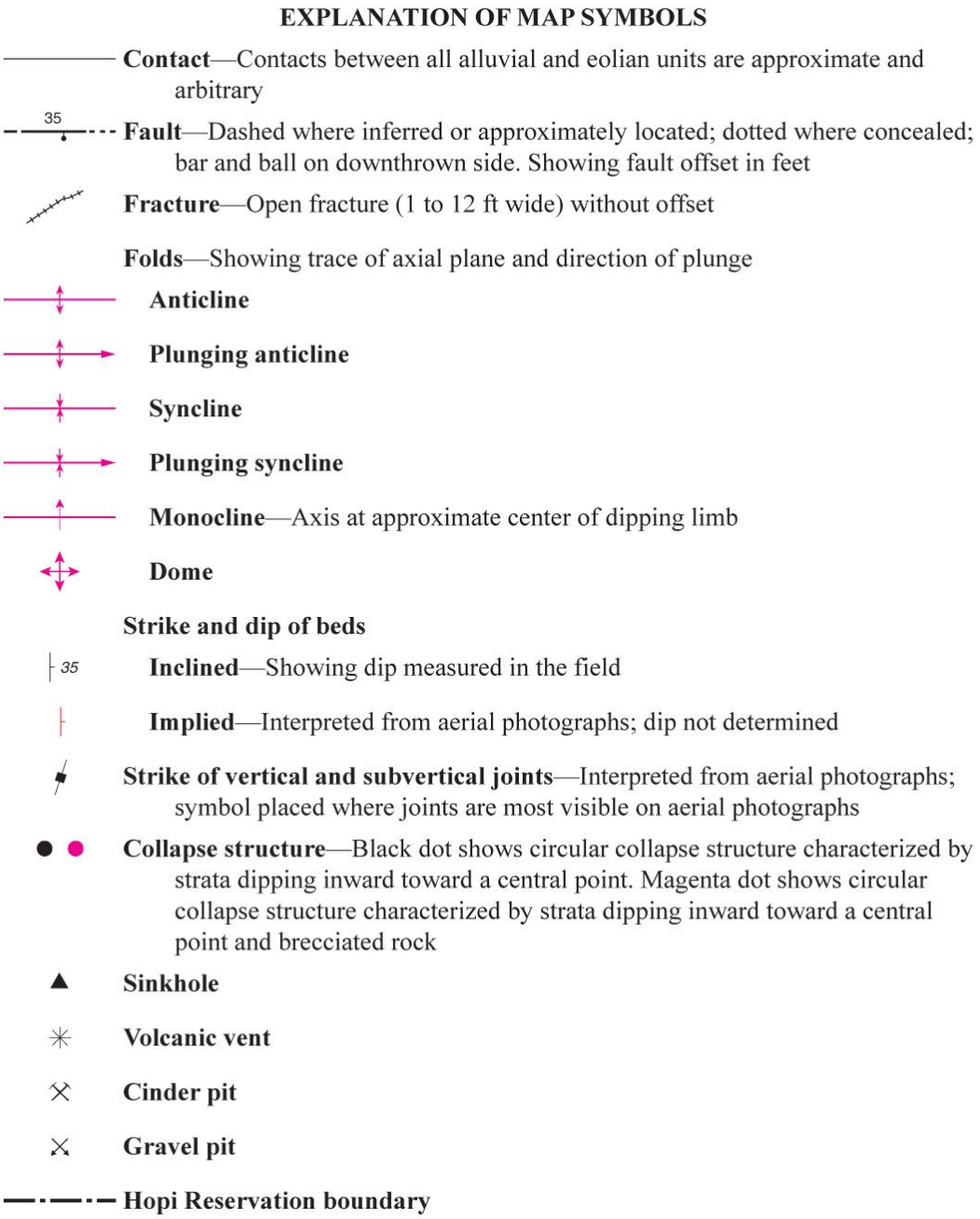
Note: Data for this project was derived from an updated GIS database provided by the USGS that is based on and closely resembles this publication. Although this publication has a scale of 1:50,000, the source GIS database contained 1:24,000 scale data that was utilized for this project. To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/sim/3227/

Correlation of Mapped Units



Extracted from: (Tuba City 30 x 60).

Legend



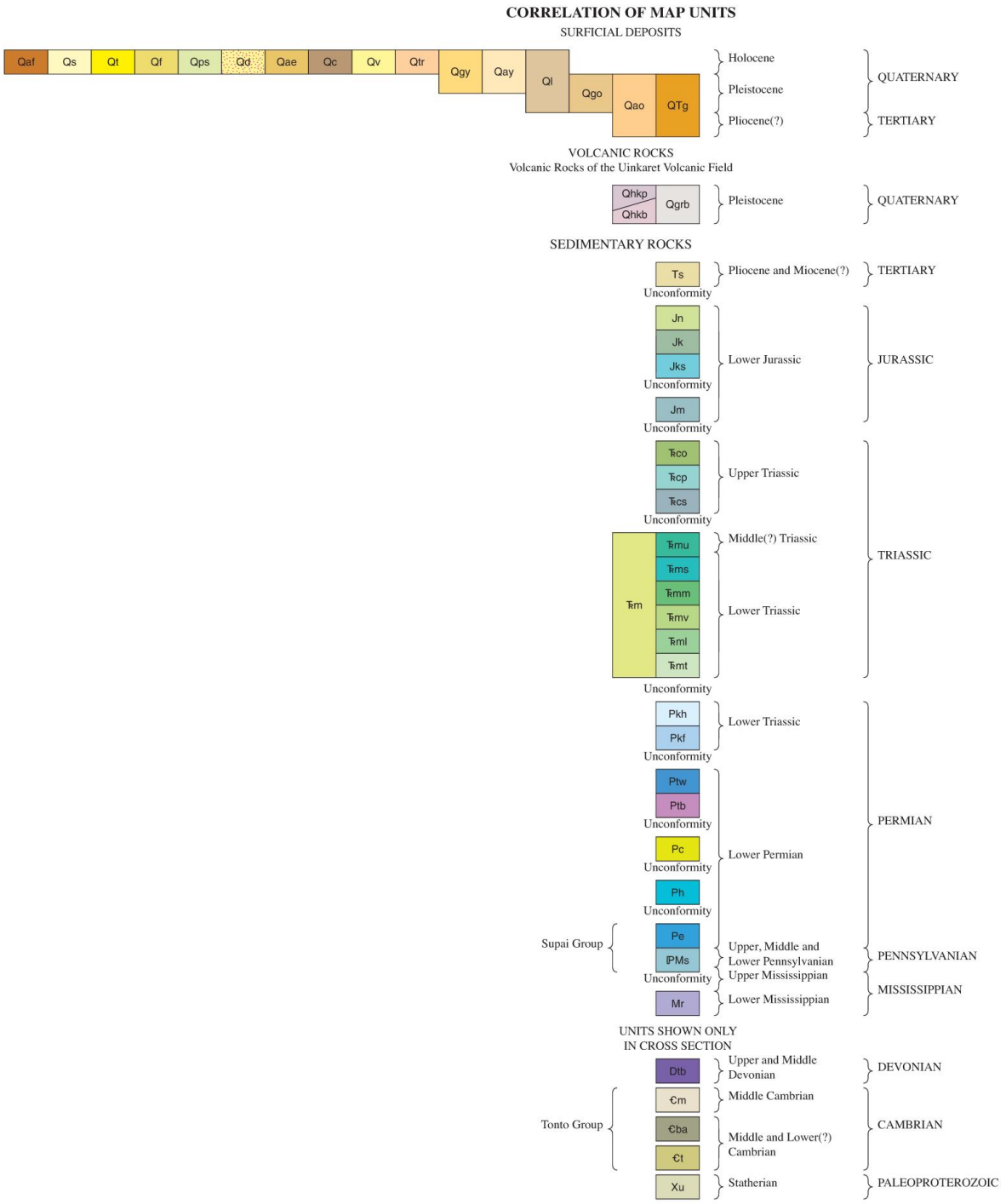
Extracted from: (Tuba City 30 x 60).

Fredonia 30' x 60' Quadrangle

Billingsley, G.H., Priest, S.S., and Felger, T.J., 2008, Geologic Map of the Fredonia 30' x 60' Quadrangle, Mohave and Coconino Counties, Northern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-3035, 1:100000 scale. (GRI Source Map ID 75234).

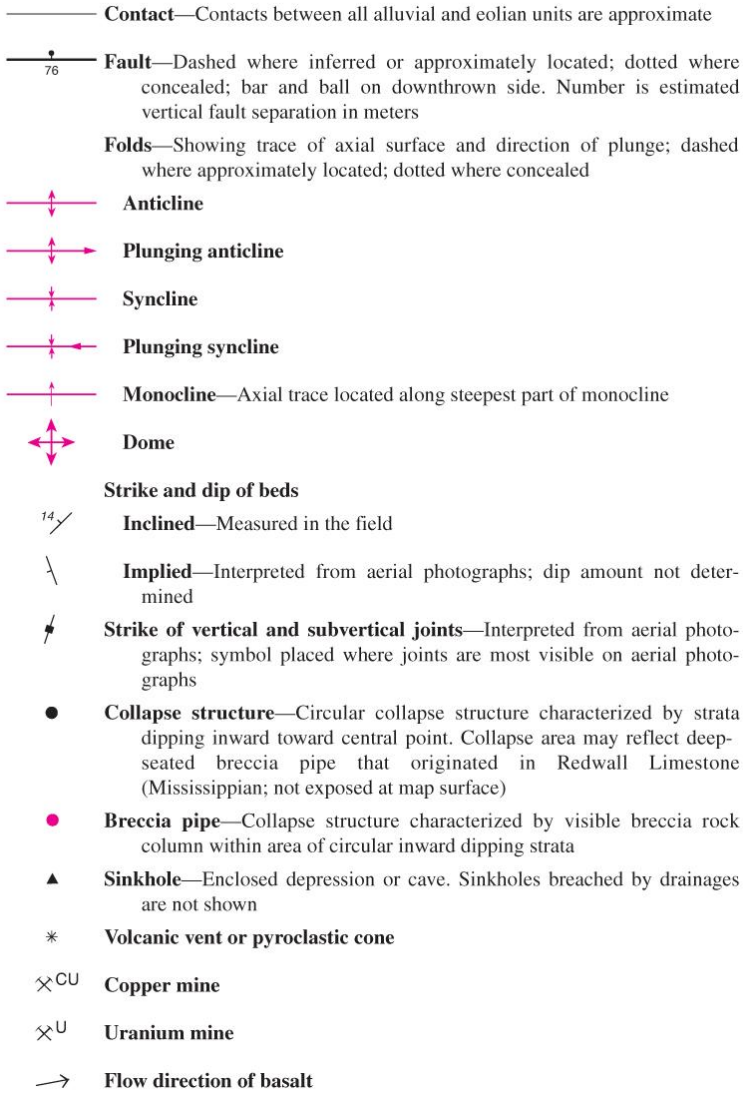
Note: Data for this project was derived from an updated GIS database provided by the USGS that is based on and closely resembles this publication. Although this publication has a scale of 1:100,000, the source GIS database contained 1:24,000 scale data that was utilized for this project. To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/sim/3035/

Correlation of Mapped Units



Extracted from: (Fredonia 30 x 60).

Legend



Contact—Contacts between all alluvial and eolian units are approximate

76 **Fault**—Dashed where inferred or approximately located; dotted where concealed; bar and ball on downthrown side. Number is estimated vertical fault separation in meters

Folds—Showing trace of axial surface and direction of plunge; dashed where approximately located; dotted where concealed

Anticline

Plunging anticline

Syncline

Plunging syncline

Monocline—Axial trace located along steepest part of monocline

Dome

Strike and dip of beds

14 **Inclined**—Measured in the field

Implied—Interpreted from aerial photographs; dip amount not determined

Strike of vertical and subvertical joints—Interpreted from aerial photographs; symbol placed where joints are most visible on aerial photographs

Collapse structure—Circular collapse structure characterized by strata dipping inward toward central point. Collapse area may reflect deep-seated breccia pipe that originated in Redwall Limestone (Mississippian; not exposed at map surface)

Breccia pipe—Collapse structure characterized by visible breccia rock column within area of circular inward dipping strata

Sinkhole—Enclosed depression or cave. Sinkholes breached by drainages are not shown

Volcanic vent or pyroclastic cone

CU **Copper mine**

U **Uranium mine**

Flow direction of basalt

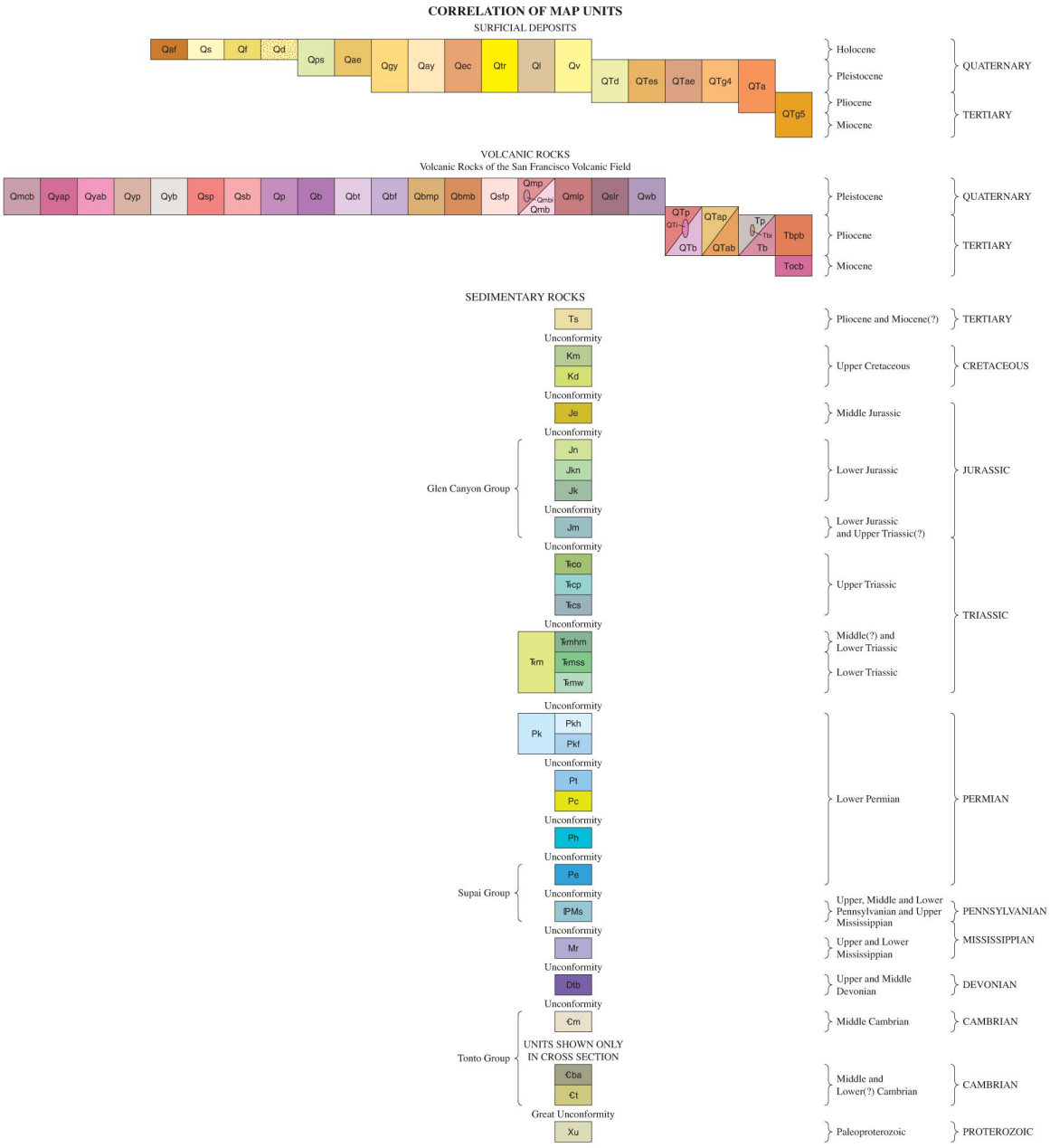
Extracted from: (Fredonia 30 x 60).

Cameron 30' x 60' Quadrangle

Billingsley, G.H., Priest, S.S., and Felger, T.J., 2007, Geologic Map of the Cameron 30' x 60' Quadrangle, Coconino County, Northern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-2977, 1:100000 scale. (GRI Source Map ID 7454)

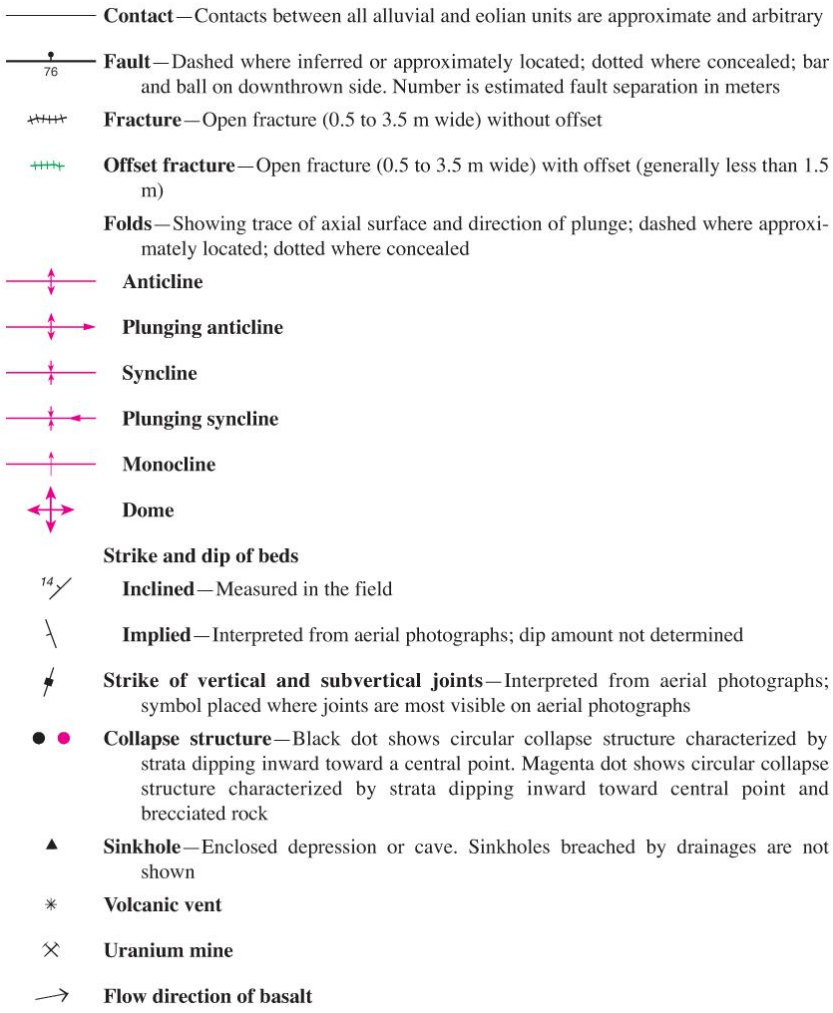
Note: Data for this project was derived from an updated GIS database provided by the USGS that is based on and closely resembles this publication. Although this publication has a scale of 1:100,000, the source GIS database contained 1:24,000 scale data that was utilized for this project. To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/sim/2007/2977/

Correlation of Mapped Units



Extracted from: (Cameron 30 x 60).

Legend



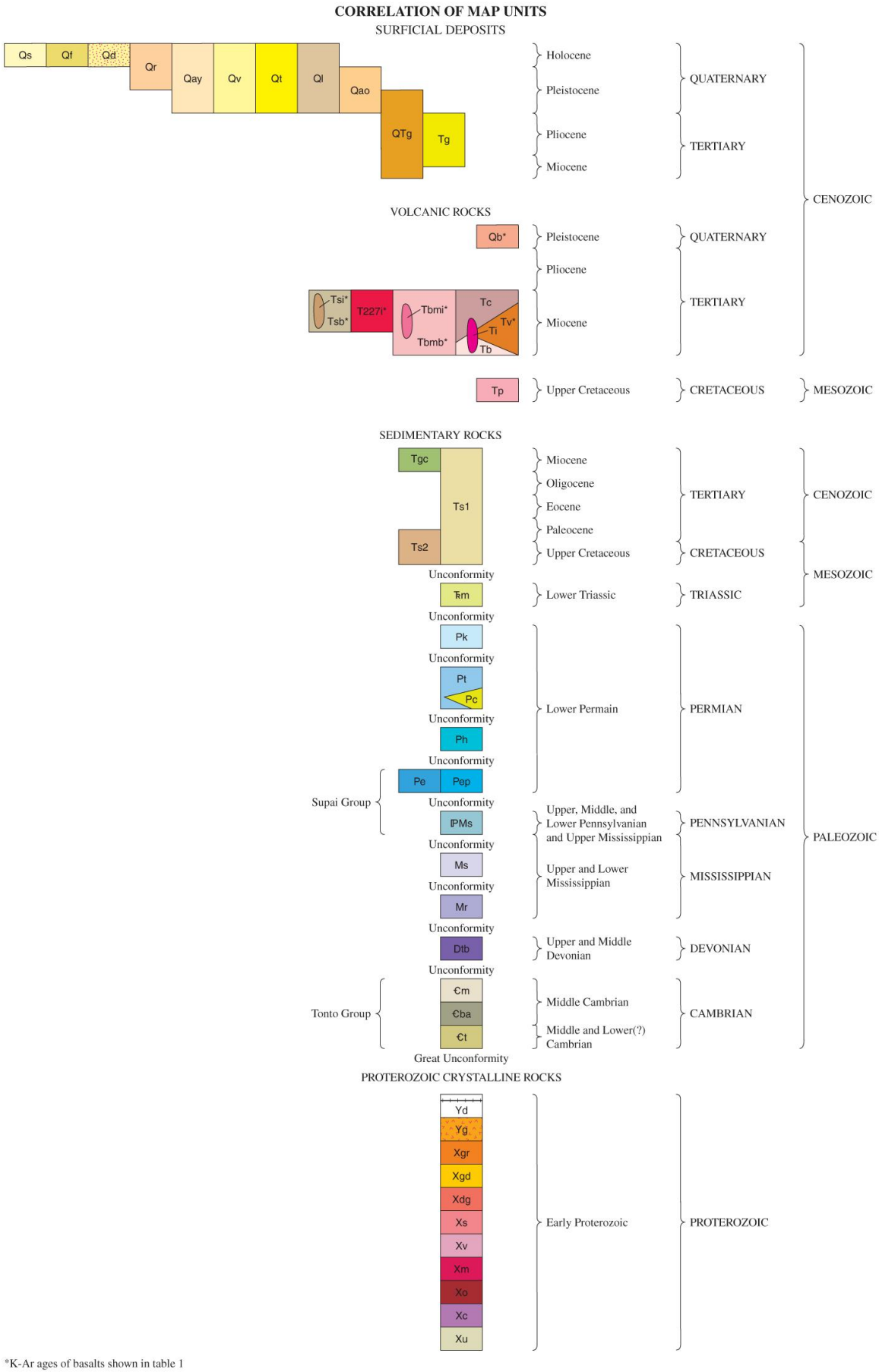
Extracted from: (Cameron 30 x 60).

Peach Springs 30' x 60' Quadrangle

Billingsley, G.H., Block, D.L., and Dyer, H.C., 2006, Geologic Map of the Peach Springs 30' x 60' Quadrangle, Mohave and Coconino Counties, Northwestern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-2900, 1:100000 scale. (GRI Source Map ID 4151)

Note: Data for this project was derived from an updated GIS database provided by the USGS that is based on and closely resembles this publication. Some differences may exist. To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/sim/2006/2900/

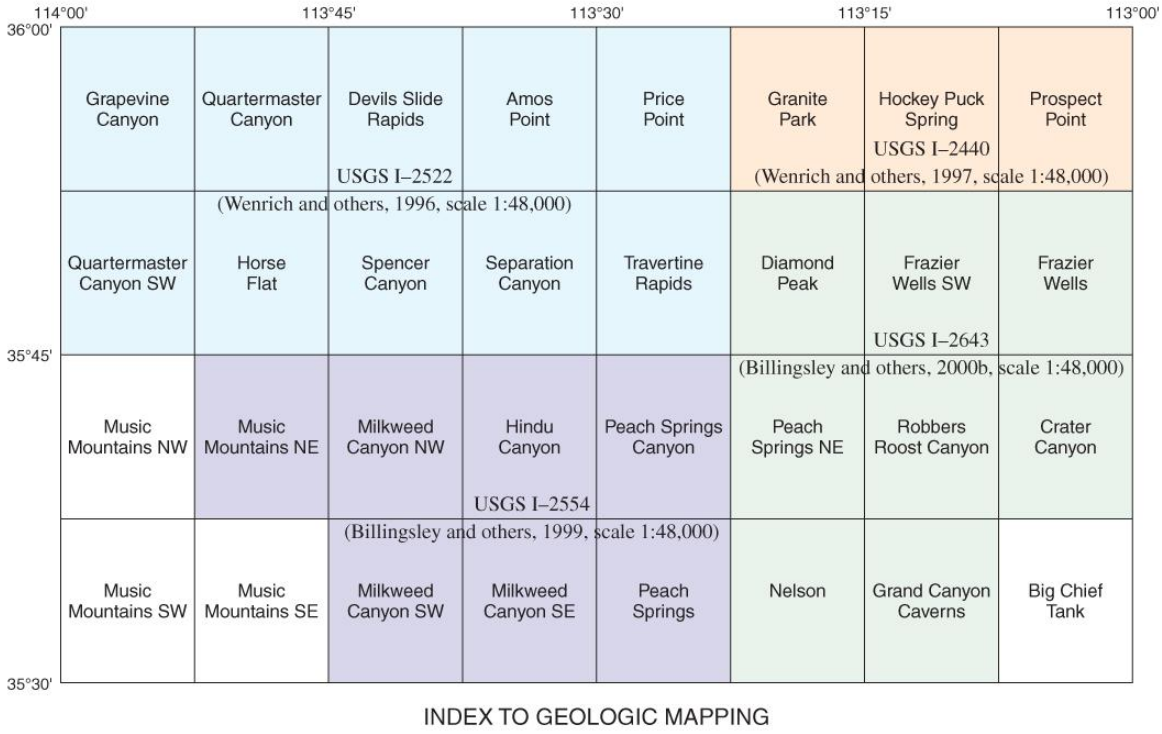
Correlation of Mapped Units



*K-Ar ages of basalts shown in table 1

Extracted from: (Peach Springs 30 x 60).

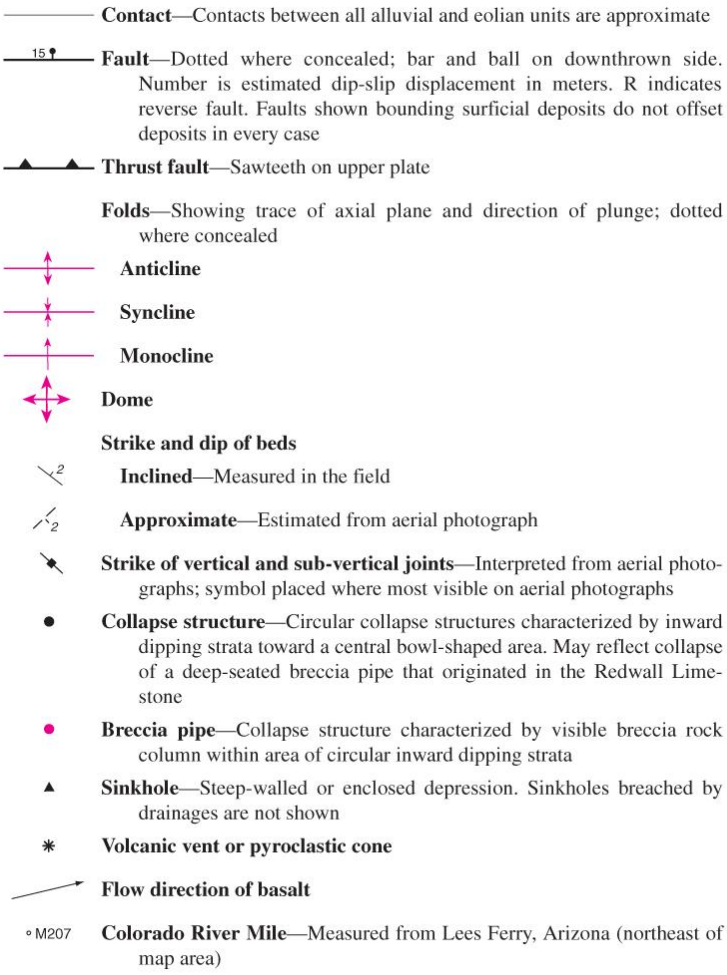
Index to Mapping



INDEX TO GEOLOGIC MAPPING

Extracted from: (Peach Springs 30 x 60).

Legend



Extracted from: (Peach Springs 30 x 60).

Table 1 - K/Ar Ages of Volcanic Rocks

Table 1. *K/Ar ages of volcanic rocks within the Peach Springs 30' x 60' quadrangle and vicinity*

Unit Label	Unit	K-Ar ages (Ma)
Qb	Quaternary basalt	
	Basalt at Colorado River Mile 206 (north of map)	0.174±0.39 (Wenrich and others, 1995)
Tsi, Tsb	Shivwits basalt, undivided	
	Shivwits basalt (north of map)	4.75±0.26 (Best and others, 1980)
	Shivwits basalt (north of map)	6.20±0.30 (Lucchitta and McKee, 1975)
	Dellenbaugh basalt (north of map)	6.78±0.15 (Reynolds and others, 1986)
	Mount Dellenbaugh basalt (north of map)	7.06±0.49 (Best and others, 1980)
	Shivwits basalt (north of map)	7.64±0.30 (Lucchitta and McKee, 1975)
	Price Point basalt (Shivwits Plateau)	8.20±0.1 (Wenrich and others, 1995)
T227i	227-Mile intrusive (Grand Canyon, east central)	13.5±0.3 (Wenrich and others, 1995)
Tbmi, Tbmb	Blue Mountain Basalt (Aubrey Valley)	14.63±1.10 (Damon, 1968)
Tv	Volcanic rocks of the Hualapai Plateau, undivided	
	Grapevine Canyon volcanics (NW corner of map)	15.3±0.3 (Wenrich and others, 1995)
	Iron Mountain basalt (NW corner of map)	17.4±0.9 (Wenrich and others, 1995)
	Peach Springs Tuff (Milkweed Canyon)	18.5±0.2 (Neilson and others, 1990)
	Separation Hill basalt (south Separation Canyon)	19.0±0.44 (Wenrich and others, 1995)
	Peach Springs basalt (at Peach Springs, Ariz.)	19.9±0.4 (Wenrich and others, 1995)
Tp	Quartz monzonite pluton (NW corner of map)	65.5±3.5 (Young, 1979)

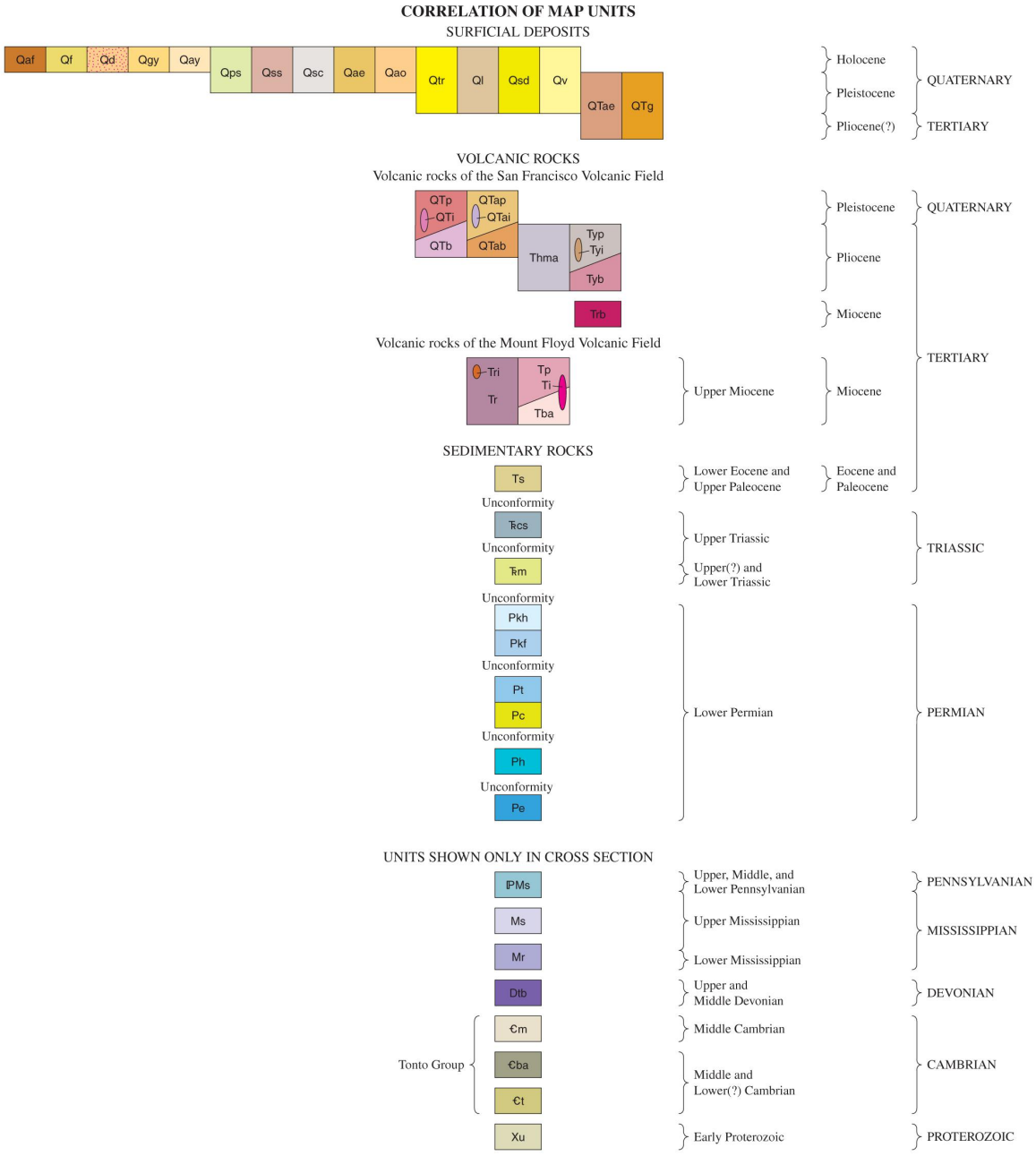
Extracted from: (Peach Springs 30 x 60).

Valle 30' x 60' Quadrangle

Billingsley, G.H., Felger, T.J., and Priest, S.S., 2006, Geologic Map of the Valle 30' x 60' Quadrangle, Coconino County, Northern Arizona, U.S. Geological Survey, Scientific Investigations Map SIM-2895, 1:100000 scale. (GRI Source Map ID 7453)

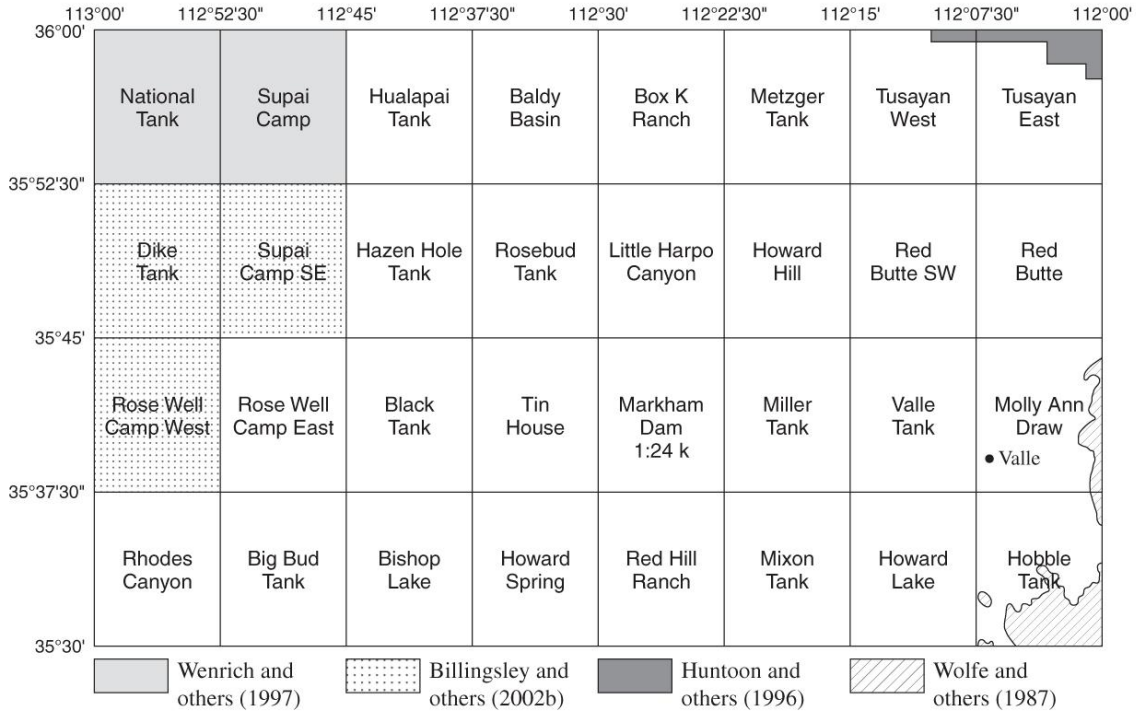
Note: Data for this project was derived from an updated GIS database provided by the USGS that is based on and closely resembles this publication. Although this publication has a scale of 1:100,000, the source GIS database contained 1:24,000 scale data that was utilized for this project. To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/sim/2006/2895/

Correlation of Mapped Units



Extracted from: (Valle 30 x 60).

Index to Mapping



Index to geologic mapping of the Valle 30' x 60' quadrangle, Arizona

Extracted from: (Valle 30 x 60).

Legend

Contact—Contacts between all alluvial and eolian units are approximate and arbitrary

12 **Fault**—Dashed where inferred or approximately located; dotted where concealed; bar and ball on downthrown side. Number is estimated fault separation in meters

Folds—Showing trace of axial surface and direction of plunge; dotted where concealed

Anticline

Plunging anticline

Doubly plunging anticline

Syncline

Plunging syncline

Doubly plunging syncline

Monocline

Dome

Strike and dip of beds

3 **Inclined**—Measured in the field

Implied—Interpreted from aerial photographs; dip amount not determined

Strike of vertical and subvertical joints—Interpreted from aerial photographs; symbol placed where joints are most visible on aerial photographs

Collapse structure—Circular collapse structure characterized by strata dipping inward toward a central point. Collapse area may reflect deep-seated breccia pipe that originated in Redwall Limestone (Mississippian; not exposed at map surface)

Sinkhole—Enclosed depression or cave. Sinkholes breached by drainages are not shown

Volcanic vent or pyroclastic cone

CU **Copper mine**

U **Uranium mine**

Flow direction of basalt

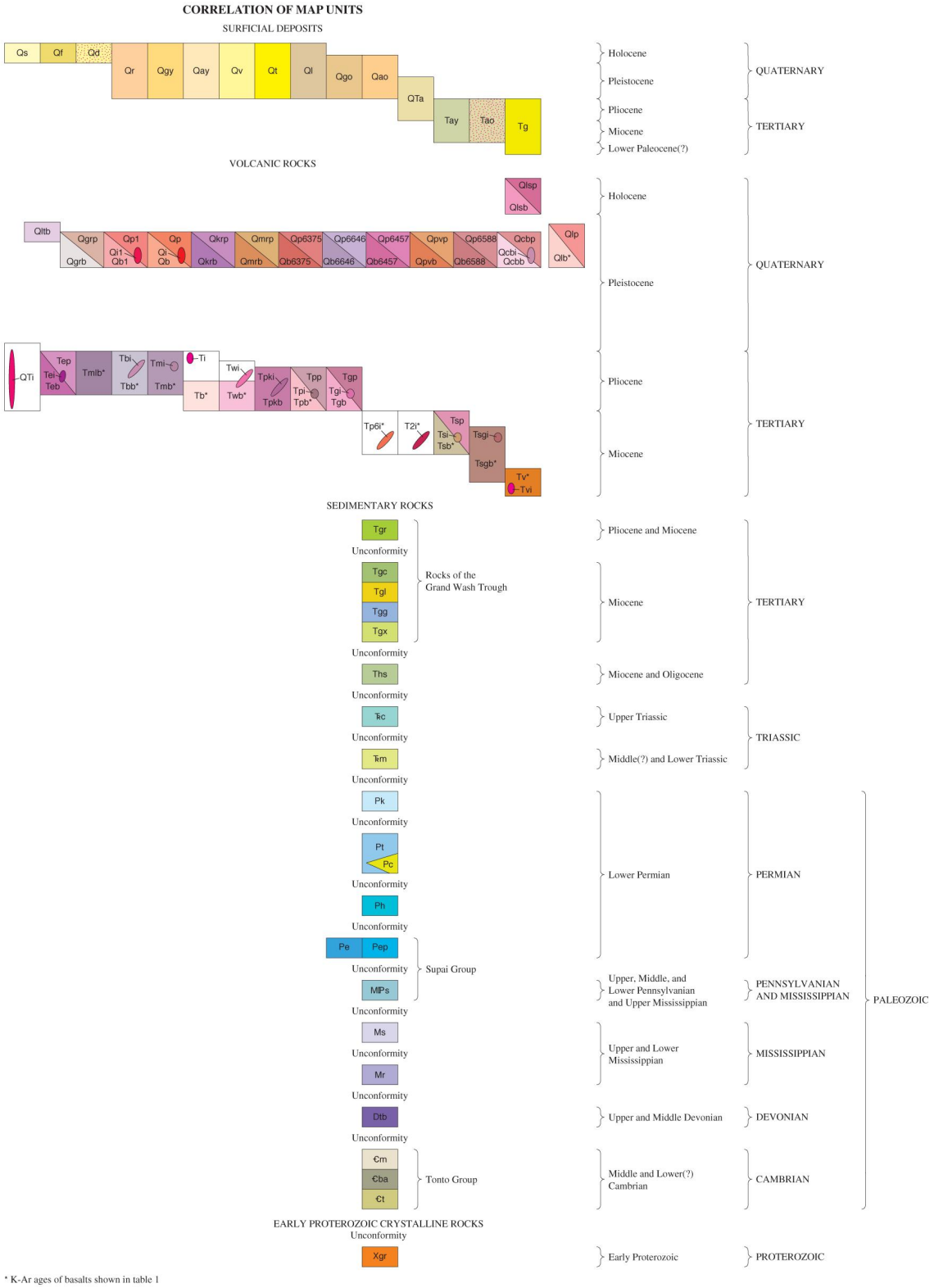
Extracted from: (Valle 30 x 60).

Mount Trumbull 30' x 60' Quadrangle

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, 1:100000 scale. (GRI Source Map ID 4152)

Note: Data for this project was derived from an updated GIS database provided by the USGS that is based on and closely resembles this publication. Some differences may exist. To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/imap/i2766/

Correlation



Extracted from: (Mount Trumbull 30 x 60).

Legend

Extracted from: (Mount Trumbull 30 x 60).

Table 1 - K/Ar Ages of Basalts

Table 1. *Table showing K-Ar ages of basalts*

Unit label	Unit	K-Ar ages (Ma)
Qlb	Little Tanks Basalt	1.0 ± 0.4
Tmlb	Basalt of Mount Logan	2.63 ± 0.34
Tbb	Basalt of Bundyville	3.6 ± 0.18
Tmb	Basalt of Mount Trumbull	3.6 ± 0.18 and 3.67 ± 0.09
Tb	Basalt of the Grand Wash Trough	3.99 ± 0.06; 3.24 ± 0.05; 4.70 ± 0.07
Twb	Whitmore dike swarm	4.56 ± 0.12
Tpb	Poverty Mountain Basalt	4.75 ± 0.26
Tp6i	Dikes of Parashant Canyon and Hundred and Ninetysix Mile Creek	6.34 ± 0.1
T2i	Dikes of Colorado River Mile 202	5.76 ± 0.26
Tsb	Basalt of Shivwits Plateau	6.2 ± 0.30; 7.64 ± 0.30; 6.78 ± 0.15; 7.06 ± 0.49; 8.2 ± 0.1
Tsgb	Snap Point Basalt and Garrett dikes	9.07 ± 0.80; 9.2 ± 0.13
Tv	Volcanic rocks of the Hualapai Plateau, undivided	15.3 ± 0.3; 17.4 ± 0.3; 17.4 ± 0.9

Extracted from: (Mount Trumbull 30 x 60).

Table 2 - Correlation of Units to Photographs

Table 2. *Geologic units unique to the photographs correlated with geologic map units*

Unit label (photographs)	Unit label (map)	Unit name
Qwb	Qb	Basalt flow of Whitmore Canyon unit of Basalt of the Uinkaret Plateau (Hamblin, 1994)
Qbl	Qb	Black Ledge basalt unit of Basalt of the Uinkaret Plateau (Hamblin, 1994)
Qgl	Qb	Grey Ledge basalt unit of Basalt of the Uinkaret Plateau (Hamblin, 1994)
Tgw	Qay	Young alluvial fan deposits
Tgw	Qao	Older alluvial fan deposits
Tgw	Tgc	Surficial and sedimentary rocks of the Grand Wash Trough
Ŧmu	Ŧm	Upper red member of the Moenkopi Formation
Ŧms	Ŧm	Shnabkaib Member of the Moenkopi Formation
Ŧmm	Ŧm	Middle member of the Moenkopi Formation
Pz	Pk–Ȼt	All Paleozoic units on the map
Pkh	Pk	Harrisburg Member of the Kaibab Formation
Pkf	Pk	Fossil Mountain Member of the Kaibab Formation
Ptw	Pt	Woods Ranch Member of the Toroweap Formation
Ptb	Pt	Brady Canyon Member of the Toroweap Formation
Pts	Pt	Seligman Member of the Toroweap Formation
Ȼu	Ȼm	Undifferentiated dolomites of the Muav Limestone
Ȼh	Ȼm	Havasu Member of the Muav Limestone
Ȼg	Ȼm	Gateway Canyon Member of the Muav Limestone
Ȼk	Ȼm	Kanab Member of the Muav Limestone
Ȼp	Ȼm	Peach Springs Member of the Muav Limestone
Ȼs	Ȼm	Unnamed shale of the Muav Limestone
Ȼsp	Ȼm	Spencer Canyon Member of the Muav Limestone
Ȼsa	Ȼm	Sanup Plateau Member of the Muav Limestone
Ȼr	Ȼm	Rampart Cave Member of the Muav Limestone
Ȼrb	Ȼba	Red-brown sandstone member of the Bright Angel Shale
Ȼbm	Ȼba	Unnamed shale and dolomite of the Bright Angel Shale

Extracted from: (Mount Trumbull 30 x 60).

Geologic Photographs



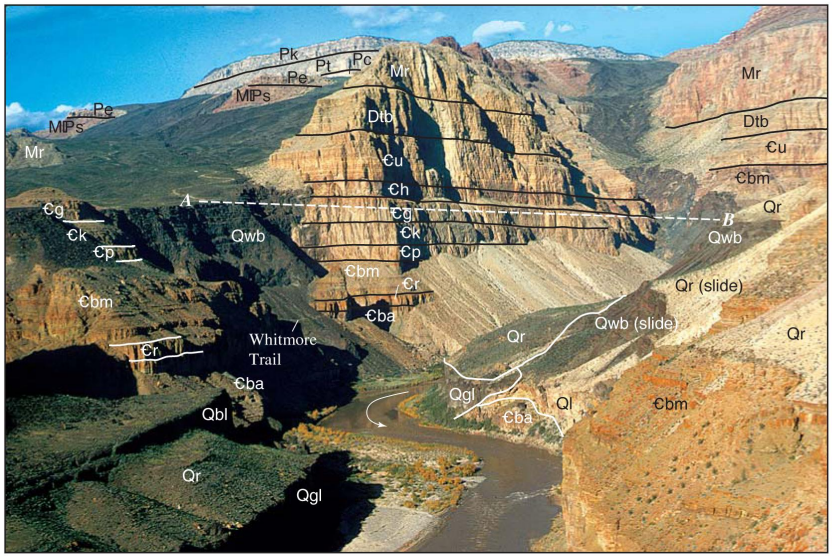
1986 photograph of the mouth of Grand Canyon looking northeast towards the lower Grand Wash Cliffs. Dashed line represents the approximate location of the Grand Wash Fault that separates the Colorado Plateau and Basin and Range geologic provinces (U, upthrown side; D, downthrown side). Rocks of the Grand Wash Trough (Tgw) of the Basin and Range cover the Grand Wash Fault and Paleozoic (Pz) rocks of the lower Grand Wash Cliffs of the Colorado Plateau. (See table 2 for correlation to map units.)



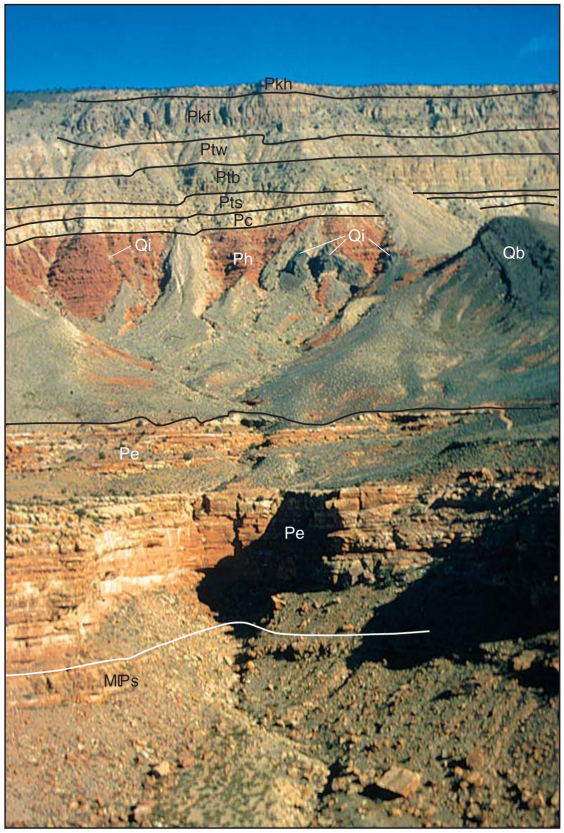
1972 photograph looking northwest into Parashant Canyon at Parashant Graben (U\D/U: D, downthrown side of fault; U, upthrown side) in bottom of canyon. Grassy Mountain is on the skyline. (See table 2 for correlation to map units.)



1985 photograph looking east at Colorado River Mile 190 landslide above and east of Colorado River Mile 190. Bottom of slide has moved horizontally along the top of the Rampart Cave Member (Cr) of the Muav Limestone. There are two concave fault slip planes (arrows ***A*** and ***B***). (See table 2 for correlation to map units.)



1972 photograph looking north and upstream at Colorado River Mile 188 in Whitmore Canyon. Arrow on river shows current direction. Dashed line A–B indicates top of eroded Whitmore basalt dam. (See table 2 for correlation to map units.)



1972 photograph looking east at the west-facing wall of upper Whitmore Canyon near Paws Pocket showing Quaternary intrusive basalt dikes (Qi) and associated flow (Qb). Estimated age of basalt, about 200,000 years (Fenton, 1998). (See table 2 for correlation to map units.)



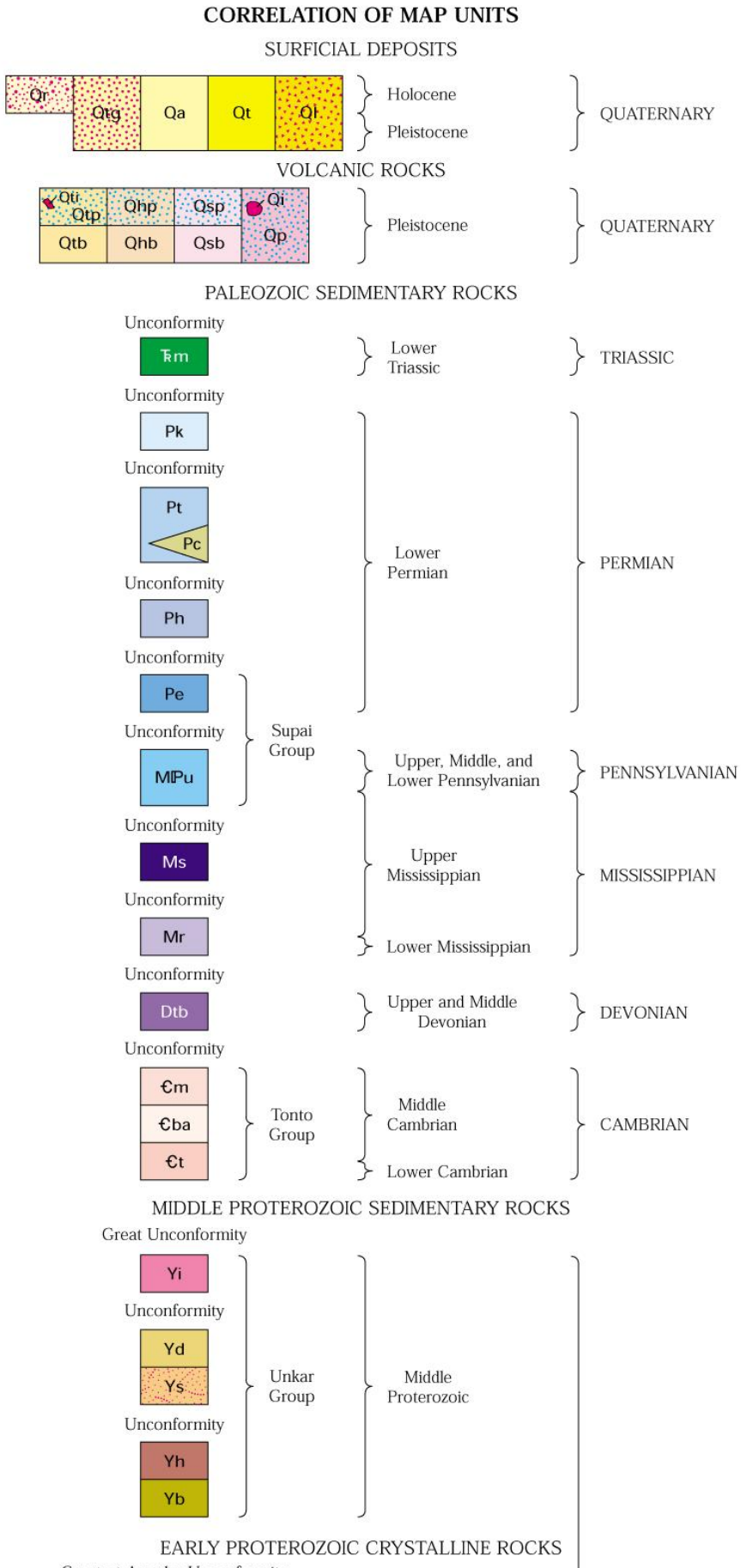
1987 photograph looking west into Hells Hole of upper Whitmore Canyon from the top of Mount Logan showing nearly 1,000 feet of the Moenkopi Formation. (See table 2 for correlation to map units.)

Grand Canyon 30' x 60' Quadrangle

Billingsley, G.H., and Hampton, H.M., 2000, Geologic Map of the Grand Canyon 30' X 60' Quadrangle, Coconino and Mohave Counties, Northwestern Arizona, U.S. Geological Survey, Geologic Investigations Series Map I-2688, 1:100000 scale. (GRI Source Map ID 1309)

Note: To view this publication and the accompanying pamphlet, which contains additional information to what is in this PDF, visit the USGS publications webpage here: http://pubs.usgs.gov/imap/i-2688/

Correlation of Mapped Units



Extracted from: (Grand Canyon 30 x 60).

Legend

Contact

Fault—Dashed where inferred or approximately located; dotted where concealed. Bar and solid ball on downthrown side of Paleozoic displacement; bar and open ball on downthrown side of Precambrian displacement. *R* indicates reverse fault. Number is estimated offset along fault in meters

Folds—Dashed where approximately located; dotted where concealed

Anticline—Showing trace of axial surface and direction of plunge

Syncline—Showing trace of axial surface and direction of plunge

Monocline—Axial trace located approximately midway between top and bottom hinges of fold

Strike and dip of beds

Horizontal

Inclined

Strike of vertical and subvertical joints in Paleozoic rocks

Strike and dip of metamorphic foliation

Inclined

Vertical

Strike and dip of early penetrative layering, and trend and plunge of metamorphic mineral lineation

Strike and dip of main differentiated crenulation cleavage

Strike and dip of late incipient crenulation cleavage

Strike and dip of magmatic foliation

Collapse structure—Black dot shows circular collapse structure characterized by strata dipping inward toward central point; magenta dot shows circular collapse structure characterized by inward-dipping strata and brecciated rock. May reflect collapse of deep-seated breccia pipe that originated in Redwall Limestone

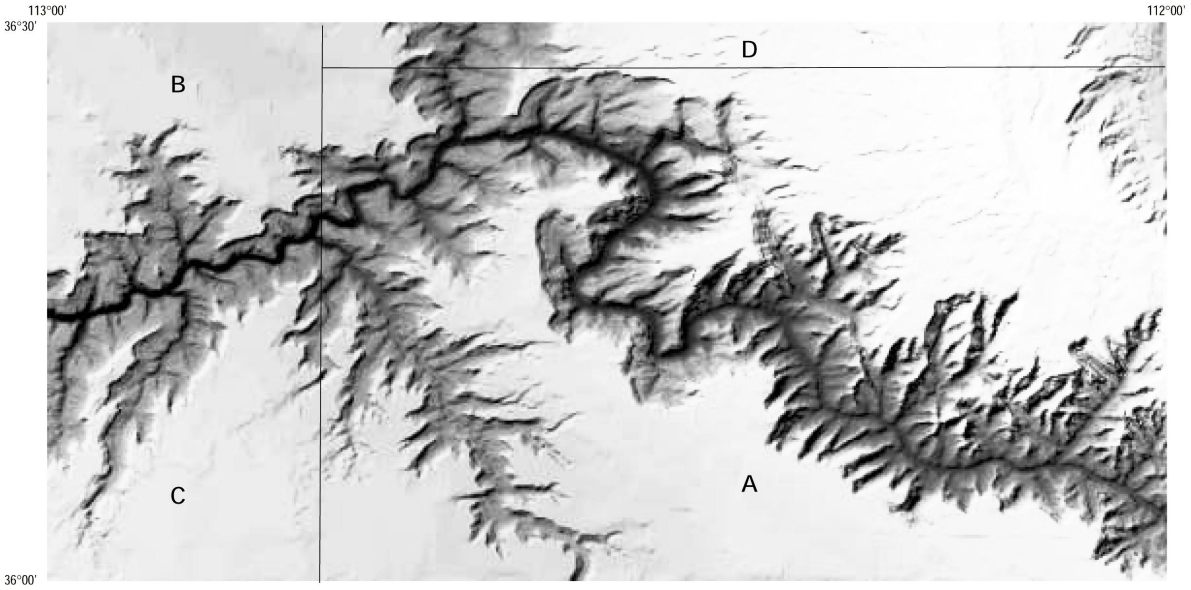
Flow direction of basalt

Pyroclastic cone or vent area

Sinkhole

Extracted from: (Grand Canyon 30 x 60).

Index to Mapping

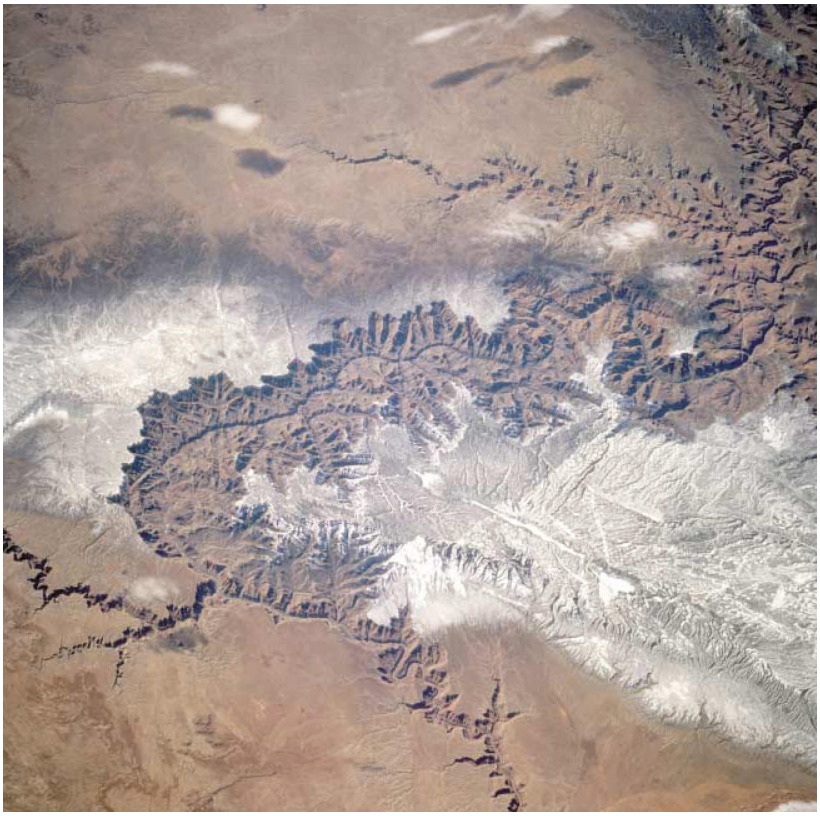


INDEX TO GEOLOGIC MAPPING

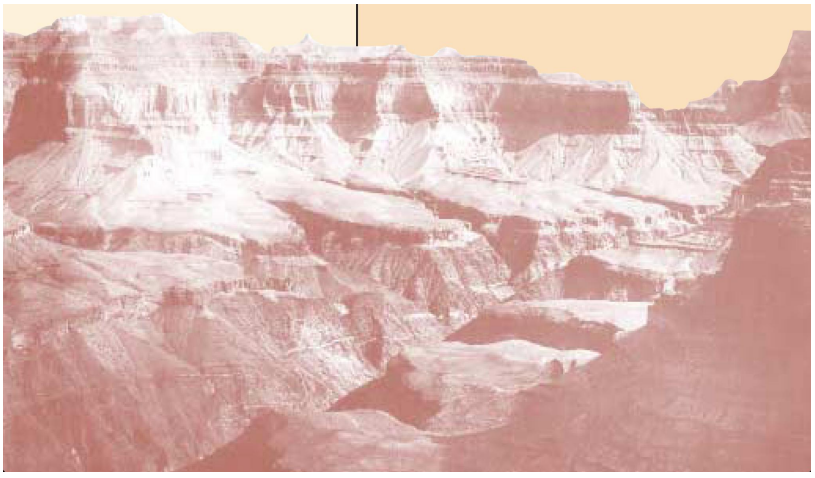
A, Huntoon and others (1996)
B, Billingsley and Huntoon (1983)
C, Wenrich and others (1997)
D, New mapping by George Billingsley, 1997

Extracted from: (Grand Canyon 30 x 60).

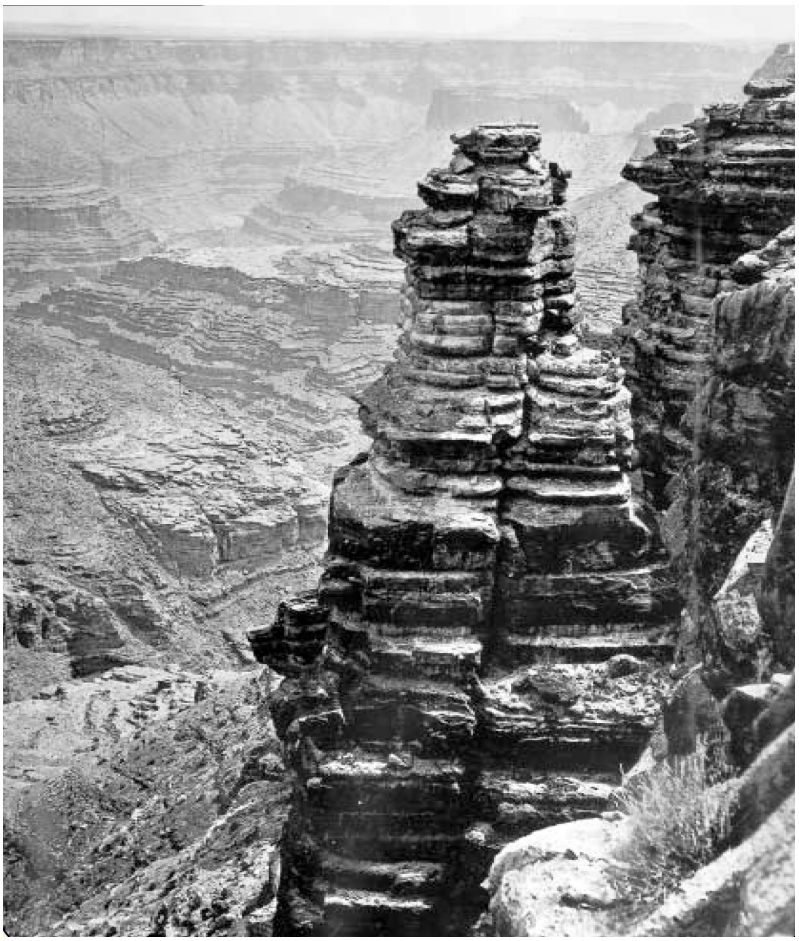
Geologic Photographs



Grand Canyon. West-looking, low-oblique image of the Grand Canyon, Ariz., taken from the Space Shuttle in February 1994 (STS060-083-005). The snow-covered, forested Kaibab Plateau (north of the canyon) and the Coconino Plateau (south of the canyon) are visible. The western portions of the Painted Desert can be seen east of the canyon where the Little Colorado River joins the Colorado River. *Source of image: http://earth.jsc.nasa.gov/lores.cgi?PHOTO=STS060-083-005*



Tonto Platform. View eastward up Kaibab division of Grand Canyon from level of the Esplanade directly under Havasupai Point. *Photograph by N.W. Carkhuff.*



Marble Canyon. Looking into the Marble Canyon of the Colorado River. The Shinumo Altar is in the distance. *Photograph by J.K. Hillers.*

Extracted and modified from: (Grand Canyon 30 x 60).

Geologic Figures



Figure 1. Aerial view looking south at Supai in Havasu Canyon of Havasu Creek. Downtown Supai is lower left of photo. The cliffs are those of the Supai Group [Esplanade Sandstone (Pe), Wescogame Formation (Pwe), Manakacha Formation (Pm), and Watahomigi Formation (MPwa)]. Unit Qt is travertine deposits. The Redwall Limestone is under the alluvial valley floor. *Photograph by G.H. Billingsley*.

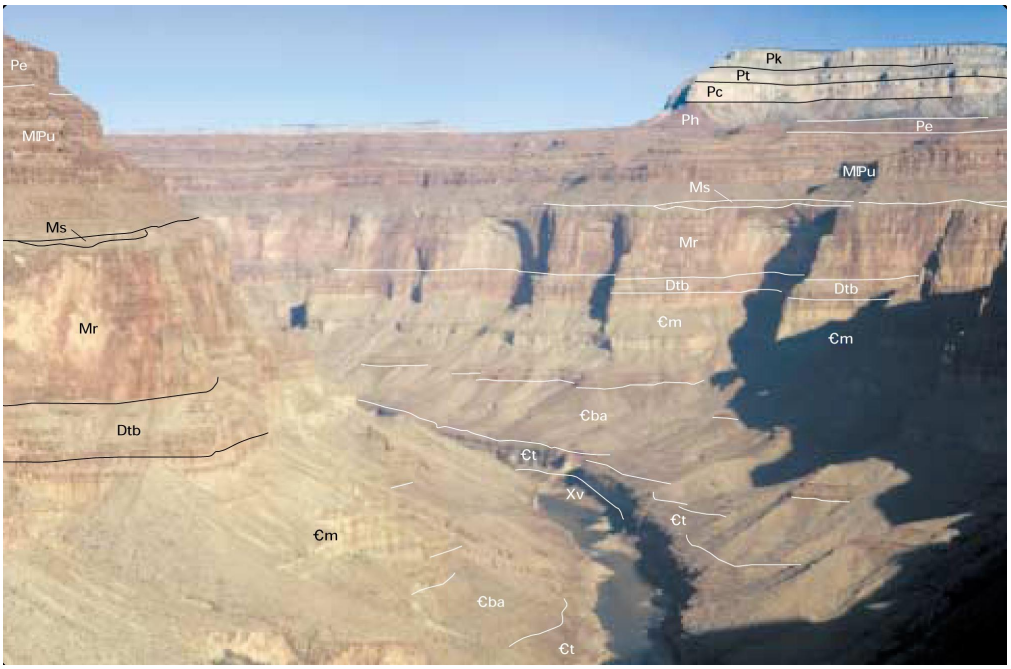


Figure 2. Aerial view looking north down Colorado River towards the southwestern end of Powell Plateau. Kaibab Formation (Pk), Toroweap Formation (Pt), Coconino Sandstone (Pc), Hermit Formation (Ph), Esplanade Sandstone (Pe), Wescogame, Manakacha, and Watahomigi Formations, undivided (MPu), Surprise Canyon Formation (Ms), Redwall Limestone (Mr), Temple Butte Formation (Dtb), Muav Limestone (Cm), Bright Angel Shale (Cba), Tapeats Sandstone (Ct), and Vishnu Schist (Xv). *Photograph by G.H. Billingsley*.



Figure 3. Aerial view looking northwest towards Shinumo Creek and Powell Plateau. Faults are not shown because of perspective problems in this view. Only general contacts in Late Proterozoic units are shown as a general guide to this complicated region. Paleozoic rocks: Kaibab Formation (Pk), Toroweap Formation (Pt), Coconino Sandstone (Pc), Hermit Formation (Ph), Esplanade Sandstone (Pe), Wescogame, Manakacha, and Watahomigi Formations, undivided (MPu), Redwall Limestone (Mr), Temple Butte Formation (Dtb), Muav Limestone (Cm), Bright Angel Shale (Cba), and Tapeats Sandstone (Ct). Proterozoic rocks: unnamed diabase sills and dikes (Yi), Shinumo Quartzite (Ys), Hakatai Shale (Yh), Bass Formation (Yb), and Vishnu Schist (Xv). *Photograph by G.H. Billingsley*.

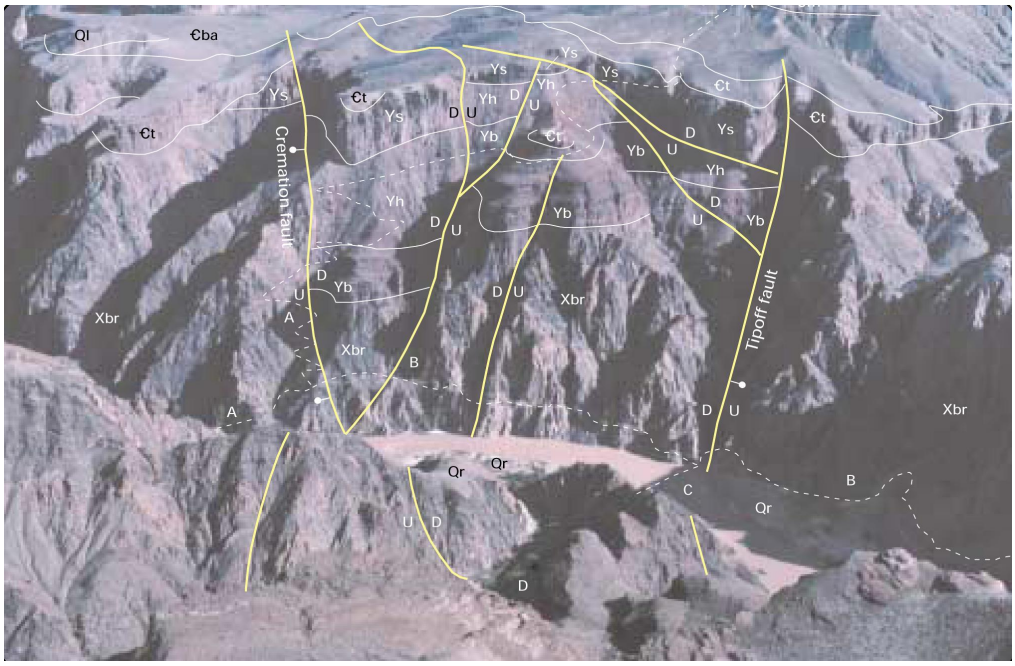


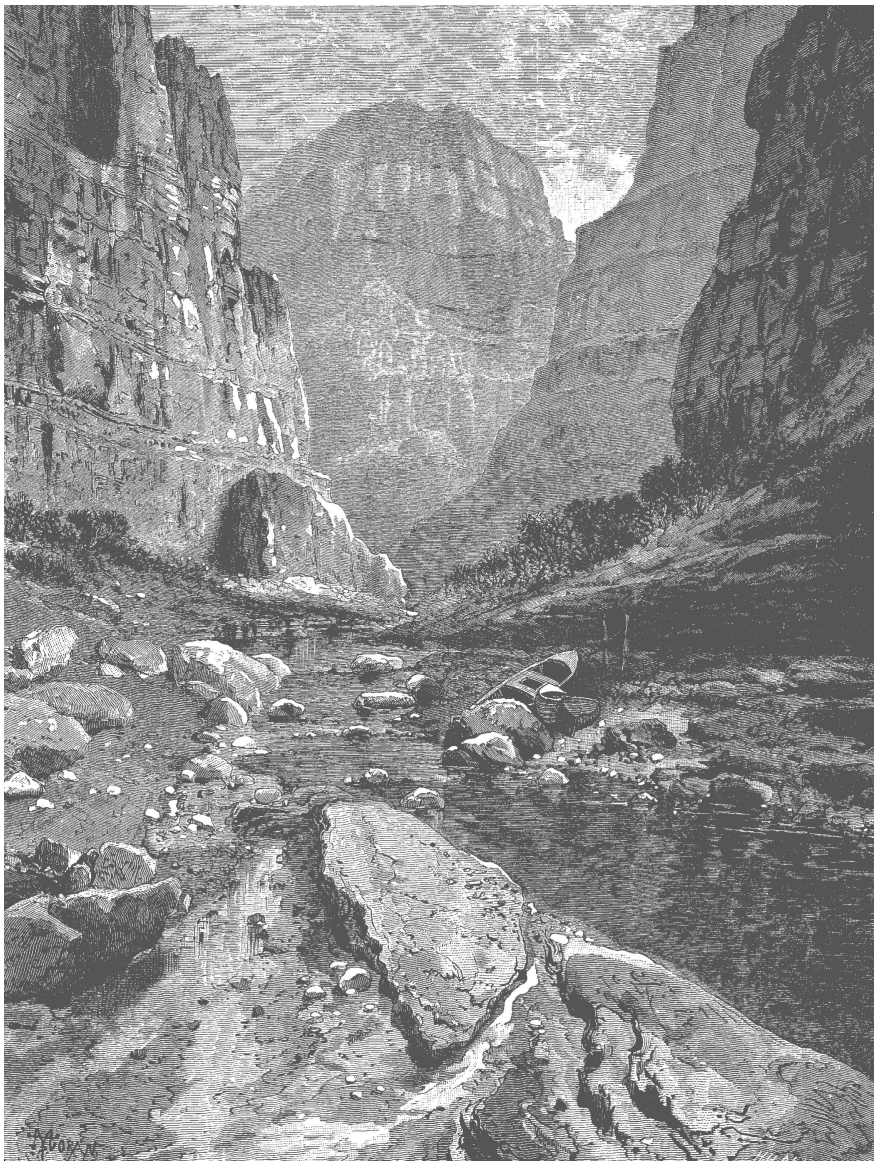
Figure 4. Aerial view looking southeast to the mouth of Bright Angel Creek, Bright Angel Campground (D), lower part of south Kaibab Trail (A), Bright Angel Trail (B), and lower bridge crossing (C) of the Colorado River. View shows a Proterozoic-age graben that is now a Paleozoic horst between the Cremation and Tipoff faults; Paleozoic offsets shown by bar and ball; Proterozoic offsets shown by U (upthrown) and D (downthrown). Colorado River gravel deposits (Qr), landslide deposits (Ql), Muav Limestone (Ꞓm), Bright Angel Shale (Ꞓba), Tapeats Sandstone (Ꞓt), Shinumo Quartzite (Ys), Hakatai Shale (Yh), Bass Formation (Yb), and Brahma Schist (Xbr). *Photograph by G.H. Billingsley*.



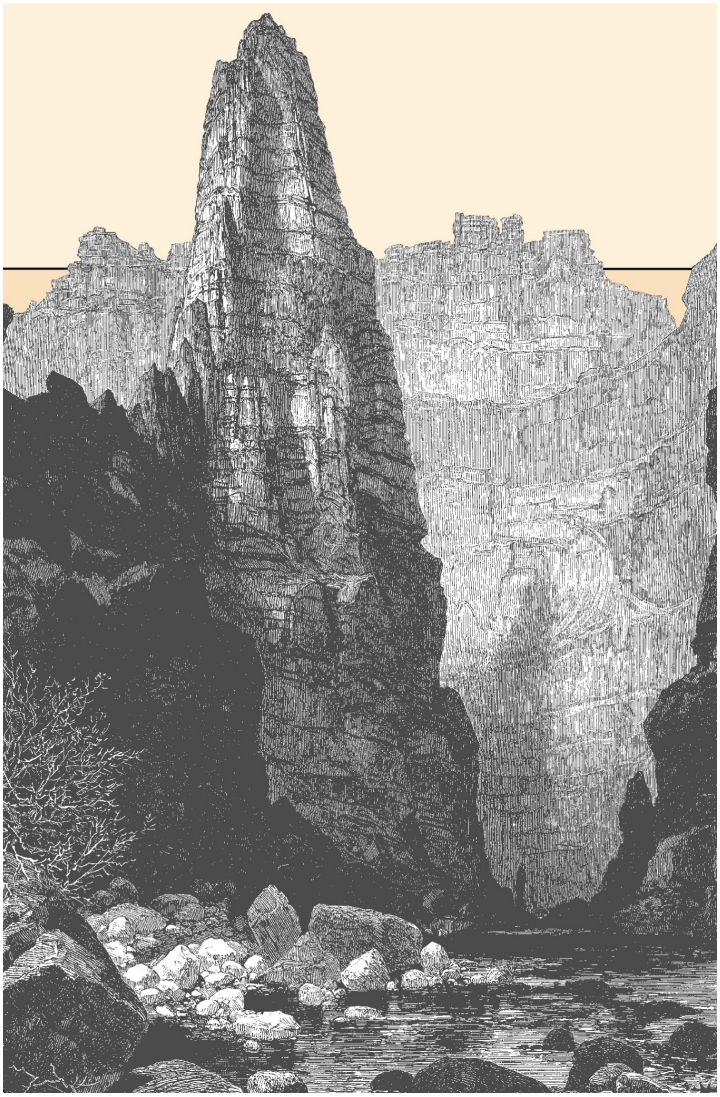
Figure 5. Aerial view looking northwest towards Thunder Spring and Thunder River, which joins Tapeats Creek just below photo. Surprise Valley landslide (Ql) is one of the largest landslides in the map area. Redwall Limestone (Mr), Temple Butte Formation (Dtb), Muav Limestone (Ꞓm), Bright Angel Shale (Ꞓba), and Shinumo Quartzite (Ys). The red-brown member of the Bright Angel Shale (rb) overlies the Shinumo Quartzite and is a tongue of sandstone lithologically similar to the Tapeats Sandstone. *Photograph by G.H. Billingsley.*

Extracted from: (Grand Canyon 30 x 60).

Geologic Sketches



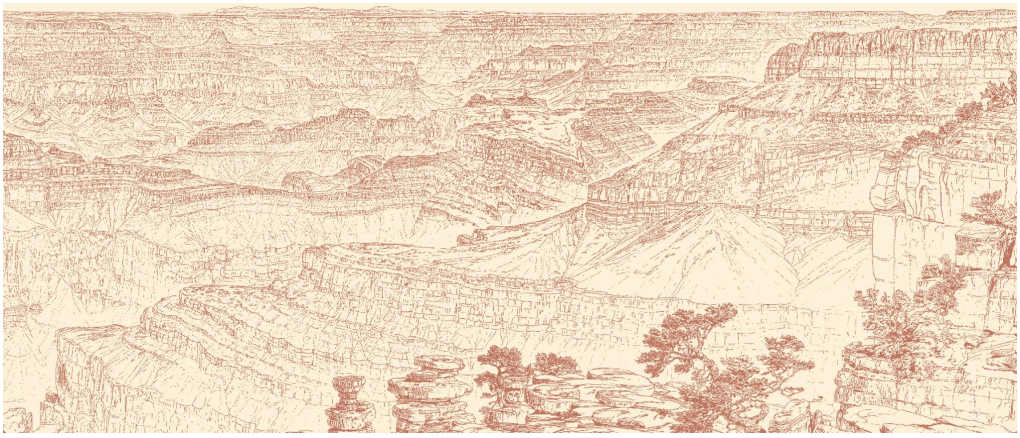
Kanab Canyon. Woodcut of drawing by Thomas Moran showing Kanab Canyon, near the junction of Kanab Creek with the Colorado River. About 2,800 feet of wall is shown here, the upper portion being the Red Wall. The upper walls (Aubrey Cliffs) are not disclosed. The depth of Kanab Canyon here is about 4,700 feet. *From U.S. Geological Survey Second Annual Report (1880–1881).*



Kanab Canyon. The pinnacle or tower is in the Redwall Limestone of the Kanab Canyon and is about 780 feet high. This woodcut is from an original drawing by Thomas Moran. *From U.S. Geological Survey Second Annual Report (1880–1881).*



Panorama from Point Sublime, looking east. From original drawing by W.H. Holmes. *From U.S. Geological Survey Second Annual Report (1880–1881).*



Panorama from Point Sublime, looking west. From original drawing by W.H. Holmes. *From U.S. Geological Survey Second Annual Report (1880–1881).*



The Toroweap. A pinnacled gable of the Toroweap. Woodcut from the original drawing by W.H. Holmes. *From U.S. Geological Survey Monograph 2 (1882).*

Extracted from: (Grand Canyon 30 x 60).

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This document was developed and completed by James Winter, Kari Lanphier and James Chappell (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory(GRI) Program. Quality control of this document by James Chappell (Colorado State University).

The information in this document was compiled from GRI source maps, and intended to accompany the digital geologic-GIS maps and other digital data for Grand Canyon National Park, Arizona (GRCA) developed by Derek Witt and James Chappell (Colorado State University) (see the GRI Digital Maps and Source Map Citations section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS maps).

GRI finalization by Jim Chappell (Colorado State University).

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