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

Montezuma Castle National Monument and Tuzigoot National Monument

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Montezuma Castle National Monument and Tuzigoot National Monument

moca_tuzi_geology.pdf

Version: 5/6/2019

Geologic Resources Inventory Map Document for Montezuma Castle National Monument and Tuzigoot National Monument

Table of Contents

Geologic Resources Inventory Map Document 1
About the NPS Geologic Resources Inventory Program 3
GRI Digital Maps and Source Map Citations 5
Index Map 6
Digital Surficial Geologic-GIS Map of Tuzigoot National Monument, Arizona (GRI MapCode CLAR) 7
Map Unit List 7
Map Unit Descriptions 8
Qaf1 - Quarry (Holocene) 8
Qaf2 - Tailings (Holocene) 8
Qyr - Active channels of major streams (Holocene) 8
Qyt - Young terraces (late Holocene) 8
Qyp - Young piedmont alluvium (late Holocene) 8
Qs - Sheepshead Group, undivided (late Pleistocene to Holocene) 9
Qs2 - Sheepshead Group, younger unit (Holocene) 9
Qs1 - Sheepshead Group, older unit (late Pleistocene) 9
Chuckwalla Terraces (middle Pleistocene to early Holocene) 9
Qct2 - Chuckwalla Terraces, younger terraces (middle Pleistocene to early Holocene) 10
Qct1 - Chuckwalla Terraces, older terraces (middle Pleistocene to early Holocene) 10
Chuckwalla Group (middle Pleistocene to early Holocene) 10
Qc2 - Chuckwalla Group, youngest member (latest Pleistocene to early Holocene) 10
Qc1 - Chuckwalla Group, older deposits (middle to late Pleistocene) 11
Qc1b - Chuckwalla Group, older deposits, subunit 1b (middle to late Pleistocene) 11
Qc1a - Chuckwalla Group, older deposits, subunit 1a (middle to late Pleistocene) 11
Qmt - Montezuma Terraces (middle Pleistocene) 11
Qm - Montezuma alluvial fan complex (middle Pleistocene) 12
Oxbow Terraces (early Pleistocene) 12
Qot3 - Oxbow Terraces, terrace 3 (early Pleistocene) 12
Qot2 - Oxbow Terraces, terrace 2 (early Pleistocene) 13
Qot1 - Oxbow Terraces, terrace 1 (early Pleistocene) 13
Oxbow Group (early Pleistocene) 13
Oxbow Group, subunit 2 (early Pleistocene) 13
Qo2a - Oxbow Group, subunit 2a (early Pleistocene) 14
Qo2b - Oxbow Group, subunit 2b (early Pleistocene) 14
Qvx - Verde Mix (Quaternary) 14
Tvl - Verde Formation, lacustrine facies (late Miocene to Pliocene) 14
Tvg - Verde Formation, gravel facies (late Miocene to Pliocene) 14
Tb - Basalt (Miocene to Pliocene) 14
PZs - Sedimentary rocks (Paleozoic) 15
Xmv - Metavolcanics (Precambrian) 15
AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4) Source Information 15
Index Map 16
Report 16

Digital Geologic-GIS Map of Tuzigoot National Monument, Arizona (GRI MapCode TUZI) 17

Map Unit List 17
Map Unit Descriptions 18
Qaf - Artificial fill (Quaternary) 18
Alluvial river terraces and riverwash (Quaternary) 18
Qr - River wash (Quaternary) 18
Qt - Terrace deposits (Quaternary) 18
Qg - Gravel deposits (Quaternary) 19
Verde Formation (Quaternary) 19
QTv - Verde Formation, lacustrine deposits (Quaternary) 23
QTvg - Verde Formation, gravel deposits (Quaternary) 23
QTvv - Verde Formation, volcanic rocks (Quaternary) 23
Hickey Formation (Tertiary) 23
Thv - Hickey Formation, volcanic rocks (Tertiary) 27
Ths - Hickey Formation, sedimentary rocks (Tertiary) 28
Supai Formation (Permian and Pennsylvanian) 28
Psu - Supai Formation, upper member (Permian) 32
Psm - Supai Formation, middle member (Permian) 32
PPNsl - Supai Formation, lower member (Permian and Pennsylvanian) 32
Mr - Redwall Limestone (Mississippian) 33
Dm - Martin Limestone (Devonian) 35
Ct - Tapeats Sandstone (Cambrian) 39
Precambrian rocks 40
PCg - Gabbro (Precambrian) 42
PCq - Quartz porphyry (Precambrian) 42
PCgg - Grapevine Gulch Formation (Precambrian) 42
PCd - Deception Rhyolite (Precambrian) 42
Geologic Cross Sections 42
Cross Section A-A' 42
Cross Section B-B' 42
Cross Section C-C' 42
Cross Section D-D' 43
Cross Section E-E' 43
Cross Section F-F' 43
USGS Bulletin 1021-N, Plate 45 Source Information 43
Correlation of Units 44
Map Legend 45
Stratigraphic Section 46
Report 46

Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (GRI MapCode MOTU) 48

Map Unit List 48
Map Unit Descriptions 50
Qa - Artificial fill (Holocene) 50
Qal - Alluvium (Holocene) 50
Qc - Colluvium and sedimentary breccia (Holocene and Pleistocene) 50
Qf - Fanglomerate (Holocene and Pleistocene) 50
Qt - Terrace gravel (Holocene and Pleistocene) 50
Qg - Gravel (Holocene and Pleistocene) 51
Qs - Sediment (Holocene and Pleistocene) 51
QTl - Landslide deposits (Pliocene to Holocene) 51
QTf - Fanglomerate (Pleistocene and Pliocene) 51
QTg - Gravel (Pleistocene and Pliocene) 51

QTs - Sedimentary rocks (Pleistocene and Pliocene) 51
Verde Formation (Pliocene and Miocene) 51
Tvs - Verde Formation, undivided sedimentary rocks (Pliocene and Miocene) 51
Tvl - Verde Formation, lacustrine rocks (Pliocene and Miocene) 52
Tvls - Verde Formation, limestone (Pliocene and Miocene) 52
Tvg - Verde Formation, gravel (Pliocene and Miocene) 52
Tvt - Verde Formation, travertine (Pliocene) 52
Tve - Verde Formation, evaporite beds (Miocene) 52
Younger volcanic and sedimentary rocks (Pliocene and Miocene) 52
Taby - Younger volcanic and sedimentary rocks, alkali basalt (Pliocene and Miocene) 52
Tby - Younger volcanic and sedimentary rocks, basalt (Pliocene and Miocene) 53
Tdy - Younger volcanic and sedimentary rocks, dacite (Pliocene and Miocene) 53
Tbsy - Younger volcanic and sedimentary rocks, basalt and sedimentary (Pliocene and Miocene) 53
Tsvy - Younger volcanic and sedimentary rocks, sedimentary and volcanic (Pliocene and Miocene) 54
Tsy - Younger volcanic and sedimentary rocks, sedimentary (Pliocene and Miocene) 54
Older volcanic and sedimentary rocks (Miocene) 54
Tabo - Older volcanic and sedimentary rocks, alkali basalt (Miocene) 54
Tbo - Older volcanic and sedimentary rocks, basalt (Miocene) 54
Tco - Older volcanic and sedimentary rocks, cinders and cinder cones (Miocene) 55
Tao - Older volcanic and sedimentary rocks, andesite (Miocene) 55
Tto - Older volcanic and sedimentary rocks, tuff (Miocene) 55
Hickey Formation (Miocene) 55
Thab - Hickey Formation, alkali basalt (Miocene) 56
Thb - Hickey Formation, basalt (Miocene) 56
Tha - Hickey Formation, trachyandesite (Miocene) 57
Thbs - Hickey Formation, basalt and sedimentary rocks (Miocene) 57
Thsb - Hickey Formation, sedimentary rocks and basalt (Miocene) 57
Ths - Hickey Formation, sedimentary rocks (Miocene) 57
Lati-andesite of Sullivan Buttes and Santa Maria Mountains (Miocene? and Oligocene) 58
Tlal - Lati-andesite of Sullivan Buttes and Santa Maria Mountains, lower unit (Miocene? and Oligocene) 58
Pk - Kaibab Limestone (Lower Permian) 58
Pkt - Kaibab Limestone and Toroweap Formation, undivided (Lower Permian) 58
Ptc - Toroweap Formation and Coconino Sandstone (Lower Permian) 58
Psh - Schnebly Hill Formation (Lower Permian) 58
Ph - Hermit Formation (Lower Permian) 58
PNs - Supai Formation (Upper Mississippian or Upper Pennsylvanian to Lower Permian) 59
Mr - Redwall Limestone (Mississippian) 59
MDrm - Redwall Limestone and Martin Formation, undivided (Middle? Devonian to Mississippian) 59
Dm - Martin Formation (Upper and Middle? Devonian) 59
DCmt - Martin Formation and Tapeats Sandstone, undivided (Upper Devonian through Lower Cambrian) 59
Ct - Tapeats Sandstone (Middle and Lower Cambrian) 59
Tonalitic rocks (Early Proterozoic) 59
Xchd - Tonalitic rocks, dikes of Cherry (Early Proterozoic) 60
Xch - Tonalitic rocks, Cherry Tonalite (Early Proterozoic) 60
Xtgr - Texas Gulch Formation, rhyolitic meta-tuffaceous rocks (Early Proterozoic) 60
Xtgs - Texas Gulch Formation, purple slate (Early Proterozoic) 60
Gabbroic rocks (Early Proterozoic) 61
Xgb - Gabbroic rocks, gabbro (Early Proterozoic) 61
Xb - Basaltic flows (Early Proterozoic) 62
Xa - Andesitic flows (Early Proterozoic) 63
Xd - Dacitic flows (Early Proterozoic) 63
Xrd - Rhyodacitic flows (Early Proterozoic) 64
Xr - Rhyolitic flows and pyroclastic rocks (Early Proterozoic) 64
Xah - Altered andesitic rocks (Early Proterozoic) 65

Xrh - Altered rhyolitic and pyroclastic rocks (Early Proterozoic) ... 66
Xmv - Mafic rocks (Early Proterozoic) ... 66
Xt - Tuffaceous metasedimentary rocks (Early Proterozoic) ... 66
Xa1 - Andesitic breccia (Early Proterozoic) ... 67
Xr1 - Rhyolitic breccia (Early Proterozoic) ... 67
Xd1h - Altered dacitic breccia (Early Proterozoic) ... 67
Xr1h - Altered rhyolitic breccia (Early Proterozoic) ... 67
Xd2 - Dacitic tuff (Early Proterozoic) ... 67
Xr2 - Rhyolitic tuff (Early Proterozoic) ... 68
Xr2h - Altered rhyolitic tuff (Early Proterozoic) ... 69
Xd3 - Dacitic intrusive rocks (Early Proterozoic) ... 69
Xr3 - Rhyolitic intrusive rocks (Early Proterozoic) ... 69
USGS SIM-2996 Source Information ... 69
Location Map ... 69
Index to Sources of Geologic Mapping ... 70
Correlation of Units ... 71
List of Map Units ... 72
Map Legend ... 73
Geochemistry Data ... 74
Pamphlet ... 75
Photographs ... 76
Travertine vent in Tertiary Verde Formation ... 76
Metamorphosed basaltic agglomerate ... 77
Massive sulfide ore ... 78
GRI Digital Data Credits ... 79

Geologic Resources Inventory Map Document

Montezuma Castle National Monument and Tuzigoot National Monument, Arizona

Document to Accompany Digital Geologic-GIS Data

moca_tuzi_geology.pdf

Version: 5/6/2019

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (MOCA and TUZI).

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.

This document contains the following information:

1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.

2) **GRI Digital Maps and Source Citations** – A listing of all GRI digital geologic-GIS maps produced for this project along with sources used in their completion. In addition, a brief explanation of how each source map was used is provided.

3) **Digital Surficial Geologic-GIS Map of Tuzigoot National Monument, Arizona (*GRI MapCode CLAR*)**

   A) **Map Unit List** – A listing of all geologic map units present on the Digital Surficial Geologic-GIS Map of Tuzigoot National Monument, generally listed from youngest to oldest.

   B) **Map Unit Descriptions** – Descriptions for all surficial geologic map units present on the Digital Surficial Geologic-GIS Map of Tuzigoot National Monument.

   C) **AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4) Source Information -** Additional source map information including a report and an index map.

4) **Digital Geologic-GIS Map of Tuzigoot National Monument, Arizona (*GRI MapCode TUZI*)**

A) **Map Unit List** – A listing of all geologic map units present on the Digital Geologic-GIS Map of Tuzigoot National Monument, generally listed from youngest to oldest.

B) **Map Unit Descriptions** – Descriptions for all geologic map units present on the Digital Geologic-GIS Map of Tuzigoot National Monument.

C) **Geologic Cross Sections** – Geologic cross section graphics with source geologic cross section abbreviations.

D) **USGS Bulletin 1021-N, Plate 45 Source Information -** Additional source map information including a report, correlation of units, and map legend.

5) **Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (*GRI MapCode MOTU*)**

A) **Map Unit List** – A listing of all geologic map units present on the Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument, generally listed from youngest to oldest.

B) **Map Unit Descriptions** – Descriptions for all geologic map units present on the Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument.

C) **USGS SIM-2996 Source Information -** Additional source map information including a pamplet, location map, correlation of units, and other ancillary map information.

6) GRI Digital Data Credits – GRI digital geologic-GIS data and ancillary map information document production credits.

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

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

About the NPS Geologic Resources Inventory Program

Background

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

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

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

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

Products

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

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

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

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

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

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park(s), enter “GRI” as a Search Text term, and then select the Search Button.

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

Jason Kenworthy
Inventory Report Coordinator
National Park Service Geologic Resources Division
P.O. Box 25287
Denver, CO 80225-0287
phone: (303) 987-6923
fax: (303) 987-6792
email: Jason_Kenworthy@nps.gov

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

GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS maps for Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (MOCA and TUZI). For each GRI digital geologic-GIS map the source map used, and its contribution, is presented.

Digital Surficial Geologic-GIS Map of Tuzigoot National Monument, Arizona (*GRI MapCode CLAR*)

House, Kyle P. and Pearthree, Philip A., 1993, Surficial Geology of the Northern Verde Valley, Yavapai County, Arizona: Arizona Geological Survey, Open-File Report 93-16, Sheet 1 of 4, scale 1:24,000 (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4). (*GRI Source Map ID 1091*).

The GRI used the full extent of the source digital GIS data, and incorporated prominent components of the provided source map and report (e.g., unit colors and unit descriptions) into the GRI digital geologic-GIS dataset and product.

Digital Geologic-GIS Map of Tuzigoot National Monument, Arizona (*GRI MapCode TUZI*)

Lehner, Robert E., 1958, Geology of the Clarkdale Quadrangle: U.S. Geological Survey, Bulletin 1021-N, Plate 45, scale 1:48,000 (USGS Bulletin 1021-N, Plate 45). (*GRI Source Map ID 1092*).

The GRI used the full extent of the source digital GIS data, and incorporated prominent components of the provided source map and report (e.g., unit colors and unit descriptions) into the GRI digital geologic-GIS dataset and product.

Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (*GRI MapCode MOTU*)

DeWitt, E., et. al., 2008, Geologic Map of the Prescott National Forest and the Headwaters of the Verde River, Yavapai and Coconino Counties, Arizona: U.S. Geological Survey, Scientific Investigations Map, SIM-2996, scale 1:100,000 (USGS SIM-2996). (*GRI Source Map ID 75246*).

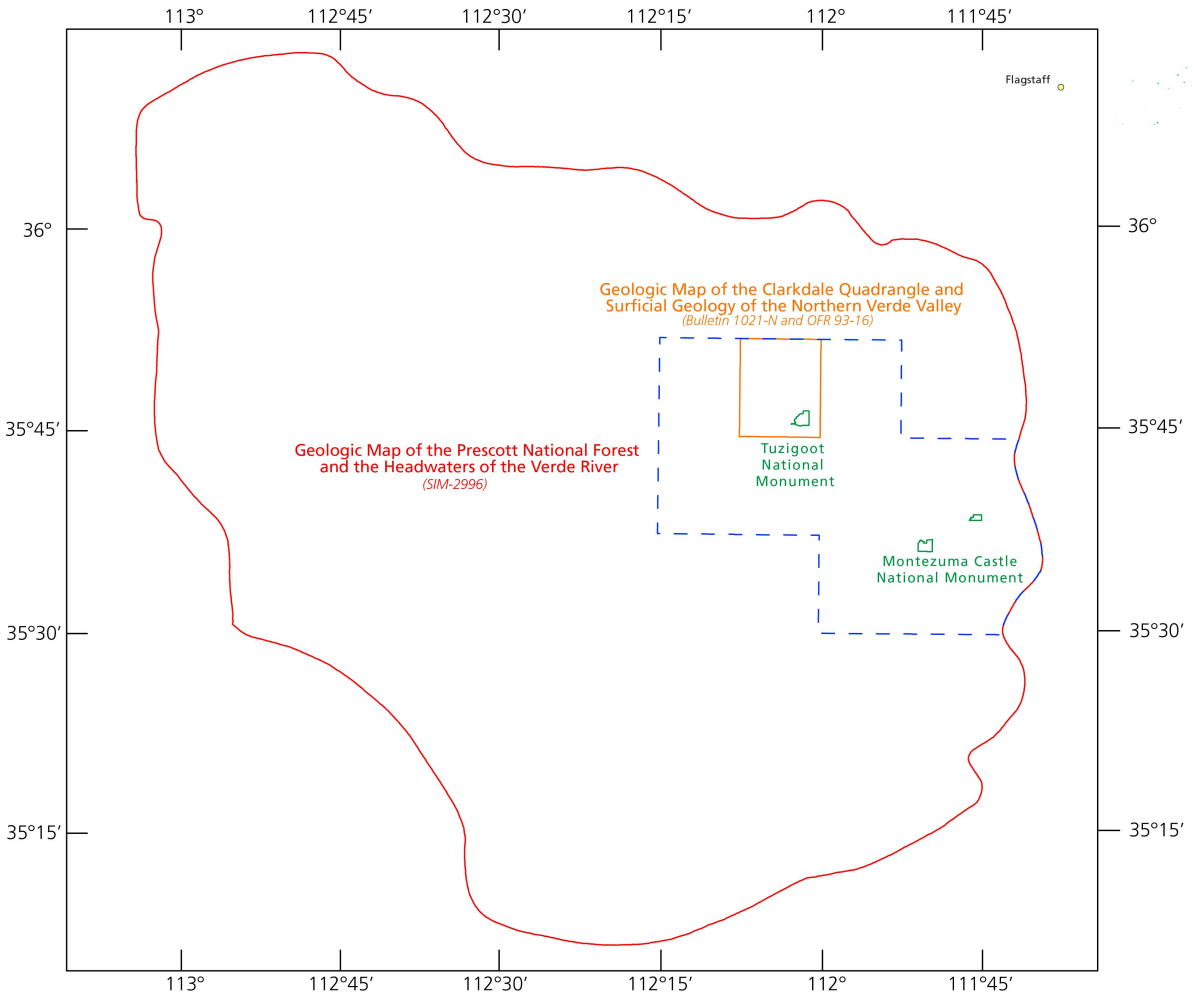
The GRI used only a partial extent of the source digital GIS data, and incorporated prominent components of the provided source map and report (e.g., unit colors and unit descriptions) into the GRI digital geologic-GIS dataset and product.

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

Index Map

The following index map displays the park boundaries for Montezuma Castle National Monument and Tuzigoot National Monument, as well as the extent of GRI digital geologic-GIS maps produced for these park units, and the extent of source maps used to produce these maps.

The extent of the GRI Digital Surficial Geologic-GIS Map of Tuzigoot National Monument (*GRI MapCode CLAR*) and the GRI Digital Geologic-GIS Map of Tuzigoot National Monument (*GRI MapCode TUZI*) are indicated in orange. The extent of the GRI Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument (*GRI MapCode MOTU*) is shown as a dashed blue line. For source map extents (see the section above for source map citations and their contribution), the Geologic Map of the Prescott National Forest and the Headwaters of the Verde River (SIM-2996) is shown red, whereas the extents of the Geologic Map of the Clarkdale Quadrangle (Bulletin 1021-N) and the Surficial Geology of the Northern Verde Valley (OFR 93-16) are shown in orange. The boundary of each park unit is shown in green.



Digital Surficial Geologic-GIS Map of Tuzigoot National Monument, Arizona (GRI MapCode CLAR)

Map Unit List

The surficial geologic units present in the Digital Surficial Geologic-GIS Map of Tuzigoot National Monument, Arizona (*GRI MapCode CLAR*) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qaf1 - Quarry). Units are listed from youngest to oldest. Information about each surficial geologic unit is also presented in the GRI Surficial Geologic Unit Information (CLARUNIT) table included with the geologic-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. This was done if a unit was considered to be the same unit as one or more units on other source maps used for this project, and these unit symbols, names and/or ages differed. In this case a single unit symbol and name, and the unit's now recognized age, was adopted. Unit symbols, names and/or ages in a unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI the unit's source map symbol, name and/or age appears with the unit's source map description.

Cenozoic Era

Quaternary Period

Qaf1 - Quarry
Qaf2 - Tailings
Qyr - Active channels of major streams
Qyt - Young terraces
Qyp - Young piedmont alluvium
Qs - Sheepshead Group, undivided
  Qs2 - Sheepshead Group, younger unit
  Qs1 - Sheepshead Group, older unit
Chuckwalla Terraces
  Qct2 - Chuckwalla Terraces, younger terraces
  Qct1 - Chuckwalla Terraces, older terraces
Chuckwalla Group
  Qc2 - Chuckwalla Group, youngest member
  Qc1 - Chuckwalla Group, older deposits
    Qc1b - Chuckwalla Group, older deposits, subunit 1b
    Qc1a - Chuckwalla Group, older deposits, subunit 1a
Qmt - Montezuma Terraces
Qm - Montezuma alluvial fan complex
Oxbow Terraces
  Qot3 - Oxbow Terraces, terrace 3
  Qot2 - Oxbow Terraces, terrace 2
  Qot1 - Oxbow Terraces, terrace 1
Oxbow Group
  Oxbow Group - subunit 2
    Qo2a - Oxbow Group, subunit 2a
    Qo2b - Oxbow Group, subunit 2b
Qvx - Verde Mix

Tertiary Period

Tvl - Verde Formation, lacustrine facies
Tvg - Verde Formation, gravel facies
Tb - Basalt

Paleozoic Era

PZs - Sedimentary rocks

Precambrian
Xmv - Metavolcanics

Map Unit Descriptions

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

Qaf1 - Quarry (Holocene)

Qaf1 - Quarry (Recent)
Areas mapped as quarries. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Qaf2 - Tailings (Holocene)

Qaf2 - Tailings (Recent)
Areas mapped as tailings. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Qyr - Active channels of major streams (Holocene)

Qyr - Active Channels of Major Streams (Recent)
Active channel and flood channel deposits of the Verde River and Oak Creek. This unit consists of silt, sand, gravel, and cobbles in the active channel areas of both major drainages in this portion of the Verde Valley. Most of this unit is the active bed of each stream, the remainder includes areas that convey floodwaters frequently enough to limit the development of mature riparian plant communities (i.e. dense stands, no large trees). (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Qyt - Young terraces (late Holocene)

Young (typically tens of years to a few thousand years old), relatively thin terrace deposits along the Verde River and Oak Creek. Composed of two distinct facies: a coarse gravel facies of abandoned channels and bars, and a fine facies composed of sand deposited in low velocity, slack-water areas during large floods. Qyt is less than about 6 m (20 ft) above the lowest portions of river channels and is almost always found directly adjacent to the channels. The principal exception to this is at Pecks Lake, where a meander of the Verde River has evidently been cut off quite recently leaving a low area covered with late Holocene deposits. Piedmont channels (Qyp) are graded Qyp in some places. Qyt deposits are weakly consolidated and are susceptible to bank erosion, although riparian vegetation tends to stabilize these deposits. Most if not all Qyt terraces may be subject to inundation during large floods. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: < 5,000 years

Qyp - Young piedmont alluvium (late Holocene)

This unit consists of modern channel deposits and low terraces along piedmont drainage courses. It also includes small alluvial fans that have prograded onto the youngest terraces of the Verde River and Oak Creek. Composition ranges from extremely coarse very near the Black Hills (sand, gravel, cobbles, and boulders) to more fine-grained (silt, sand, gravel) elsewhere. Unit Yp is found throughout

the map area in and near ephemeral drainage courses. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: < 5,000 years

Qs - Sheepshead Group, undivided (late Pleistocene to Holocene)

The Sheepshead Group consists of relatively fine-grained late Quaternary alluvium eroded from the Verde Formation. Unit S deposits consist of thin alluvial fan remnants, restricted piedmont stream deposits, and colluvium derived from cliffs of the Verde Formation. In many areas, unit S can be subdivided on the basis of soil development and relative topographic position (units Sl and S2). In areas where such distinction is not possible, the alluvium is labeled S. Sheepshead alluvium is extensive in most of the Page Springs quadrangle, the Cornville quadrangle between Oak Creek and the Verde River, along the flanks of the White Hills throughout the map area, and in the vicinity of Hayfield Draw in the Cottonwood quadrangle where a clay-rich unit in the Verde Formation is extensively exposed. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: 125,000 years to present

The Sheephead Group is mapped as unit Qs and is also mapped as the following subunits:

Qs2 - Sheepshead Group, younger unit (Holocene)

The younger unit of the Sheepshead Group includes small alluvial fans, discontinuous stream deposits and low stream terraces adjacent to modern piedmont drainages. Along the east flank of the White Hills (Page Springs quadrangle) this unit is easily distinguished from Sl because it is not as red. The surface color is grayish brown to dull brown (7.5 YR 6/2 - 6/3). S2 alluvium is typically fine-grained and consists primarily of clay, silt, sand, and minor gravel. The soil is very calcareous due to the abundance of calcium carbonate in the source rocks. Deeply incised, narrow arroyos are common in areas of S2 alluvium. Creosote bush and assorted grasses are common plants; vegetation density is variable. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: 10,000 years to present

Qs1 - Sheepshead Group, older unit (late Pleistocene)

The older unit of the Sheepshead Group is most extensive along the foot of the White Hills in the Page Springs quadrangle. Here the unit is fairly oxidized such that the surface color is approximately bright reddish brown (5YR 5/8 - 5/6). The degree of reddening imparted by soil development and weathering is uncertain because of an abundance of red sandstone layers in the Verde Formation in this vicinity, but the soil color is redder than that of S2 alluvium. The unit consists of primarily relatively fine-grained sediments (clay, silt and sand) with lesser amounts of gravel. Because these sediments are derived from the Verde Formation, the soil is very calcareous. Vegetation is dominated by creosote and assorted grasses of low to moderate density. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: 125,000 to 10,000 years

Chuckwalla Terraces (middle Pleistocene to early Holocene)

Chuckwalla Terraces are found in very close proximity to the present positions of the Verde River and Oak Creek. They are of limited areal extent and are restricted to the interior of narrow canyon

reaches. The older terrace (CT1) ranges from about 12 to 18 m (40-60 ft) above modern river channels; C1 piedmont deposits are graded to terrace CT1. CT1 thus dates to the middle to late Pleistocene. The younger terrace (CT2) is about 6 to 12 m (20-40 ft) above modern river channels; C2 piedmont deposits are graded to CT2 terraces, implying that CT2 terraces are of latest Pleistocene to early Holocene age. Typically, deposits are coarse gravel facies of relict channels and bars and are less than 5 m thick. Soil development is moderate, with some clay accumulation. CT terraces are fairly resistant to stream erosion and are not inundated during large floods. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

The Chuckwalla Terraces are mapped as the following units:

Qct2 - Chuckwalla Terraces, younger terraces (middle Pleistocene to early Holocene)

No additional unit description provided. See Chuckwalla Terraces description above.

Unit age: 250,000 to 5,000 years

Qct1 - Chuckwalla Terraces, older terraces (middle Pleistocene to early Holocene)

No additional unit description provided. See Chuckwalla Terraces description above.

Unit age: 250,000 to 5,000 years

Chuckwalla Group (middle Pleistocene to early Holocene)

The Chuckwalla Group consists of relatively thin, broad, alluvial fans, and narrow stream terraces. Surfaces of the Chuckwalla Group are much closer to the altitude of modern drainages than adjacent M and 0 surfaces. There typically is not substantial relief between the three units in the Chuckwalla Group (Cla, Clb, and C2). Soil development differs substantially between the three units, however, indicating that the Chuckwalla Group probably spans much of the late Quaternary (–250 to 10 ka). (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

The Chuckwalla group is mapped as the following units:

Qc2 - Chuckwalla Group, youngest member (latest Pleistocene to early Holocene)

The youngest member of the Chuckwalla Group (C2) includes thin alluvial fans adjacent to or very slightly inset into older C1 alluvium. C2 also includes low terraces adjacent to stream channels confined by higher, older alluvium or bedrock. Areas where C2 surfaces are tightly interspersed with young stream sediments (Yp) are labeled as C2/Yp.

Unit C2 is composed primarily of coarse sediments ranging from sand to large cobbles and small boulders. Near the Verde River at Cottonwood the composition of the C2 alluvial fans is finer-grained and dominated by sand, pebbles, and minor silt. In the middle and upper piedmont areas, the C2 surface is characterized by a dense thornscrub thicket including catclaw, mesquite, and holly. Near the river, the vegetation is sparse. Much of the recent development in the city of Cottonwood has been on C2 fans. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: 20,000 to 5,000 years

Qc1 - Chuckwalla Group, older deposits (middle to late Pleistocene)

The older deposits of the Chuckwalla Group consist of extensive alluvial fans and terraces. The two subunits (C1a and C1b) differ primarily in degree of soil development and surface color. In areas where they are indistinguishable or intricately interspersed, they are grouped together in unit C1. C1 deposits cover much of the piedmont of the Black Hills west-northwest of Cottonwood. Unit C1a locally occurs as a terrace surface carved in extensive deposits of Montezuma alluvium. An example of this occurs on the southern side of the large fan emanating from Black Canyon in the Cottonwood and Cornville quadrangles.

C1a and C1b are both composed primarily of coarse sediments ranging from sand to large cobbles and small boulders. The C1a surface color ranges from dull reddish brown to bright brown (5 YR 5/4 - 7.5 YR 5/6). Soils typically have strong argillic horizons with light clay textures and moderately developed calcic horizons (stage II to III). In general, C1a is characterized by a relatively sparse shrub community and fairly good grass cover, but this varies considerably with local conditions and source area lithology. Predominant plants include prickly pear cactus, catclaw, assorted grasses. Based on the relatively strong soil development associated with C1a surfaces, we estimate their age to be -125 to 250 ka. C1b surface color typically is slightly less red than C1a; soils are characterized by moderately developed argillic horizons (clay loam textures) and relatively weak calcic horizons (stage I to II). C1b surfaces are dominated by a relatively high-density thorn scrub assemblage including acacia, mesquite, and holly. Based on soil development, we estimate that C1b surfaces are significantly younger than C1a (–50 to 125 ka). (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: 250,000 to 50,000 years

The Chuckwalla Group is also mapped as the following subunits:

Qc1b - Chuckwalla Group, older deposits, subunit 1b (middle to late Pleistocene)

No additional unit description provided. See Chuckwalla Group and Chuckwalla Group, older deposits descriptions above.

Unit age: 125,000 to 50,000 years

Qc1a - Chuckwalla Group, older deposits, subunit 1a (middle to late Pleistocene)

No additional unit description provided. See Chuckwalla Group and Chuckwalla Group, older deposits descriptions above.

Unit age: 250,000 to 125,000 years

Qmt - Montezuma Terraces (middle Pleistocene)

Montezuma Terraces (MT) are still high above the modem rivers but are found in locations relatively close to the present positions of the Verde River and Oak Creek. MT terraces are not, however, restricted to the interiors of relatively narrow canyon reaches and in fact are often found on bedrock shelves that line the periphery of such reaches. They are typically 25 to 30 m (80-100 ft) above the modern river channels. The Montezuma alluvial fan complex is clearly graded to the MT near the Verde River, so they must be of equivalent age (middle Pleistocene). Soil development is fairly strong, and deposits are typically coarse gravel facies. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: ~500,000 years

Qm - Montezuma alluvial fan complex (middle Pleistocene)

Extensive middle Pleistocene Montezuma alluvial fans comprise the thickest Quaternary deposits observed in the map area. These fan remnants are inset well below adjacent Oxbow surfaces but are 25 to 30 m (80-100 ft) above modern drainages. In the vicinity of Black Canyon, the alluvium is locally at least 25 m (80 ft) thick. Considerable variations in thickness of this unit suggest that it partially filled fairly deep valleys carved into the Verde Formation after deposition of the O2 alluvium. The best example of an M surface occurs along the northern side of Black Canyon in the southern portion of the Cottonwood quadrangle.

Montezuma surfaces are dominated by angular clasts of metavolcanic, volcanic, or granitic rocks. In some places a weak desert pavement is developed on the surface. The M surface is dull yellowish brown to brown. It hosts a low to moderate density community of prickly pear, mesquite and assorted desert grasses. Closer to the mountains and at higher altitudes the plant community is composed of moderate to high density stands of acacia, mesquite, and holly. Greater vegetation densities are also associated with M surfaces derived from granitic source areas south of Black Canyon. Soils associated with M surfaces are strongly developed with clay textures and moderately developed calcic horizons (stage II to III) at an approximate depth of 90 cm. Soft carbonate concretions are present below about 40 cm. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: ~500,000 years ago

Oxbow Terraces (early Pleistocene)

Three very high and old terrace remnants are found along Oak Creek and the Verde River. These O terraces were grouped together because of their topographic isolation above other terraces. The oldest terraces (OT1) are about 85 to 100 m (280-350 ft) above the modern river channels; OT2 terraces range from about 55 to 70 m (180-220 ft) above the river; OT3 terraces range from about 50 to 55 m (160-180 ft) above the river. They all likely date to the early Pleistocene, and thus were deposited during the same general interval as the Oxbow piedmont alluvial units.

The oldest river terraces (OT1) are about 200 m (700 ft) below the highest levels of the fine-grained facies of the Verde Formation. Thus, OT1 is almost certainly much younger than the O1 piedmont surfaces, which probably represent the highest levels of the Verde Formation. O2a alluvial-fan remnants are at about the same altitude as OT2 near the Verde River, so they are of similar age. O2b can not be directly correlated with OT3, but O2b is well above the level of the next younger river terrace (MT), suggesting that it generally correlates with OT3. Terraces in the O group are found much farther from the present courses of Oak Creek and the Verde River than any of the younger terraces. Deposits are typically fairly thin, poorly sorted silt to gravel. Soil development is strong, with substantial clay and calcium carbonate accumulation; locally, soil horizons are cemented with calcium carbonate. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

The Oxbow Terraces are mapped as the following units:

Qot3 - Oxbow Terraces, terrace 3 (early Pleistocene)

No additional unit description provided. See Oxbow Terraces description above.

Unit age: 2,000,000 to 800,000 years

Qot2 - Oxbow Terraces, terrace 2 (early Pleistocene)

No additional unit description provided. See Oxbow Terraces description above.

Unit age: 2,000,000 to 800,000 years

Qot1 - Oxbow Terraces, terrace 1 (early Pleistocene)

No additional unit description provided. See Oxbow Terraces description above.

Unit age: 2,000,000 to 800,000 years

Oxbow Group (early Pleistocene)

The Oxbow Group includes three levels of alluvial fans representing the oldest surficial alluvium preserved in the northern Verde Valley. These alluvial-fan remnants range from about 80 to 150 m above modern drainages and were likely deposited during the early Pleistocene to latest Pliocene (0.8 to 2.5 Ma). There is as much as 60 m of relief between older (O1) and younger (O2a and O2b) surfaces, implying that these units were deposited over a substantial interval. Soils developed on these units have well-developed calcic horizons (typically stage III to V; after Machette, 1985) and are extremely clay-rich where well preserved. Oxbow alluvium is a relatively thin veneer capping erosion surfaces cut on the Verde Formation. Deposit thickness typically is several meters and probably does not exceed 10 meters. Deposits are very poorly sorted coarse gravels. Particle sizes range from silt and sand to boulders, and clasts are typically subangular. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Oxbow Group, subunit 2 (early Pleistocene)

O2 units are high, thin, early Pleistocene alluvial fan remnants deposited on erosional surfaces cut into both the lacustrine and gravel facies the Verde Formation. O2 surfaces are fairly widespread in the Black Hill piedmont area south of Black Canyon and north of Cherry Creek. The most extensive well-preserved remnants are found below Catpaw Mesa where the source area lithologies are most resistant to erosion (metavolcanic and volcanic rocks).

In some areas there are two distinct levels of O2 surfaces (O2a and O2b). Physical characteristics of these surfaces are similar, so they can be distinguished only in areas where they are adjacent to each other. In some places, as in the vicinity of Catpaw Mesa, O2a is as much as 15 m (50 ft) higher than O2b. Closer to the Verde River, they differ by as little as 5 m (20 ft). The O2 designation is used in areas where it is not possible to distinguish two discrete surface levels.

O2 deposits are composed of sediment ranging from silt to boulders. Most of the clasts are metavolcanics and basalt. Surface color is dull reddish brown (5YR 4/4-5/4). The soil on well-preserved O2 surfaces is extremely strongly developed. Argillic horizons have heavy clay textures and are dark reddish brown (2.5 YR 3/3). A stage III to IV calcic horizon exists at approximately 80 cm. Soil structure is angular blocky to prismatic. On degraded surface remnants, the argillic horizon has been partially or completely stripped and the calcic horizon is encountered at or near the surface. Well-preserved O2 surfaces support grasses, small acacias, prickly pear cactus, and scattered junipers. In the areas where the surface has been eroded and the calcic horizon is either shallow or at the surface, the density of juniper is higher and crucifixion thorn is abundant. The extremely strong soil development associated with O2 surfaces and the high topographic positions they occupy indicate that they are very old. The fact that O2 surfaces were deposited at levels that are much lower than adjacent O1 surfaces implies that they are significantly younger than unit O1. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

The Oxbow group, subunit 2 is mapped as the following units:

Qo2a - Oxbow Group, subunit 2a (early Pleistocene)

No additional unit description provided. See Oxbow Group and Oxbow Group, subunit 2 descriptions above.

Unit age: 2,000,000 to 800,000 years

Qo2b - Oxbow Group, subunit 2b (early Pleistocene)

No additional unit description provided. See Oxbow Group and Oxbow Group, subunit 2 descriptions above.

Unit age: 2,000,000 to 800,000 years

Qvx - Verde Mix (Quaternary)

Qvx - Verde Mix (Indeterminate age)
Unit designation Vx is used in areas where weathered bedrock, alluvium, and eolian materials are essentially indistinguishable. Typically, this unit consists of a very thin mantle of unconsolidated deposits of uncertain origin over Verde Formation. Unit Vx is exclusively related to the Verde Formation; it is most extensive in the Page Springs quadrangle and in the area north of the confluence of the Verde River and Oak Creek in the Cornville quadrangle. Some contacts between Vx and Sheepshead alluvium are arbitrary because they grade together. In general the Vx designation was reserved for interfluve areas relatively high above modern washes. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Tvl - Verde Formation, lacustrine facies (late Miocene to Pliocene)

Lacustrine facies are composed of freshwater limestone, sandstone, siltstone and marl This unit is exposed throughout the map area particularly in the White Hills and along the Verde River south of the Oak Creek Confluence. In most areas, the Verde Formation is a cliff forming unit, but in areas where clay rich layers are exposed it is characterized by soft-looking slopes and occasional badlands-type topography. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: 2,500,000 to 850,000 years

Tvg - Verde Formation, gravel facies (late Miocene to Pliocene)

Gravel facies the alluvial fan deposits composed of primarily gravel and cobbles. Diverse lithologies. This unit is concentrated along the eastern flank of the Black Hills and occurs as rounded, high-standing hillocks that are conspicuously gray-colored. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Unit age: 2,500,000 to 850,000 years

Tb - Basalt (Miocene to Pliocene)

Late Cenozoic basalt flows and local sediments. This bedrock type is found scattered through the map area. It caps Mingus Mountain and several mesas along the Mogollon rim. Some basalt also

occurs in Box canyon along the Verde River north of Clarkdale where flows occur within the Verde Formation. The largest exposure of Tb is in the Page Springs Quadrangle in the area between the White Hills and Oak Creek. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

PZs - Sedimentary rocks (Paleozoic)

Sedimentary rocks ranging from limestone and dolomite to sandstone. These rocks are abundant in the Black Hills west of the Verde Fault and in scattered locations in the foothills. The largest exposures are in the Black Hills and Mogollon Rim areas north and east of Clarkdale. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

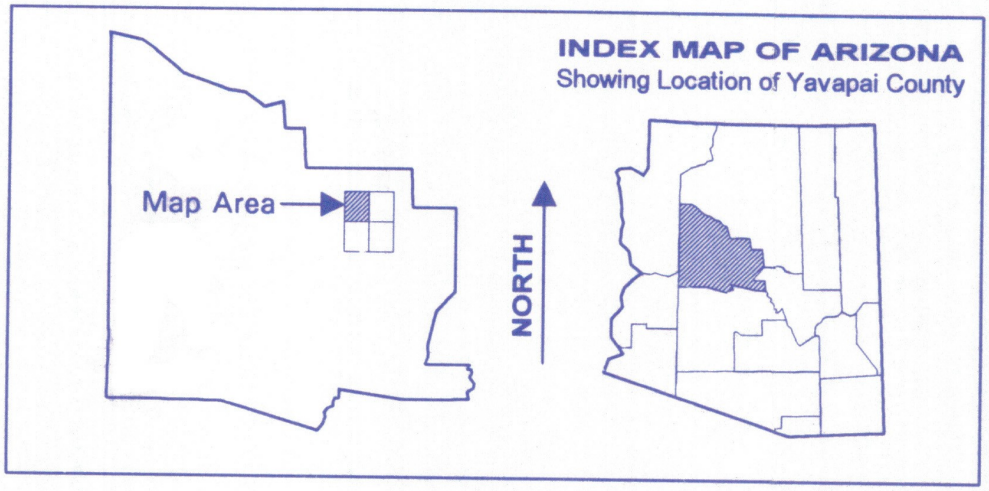
Xmv - Metavolcanics (Precambrian)

Metavolcanic rocks ranging from basalt to rhyolite. These rocks are found throughout the black hills north of Black Canyon. (*GRI Source Map ID 1091)* (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4) Source Information

House, Kyle P. and Pearthree, Philip A., 1993, Surficial Geology of the Northern Verde Valley, Yavapai County, Arizona: Arizona Geological Survey, Open-File Report 93-16, Sheet 1 of 4, scale 1:24,000 (*GRI Source Map ID 1091*).

Index Map



Extracted from: (AZGS OFR 93-16 (Clarkdale 7.5' Quadrangle, Sheet 1 of 4)).

Report

The report for the Surficial Geology of the Northern Verde Valley, Yavapai County, Arizona is presented below.

Open-File Report 93-16

The report contains the following sections:

Introduction
Methods and Materials Used in Mapping
Map Unit Descriptions
General Geologic Setting of the Verde Valley
Quaternary Geology and Geomorphology of the Northern Verde Valley
Summary
References

Digital Geologic-GIS Map of Tuzigoot National Monument, Arizona (GRI MapCode TUZI)

Map Unit List

The geologic units present in the Digital Geologic-GIS Map of Tuzigoot National Monument, Arizona (*GRI MapCode TUZI*) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qaf - Artificial fill). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (TUZIUNIT) table included with the GRI geologic-GIS data.

Cenozoic Era

Quaternary Period
Qaf - Artificial fill
Alluvial river terraces and riverwash
- Qr - River wash
- Qt - Terrace deposits

Qg - Gravel deposits
Verde Formation
- QTv - Verde Formation, lacustrine deposits
- QTvg - Verde Formation, gravel deposits
- QTvv - Verde Formation, volcanic rocks

Tertiary Period
Hickey Formation
- Thv - Hickey Formation, volcanic rocks
- Ths - Hickey Formation, sedimentary rocks

Paleozoic Era

Permian Period
Suspai Formation
- Psu - Supai Formation, upper member
- Psm - Supai Formation, middle member

Permian and Pennsylvanian Periods
- PPNsl - Supai Formation, lower member

Mississippian Period
Mr - Redwall Limestone

Devonian Period
Dm - Martin Limestone

Cambrian Period
Ct - Tapeats Sandstone

Precambrian

Precambrian rocks
- PCg - Gabbro
- PCq - Quartz porphyry
- PCgg - Grapevine Gulch Formation

PCd - Deception Rhyolite

Map Unit Descriptions

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

Qaf - Artificial fill (Quaternary)

Qaf - Artificial Fill (Recent)
Quarry and tailings features related to historic mining activity and mineral resource development. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

Alluvial river terraces and riverwash (Quaternary)

The terrace sediments were deposited by the Verde River upon its flood plain at a time when the river had attained a temporary base level and was broadening its valley by lateral planation. Subsequent rejuvenation of the river has resulted in cutting downward, sideward, headward, and removing the earlier sediments except for segments, now terraces, along the flanks of the valley.

Alluvial terraces and riverwash occur mostly in and along the channel of the Verde River from a point about 3 miles north of Clarkdale, south to where the river leaves the quadrangle. In the Packard Ranch area where the Verde River and Sycamore Creek join, terrace deposits and riverwash are present, but the terrace deposits are so small that they were included with the riverwash in mapping. Along the Verde River at Perkinsville, the riverwash and the terrace deposits are differentiated.

The alluvial river terraces are 5-10 feet high and border the wide wash of the Verde River bed. The deposits consist of a wide succession, and mixture, of unconsolidated clay, silt, sand, and gravel; finely stratified. Most of the sediment was derived from rocks of Paleozoic age, and, locally, much of the silt was derived from heterogeneous poorly sorted lakebeds of the Verde Formation.

The thickness of the riverwash has not been determined, however, the deposits are not believed to be very thick. The riverwash contrasts strongly to the terrace deposits in that the wash is generally much coarser; it consists of fine to coarse gravel, which is poorly sorted. During floods large boulders are carried downstream, and as the floods ebb, finer sediment is deposited and fills in and around the boulders. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

Alluvial river terraces and riverwash are mapped as the following units:

Qr - River wash (Quaternary)

Qr - River wash (Recent)
No additional unit description provided. See Alluvial river terraces and riverwash description above.

Qt - Terrace deposits (Quaternary)

Qt - Terrace deposits (Recent)
No additional unit description provided. See Alluvial river terraces and riverwash description above.

Qg - Gravel deposits (Quaternary)

Quaternary gravel covers a small part of the area within the Clarkdale quadrangle, and is confined to three widely separated localities. One of these is in the southwest corner where a large sheet of Quaternary gravel forms the floor of Chino Valley. Another gravel locality is in the valley of the Verde River. Here the gravel extends from a locality west of Clarkdale, through Clarkdale, and southeastward into the Mingus Mountain quadrangle, where it is very extensive. The third area in which the gravel occurs is on the southeast side of Black Mountain along the east border of the quadrangle. Here, also, the gravel is part of a thin, alluvial veneer that extends eastward from the quadrangle.

Thickness and Stratigraphic Relationship
The Quaternary gravel in all three localities described above occurs as an alluvial veneer on flat, but gently sloping, pediment surfaces. The gravel ranges in thickness from a few inches to as much as 30 feet, but commonly is less than 5 feet. The pediment surfaces are trenched by channels which increase in depth toward the Verde River. The best exposures of these gravel beds are in some of the channels that U. S. Highway 89A crosses between Clarkdale and Cottonwood. At these localities exposures of the carved surface of the Verde Formation beneath the gravel show the remnant of a pediment

The gravel unconformably overlies all older formations with which they come into contact. In turn, the gravel deposits along the Verde River have cut terraces and are covered by riverwash of Recent age, which has collected in the drainage systems that dissect them.

Lithology

The Quaternary deposits consist of fine to coarse gravel that is subrounded, but poorly sorted and occurs in a matrix of fine-grained sediment. The gravel beds are not consolidated, except locally where cemented by caliche. Most of the beds contain rock types of Precambrian and Paleozoic ages and also Tertiary basalt. Only the gravel southeast of Black Mountain is barren of Precambrian rock types. The Quaternary gravel in the southeastern part of the quadrangle has a high percentage of Precambrian fragments; whereas gravel in the southwest corner of the quadrangle has a high percentage of Paleozoic fragments. The gravel beds are dark reddish brown where composed of a high percentage of Precambrian fragments, but are gray where they consist chiefly of Paleozoic fragments. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

Verde Formation (Quaternary)

Distribution
Jenkins (1923) was the first to map, study, and describe the lakebeds in the drainage basin of the Verde River. He assigned to these beds the name Verde Formation. The lakebeds are confined to this basin on the west by the Black Hills; on the east and north by the deeply dissected Mogollon Rim; and on the south by hills of volcanic rocks. The Verde Formation is a thick sequence of limy lacustrian deposits, the areal extent of which covers more than 300 square miles, including a maximum width of 15 miles and a length of 40 miles. The northwest limits of this formation occur in the southeast quarter of the Clarkdale quadrangle.

Marginal to, and intertonguing with the fine-grained lakebed facies of the Verde Formation is a gravel facies. This facies extends westward from Clarkdale almost to Jerome, but northward it diminishes in width toward the S O B Canyon area where it forms a narrow band of gravel cropping out from beneath the fine-grained carbonate facies. Isolated patches of gravel occur near the junction of the Verde River and Sycamore Creek. A few patches of the gravel are present on the south slopes of Black Mountain and in the upper part of Sycamore Canyon.

The volcanic rocks of the Verde Formation consist of basalt flows interbedded with the gravel and fine-grained carbonate rocks. Basalt flowed down Sycamore Canyon and then followed the course of

the Verde River canyon. Remnants of this flow are exposed intermittently along the inner walls of Sycamore Canyon. The largest continuous segment of the flow is exposed from the confluence of Sycamore Canyon and the Verde River canyon, south along the Verde River to a point about 3 miles north of Clarkdale, where it is concealed by younger lakebeds of the Verde Formation.

Thickness and Stratigraphic Relationship
The total thickness of the Verde Formation is not known because a complete section is not exposed. Jenkins (1923, p. 71) reported that the log data from a well above the smelter at Clarkdale, together with the thickness of additional beds exposed nearby at the surface, indicate a total thickness of 1,400 feet or more for this area. Also, with information from a well 2 miles south of Camp Verde at the south end of the drainage basin of the Verde River, plus the surface exposure, he obtained a total minimum thickness of 2,000 feet. Mahard (1949, p. 104) measured an incomplete but detailed section along the west bank of the Verde River, 1 mile north of the smelter, which totaled 733 feet. He also measured a section 1,040 feet thick 2 miles north of where U. S. Highway 89A crosses the Verde River. These figures of Mahard must be increased by an unknown thickness lying below the present river level if a complete thickness is to be calculated. Within the Clarkdale quadrangle, a little more than 1,000 feet of the Verde Formation is exposed.

Following deposition of the Hickey Formation, a prolonged period of erosion ensued, and this was followed by faulting and uplift relative to the areas to the west and north of the quadrangle. Accumulation of the Verde Formation followed shortly thereafter, and it is in unconformable relationship with all the older formations with which it comes into contact. The gravel and lava of the Perkinsville Formation accumulated at about the same time as the Verde and they are tentatively correlated with it. Quaternary gravel beds have subsequently formed as pediment veneers, terraces, and river wash on the Verde Formation.

South from the junction of Sycamore Canyon and Verde River canyon, two flows are exposed along the walls of the river gorge. The lower lava has been interpreted by Mahard (1949) to have flowed down S O B Canyon, and the upper lava from Sycamore Canyon. Observations by the writer, however, indicate that both flowed from Sycamore Canyon. The older flow is a single layer of basalt; its base is at an altitude of 4,000 feet in Sycamore Canyon but descends below the present Verde River bed opposite S O B Canyon—a drop in altitude of about 550 feet. In the mouth of Sycamore Canyon, this older flow is about 50 feet higher than the younger, showing that Sycamore Creek cut down its floor about 50 feet between the time of the first and second lava flows. Downcutting during this interval may have removed all vestige of the early flow up Sycamore Canyon. The lava in S O B Canyon is almost accordant with the underlying Supai Formation that dips about 15° E; this gives the erroneous impression that the lava flowed down S O B Canyon. Actually it is part of the Hickey Formation which was deformed during the period of structural adjustment which preceded deposition of the lavas of the Verde Formation. This structure is a southern extension of a monocline which is prominent about 11/2 miles to the north. It has been referred to by Mahard (1949, p. 122) and Jenkins (1923, p. 70) as the "Railroad Bend Structure" (see page 578). The lava in S O B canyon is a continuation of one of the flows of Hickey age partly covered by the Verde Formation to the southwest.

Outside the limits of the Clarkdale quadrangle, other occurrences of lava has been reported interbedded with the lakebeds. Mahard (1949, p. 108-118) reported two thin lava flows interbedded with the lakebeds at a point 8 miles north of Camp Verde where the Montezuma Castle highway follows the valley of Dry Beaver Creek. He stated that 100 feet of lakebeds separate the lower and upper flows, which are 23 and 34 feet thick, respectively, and that they can be traced northward to House Mountain. Jenkins (1923, p. 69) wrote that the old Verde lake was formed through the damming of the Verde River by surface lava flows. About 6-8 miles south of Camp Verde, lava and lakebeds are interbedded in about equal amounts.

Lithology
Most of the Verde Formation consists of fine-grained carbonate rocks including limestone, calcareous sandstone, limy siltstone, and marl. Marginal, to, and intertonguing with these carbonate rocks that

are interpreted as lake deposits, are gravel beds accumulated as fans along steep hills that probably surrounded the basin. Interbedded with these two types of rock in parts of the basin are basalt flows which are considered a part of the Verde Formation. These three rock types are described separately below.

Fine-grained carbonate facies - The fine-grained carbonate rocks of the Verde Formation consist of limestone, calcareous sandstone, and calcareous clay which are lenticular, and variable in proportion from place to place. Mahard (1949, p. 104-105) concluded from studies of two sections, which lie measured 5 miles apart, that none of the detailed units recognized in either section could be correlated. He also noted that the uppermost beds in both sections are largely composed of limestone. He stated

> *The Verde Formation is not composed of beds which were uniformly spread over wide areas but instead is built up of thin lenses of material of varying composition, the lenses overlapping and interfingering with one another.*

Limestone is the most conspicuous lithologic type in the Verde Formation, probably because of its normal light color and its resistance to erosion. Most of the beds are characteristically white, though some are light gray or pink. The rock is very hard, impure, aphanitic, and vuggy. Jenkins (1923, p. 77) suggested that the hardness probably has resulted from reprecipitation. The beds, which range from 1 to 10 feet in thickness, weather into shelves or ledges, and some cap hills. Most of the limestone beds are argillaceous, and contain many rounded grains of quartz. Small tubelike structures, about the diameter of a pencil, and several inches long, are present in many of the beds; these tubes closely resemble plant stems.

Sandstone, siltstone, and marl alternate with limestone beds. These rocks are most abundant near the margins of the formation and in the lower parts of exposures. Most of them are pinkish gray to grayish orange. A majority of the sandstone beds are fine grained and calcareous, and most of the grains are rounded quartz. The siltstone and marl are likewise calcareous. These lithologic types are not as resistant to weathering as limestone. They are friable, and weather into slopes, to form colluvial material.

Saline deposits are reported about 20 miles south of the Clarkdale quadrangle in the Verde Formation in the vicinity of Camp Verde by Jenkins (1923, p. 73-75). He stated:

> *…here must have been the deepest portion of the old lake in which the strata were formed, for here its sediments are thickest, and here deposits of salts (sodium sulfate, principally) are found in quantities, showing that at times where the lake evaporated down to brine the only remaining portion of the body of water was at this place.*

Gravel facies - The gravel deposits are gray and consist of coarse to fine gravel, sand, and silt. Sand and gravel both are very lenticular, and many small channels of gravel are cut throughout the sand layers.

The lithology of the gravel differs from place to place and reflects the types of bedrock surrounding the basin of accumulation. The gravel consists of abundant Precambrian rock fragments below Jerome, whereas largely rocks of Paleozoic and Tertiary ages are commonly found on the south slopes of Black Mountain. The gravel in Sycamore Canyon, beneath and above the intracanyon basalt flow, is comprised mostly of rock types from the Mogollon Rim. The gravel is progressively much finer towards the area of fine-grained carbonate deposits. These beds appear to have been deposited primarily as fans, which extended into the old Verde lake, periodically interrupting accumulation of fine-grained lake deposits. The result is an inter-fingering of gravel and lake deposits.

Gravel of the Verde Formation weathers into a loose, incoherent surface accumulation on the tops and sides of hills, and well-preserved exposures are few. The best exposures of these deposits are along U. S. Highway 89A between Jerome and Cottonwood, where roadcuts reveal the details of

bedding and plainly show the interfingering relationship between gravel and lakebeds.

Volcanic rocks - Lava of the Verde Formation is basaltic rock similar to that which occurs in other formations of the Clarkdale quadrangle. The flows are holocrystalline olivine basalt, showing intergranular texture. Interstitial pyroxene crystals occur as aggregates. Probably a little more secondary interstitial calcite is found in these rocks than in other basalts. Columnar jointing is typical but there is no evidence of pillow structure in the flows, indicating that the old Verde lake may have been dry at the time of extrusion.

Age and Correlation
No diagnostic fossils have been found in the Verde Formation. Jenkins (1923, p. 76-77) found a few poorly preserved gastropods, similar in appearance to some fresh-water types, which he collected south of Black Mountain (coordinates N. 1,404,000; E. 468,500). From a collection of mollusks made by Mahard (1949, p. 119) from the summit of a lakebed mesa, 1 mile north of the Clarkdale smelter on the west side of the Verde River, the following genera were identified : Sphaerium sp., Lymnaea sp., Physa sp., Gyraulus sp., Papilla sp. Mahard stated that species of these genera indicate an environment of submerged plants in a body of water not more than 10 feet deep. This may account for many tubelike structures, in some of the limestone, which appear to be plant stems.

Jenkins (1923, p. 77) suggested that the Verde Formation is late Tertiary or very early Pleistocene in age, because he considered the lava, with which the Verde Formation is associated, to be of late Tertiary age. Mahard (1949, p. 126) similarly postulated a late Pliocene or Pleistocene age for the Verde Formation. This is based on Robinson's (1913) conclusions that all igneous activity associated with the San Francisco Mountain area falls within these time limits. However, as previously stated (page 555) Robinson's dating of the earliest lava was based on invalid evidence.

The lava, which is interbedded with the lakebeds of the Verde Formation and which represents the youngest period of volcanism recognized in the area, may be correlative with Robinson's third-period basalt flows. Robinson (1913, p. 93-95) placed these lava flows in the Quaternary period (Pleistocene) because of the relationship of the lava to topography and the lack of appreciable erosion. He noted that the third-period flows followed youthful drainage courses (as shown by the lava in Sycamore Canyon) and flowed off the plateau edge, which shows little subsequent recession.

From studies of the glaciation of San Francisco Mountain, Sharp (1942) found evidence of Wisconsin glaciation which spread out wash later covered by third-period basalt flows of Robinson. This, of course, dates the basalt at base of the San Francisco Mountains, but it does not show that the Perkinsville and Verde lava flows are correlative with Robinson's third-period basalt flows. Maxson (1950, p. 14) favored a Pleistocene age for young lava that has flowed down tributary canyons to the Grand Canyon and cascaded down the walls of the Grand Canyon. However, it is not intended here to conclude that all lava flows which have flowed over canyon walls or on canyon floors are Pleistocene, but to indicate that they may be of the same general period of extrusion in this region.

The Verde Formation accumulated after the major movement of the Verde fault which elevated and blocked out the Black Hills on the east, of which Woodchute Mountain is a part. The block faulting of the Black Hills may have started in late Tertiary time. The geologic history following the accumulation of the Verde Formation includes the formation of three pediment levels (Anderson and Creasey, 1957) on the Verde Formation, and the dissection of lakebeds of the Verde by erosion so that the present relief is now more than 1,000 feet in the area.

A tentative age assignment from late Tertiary (probably Pliocene) to Pleistocene is inferred.

Even though a precise age cannot be determined for the Verde Formation, the relative age in relation to other formations within the quadrangle seems clear. The Verde is doubtless younger than the Hickey, and is correlated with the Perkinsville. This correlation is based on the belief that structural control was the cause of accumulation in both formations, and in relation to the present erosion cycle. Both the Verde and the Perkinsville accumulated after faulting of the Hickey, and uplift of the Black

Hills mountain block. Volcanism during accumulation is a feature common to both formations. The lava flows of the Perkinsville which spread south over the rim of the plateau into the northern part of the Clarkdale quadrangle, are interpreted as contemporaneous with those intercalated in the Verde. (GRI Source Map ID 1092) (USGS Bulletin 1021-N, Plate 45).

The Verde Formation is mapped as the following units:

QTv - Verde Formation, lacustrine deposits (Quaternary)

No additional unit description provided. See Verde Formation description above.

QTvg - Verde Formation, gravel deposits (Quaternary)

No additional unit description provided. See Verde Formation description above.

QTvv - Verde Formation, volcanic rocks (Quaternary)

No additional unit description provided. See Verde Formation description above.

Hickey Formation (Tertiary)

Distribution
The Hickey Formation was named by Anderson and Creasey (1957) from exposures of lava flows and gravel on Hickey Mountain, which is just south of Woodchute Mountain. According to Anderson and Creasey some of the lava and gravel in Lonesome Valley on the west side of Hickey and Mingus Mountains also are part of the Hickey Formation. The physical continuity between rocks of the Hickey Formation in Lonesome Valley and those on the summit of Mingus Mountain is broken by the marginal fault along Mingus Mountain. From the summit area of this mountain, the Hickey Formation extends northward into the Clarkdale quadrangle.

The Hickey Formation in the Clarkdale quadrangle is, to a large extent, confined to the high topographic features. Areas which structurally have been lowered and isolated from the larger masses are exceptions. The sedimentary rocks of the Hickey Formation in the Clarkdale quadrangle appear to be stream deposits, confined to northward- and northeastward-trending relict channels beneath the volcanic flows. Judging from the pattern of outcrops (pl. 45) , two major channels seem to be represented : one trends northeastward from the southwest corner of the quadrangle, and the other trends northward from Jerome; they join near the headwaters of S O B Canyon, and extend from there in a northeasterly direction, and pass through the west side of Black Mountain. Other minor channels tributary to the major ones are present in many places at the base of the volcanic flows of the Hickey Formation.

The volcanic rocks of the Hickey Formation cover the top of Woodchute Mountain and extend southward as a capping on Mingus Mountain. On the north side of Woodchute Mountain, they occur on the tops of ridges which radiate out from the mountain. Large patches of the volcanic rocks occur northward from Jerome in the hanging-wall block of the Verde fault. Much of the Hickey probably extends eastward from the Jerome area for some distance, probably as faulted segments, under the younger Verde Formation. In the central part of the quadrangle the Hickey blankets the Antelope Hills, and occurs as isolated remnants on both sides of the Verde River in the vicinity of Mormon Pocket. Black and Casner Mountains are also capped with Hickey Formation. Atop the plateau it forms outliers and parts of a broad, volcanic sheet that extends far to the north over the plateau surface.

Thickness and Stratigraphic Relationship
Regionally, the Hickey Formation is variable in proportion of volcanic to sedimentary rocks. Flows

coalesce and interfinger with each other and with thick deposits of detrital material which accumulated in valleys and basins. In the Clarkdale quadrangle, the Hickey Formation consists of much more volcanic than sedimentary rocks.

The thickness of the Hickey Formation is extremely variable, owing to the fact that it accumulated on a highly irregular surface. The quadrangle has no complete sections because erosion has removed different amounts from the top of the formation.

The most conspicuous exposure of the Hickey Formation occurs on Woodchute Mountain. Here, about 1,400 feet of volcanic flows occur plus about 50 feet of gravel in minor channels at the base of the flows. In the Antelope Hills in the central part of the quadrangle, the volcanic rocks of the Hickey Formation range in thickness from 100 to 300 feet. The thickness of the volcanic rocks of the Hickey formation on Black Mountain ranges from almost 50 feet on the northeast side to more than 500 feet on the southwest side. On Casner Mountain and on the part of the plateau which projects into the northern part of the quadrangle these volcanic rocks are as much as 250 feet thick and are even thicker to the north away from the plateau edge.

The channels containing the sedimentary rocks of the Hickey Formation range from a few feet to more than several hundred feet in depth. The maximum thickness of the sedimentary rocks of the Hickey Formation within the Clarkdale quadrangle is on the west side of Black Mountain along Sycamore Canyon.

Deformation and erosion followed accumulation of the Hickey Formation so the younger Verde and Perkinsville formations overlie it unconformably. In the southwest corner of the Clarkdale quadrangle Quaternary gravel beds, which extend southwestward into Lonesome Valley, mask the Hickey Formation. This gravel may represent the means by which the extensive pediment surface was carved in the valley.

Lithology
Sedimentary rocks - The sedimentary deposits of the Hickey Formation in the Clarkdale quadrangle are believed to be relics of former stream deposits beneath the volcanic rocks and they consist of materials that are variable both in composition and in grain size. Also, the thickness of these deposits within the quadrangle ranges from a few inches to about 200 feet. The gravel grades from fine to coarse and includes some silt and sandy beds and lenses. The degree of sorting and the Formation of bedding differ greatly. The sandy beds are well sorted and many are intercalated as lenses within beds that contain large boulders. These rest in a matrix of unsorted cobbles, pebbles, and silt. There are also local, well-bedded gravel beds throughout the formation. Most beds contain some angular to sub-rounded boulders 2–4 feet in diameter, although the average diameter of the gravel probably is 2-8 inches.

The degree of consolidation of the gravel in the Hickey Formation is variable, and in many places the gravel beds are so weakly bound together that they do not withstand weathering. Elsewhere the gravel is well lithified with lime cement and clay matrix.

Gravel of the Hickey Formation includes lithologic representatives of the Paleozoic formations within the quadrangle; a small amount of basaltic material derived from the penecontemporaneous Tertiary volcanic rocks of the Hickey Formation; and Precambrian rocks that consist of quartz diorite porphyry, Deception Rhyolite, breccia of the Spud Mountain volcanics, foliated rocks that include hornblende schist, alaskite, aplite, quartz porphyry, and rocks that resemble those of the Grapevine Gulch Formation and gabbro. Basaltic gravel of Tertiary age forms a minor percentage of the total deposits. Inasmuch as the channels that contain these gravel deposits are below all the lava flows in the quadrangle, the presence of lava among the gravel indicates that some volcanism was active in the region to the south and east of the quadrangle before the major outpouring of lava during Hickey time. Probably the source of the gravel was to the southwest of the Clarkdale quadrangle, although more information on the Precambrian rocks of central Arizona is necessary before a more positive statement can be made. Many of the gravel deposits of Precambrian rock types appear to have been derived from sources of restricted occurrence. Anderson (oral communication, 1953) stated that

foliates such as the hornblende schist are common in the Prescott quadrangle where the grade of metamorphism is higher than in the Mingus Mountain quadrangle. Furthermore, he reported that there is no alaskite and very little aplite in the Mingus Mountain quadrangle, whereas Krieger 5 has mapped these rocks in the southeastern corner of the Prescott quadrangle. The breccia of the Spud Mountain volcanics has been mapped by Anderson and Creasey (1957) along the west margin of the Black Hills in the Mingus Mountain quadrangle, and Kreiger has mapped large areas of the breccia in the Prescott quadrangle.

Volcanic rocks - The volcanic rocks of the Hickey Formation consist almost entirely of basalt flows, but contain small amounts of detrital accumulation of basalt, andesite flows, and thin beds of pumiceous tuff.

The individual flows range in thickness from about 20 to almost 60 feet, but probably average 40-50 feet. They are massive—although in places somewhat vesicular - and some have scoriaceous tops. Brecciated zones consist of angular fragments and blocks of both scoriaceous and massive material. Columnar jointing is common and is most frequently observed on steep slopes or cliffs where talus does not obscure the tiers of the flows.
The basalt of the Hickey Formation is typically medium gray to grayish black on fresh surfaces but weathers brown on exposed surfaces. Megascopically it is mostly porphyritic with an aphanitic groundmass. A majority of the phenocrysts are glassy olivine, or iddingsite pseudomorphs after olivine, but augite and feldspar crystals have been recognized in hand specimens. Under the microscope the basalts appear completely holocrystalline. The textural varieties range from intergranular, where interstitial augite occurs in an aggregate of grains and not in large crystals, to subophitic, where the plagioclase and olivine crystals are separated by interstitial pyroxene and scattered iron ores. Intergranular textures are the most common.

The mineralogy of the basalts consists of a typical olivine basalt assemblage. Minerals present are olivine, plagioclase, pyroxene, magnetite, and some calcite. The olivine crystals are euhedral and are porphyritic or glomerophorphyritic; olivine also is present in the groundmass. Some olivine phenocrysts show rims, as well as whole crystals, which are altered to iddingsite, and still others are serpentinized. The interstitial olivine in the groundmass is less altered than the phenocrystic olivine. Plagioclase feldspar occurs as phenocrysts but more commonly is confined to the groundmass. The plagioclase is between An_{60} and Ann_{70}. The pyroxene is a greenish-gray augite with a weak purplish tint. The plagioclase and pyroxene appear to have two distinct associations within the groundmass; in some rocks the plagioclase feldspar is in euhedral prisms in a matrix of olivine and pyroxene, whereas in other rocks interstitial plagioclase separates euhedral pyroxene prisms. Magnetite occurs either as dust particles throughout the rock, or as scattered grains of coarse size. The rock is a light gray where the magnetite is in large grains, and grayish black where the magnetite is disseminated as fine dust. Calcite in the basalt is assumed to be secondary.

Basalt in dikes, which are present at the base of the Mogollon escarpment just north of Henderson Flat and on top of Packard Mesa above the Verde River, is similar in mineralogic structure and assemblage to that in the flows. Some of the dikes also have calcite amygdules. Many dikes that are too small to map, are present along the Jerome-Perkinsville road in the vicinity of Woodchute Mountain.

In areas where there is little topographic relief, the basalt decomposes at the surface and forms a thin layer of brown powdery soil. The residual soil contains abundant angular fragments and boulders with rounded edges which were derived from the lava.

Included in the volcanic rock series are local biotite- and hornblende-bearing lava flows, which probably are andesites but which are too small to differentiate on plate 45. Localities in which these rocks were noted are on top of the hill at First View Pass on the Jerome Perkinsville road (coordinates E. 432,500; N. 1,374,500), at the base of the volcanic rocks of the Hickey Formation southwest corner of the quadrangle (coordinates E. 406,500; N. 1,371,000) and in the hill which projects into the west boundary of the quadrangle (coordinates N. 1,371,000). Similar rocks may

occur elsewhere among the volcanic rocks of the Hickey Formation. In the Prescott quadrangle, to the southwest, Krieger 6 separated biotite and hornblende andesites from the upper Tertiary rocks; large areas of andesite occur in the Paulden quadrangle.

The tuffaceous and basaltic sedimentary rocks of the Hickey formation are composed of pyroclastic materials and of materials derived from the basalt flows, which accumulated in local depressions during lulls of volcanism. The rocks are pale red, grayish red, and light brownish gray and are well sorted and bedded. The detritus is nearly all basalt; it ranges from microscopic particles to pieces the size of hickory nuts, all of which are subangular to subrounded. Locally the sedimentary rocks contain vitric and crystal fragments. Opaline material commonly fills the interstices surrounding large particles. A good exposure of these sedimentary rocks is in the roadcut leading to the summit of Black Mountain on the east side. Thin wedges of rocks also are present between flow-layers on Woodchute Mountain. They have been described by Anderson and Creasey (1957) and occur along Highway 89A where it crosses the summit of Mingus Mountain.

A single deposit of tuffaceous sedimentary rocks, that contains largely pumice, quartz grains, and a few scattered crystal grains of olivine, pyroxene, and unidentifiable minerals, is present in the southwest corner of the quadrangle (coordinates N. 1,376,000; E. 407,500). This deposit is in beds 1/8-1 inch thick. They are white and gray in alternating bands which are reminiscent of varved sediments. Most of the light beds generally are coarse grained and are composed almost wholly of pumice fragments, but they contain some quartz grains and scattered dark minerals; all grains are rounded to subrounded. Comparable pumice-bearing, tuffaceous sediments were recognized by Anderson and Creasey (1957) in one small area in the Mingus Mountain quadrangle and Krieger (written communication, 1955) has found similar beds associated with andesite in the Pauldren quadrangle. Widespread occurrences of rhyolitic tuff are common near Prescott and farther south.

Age and Correlation

The age of the Hickey Formation is unknown because no diagnostic fossils have been discovered in it. Kreiger and Anderson and Creasey (1957) had assigned the Hickey to the Pliocene but this age determination is based largely on inference which can be summarized as follows : (1) Much of the satisfactory dating of the Cenozoic basin deposits in central Arizona, which are similar to the Hickey formation, has been made to the Pliocene epoch (Gidley, 1922 and 1926; Knechtel, 1936, p. 86-87); (2) fragmentary antelope and llamalike camel bones found in late Tertiary (?) rocks near Prescott do not preclude the possibility of a Pliocene age (Anderson and Creasey, 1957); (3) the complexity of geologic events subsequent to deposition of the Hickey Formation does not favor a Pleistocene age for the Hickey; and (4) general similarity to gravel of early Pliocene age, 20 miles south of Prescott near Milk Creek in the Walnut Grove basin (Anderson and Creasey, 1957).

The possibility exists that gravel at the base of the Hickey is significantly older than gravel deposits such as those in Lonesome Valley which are higher in the section. The youngest formation older than the Hickey known in the vicinity of the Clarkdale quadrangle is the Moenkopi Formation of Triassic age. Any gravel that accumulated between Moenkopi and the beginning of Hickey time might be included in the basal gravel of the Hickey Formation, for there is no criterion by which they could be separated. Price (1950a, p. 505– 507) , who studied these gravel deposits about a mile north of the Clarkdale area in Sycamore Canyon, believed that they are probably Miocene to Pliocene in age.

Robinson (1913) recognized three general periods of volcanic activity of the San Franciscan field in the Flagstaff-Williams area of the plateau—first period, basalt flows ; second period, andesite and rhyolite flows; and third period, basalt flows. In the Clarkdale quadrangle, two periods of volcanism are recognized—older basalt flows (Hickey) and younger basalt flows (Perkinsville and Verde). It is possible that the volcanic rocks of the Hickey represent Robinson's first-period basalt flows, and that the younger volcanic facies of the Perkinsville and Verde represent his third-period basalt flows. Robinson (1913, p. 88) stated that some of the basalt of the third period flowed off the edge of the plateau and reached the lower country to the south, which is precisely the relationship of the volcanic flows of the Perkinsville and Verde formations. Robinson (p. 91-92) placed the first-period basalt in late Pliocene. He arrived at this age determination by correlating a supposed peneplain, upon which the older basalt rests, with a similar feature in the physiographic cycles of southern Nevada in the

Basin and Range province. However, significant data obtained by Koons (1945) on the prelava surface of erosion, indicates that early concepts of a buried peneplain are not supported by the facts. Robinson's age designation, therefore, seems inconclusive.

Lake deposits of the Bidahochi Formation in the Hopi Butte Country east-northeast of Flagstaff are of middle or late Pliocene age (Williams, 1936; Hack, 1942). Stratigraphically, this formation has been shown to be older than the oldest lava of the San Franciscan field by Childs (1948, p. 378) who traced a pediment which truncates the Bidahochi Formation from the Hopi Buttes to northeast of Flagstaff, where Robinson's first-period basalt is above the pediment. He therefore suggests a very late Pliocene or early Pleistocene age for the oldest basalt.

In the Clarkdale quadrangle evidence shows that erosion produced about 1,300 feet of relief after the accumulation of the Hickey but before the accumulation of the Perkinsville and Verde formations. This erosion, introduced by regional uplift, resulted in southward drainage, which generally has persisted to the present, and this pattern was well established before the accumulation of the lava of the Perkinsville and Verde formations. This sequence of physiographic events in relation to the general periods of basalt flows in the quadrangle, conform to the sequence described by Robinson (1913, p. 92-95) for the Flagstaff region, Koons (1945, p. 179-189), for the western Grand Canyon region, and to those of Maxson (1950, p. 14) from work in the Grand Canyon. Koons correlated the stages of eruption in the Uinkaret volcanic field with the stages postulated by Colton (1937) in the San Franciscan field, and he stated that the oldest flows antedate cutting of the Grand Canyon.
From his studies on the age of the Colorado River, Longwell (1946, p. 832) suggested that the plateau was uplifted in late Miocene or early Pliocene time. This age is tentatively based on the fact that the Muddy Creek Formation is the youngest formation through which the river cuts. The Muddy Creek Formation is believed to be as old as Miocene.

The local Cenozoic volcanic history of the Clarkdale quadrangle may be correlated with the general history of the Colorado Plateau, which is based on relationship of the lava to topography. Although the chronology of the volcanic history is clear in each area, attempts to date these events in terms of absolute geologic time is difficult.

The earliest series of plateau lava flows and those of Woodchute and Mingus Mountains are probably contemporaneous, but this cannot be proved. Undoubtedly, lava from different centers coalesced with other lava that erupted within the same general period. The location of these areas of coalescence is unknown because of the similarity of the extrusive material from the different centers. Woodchute and Mingus Mountains are composed of a very thick sequence of lava flows and a few interbedded sedimentary deposits, therefore, they probably are close to a locus of extrusion.

Basaltic dikes north of Henderson Flat are considered to be feeders for the volcanic flows in the Hickey Formation for the following reasons : These dikes are not spatially associated with the young basalt of the Perkinsville and Verde formations which, for the most part, flowed south into the quadrangle from the plateau. With the exception of Black Mesa southwest of Perkinsville, no centers of eruption of the young lava flows are recognized within the Clarkdale quadrangle. In contrast, dikes spatially associated with the volcanic flows of the Hickey Formation are common throughout the quadrangle. The spatial relationship of dike to flow is particularly close on the Sycamore Canyon side of Casner Mountain. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

The Hickey Formation is mapped as the following units:

Thv - Hickey Formation, volcanic rocks (Tertiary)

No additional unit description provided. See Hickey Formation description above.

Ths - Hickey Formation, sedimentary rocks (Tertiary)

No additional unit description provided. See Hickey Formation description above.

Supai Formation (Permian and Pennsylvanian)

Distribution
The Supai Formation has greater areal distribution in the quadrangle than any other formation, and presents a vast expanse of red rocks that extend from the north side of Woodchute Mountain northward and northeastward in many places to the limits of the quadrangle. Elsewhere, the Supai is present for the most part, as inliers or outliers except for the southeastern part of the quadrangle where it is covered by the younger Verde Formation. The Supai Formation has a general northeasterly dip except in the northeastern part of the quadrangle where it flattens as it approaches the Mogollon Rim. Erosion has beveled these dipping beds so that they thin to the south and are largely absent on Mingus Mountain south of the quadrangle.

Thickness and Stratigraphic Relationship
The Supai Formation ranges from 1,550 to 1,665 feet in thickness within the Clarkdale area. The latter figure was determined by McKee (oral communication, 1953) from a section in Sycamore Canyon. McKee believes that the basal 332 feet of the section is equivalent to the Naco Formation of Pennsylvanian age, but this part is included in the Supai in this report. The 1,550 feet of Supai was measured in a composite section from the Verde River in the vicinity of Mormon Pocket north to Henderson Flat at the base of the Mogollon Rim. Most of the Supai, particularly the lower and upper parts, forms cliffs, which confine examination to the few accessible canyon walls or slopes.

Hughes (1949, p. 33; 1952) measured a maximum of 1,155 feet of Supai at Black Mesa about 10 miles south of Ashfork. In the vicinity of Fossil Creek, Huddle and Dobrovolny (1945) measured 2,200 feet of Supai; this excluded the basal 470 feet which they assigned to the Naco Formation of Pennsylvanian age. McNair, (1951, p. 530) measured a section of the Supai in Chino Valley near the south edge of Picacho Butte; it totaled 1,052 feet.

The Supai Formation rests unconformably on the Redwall limestone. The unconformity is marked by an erosion surface on the Redwall Limestone which shows a relief of about 15 to 30 feet in the area. Upon this surface rests a basal limestone conglomerate and (or) chert breccia of the Supai which is held together by a matrix of red mud. The contact is conspicuous because of the striking difference in lithology and color between the two formations.

Overlying the Supai Formation in the Clarkdale quadrangle is the Coconino sandstone, whereas in the Grand Canyon area the Hermit shale separates the Supai from the Coconino. The contact between the Supai and the Coconino is intertonguing. The contact has been assigned primarily on the basis of differences in the type of cross-bedding shown by each formation. Crossbedding in the upper part of the Supai Formation consists of thick coextensive sandstone beds that contain one or more sets of torrential-type cross laminae, the beveled surfaces of which are covered by horizontal beds of very thinly laminated siltstone and fine-grained sandstone. In contrast, the Coconino sandstone is considered to be an eolian deposit, and displays giant, wedge-shaped, crossbeds throughout its vertical range.

McKee (oral communication, 1953), in his regional studies has recognized the problem of drawing a boundary between the Supai and the Coconino and has arbitrarily placed the upper limits of the Supai at the top of the uppermost flat-bedded siltstone or sandstone, and this procedure is followed through this report.

Lithology
The Supai Formation, which is a red-bed deposit, consists of both detrital and chemical rocks. The detrital rocks, which are the most abundant, occur chiefly as sandstone, siltstone, and shaly

mudstone, whereas the chemically deposited rocks, which consist of limestone and chert, and are most abundant near the base, constitute a very minor part of the formation. Such a diversity of sedimentary rocks indicates that the formation must have accumulated in a complex environment.

The Supai Formation has been divided into members in order to interpret structure more precisely. The subdivision of the formation into members is based on the divisions of Huddle and Dobrovolny (1945) which include lower, middle, and upper members. McKee (oral communication, 1953), recognized these same subdivisions in Oak Creek Canyon and elsewhere. These members are distinctly different in lithology, color, and topographic expression.

Lower member - The lower member of the Supai Formation ranges from 580 to 625 feet in thickness and consists chiefly of sandstone and siltstone and minor amounts of shaly mudstone; it contains a few limestone beds, and some chert breccia and (or) limestone conglomerate. In the lower part of the member the beds are thinner.

Shaly mudstone is commonplace, so that the unit forms a gentle slope at the base but is increasingly steep toward the top, as the amount of shaly mudstone decreases. Some beds crop out prominently, other beds are concealed; the result is a stairlike slope typical of nearly flatlying beds of different composition. The lower member of the Supai is the only one exposed south of the Verde River. Prominent outcrops of this member north of the river make up the top of Packard Mesa, form the clifflike walls of the inner gorge of Sycamore Canyon from its mouth almost to the northeast corner of the quadrangle, and crop out in large areas northeast and northwest of Perkinsville, in places where overlying Tertiary or Quaternary gravel has been eroded away.

Many beds of the lower member of the Supai are lenticular. The sandstone beds commonly are laminated or cross laminated. They are generally fine grained and in places grade into siltstone. Conglomerate deposits are lenticular and contain medium-gray limestone and pale-red siltstone pebbles, which are as much as an inch in diameter. The few limestone beds in the lower part of the member are light bluish gray to light brownish gray aphanitic to coarsely crystalline, and form conspicuous ledges 1-6 feet thick. The siltstone is pale to dark reddish brown and thin to thick bedded. Many beds are cross laminated. The thin beds are more friable and are a deeper red than the thick beds.

At the base of the lower member is a conglomerate and (or) breccia zone locally as much as 15 feet thick, which rests unconformably on the Redwall Limestone. The conglomerate consists of pebbles and boulders of limestone, which are loosely cemented with a purplish-red and green to gray silty shale. Many spherical to ovoid chert concretions which range from several inches to several feet in diameter, and which show concentric banding of many colors, weather out from this zone. Some chert fragments are present in the conglomerate, but they are rare in comparison with limestone gravel. The conglomerate occurs in pockets, and was undoubtedly derived from the Redwall limestone with little transportation. In other places a breccia consists entirely of chert and is dark reddish brown and poorly sorted. It has an even upper surface. The chert fragments range from a fraction of an inch to as much as an inch in diameter. The conglomerate is common in the vicinity of Jerome and Woodchute Mountain. Elsewhere, in the area west of Antelope Hills, the breccia is more common.

Approximately the basal third of the lower member of the Supai, overlying the basal breccia or conglomerate beds, is composed chiefly of siltstone, but contains some shaly mudstone. Intercalated within this part of the member are beds of limestone conglomerate, limestone, and sandstone. This part of the member forms a moderate slope.

The upper half to two-thirds of the basal member is comprised chiefly of sandstone, but contains thin intercalated siltstone and some limestone beds. The bedding is thicker and more massive toward the top of the member so that in most places this part forms a very steep slope or, more commonly, a cliff. The upper 70-90 feet is a conspicuous sandstone unit, which is pale red to pink, very fine grained, thick bedded, with cross laminae in the beds, partly calcareous, and cliff forming. Its surfaces weather pale reddish brown to light brown. This massive cliff-forming sandstone contrasts sharply to the overlying, slope-forming sequence of siltstone and conglomerate of the middle member.

Middle member - The middle member which ranges from 250 to 300 feet in thickness, is present only north of the Verde River; erosion has stripped it from the area south of the river. The middle member topographically forms broad flat areas with a few gently rolling and rounded hills such as occur north of the Mormon Pocket area and northwest of Black Mountain in the Cow and Henderson Flats. It forms a moderate slope above the inner walls of Sycamore Canyon west of Black Mountain where erosion is especially active. The middle member also crops out north and south of the Drake road where it leaves the west side of the quadrangle north of coordinate N. 1,440,000; within a mile radius circumscribing the intersection of coordinates N. 1,430,000 and E. 420,000; and north along the course of Sycamore Canyon to where it leaves the northeast corner of the quadrangle.

The principal rock in this member is siltstone, but it is intercalated with conglomerate, sandstone, and some limestone. The siltstone ranges in color from reddish brown to grayish red. Throughout the member, zones of thin layers alternate with beds that are -from 6 inches to 3 feet thick. Massive siltstone beds are relatively resistant to weathering and form weak rounded ledges. Some of the siltstone beds are calcareous and contain nodules ; they have been traced laterally into gray limestone.

Few of the conglomerate beds are thicker than 3 feet, although one bed at the top of the member is nearly 10 feet in places. Probably 25 percent of the middle member consists of conglomerate beds; the so-called "intraformational conglomerates" of the Supai. The conglomerate beds are very lenticular and many grade both laterally and upward into siltstone. The gravel constituents of the conglomerate include pale-brown to pale-red siltstone (some of which is laminated), and light-brownish-gray to medium-gray limestone.

The pebbles range from y2 to 5 inches in diameter, but more commonly are an inch or less; they are well rounded. The matrix is usually a pale-red to reddish-brown siltstone.

The sandstone is limited to perhaps three or four beds that are thick in comparison with the other rocks of this member. The sandstone is light brown to pale reddish brown, fine grained, and generally forms resistant, rounded ledges. Some beds are calcareous and show prominent cross lamination. They commonly range from 5 to 10 feet in thickness.

Limestone is the least common rock type in the middle member. Only a few beds are present in most sections. Locally a dark-pinkishgray aphanitic sandy cross-laminated limestone occurs at the base of the member. This limestone weathers into a pitted surface and is lighter on the weathered than on the unweathered surfaces. It wedges laterally and commonly is 1-11/2 feet thick, though in a few places it is almost 5 feet thick.

The contact between the middle and upper members is placed at the base of the lowest reddish-orange to light-brown friable large scale cross-laminated sandstone. The sandstone weathers into slabs several inches thick and is typical of the sandstone throughout the upper member. Inasmuch as the upper member is predominantly a sequence of medium- to coarse-grained sandstone, its basal contact is prominent.

Upper member - The upper member of the Supai Formation ranges from 650 to 750 feet in thickness, and is present only north of the Verde River. This member forms a wide peripheral band around Black and Casner Mountains, and comprises nearly half the rocks that make up the precipitous Mogollon Rim, which projects into the northern part of the quadrangle and extends along Sycamore Canyon where it has been cut into the Colorado Plateau. In the northwest quarter of the quadrangle most of the upper member of the Supai is covered by lava and gravel so that inliers of this member occur in many of the drainage systems which traverse the beds of lava and gravel.

The contact between the middle and upper members is characterized by a sharp break in topography and lithology. In contrast to the slope-forming, dominantly siltstone sequence of the middle member, the upper member is a sequence of sandstone and a few interbedded siltstone beds that form cliffs, buttresses, and pinnacles.

This member contains about eight times as much sandstone as siltstone. The sandstone has a distinct outcrop and color which is not readily confused with lithologic characteristics in other members; it is dominantly reddish orange though some is light brown to moderate reddish brown. Most of the sandstone is cross laminated on a large scale, and, the rock weathers into slabs and plates. The sandstone beds generally are very friable and form a sandy soil. Some are calcareous and most are medium to coarse grained. The bedding is massive; some beds measure more than 150 feet in thickness, and, commonly, include a few partings or lenses of flat-bedded siltstone. Irregular folding due to penecontemporaneous deformation is conspicuous in the upper member at Sand Flat (coordinates N. 1,446, 500; E. 421,200) , but was not seen anywhere else.

Intercalated in the upper member are beds of pale-reddish-brown siltstone which range from a few feet to almost 30 feet in thickness, and probably averages 6-8 feet. The siltstone beds show irregular wavy laminae. Cross laminae, in most places, are absent, and the horizontal bedding of the siltstone beds is usually very noticeable where they separate strongly cross-laminated sandstone. The siltstone weathers into rounded ledges.

The contact between the upper member of the Supai and the Coconino sandstone is difficult to determine in places. Because there are no siltstone beds in the Coconino of other areas, and because at close range the crossbedding in the upper member of the Supai resembles that of the Coconino, the contact is arbitrarily placed at the top of the uppermost flat or horizontally bedded red siltstone. However, in many places talus blocks of the Coconino sandstone conceal parts of the upper Supai so that locally it is difficult to locate the uppermost siltstone. The Coconino sandstone is typically buff to cream, but locally may have the same reddish color as the Supai. However, the color boundary commonly is in close coincidence with the top of the uppermost flat-lying bed of the Supai. The Supai has horizontal-bedding planes, throughout, whereas the Coconino has huge, sweeping planes that separate individual wedges or sets of cross-bedding. The structures of the eolian Coconino sandstone are on such a large scale that they have very shallow angles and are almost horizontal in places. The low angles of these parting planes add difficulty in placing the contact on the basis of the highest horizontal-bedding plane. From a distance, a greater length of the contact can be observed, and the boundary at once becomes evident.

Age and Correlation

The Supai Formation, as originally defined by Darton (1910, p. 25-27) in the eastern Grand Canyon region of northern Arizona, included about 800 feet of red sandstone and shale underlying the Coconino sandstone and overlying the Redwall Limestone. As defined by Darton the Redwall Limestone included rocks of both Mississippian and Pennsylvanian or Permian age, but Noble (1922, p. 59-62) redefined the Supai Formation, assigning to it about 250 feet of red shale, purple and gray limestone with chert and red calcareous sandstone formerly included in the Redwall. Noble also redefined about 300 feet of red shaly siltstone and fine-grained sandstone from the top of the Supai and assigned to it the name Hermit shale. When redefining the Supai Formation, Noble (1922, p. 62) regarded the entire Supai as probably Pennsylvanian in age.

The Supai Formation, as now classified, is Permian and Pennsylvanian. Work by Huddle and Dobrovolny (1945) has resulted in an attempt to define the age of the Supai Formation more closely. They stated that the formation transgresses time lines and probably ranges in age from Des Moines (Pennsylvanian) through Leonard (Permian). In addition, they reported that the lower member probably ranges from Des Moines through Wolfcamp, and interfingers with the underlying Naco Formation (Pennsylvanian). Also, they correlated the middle member of the Supai with the Abo Formation of New Mexico and assigned it to Leonard age and possibly in part to Wolf camp age. They assigned the upper member entirely to Leonard age and equated it with the Yeso Formation of New Mexico.

In recent years there has been a tendency among geologists to separate beds of Pennsylvanian age from the Supai Formation. In the Clarkdale quadrangle, however, the lack of an unconformity, the apparent absence of fossils, and the similarity of lithology in the Pennsylvanian and the Permian beds make this separation impractical.

Ransome (1904, p. 44-54) introduced the term Naco for limestone of Pennsylvanian age overlying the Escabrosa limestone of early Mississippian age in the Bisbee quadrangle. Later, the limits of the Naco were extended northwestward from Bisbee to the Globe-Miami area of Arizona.

Huddle and Dobrovolny (1945) further extended the limits northward into the Pine-Payson area of central Arizona, which is about 50 miles southeast of Jerome. Here, they differentiated strata of Pennsylvanian age from the Supai Formation and referred them to the Naco Formation. The Naco-Supai contact was placed above a sequence of gray limestone and shale beds and below a sequence of beds consisting of sandstone, shale, and some limestone. They regarded the Naco as of Pennsylvanian age, ranging from Lampasas to Virgil.

Jackson and Winters (whose stratigraphic work in the Fort Apache area of Arizona has not been published but is quoted by Jackson) removed the Pennsylvanian beds from the Supai and assigned them to the Naco. The similarity between the Permian and Pennsylvanian rocks forced these workers to select for the contact an arbitrary plane above the highest bed containing a marine Pennsylvanian fauna.

Winters regarded the Pennsylvanian-Permian boundary proposed by Huddle and Dobrovolny (1945) as an arbitrary one which forms an unnatural break in a continuous rock sequence that has similar lithology and faunal assemblages ; therefore, he assigned 410 feet to the proposed boundary. Winters' Naco Formation has an uppermost bed of gray ripple-marked fossiliferous thin-bedded limestone, which is overlain by gray reddish-brown claystone that grades upward into noncalcareous siltstone and sandstone. From fusilinids present in the limestone, Winters established a Virgil age for the upper Naco.

West of Fort Apache, where Winters had worked, Jackson 3 found fossils of Des Moines age at Fossil Creek, in the Pine-Payson area, in the highest fossiliferous unit of the Naco. Jackson stated that the distribution of the lithologic assemblages between the Fossil Creek and the Fort Apache areas clearly indicate a regression of the Pennsylvanian sea toward the south and southeast as sedimentation exceeded subsidence. He suggested also in his stratigraphic work, the name Packard Ranch member for a subdivision of the Supai (lower half of lower member in this report) which he could trace to the east. He stated that his Packard Ranch member becomes more calcareous eastward and intertongues with the Naco, and is evident, therefore, that the basal part of the Supai is of Pennsylvanian age in that area.

Gilluly, Cooper, and Williams (1954) have subsequently assigned the name Naco to a group, subdivided into several formations. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

The Suspai Formation is mapped as the following units:

Psu - Supai Formation, upper member (Permian)

No additional unit description provided. See Supai Formation description above.

Psm - Supai Formation, middle member (Permian)

No additional unit description provided. See Supai Formation description above.

PPNsl - Supai Formation, lower member (Permian and Pennsylvanian)

No additional unit description provided. See Supai Formation description above.

Mr - Redwall Limestone (Mississippian)

Distribution
The Redwall Limestone occurs sporadically throughout the south half of the Clarkdale quadrangle, except in the southeast corner where it is entirely hidden by younger rocks. It occurs extensively along the west margin of the quadrangle as far north as the Verde River, and in the vicinity of Jerome it forms a peripheral band that crops out on the steep slopes around Woodchute and Mingus Mountains to the south. Also, east of the Verde fault, the Redwall has been exposed by subsidiary faulting and large patches of the formation crop out north of Woodchute Mountain where erosion has stripped the overlying Supai Formation from uplifted fault blocks. The Redwall occurs along scarps of the north-northwestward-trending faults which branch from the Verde vault in the vicinity of the Jerome area. A small and isolated occurrence of it may be seen in S O B Canyon. Almost a continuous exposure occurs along the entire course of the Verde River from where it enters the quadrangle on the west to where Sycamore Creek joins it.

The only exposures of the Redwall Limestone north of the Verde River are in Sycamore Canyon, along the scarp of the Railroad fault on the west side of Packard Mesa, and along the scarps of the Verde and Orchard faults east and northeast of Perkinsville. The best exposures are in Sycamore Canyon, the Verde River canyon, and in the vicinity of Jerome.

Thickness and Stratigraphic Relationship
The Redwall Limestone ranges in thickness from 235 to 285 feet within the quadrangle, but probably averages about 250 feet. The greatest thickness in any of the five sections measured is in Haynes Gulch in the vicinity of Jerome, where the section is 285 feet thick. The thinnest section, 235 feet, is in S O B Canyon. The Redwall is 255 feet (incomplete section) in Little Coyote Canyon on the west side of Woodchute Mountain about 2 miles south of the quadrangle border ; 252 feet in the Verde River canyon (coords. N. 1,412,000; E. 423,000) ; and 241 feet in Sycamore Canyon (coords. N. 1,413,400; E. 454,000). These data show that the Redwall Limestone is progressively thinner from Jerome towards the northeast.

The Redwall Limestone unconformably overlies the Martin limestone of Late Devonian age, and is unconformably overlain by the Supai Formation. The exact position of the contact between the Martin and the Redwall is not everywhere discernible because the lowest unit of the Redwall contains reworked sediments from the Martin and therefore resembles the Martin. The zone of reworked material is as much as 35 feet thick in places but at other places it is absent, owing to the relief on the Devonian surface. The contact is gently undulating and from a distance the two formations appear conformable. The base of a massive bluish-gray oolitic limestone member, which directly overlies the reworked residual material above the Martin Limestone, was used for mapping the contact between the Redwall and the Martin.

The contact between the Redwall Limestone and the overlying Supai Formation is easily determined. It can readily be observed on the east and north sides of Woodchute Mountain along the road from Jerome to Perkinsville. The Redwall generally is a massive limestone that forms conspicuous cliffs. The top of this limestone commonly forms a bench from which the soft red shale and siltstone of the basal Supai Formation have been eroded. The contact is irregular; the local relief is as much as 15-30 feet in a lateral distance of 100 feet, and fragments of limestone and chert fill the hollows.

Lithology
The Redwall Limestone, which is generally a cliff-forming unit, consists chiefly of light-gray to white aphanitic to coarsely crystalline thin- to thick-bedded limestone. It has an overall massive appearance, which is due partly to the homogeneity of the beds but chiefly to planes of separation between many of the beds which are so inconspicuous when viewed from a distance, that the formation appears to be a single stratum. The limestone generally is fossiliferous throughout, though locally beds are barren. The limestone characteristically contains solution channels and caverns, many of which have collapsed or have been filled. Where they have collapsed, large blocks of limestone conglomerate that fill them are cemented with a bright red, claylike sediment, which probably is a residue from solution of the limestone. The channel-filling consists chiefly of chert

released by solution from limestone matrix. The caverns are both vertical and horizontal in attitude; the horizontal ones extend along the strike of the bedding. Many of these occur along the Chino Valley-Perkinsville road where the road meanders through Wildcat Draw just outside of the west border of the quadrangle.

Woodell (Stoyanow, 1936, p. 514), Gutschick (1943), and Gutschick and Easton (1953) have studied the Mississippian strata in the Jerome area in detail. Woodell divided the limestone into six faunal zones and listed the species of fossils present in each. Gutschick (1943, p. 2-5), who studied the Redwall Limestone from the Pine-Payson area northwestward along the margin of the Colorado Plateau to near Seligman, Ariz., divided the formation into four members. The four members as designated by Gutschick are as follows, from the base upward: (I) A white crystalline oolitic limestone member; (II) a fine-grained cherty porous limestone member; (III) a massive coarsely crystalline limestone member; and (IV) a gray, micro-oolitic aphanitic limestone member. The units used in describing the Redwall in the text of this report correspond to the members of Gutschick, but the contact between units 3 and 4 was located in a different place. In this report it is placed at the base of the bluish-gray micro-oolitic limestone near the top of the formation, whereas Gutschick and Easton (1953, p. 4) placed it about 25 feet below where they believed that they recognized a disconformity. No disconformity could be found at this horizon by the writer.

Although the four members of Gutschick were recognized during the present study, they were not mapped separately except in a few local areas where detailed information was desired for interpreting the structure. For this reason they are not shown on plate 45. In order to describe the Redwall Limestone as adequately as possible, each of the four units is described separately.

Unit 1 - Unit 1 of the Redwall consists of a lower thin-bedded clastic unit that constitutes reworked deposits of the Martin Limestone, and an upper unit that constitutes bluish-gray oolitic thick-bedded limestone. The lower unit consists chiefly of limestone, arenaceous limestone, and calcareous sandstone—materials which resemble many of the Upper Devonian lithologies. This unit wedges out against topographic highs that remain on the upper surface of the Martin Limestone. As much as 35 feet of these beds has been measured in some places. The beds are very light gray and lavender to pink; the pink results from impurities. Most of the beds in the lower part of the unit are thin, but higher up they are moderately thick (several feet). Locally a thin zone of sandstone, partly conglomeratic, is present at the base. The thin beds normally weather to slopes.

The upper part of unit 1 consists of massive beds of aphanitic oolitic limestone, which range from 25 to 55 feet in thickness, and is characteristically bluish gray and cliff forming. The rock generally is a mass of conspicuous oolites, which stand out in relief on weathered surfaces.

Gutschick and Easton (1953, p. 3), stated that an unconformity which cuts out the oolitic limestone to the north and northwest, is at the top of their member I. They believed that because of this unconformity the oolitic limestone is not recognized in the Grand Canyon area. Huddle and Dobrovolny (1952, p. 87), however, traced this unit laterally into a rubble breccia that consisted of large limestone and chert blocks in a matrix of red sandy mudstone. This relationship conforms with observations made by the writer in the Clarkdale quadrangle, and indicates that the oolitic blue limestone unit is conformable with the overlying member, but that laterally parts of it that were especially susceptible to solution formed in caves that later collapsed to form thick irregular breccia zones.

Unit 2 - Unit 2, which ranges from 55 to 80 feet in thickness, is a light gray to cream fine-grained cherty limestone. The abundance of alert in this unit is characteristic. The chert, which is white to yellow and weathers to a rusty brown, occurs as nodules, lenses, and layers within the beds and along the bedding planes of the limestone. Fossils are commonly preserved in the many chert nodules. Where this unit is exposed to weathering, large blocks of chert are scattered about on the surface. The limestone occurs as beds 2-5 feet thick, and is fine to medium grained. It is fossiliferous though not abundantly so. This unit appears to have been especially susceptible to the formation of caverns. These caverns have collapsed or been refilled with limestone and chert breccia.

Unit 3 - Unit 2 is overlain conformably by unit 3. Unit 3 is a yellowish- to light-gray homogeneous coarsely crystalline crinoidal limestone, which probably averages 100 feet in thickness. It is thick bedded and the most fossiliferous unit of the formation. The weathered surface of the limestone is rough as a result of its coarse crystallinity and the abundance of small crinoidal discs that it contains. Unit 3 differs from unit 2 in grain size, color, and absence of chert.

Unit 4 - Unit 4 consists of a bluish-gray aphanitic to oolitic cliff-forming limestone that is present nearly everywhere in the Clarkdale quadrangle except where it has been removed by pre-Supai erosion. It averages about 40 feet in thickness, and resembles the oolitic phase of unit 1, except that it is more aphanitic, lighter, and has smaller oolites that can be recognized only with the lens. This unit, because of its color and its cliff-forming tendencies, forms a nearly continuous hand at the top of the formation, visible for several miles or more.

Age and Correlation
In Arizona, rocks of early Mississippian age have been called the Redwall Limestone in the northern part of the State and the Escabrosa limestone in the southeastern part of the State. The Redwall, as originally defined by Gilbert (1875, p. 162, 177-186) , included rocks both older and younger than Mississippian. Later, Noble (1922, p. 26, 54) , who made detailed studies in the Grand Canyon area, restricted the name to strata of Mississippian age. The Escabrosa limestone was a name proposed by Ransome (1904, p. 42-44), for the strata of Mississippian age in the Bisbee area of southern Arizona, and this term has been widely used in the southeastern part of the State. In central Arizona, Huddle and Dobrovolny (1952, p. 86) have shown that the two formations probably are continuous and form a single mappable unit. In their report dealing with the Mississippian limestone of central Arizona, they use the name Redwall Limestone.

The Mississippian strata in the Jerome area have long been referred to as the Redwall Limestone. Ransome (1916, p. 162) reported that the faunas show close affinities with the lower Burlington (lower Osage group). Stoyanow (1936, p. 505) stated that the Escabrosa and the Redwall Limestone formations are not exactly taxonomic equivalents but overlap each other; he believed that the Redwall began somewhat later than the Escabrosa. He further stated (Stoyanow, 1936, p. 514) that species collected by Woodell in the Redwall limestone of the Jerome area indicate that the faunas range from late Kinderhook into Keokuk and Burlington times.

Gutschick (written communication, 1955) assigned his member I to Kinderhook age and placed the break between Kinderhook and Osage between his member I and II. He correlated his member II with the top of the Alamogordo and the base of the Nunn members of Laudon and Bowsher of the Lake Valley limestone in New Mexico. His member III is Osage in age and correlated with the Burlington limestone of the Mississippi Valley. Gutschick tentatively placed his member IV in the uppermost part of the Osage (Keokuk affinity) but felt that this did not necessarily preclude a Meramec assignment. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

Dm - Martin Limestone (Devonian)

Distribution
The Martin Limestone is limited chiefly to that part of the quadrangle which is south of the Verde River. The most extensive exposures are along the southwest boundary of the quadrangle where the Redwall Limestone of Mississippian age has been eroded from the foot-wall blocks adjacent to large normal faults. In the vicinity of Jerome the Martin Limestone crops out beneath younger rocks that compose Woodchute Mountain, and extends southward in a peripheral band around Mingus Mountain to the south. Outcrops of this limestone also are abundant along the footwall of the Verde fault and subsidiary faults where erosion has exposed them. Northward, between Woodchute Mountain and the Verde River, the Martin Limestone is exposed along many of the fault scarps. It is well exposed in the canyons of the Verde River and Sycamore Creek, and in a small area in S- O B Canyon (coords. N. 1,395,000; E. 447,400). The only exposure of the Martin north of the Verde River is in Sycamore Canyon.

Thickness and Stratigraphic Relationship
The thickness of the Martin Limestone, which was measured in four widely separated localities, averages about 455 feet. It is 465 feet thick in the Mingus Mountain quadrangle, 21/2 miles south of Coyote tank (coordinates N. 1,365,700; E. 407,500) , and in Haynes Gulch (coordinates N. 1,368,000; E. 433,000) ; just north of Jerome, it is 441 feet thick. A section in the Verde River canyon (coordinates N. 1,409,500; E. 427,500), west of Mormon Pocket, revealed 444 feet of Martin, and at the Packard Ranch area in the Verde River canyon (coordinates N. 1,407,000; E. 449,400) it is 480 feet—the thickest section in the Clark-dale quadrangle.

Where there are local topographic highs on the old Precambrian surface, the Martin Limestone rests directly on Precambrian rocks. Elsewhere, the Martin Limestone rests on the Tapeats Sandstone (?) . Because the contact between the Martin and the underlying Tapeats Sandstone (?) appears to be gradational, the contact has been placed arbitrarily at the base of the lowest massive limestone bed, which locally has some sandstone lenses in its basal part. The contact between the Martin and the overlying Redwall Limestone is unconformable. The cut surface on the Martin Limestone shows very little relief over short distances, and has a relief that averages 10-15 feet, with a maximum of 35 feet as observed over wide distances.

Lithology
Though Martin Limestone is the formal designation, this formation consists of limestone, dolomitic limestone, dolomite, some limy siltstone and sandstone, and copious amounts of disseminated argillaceous and arenaceous impurities among the carbonate rocks. The formation as a whole is progressively darker from bottom to top as the result of an increase in impurities. The formation is uniformly bedded and forms step like slopes. These characteristics help to easily distinguish it from the overlying Redwall Limestone, which is more massive and lighter.

The Martin Limestone has comparatively few fossils, and the lower part of the formation seems to be barren. The beds generally are fossiliferous towards the top of the formation, and a few are very fossiliferous, containing abundant gastropods, brachiopods, and corals. No fossils were collected and no paleontologic data were gathered while mapping the quadrangle.

In the Jerome area the Martin Limestone can be subdivided into four parts which may be classified as members in detailed mapping. They do not correspond to the subdivisions of Huddle and Dobrovolny (1945; 1952, p. 73), who arbitrarily divided the Martin farther east into three members. The units chosen were used chiefly for structural control in this study. Although they are not differentiated on plate 45, they are described individually and are designated from bottom to top as units A, B, C, and D.

Unit A - Unit A includes a nonpersistent basal sandstone and a thin, bedded dark-gray dolomitic limestone, which ranges from 20 to 50 feet in thickness. The basal sandstone, of local occurrence in the Clarkdale quadrangle, has a uniform texture containing well-rounded and frosted grains. In places it contains limonitic spots, which give it a "freckled" appearance. It is lenticular and seldom more than 11/2 feet thick. This sandstone may be reworked Tapeats Sandstone (?). The overlying ledge-forming dolomitic unit is very persistent and has uniform lithologic characteristics which make it an excellent marker bed. Stoyanow (1936, p. 497) has noted this unit at Jerome and says that it can be recognized at the headwaters of the East Verde River near Pine and Payson. It is also present near Simmons, about 20 miles to the west, and probably extends northward from there.

The dolomitic limestone ranges from light brownish gray to brownish gray, and contains minor areas of yellowish gray and pale red, visible upon close inspection. The colors appear to be locally affected by the coarseness of grains and by the percentage of the argillaceous impurities. Acid tests indicate that the rock is more dolomitic where it is coarse grained and more calcitic where it is fine grained. The fine-grained areas which are lighter in color occur interstitially in larger areas of coarse-grained material. The grain size as a whole ranges from fine to coarse, but medium to coarse sizes are predominant. Possibly much of the coarseness is due to recrystallization.

Beds range from 1/4 inch to 3 feet in thickness, and the thinner beds alternate with the more massive

ones. Weathering of the faces of the thicker beds has etched out textures and structures of these rocks so that it is not uncommon to see crossbedding, channeling, and fragments of limestone in relief on the surfaces. These features indicate that, although the carbonate materials are of subaqueous origin, they were mechanically transported and deposited.

The massive beds which commonly are more dolomitic and coarser grained than the thin ones show many ovoid to circular accretionary masses of white calcite. Chert occurs as nodules and lenses in the upper few feet of the unit.

Unit B - Overlying the brownish-gray lower unit is a sequence of uniformly thin-bedded aphanitic light-colored slightly dolomitic limestone beds which are designated as unit B. This unit generally is homogeneous in appearance, and probably is the most prominent of the section because it is light and is limited at top and bottom by darker units. Because of its thin bedding, this unit commonly forms a slope. It ranges in thickness from 80 to 110 feet but averages about 85 feet.

Unit B is characteristically light gray to white on the weathered surfaces and pinkish gray on the unweathered surfaces. Locally, one or two beds near the bottom of the unit may be dark gray. The thickness of individual beds ranges from a few inches to several feet, and probably averages about 8 inches. The limestone beds are separated by shaly interbeds or partings as much as 3 inches thick. On slopes the shaly mudstone is not conspicuous and may go undetected, whereas in cliffs or steep walls, the shale interbeds are more distinct. The shale is dark gray and appears as a dark band between the lighter beds, which emphasizes the uniform bedding of the unit. A good example of this may be seen about 1 mile north of Jerome on the Jerome-Perkinsville road. The limestone is very aphanitic and in most places does not show stratification on unweathered surfaces. Disseminated sand grains stand out in relief on the weathered surfaces of some beds and locally on unweathered surfaces. Chert is fairly abundant as nodules, lenses, and thin layers parallel to the bedding; it is in shades of light yellow to dark gray or black, and is present in the limestone and the shale interbeds.

Within 6-10 feet of the top of the unit is a persistent sandstone bed that ranges from 1 to 3 feet in thickness. In some places, it is so well cemented with silica that it is more nearly an orthoquartzite than a sandstone. Chert is moderately common along this bed or zone. Some limestone grains are admixed with quartz sand grains in a few localities. The sandstone weathers from a light rusty brown to a darker brownish red, hence, the local name "Red Marker" has been applied. This horizon marker has been used extensively in the vicinity of Jerome for determining offsets on faults of minor displacement.

Unit C - Unit C overlies unit B with a distinct and abrupt lithologic change. In contrast to the underlying unit B, unit C is much darker and coarser grained, has fewer shale partings, is thicker bedded, and forms receding ledges. The thickness of this unit ranges from 65 to 80 feet but averages about 70 feet. Unit C is characteristically a sequence of mottled dolomitic limestone beds. The mottling, produced by a difference in grain size, is similar to that in the lower unit. The fine-grained areas are pale red to grayish orange pink, and the medium-grained areas are yellowish gray to light olive gray. The mottling appears to result from partial recrystallization. The size and shape of the recrystallized areas is variable, but on any given surface it is generally measured in inches. The beds range from less than an inch to about 4 feet in thickness. Stratification is not evident within most beds. Very few thin partings of shale are present. Vugs of coarsely crystalline calcite are abundant.

Unit D - In contrast to all the other units of the Martin Limestone, each of which is uniform in character, unit D shows the greatest variation in lithology, color, and texture. This unit includes all the rock types of other units, in alternating sequence. Such diverse lithology produces alternating dark and light beds which gives the unit a heterogeneous appearance. The unit ranges from 260 to 270 feet in thickness and consists chiefly of dolomitic limestone and limestone, with lesser amounts of interbedded calcareous shaly siltstone and sandstone. The limestone is less dolomitic and more argillaceous and arenaceous towards the top, except in the uppermost 50 feet.

For the most part, the lower fourth of unit D consists of interbedded light-gray aphanitic dolomitic limestone similar to the limestone of unit B, light-olive-gray to dark-gray medium- to coarse-grained

dolomitic limestone and (or) dolomite, and medium- to light-gray thin-bedded finely laminated dolomitic limestone. Chert layers and lenses are abundant in the thin-bedded zones. The bedding ranges from a few inches to several feet in thickness and is uniform and regular.

Above the lower fourth of the unit, the section becomes more argillaceous so that shaly mudstone and platy siltstone become prominent lithologic types. Because much mud apparently was introduced, the dolomitic limestone beds are contaminated with argillaceous impurities that cause a purple to red mottling. In many places, inter-beds of purple or lavender calcareous shaly mudstone separate these impure dolomitic beds.

A little less than half way up the unit, beds that total about 40 feet in thickness consist of alternating thin-bedded impure slabby dolomitic limestone and purple calcareous shale. This part of the unit forms a slope and includes most of the argillaceous impurities.

Argillaceous materials are also present, but in lesser amounts, scattered throughout the overlying beds, except in the top 50 feet of the unit. These uppermost beds consist of grayish-orange-pink medium-grained dolomitic limestone that is uniformly bedded and crops out in step like ledges.

A few distinctive beds in unit D merit individual attention as they constitute key or marker beds. In the Jerome area, two beds are lithologically unique in the section. These are light-olive-gray medium- to coarse-grained dolomitic limestone beds that contain many inclusions of fine-grained moderate red sandstone in irregularly shaped masses which range from less than an inch to about 9 inches in diameter. Each of these beds is 2 feet thick. They occur 40 and 50 feet respectively above the base of the unit. Also a 7-foot massive yellowish-gray fine-grained dolomitic limestone, bearing an abundance of solitary- and colonial-type corals, occurs 150 feet above the base of the upper unit. This bed may be fossiliferous only locally, because in other areas the fossils could not be located. A prominent feature in the Verde River canyon near the mouth of Sycamore Canyon, is a 3-foot ledge of sandstone, 175 feet above the base of the upper unit.

Age and Correlation
In Arizona, Devonian strata have been referred to as the Temple Butte limestone, a name proposed by Walcott (1890, p. 50) but used only in the Grand Canyon area in the northern part of the State; the Martin Limestone, a name that Ransome (1904, p. 33) assigned to the Devonian rocks at Bisbee, but which has been used mostly in the central and southeastern part of the State; and the Jerome Formation, a name used by Stoyanow (1926, p. 316-317) for the Devonian rocks in north-central Arizona.

Huddle and Dobrovolny (1945) demonstrated that the Martin limestone of the Globe-Miami area probably is continuous with the Devonian strata of the Pine-Payson area and stated that "there seems to be no reason for recognizing the Jerome Formation of Stoyanow." For this reason Anderson and Creasey (1957) decided to use the name Martin for the Devonian rocks in the Jerome area also. This report follows that usage.

Ransome (1916, p. 161) took a random faunal sample from a fossiliferous bed in the upper part of the Martin Limestone at Jerome. The fauna, examined by Kindle, was assigned to Late Devonian age.

Stoyanow (1936, p. 495-500) studied the Devonian section at Jerome and listed fossils and their locations in the section which proved Late Devonian in age.

McNair (1951, p. 516) compared the Martin Limestone of the Jerome area with the Devonian strata of the Grand Canyon and reported that the purple soft, crumbly, silty beds, which are more abundant in the Martin Limestone toward the north, are also a conspicuous rock type of the Temple Butte limestone.

The upper part of the Martin Limestone of central Arizona is of Late Devonian age, but the lower and middle parts may be Middle Devonian, according to Huddle and Dobrovolny (1952, p. 67, 86), who

stated that their fossil collection indicates that the Martin may contain equivalents of some of the faunal zones of the Devils Gate Formation of Merriam in central Nevada. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

Ct - Tapeats Sandstone (Cambrian)

Distribution
The Tapeats Sandstone has the smallest areal distribution of any of the Paleozoic formations in the Clarkdale quadrangle, and the combined outcrops cover less than 1 square mile. There are five small areas where the Tapeats is exposed as inliers in younger Paleozoic and Tertiary rocks.

Most of the Tapeats Sandstone outcrops are in the southwest corner of the quadrangle. This is due to the regional northeast tilt, which results in successively younger rocks cropping out to the northeast. Probably the best exposed section of Tapeats in the quadrangle is in Munds Draw (coordinates N. 1,374,000; E. 402,000).

On the east side of Woodchute Mountain above the dump of the United Verde mine at Jerome, the Tapeats crops out between the Haynes fault and other faults of that area. Another exposure of Tapeats is about 11/2 miles northeast of the pit at Jerome. Here it crops out in a continuous exposure for nearly 3,000 feet in the opencuts of the Verde Tunnel and Smelter Railroad, which formerly connected the smelter at Clarkdale with the United Verde mine (coordinates N. 1,368,000; E. 444,000).

The two other occurrences of Tapeats are in the Verde River canyon between Perkinsville and the Packard Ranch (coordinates N. 1,410,000; E. 427,000 and N. 1,406,000; E. 450,000).

Thickness and Stratigraphic Relationship
The thickness of the Tapeats Sandstone in the quadrangle ranges from a few inches to about 60 feet. The greatest thickness is in Munds Draw where the formation is 60 feet, although about 1 mile to the south it is only 25 feet. The Tapeats exposed on the east side of Woodchute Mountain near Jerome averages 50 feet in thickness. Near Packard Ranch in the Verde River canyon it is 40-60 feet, whereas west of Mormon Pocket in the Verde River canyon (coordinates N. 1,410,000; E. 427,000), it has a maximum thickness of about 15 feet. Nearby it wedges out and the overlying Devonian limestone rests directly on Precambrian rocks.

The range in thickness of the Tapeats largely results from the uneven Precambrian surface upon which it was deposited. Because of the few exposures of the basal contact of this sandstone in the quadrangle, the relief of the underlying Precambrian surface is not well known, but in the Mingus Mountain quadrangle to the south, Anderson and Creasey state that Precambrian topographic highs rise into the overlying Martin Limestone in many widely distributed areas.

The Martin Limestone of Devonian age overlies the Tapeats sandstone ( ) and the contact between them appears to be gradational. The contact has been arbitrarily placed at the base of the first massive limestone bed which overlies yellow to green limy siltstone and marl.

Krieger (oral communication, 1953), who mapped the Paulden quadrangle (adjacent on the west), stated that she has found a possible stratigraphic break between the Tapeats and the overlying Martin Limestone of Devonian age.

The lithology of the Tapeats Sandstone in the Clarkdale quadrangle shows no significant deviation in the widely separated outcrops. In nearly every exposure a basal crossbedded sandstone forms a ledge that averages 50 feet in thickness. Above this sandstone is a sequence of weaker rocks, 10-15 feet thick, that consists of calcareous shaly siltstone and mudstone. Where the basal sandstone unit locally is cut out against topographic highs on the old Precambrian surface, the upper shaly unit rests directly upon the Precambrian rocks.

The lower unit of the Tapeats is composed of medium- to coarse-grained sandstone including lenses of granules and pebbles; the pebbles are as much as one-half inch in diameter. The unit displays well-defined cross lamination in beds which range from a few inches to about 15 feet in thickness. However, not all beds show cross lamination. Lenses of granules and pebbles formed as shallow, cut-and-fill channels are relatively common. Individual laminae are well defined but adjoining strata commonly have marked contrast. The contrasts between individual laminae give an overall heterogeneous appearance to the unit. The sand is bonded with a siliceous-ferruginous cement which differs in abundance from place to place. Where the iron content is low and silica high the rocks are very hard and relatively light in color. Inversely, where the iron content is high and silica low, the rocks are somewhat friable and are relatively dark. Most commonly, however, the rocks are very ferruginous, which makes the unit appear a dusky red to dark reddish brown; the predominant color is reddish brown. The sand grains, granules, and pebbles in the Tapeats consist chiefly of jasper, quartz, and chert, with subordinate amounts of feldspathic and unidentified dark minerals.

The upper unit of the Tapeats Sandstone consists of shaly siltstone and mudstone. This unit is very thin bedded and weathers to a slope, in contrast to the ledge-forming unit below. It ranges in thickness from 10 to 15 feet. Dark-reddish-brown slightly fissile mudstone in beds 5 feet thick, rest directly on the basal sandstone unit. Structureless siltstone, in beds 2-3 inches thick, is intercalated among them. The lower reddish-brown beds grade upward into lighter rocks that range from shades of yellowish gray and pale olive to dusky yellow. The lighter beds are slightly calcareous structureless mudstone and siltstone and are separated by fissile shale partings 1-6 inches thick; these shale partings are light green and dark red. The bedding appears to be irregular but individual beds cannot be traced readily because this unit is poorly exposed. Some thin sandstone beds are at the top of the Tapeats in a few places but are not everywhere present where the Tapeats (?) is exposed throughout the quadrangle. Some siltstone beds in the upper unit of the Tapeats Sandstone are very micaceous.

The basal sandstone of Paleozoic age in the Clarkdale quadrangle appears to be gradational upward into the Martin Limestone of Devonian age, as it does in the Mingus Mountain quadrangle, but it also appears to be the stratigraphic equivalent of the Tapeats Sandstone of Cambrian age in the Grand Canyon.

The strongest evidence in support of a Devonian age for the Tapeats (?) is the gradation into, conformity with, the overlying Martin Limestone. However, this may be more apparent than real in the light of Krieger's recent investigations (oral communication, 1953) where she has found a possible break above the Tapeats in the Paulden quadrangle, which adjoins the Clarkdale quadrangle on the west. The area of Tapeats (?) which Krieger mapped is only a few miles from the Tapeats Sandstone at Simmons (fig. 70) . McNair (1951) traced the Tapeats from the Grand Canyon south and eastward to Simmons. McKee (written communication, 1953) has found many Cambrian trilobites in the shales overlying the Tapeats at Juniper Mountain (Camp Wood quadrangle) and stated that from there to the Clarkdale quadrangle, exposures are fairly continuous along the north side of Chino Valley. Less significant reasons for considering the basal sandstone of the Paleozoic as Tapeats Sandstone of Cambrian age are based partly on its stratigraphic position and partly on litho-logic similarity to known Tapeats.

No new evidence on the age of the Tapeats (?) was found in the Clarkdale quadrangle; this report, therefore, follows Anderson and Creasey (1957) who, because of the lack of a positive age and because the term Tapeats had been previously used, preferred to continue using Tapeats, but appended a query to express uncertainty. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

Precambrian rocks

Distribution

The Precambrian rocks in Arizona are divided into two major systems, older Precambrian and younger Precambrian (Butler and Wilson, 1938, p. 11; Anderson, 1951, p. 1333). Only the older Precambrian rocks are present in the area of this investigation.

The Precambrian rocks in the Clarkdale quadrangle were not studied in detail by the writer. The subdivisions and names (pl. 45) are those used by Anderson and Creasey (1957) in their report on the Jerome area except for the Spud Mountain volcanics in the southwest corner of the quadrangle, which were identified in the field by Anderson.

The Precambrian rocks comprise metamorphosed volcanic and intrusive formations. The volcanic rocks are subdivided into the Spud Mountain volcanics, the Deception Rhyolite, and the Grapevine Gulch Formation; the intrusive rocks are gabbro and quartz porphyry. Although all the Precambrian rocks have been altered by regional metamorphism, and, around the ore deposits at Jerome by hydro-thermal alteration, Anderson and Creasey were able to determine their original nature and to map each separately. The Deception Rhyolite is a fine-grained compact rock that is commonly porphyritic and contains phenocrysts of quartz and feldspar. The Grapevine Gulch formation consists of fine- to medium-grained tuffaceous sedimentary rocks. The Spud Mountain volcanics comprise andesitic breccias and tuffaceous rocks; the breccias are characterized by large equant sanssuritized crystals.

The quartz porphyry consists of relict phenocrysts of quartz in a matrix now altered to quartz and sericite. The gabbro is a dark granular rock containing hornblende and saussuritized plagioclase. The quartz porphyry is older than the gabbro, and both intrude the volcanic formations.

The reader is referred to the report on the Jerome area by Anderson and Creasey (1957) for the detailed geology of the Precambrian rocks.

Unconformity at the Base of the Paleozoic Rocks
The base of the Paleozoic rock sequence is separated from the older Precambrian basement complex by a conspicuous unconformity. The horizontal to mildly diping [sic] Paleozoic cover rests upon a surface of acutely deformed Precambrian rocks which were intruded by igneous bodies.

The erosional surface on the older Precambrian rocks in the quadrangle appears to be one of very low relief, although not much is known about it because of the few exposures. The basal sandstone of Paleozoic age which rests on this surface is locally absent because of minor topographic highs that rise as much as 50 feet above the general level. Elsewhere in the Mingus Mountain area scattered hills of the older Precambrian rocks are as much as 400 feet above the normal surface.

Paleozoic Sedimentary Rocks
Except in the southwest corner, the Clarkdale quadrangle contains rocks of Paleozoic age, and in most parts, they are exposed; In the southeast and northwest corners of the quadrangle these rocks are partly concealed by Cenozoic deposits. The total thickness of the Paleozoic rock sequence is about 3,350 feet, and the ages of the rocks range from Cambrian to Permian. The Paleozoic rocks dip, in general, about 8°-10° NE. in much of the quadrangle, but they are horizontal in the Colorado Plateau in the northeast corner of the quadrangle. Recent erosion has beveled the inclined strata, so that the older formations crop out in the southwestern part of the quadrangle, with successively younger formations cropping out to the northeast.

In the southern part of the quadrangle, the Paleozoic rocks crop out around the margins of Woodchute Mountain, and in the northern part, they are conspicuously displayed in the precipitous cliffs of the Mogollon Rim, which marks the south edge of the Colorado Plateau. In the middle part of the quadrangle they crop out in a series of northwestward-trending ridges, locally accentuated by faults of similar strike. (*GRI Source Map ID 1092)* (USGS Bulletin 1021-N, Plate 45).

Precambrian rocks are mapped as the following units:

PCg - Gabbro (Precambrian)

No additional unit description provided. See Precambrian rocks description above.

PCq - Quartz porphyry (Precambrian)

No additional unit description provided. See Precambrian rocks description above.

PCgg - Grapevine Gulch Formation (Precambrian)

No additional unit description provided. See Precambrian rocks description above.

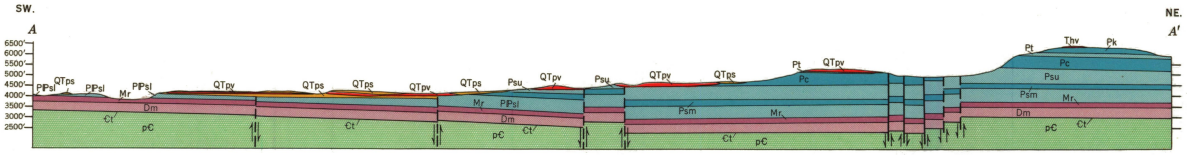
PCd - Deception Rhyolite (Precambrian)

No additional unit description provided. See Precambrian rocks description above.

Geologic Cross Sections

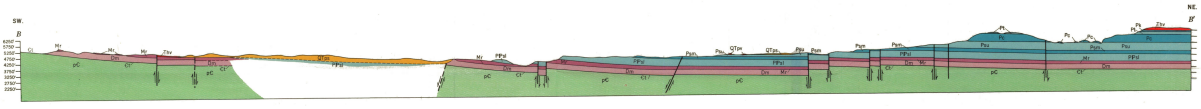
The geologic cross sections present in the Digital Geologic-GIS Map of Tuzigoot National Monument, Arizona (*GRI MapCode TUZI*) are presented below. Cross section graphics were scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document).

Cross Section A-A'



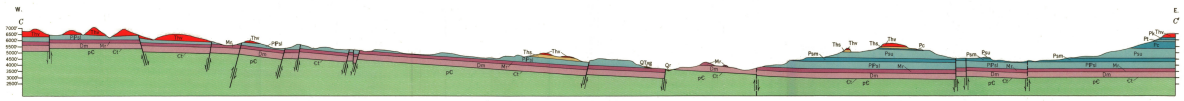
Extracted from: (USGS Bulletin 1021-N, Plate 45).

Cross Section B-B'



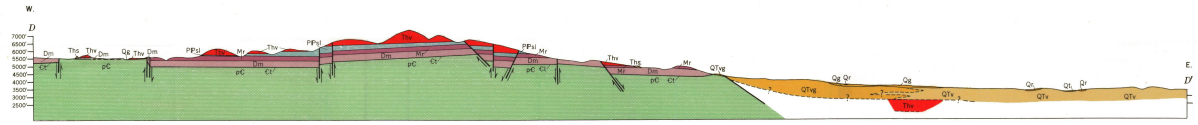
Extracted from: (USGS Bulletin 1021-N, Plate 45).

Cross Section C-C'



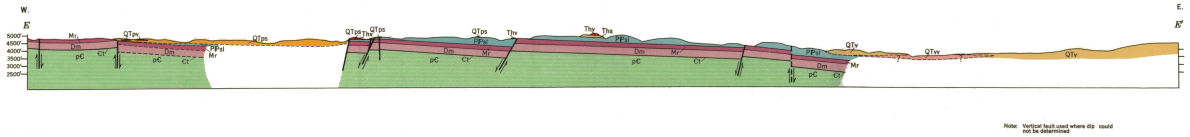
Extracted from: (USGS Bulletin 1021-N, Plate 45).

Cross Section D-D'



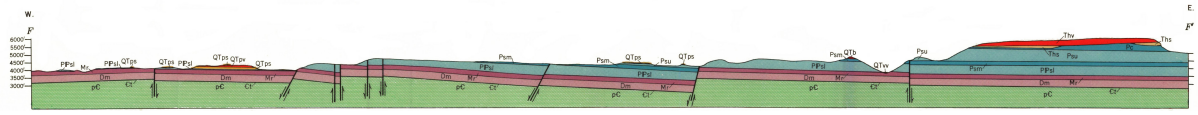
Extracted from: (USGS Bulletin 1021-N, Plate 45).

Cross Section E-E'



Extracted from: (USGS Bulletin 1021-N, Plate 45).

Cross Section F-F'

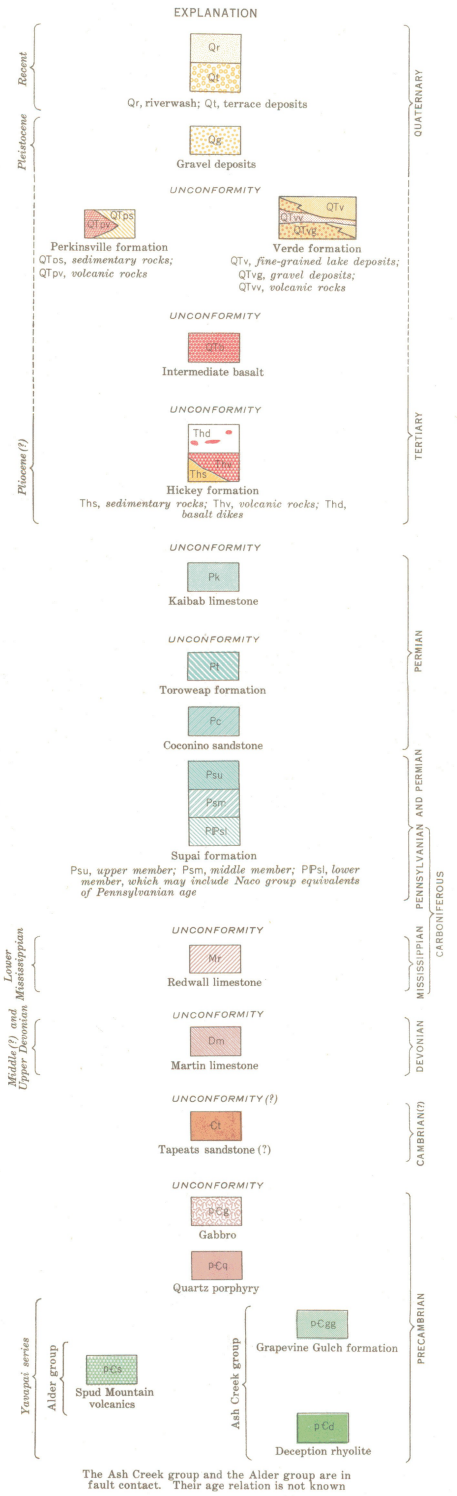


Extracted from: (USGS Bulletin 1021-N, Plate 45).

USGS Bulletin 1021-N, Plate 45 Source Information

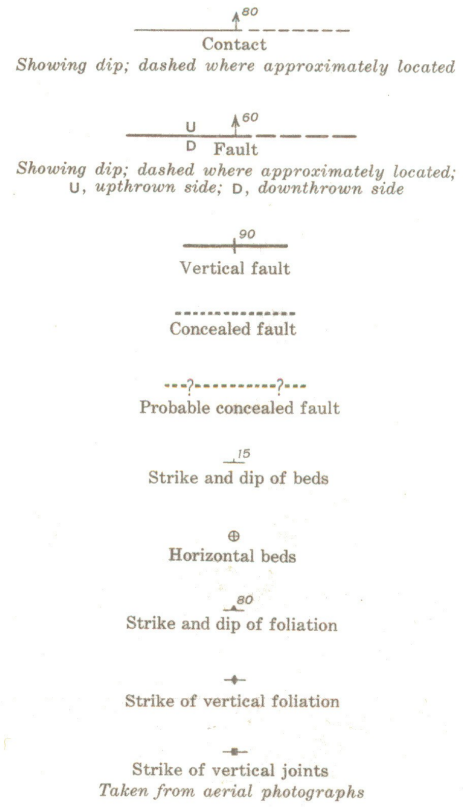
Lehner, Robert E., 1958, Geology of the Clarkdale Quadrangle: U.S. Geological Survey, Bulletin 1021-N, Plate 45, scale 1:48,000 (*GRI Source Map ID 1092*).

Correlation of Units



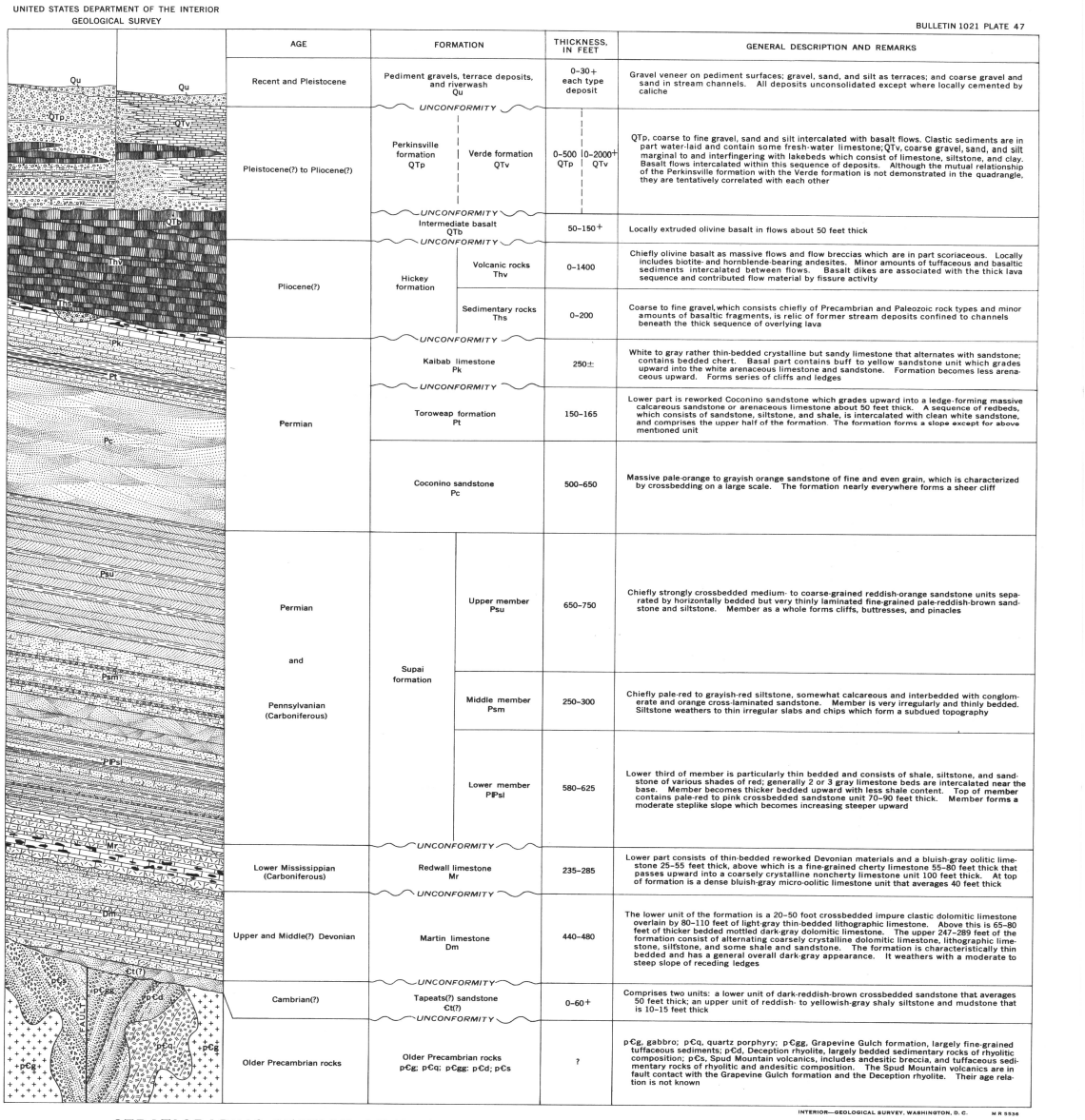
Extracted from: (USGS Bulletin 1021-N, Plate 45).

Map Legend



Extracted from: (USGS Bulletin 1021-N, Plate 45).

Stratigraphic Section



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BULLETIN 1021 PLATE 47

AGE	FORMATION	THICKNESS, IN FEET	GENERAL DESCRIPTION AND REMARKS
Recent and Pleistocene	Pediment gravels, terrace deposits, and riverwash Qu	0–30+ each type deposit	Gravel veneer on pediment surfaces; gravel, sand, and silt as terraces; and coarse gravel and sand in stream channels. All deposits unconsolidated except where locally cemented by caliche
	UNCONFORMITY		
Pleistocene(?) to Pliocene(?)	Perkinsville formation QTp / Verde formation QTv	0–500 QTp / 0–2000+ QTv	QTp, coarse to fine gravel, sand and silt intercalated with basalt flows. Clastic sediments are in part water-laid and contain some fresh-water limestone; QTv, coarse gravel, sand, and silt marginal to and interfingering with lakebeds which consist of limestone, siltstone, and clay. Basalt flows intercalated within this sequence of deposits. Although the mutual relationship of the Perkinsville formation with the Verde formation is not demonstrated in the quadrangle, they are tentatively correlated with each other
	UNCONFORMITY		
	Intermediate basalt QTb	50–150+	Locally extruded olivine basalt in flows about 50 feet thick
	UNCONFORMITY		
Pliocene(?)	Hickey formation: Volcanic rocks Thv	0–1400	Chiefly olivine basalt as massive flows and flow breccias which are in part scoriaceous. Locally includes biotite- and hornblende-bearing andesites. Minor amounts of tuffaceous and basaltic sediments intercalated between flows. Basalt dikes are associated with the thick lava sequence and contributed flow material by fissure activity
	Hickey formation: Sedimentary rocks Ths	0–200	Coarse to fine gravel, which consists chiefly of Precambrian and Paleozoic rock types and minor amounts of basaltic fragments, is relic of former stream deposits confined to channels beneath the thick sequence of overlying lava
	UNCONFORMITY		
Permian	Kaibab limestone Pk	250±	White to gray rather thin-bedded crystalline but sandy limestone that alternates with sandstone; contains bedded chert. Basal part contains buff to yellow sandstone unit which grades upward into the white arenaceous limestone and sandstone. Formation becomes less arenaceous upward. Forms series of cliffs and ledges
	UNCONFORMITY		
	Toroweap formation Pt	150–165	Lower part is reworked Coconino sandstone which grades upward into a ledge-forming massive calcareous sandstone or arenaceous limestone about 50 feet thick. A sequence of redbeds, which consists of sandstone, siltstone, and shale, is intercalated with clean white sandstone, and comprises the upper half of the formation. The formation forms a slope except for above mentioned unit
	Coconino sandstone Pc	500–650	Massive pale-orange to grayish orange sandstone of fine and even grain, which is characterized by crossbedding on a large scale. The formation nearly everywhere forms a sheer cliff
Permian and Pennsylvanian (Carboniferous)	Supai formation: Upper member Psu	650–750	Chiefly strongly crossbedded medium- to coarse-grained reddish-orange sandstone units separated by horizontally bedded but very thinly laminated fine-grained pale-reddish-brown sandstone and siltstone. Member as a whole forms cliffs, buttresses, and pinacles
	Supai formation: Middle member Psm	250–300	Chiefly pale-red to grayish-red siltstone, somewhat calcareous and interbedded with conglomerate and orange cross-laminated sandstone. Member is very irregularly and thinly bedded. Siltstone weathers to thin irregular slabs and chips which form a subdued topography
	Supai formation: Lower member PPsl	580–625	Lower third of member is particularly thin bedded and consists of shale, siltstone, and sandstone of various shades of red; generally 2 or 3 gray limestone beds are intercalated near the base. Member becomes thicker bedded upward with less shale content. Top of member contains pale-red to pink crossbedded sandstone unit 70–90 feet thick. Member forms a moderate steplike slope which becomes increasing steeper upward
	UNCONFORMITY		
Lower Mississippian (Carboniferous)	Redwall limestone Mr	235–285	Lower part consists of thin-bedded reworked Devonian materials and a bluish-gray oolitic limestone 25–55 feet thick, above which is a fine-grained cherty limestone 55–80 feet thick that passes upward into a coarsely crystalline noncherty limestone unit 100 feet thick. At top of formation is a dense bluish-gray micro-oolitic limestone unit that averages 40 feet thick
	UNCONFORMITY		
Upper and Middle(?) Devonian	Martin limestone Dm	440–480	The lower unit of the formation is a 20–50 foot crossbedded impure clastic dolomitic limestone overlain by 80–110 feet of light-gray thin-bedded lithographic limestone. Above this is 65–80 feet of thicker bedded mottled dark-gray dolomitic limestone. The upper 247–289 feet of the formation consist of alternating coarsely crystalline dolomitic limestone, lithographic limestone, siltstone, and some shale and sandstone. The formation is characteristically thin bedded and has a general overall dark-gray appearance. It weathers with a moderate to steep slope of receding ledges
	UNCONFORMITY		
Cambrian(?)	Tapeats(?) sandstone Ct(?)	0–60+	Comprises two units: a lower unit of dark-reddish-brown crossbedded sandstone that averages 50 feet thick; an upper unit of reddish- to yellowish-gray shaly siltstone and mudstone that is 10–15 feet thick
	UNCONFORMITY		
Older Precambrian rocks	Older Precambrian rocks pCg; pCq; pCgg; pCd; pCs	?	pCg, gabbro; pCq, quartz porphyry; pCgg, Grapevine Gulch formation, largely fine-grained tuffaceous sediments; pCd, Deception rhyolite, largely bedded sedimentary rocks of rhyolitic composition; pCs, Spud Mountain volcanics, includes andesitic breccia, and tuffaceous sedimentary rocks of rhyolitic and andesitic composition. The Spud Mountain volcanics are in fault contact with the Grapevine Gulch formation and the Deception rhyolite. Their age relation is not known

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C. M R 3936

STRATIGRAPHIC SECTION OF THE ROCKS IN THE CLARKDALE QUADRANGLE, ARIZONA

Extracted from: (USGS Bulletin 1021-N, Plate 45).

Report

The report for the Geology of the Clarkdale Quadrangle, Arizona is presented below.

Bulletin 1021-N

The report contains the following sections:

Abstract
Introduction
Geography
General Geology
Physiography
Geologic Structure
Geologic History
Mineral Resources
Literature Cited
Index

Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (GRI MapCode MOTU)

Map Unit List

The geologic units present in the Digital Geologic-GIS Map of Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (*GRI MapCode MOTU*) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qa - Alluvium). Units are listed from youngest to oldest. Information about each geologic unit is also presented in the GRI Geologic Unit Information (MOTUUNIT) table included with the GRI geologic-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. This was done if a unit was considered to be the same unit as one or more units on other source maps used for this project, and these unit symbols, names and/or ages differed. In this case a single unit symbol and name, and the unit's now recognized age, was adopted. Unit symbols, names and/or ages in a unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI the unit's source map symbol, name and/or age appears with the unit's source map description.

*Note unit Tve has been grouped with other Verde Formation members in the Map Unit Descriptions section of this document but its age places it between units Tsy and Tabo.

Cenozoic Era

Quaternary Period
Qa - Artificial fill
Qal - Alluvium
Qc - Colluvium and sedimentary breccia
Qf - Fanglomerate
Qt - Terrace gravel
Qg - Gravel
Qs - Sediment

Quaternary and Tertiary Periods
QTl - Landslide deposits
QTf - Fanglomerate
QTg - Gravel
QTs - Sedimentary rocks

Tertiary Period
Verde Formation
- Tvs - Verde Formation, undivided sedimentary rocks
- Tvl - Verde Formation, lacustrine rocks
- Tvls - Verde Formation, limestone
- Tvg - Verde Formation, gravel
- Tvt - Verde Formation, travertine

Younger volcanic and sedimentary rocks
- Taby - Younger volcanic and sedimentary rocks, alkali basalt
- Tby - Younger volcanic and sedimentary rocks, basalt
- Tdy - Younger volcanic and sedimentary rocks, dacite
- Tbsy - Younger volcanic and sedimentary rocks, basalt and sedimentary
- Tsvy - Younger volcanic and sedimentary rocks, sedimentary and volcanic
- Tsy - Younger volcanic and sedimentary rocks, sedimentary

Verde Formation
- *Tve - Verde Formation, evaporite beds

Older volcanic and sedimentary rocks
- Tabo - Older volcanic and sedimentary rocks, alkali basalt
- Tbo - Older volcanic and sedimentary rocks, basalt
- Tco - Older volcanic and sedimentary rocks, cinders and cinder cones
- Tao - Older volcanic and sedimentary rocks, andesite
- Tto - Older volcanic and sedimentary rocks, tuff

Hickey Formation
- Thab - Hickey Formation, alkali basalt
- Thb - Hickey Formation, basalt
- Tha - Hickey Formation, trachyandesite
- Thbs - Hickey Formation, basalt and sedimentary rocks
- Thsb - Hickey Formation, sedimentary rocks and basalt
- Ths - Hickey Formation, sedimentary rocks

Tertiary and Paleogene Periods

Lati-andesite of Sullivan Buttes and Santa Maria Mountains
- Tlal - Lati-andesite of Sullivan Buttes and Santa Maria Mountains, lower unit

Paleozoic Era

Permian Period

Pk - Kaibab Limestone
Pkt - Kaibab Limestone and Toroweap Formation, undivided
Ptc - Toroweap Formation and Coconino Sandstone
Psh - Schnebly Hill Formation
Ph - Hermit Formation

Mississippian, Pennsylvanian, and Permian Periods

PNs - Supai Formation

Mississippian Period

Mr - Redwall Limestone

Mississippian and Devonian Periods

MDrm - Redwall Limestone and Martin Formation, undivided

Devonian Period

Dm - Martin Formation

Cambrian to Devonian Periods

DCmt - Martin Formation and Tapeats Sandstone, undivided

Cambrian Period

Ct - Tapeats Sandstone

Precambrian

Proterozoic Eon

Tonalitic rocks
- Xchd - Tonalitic rocks, dikes of Cherry
- Xch - Tonalitic rocks, Cherry Tonalite

Xtgr - Texas Gulch Formation, rhyolitic meta-tuffaceous rocks
Xtgs - Texas Gulch Formation, purple slate
Gabbroic rocks

Xgb - Gabbroic rocks, gabbro
Xb - Basaltic flows
Xa - Andesitic flows
Xd - Dacitic flows
Xrd - Rhyodacitic flows
Xr - Rhyolitic flows and pyroclastic rocks
Xah - Altered andesitic rocks
Xrh - Altered rhyolitic and pyroclastic rocks
Xmv - Mafic rocks
Xt - Tuffaceous metasedimentary rocks
Xa1 - Andesitic breccia
Xr1 - Rhyolitic breccia
Xd1h - Altered dacitic breccia
Xr1h - Altered rhyolitic breccia
Xd2 - Dacitic tuff
Xr2 - Rhyolitic tuff
Xr2h - Altered rhyolitic tuff
Xd3 - Dacitic intrusive rocks
Xr3 - Rhyolitic intrusive rocks

Map Unit Descriptions

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

Qa - Artificial fill (Holocene)

Manmade structures that include waste piles and tailings ponds. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Qal - Alluvium (Holocene)

Sand, gravel, and silt in present-day stream beds. Includes minor terrace deposits along streams. Simplified from Ostenaa and others (1993) in BIg Chino Valley and from House (1994) and House and Pearthree (1993) in Verde River valley (fig. 1). Thickness highly variable, 2-20 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Qc - Colluvium and sedimentary breccia (Holocene and Pleistocene)

Debris flows and minor landslide deposits. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Qf - Fanglomerate (Holocene and Pleistocene)

Poorly sorted gravel and debris flows and minor landslide deposits. Includes much medium-grained, limestone-rich fan material in Big Chino Valley, north of Big Chino Wash. Thickness highly variable, 30–40 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Qt - Terrace gravel (Holocene and Pleistocene)

Well-sorted gravel deposits along major streams. Simplified from Ostenaa and others (1993) in Big Chino Valley and from House (1994) and House and Pearthree (1993) in Verde River valley. Thickness 2–10 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Qg - Gravel (Holocene and Pleistocene)

Well-sorted sand and gravel and minor conglomerate. Simplified from Ostenaa and others (1993) in Big Chino Valley and from House (1994) and House and Pearthree (1993) in Verde River valley. Thickness 2–15 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Qs - Sediment (Holocene and Pleistocene)

Silt and clay containing minor deposits of mixed sediment and gravel. Simplified from Ostenaa and others (1993) in Big Chino Valley. Unknown thickness. (*GRI Source Map ID 75246)* (USGS SIM-2996).

QTl - Landslide deposits (Pliocene to Holocene)

Chaotic blocks of Tertiary basalt and Tertiary sedimentary rocks, especially abundant in southwestern part of map area, along Sycamore Creek, and in southeastern part of map area, east of Verde River. In places, may be entirely Quaternary in age. (*GRI Source Map ID 75246)* (USGS SIM-2996).

QTf - Fanglomerate (Pleistocene and Pliocene)

Poorly sorted gravel conglomerate that crops out on north, east, and west sides of Sullivan Buttes as well as in other localities in map area. Gravel rich in lati-andesite fragments. Thickness 10–150 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

QTg - Gravel (Pleistocene and Pliocene)

Poorly sorted gravel and conglomerate. In southwestern Verde River valley, gravel contains angular to semi-rounded Tertiary basalt and Paleozoic limestone and sandstone cobbles that rest unconformably on Verde Formation. Thickness 2–10 m (*GRI Source Map ID 75246)* (USGS SIM-2996).

QTs - Sedimentary rocks (Pleistocene and Pliocene)

Siltstone, sandstone, and mixed sedimentary and volcaniclastic rocks. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Verde Formation (Pliocene and Miocene)

Fine-grained clastic and chemically precipitated strata deposited in lacustrine environment (Jenkins, 1923; Twenter and Metzger, 1963; Thompson, 1983; Nations and others, 1981). Two basalt flows, one near mouth of Sycamore Canyon and the other along Interstate 17, are interbedded with the lakebed sediments, but are described among the younger basalts. Thickness of exposed rocks about 480 m; thickness of entire formation about 780 m, but may exceed 950 m. Age about 2–7 Ma (Bressler and Butler, 1978; McKee and Anderson, 1971). (*GRI Source Map ID 75246)* (USGS SIM-2996).

The Verde Formation is mapped as the following units:

Tvs - Verde Formation, undivided sedimentary rocks (Pliocene and Miocene)

Includes limestone, claystone, silty limestone, and siltstone. Thickness variable. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tvl - Verde Formation, lacustrine rocks (Pliocene and Miocene)

Includes claystone, siltstone, and silty limestone. Thickness variable. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tvls - Verde Formation, limestone (Pliocene and Miocene)

Limestone and silty limestone. Thickness variable. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tvg - Verde Formation, gravel (Pliocene and Miocene)

Silty limestone that contains pebbles and cobbles of Paleozoic sandstone and limestone and Tertiary basalt. Abundant on northwest and southeast margins of outcrop of Verde Formation. Thickness variable. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tvt - Verde Formation, travertine (Pliocene)

Coarse-grained, calcite-rich travertine mounds, especially abundant near Montezuma Well, in east-central part of outcrops of Verde Formation. Thickness about 10–35 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tve - Verde Formation, evaporite beds (Miocene)

Sulfate-rich strata interbedded with minor limestone and siltstone (Thompson, 1983). Sulfate minerals include glauberite, gypsum, mirabillite, and thernardite. Thickness about 10–35 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Younger volcanic and sedimentary rocks (Pliocene and Miocene)

Alkali basalt and basalt flows and interbedded conglomeratic sedimentary rocks. In central part of map area, flows were derived from the north, along the Mogollon Rim. Flows and sedimentary rocks fill canyons cut through the ancestral Mogollon Rim. In northeastern part of map area, flows were derived from the northeast, predominantly the Mormon Mountain volcanic field (Nealey and Sheridan, 1989; Weir and others, 1989), and include the so-called “ramp” basalts that flowed into the ancestral Verde River valley. In the northwest, flows were derived from the Juniper Mountains (Goff and others, 1983), and flowed into the ancestral Big Chino Valley. Sedimentary rocks, in aggregate, predominate over flows. Individual flows 10–20 m thick. Aggregate thickness of flows highly variable, about 40–50 m. Sedimentary rocks range greatly in thickness, because they were deposited in channels cut into underlying bedrock. Channel deposits as thick as 60 m are noted in places. Includes Perkinsville Formation. Age about 4–7 Ma (McKee and Anderson, 1971; Goff and others, 1983). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Younger volcanic and sedimentary rocks are mapped as the following units:

Taby - Younger volcanic and sedimentary rocks, alkali basalt (Pliocene and Miocene)

Alkali basalt flows and minor cinder cones. Includes flows in Verde and Perkinsville Formations. Includes only those rocks that are proven to be alkalic. As such, percentage of outcrop defined as alkali basalt, versus basalt, is probably underestimated. Composition ranges from picritic basalt to alkali basalt to trachybasalt, and includes some latitic basalt (geochemistry data available at http://pubs.usgs.gov/sim/2996).

Along northern extension of Grindstone Canyon fault, north of map area, nearly all analyzed flows are

alkalic (fig. 2A), average to very potassic (fig. 2C), and average to very Fe rich (fig. 2D).

In Juniper Mountains in northwestern part of map area, alkalic flows (fig. 3A) are average in their K/Na ratio (fig. 3C) and range from very Mg rich to Fe rich (fig. 3D).

Near Paulden, alkalic rocks are represented by only one analysis of the lower flow downstream from Sullivan Lake dam and one analysis of the flow near Drake (fig. 4A); other analyses of these flows are not alkalic.

Alkalic flows in Verde Formation near mouth of Sycamore Creek range in composition from basanite to latitic basalt (fig. 5A), are average to very potassic (fig. 5C), and are average to very Mg rich (fig. 5D). Some flows in Munds Park and Schnebly Hill area, just east of map area, are alkalic, but more are not alkalic (fig. 5C).

Includes flows in Perkinsville Formation, which crops out between Paulden and Verde River valley. Age of flow in Verde Formation near mouth of Sycamore Canyon is 4.6 Ma. Age of flows in Verde Formation near Interstate 17 about 5.7–6.4 Ma (Donchin, 1983). Age of flows in Paulden area about 4.6–6.3 Ma. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tby - Younger volcanic and sedimentary rocks, basalt (Pliocene and Miocene)

Basalt flows and minor cinder cones. Includes all compositions of basalt not proven to be alkalic. Includes flows in Verde and Perkinsville Formations. As such, percentage of outcrop defined as basalt, versus alkali basalt, is probably overestimated. Composition is predominantly basalt, but includes minor andesite.

In Juniper Mountains in northwestern part of map area, flows range in composition from basalt to andesitic basalt (fig. 3A), are sodic to average in K/Na ratio (fig. 3C), and are very Mg rich (fig. 3D).

Near Paulden all flows are basalt that is average to potassic (fig. 4C) and Mg rich to average (fig. 4D).

Flows and dikes in Verde Formation, along and north of Interstate 17, appear to define two populations: basalt that is average to potassic (fig. 5C) and very Mg rich to Fe rich (fig. 5D); and andesite that is very sodic to sodic (fig. 5C) and very Mg rich to average (fig. 5D).. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tdy - Younger volcanic and sedimentary rocks, dacite (Pliocene and Miocene)

Dacite and rhyodacite domes and flows. In far southern Verde River valley includes flow dome at base of Verde Formation (Wolfe, 1983) that is a rhyodacite that is alkali-calcic (fig. 5A), mildly peraluminous (fig. 5B), very sodic (fig. 5C), and very Mg rich (fig. 5D). Age about 7.4 Ma (McKee and Elston, 1980). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tbsy - Younger volcanic and sedimentary rocks, basalt and sedimentary (Pliocene and Miocene)

Younger basalt flows and interbedded conglomerate and mixed sedimentary rocks. Flows predominate over sedimentary rocks. Basalt-cobble conglomerate is most abundant sedimentary rock. Includes parts of Perkinsville Formation, which crops out between Paulden and Verde River valley. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tsvy - Younger volcanic and sedimentary rocks, sedimentary and volcanic (Pliocene and Miocene)

Mixed sedimentary rocks and interbedded volcanic flows of mafic to intermediate composition. Sedimentary rocks predominate over flows. Sedimentary rocks include basalt-cobble conglomerate and mixed tuffaceous rocks. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tsy - Younger volcanic and sedimentary rocks, sedimentary (Pliocene and Miocene)

Mixed sedimentary rocks. Includes siltstone, sandstone, and minor conglomerate west of Williamson Valley Wash and in far southwestern Big Chino Valley. Derived from Santa Maria Mountains, to the southwest. In far southern exposures contains thin basalt flows. Thickens greatly into Williamson Valley Wash near Tucker where drilling and gravity data suggest thickness as much as 800 m (Langenheim and others, 2002). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Older volcanic and sedimentary rocks (Miocene)

Alkali basalt, basalt, andesitic basalt, and lati-andesite flows; dacite to rhyodacite flows and domes; and interbedded tuffaceous sedimentary rocks. Sedimentary rocks derived, primarily, from the south and southwest. Includes Thirteenmile volcanic rocks in southeastern part of map area and rocks younger than Hickey Formation (10–15 Ma) and older than younger basalt (4–7 Ma) throughout map area. Flows predominate over sedimentary rocks. Individual flows 10–25 m thick. Aggregate thickness of flows as much as 100 m. Age about 7–10 Ma (McKee and Elston, 1980). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Older volcanic and sedimentary rocks are mapped as the following units:

Tabo - Older volcanic and sedimentary rocks, alkali basalt (Miocene)

Alkali basalt flows near base and top of Thirteenmile volcanic rocks in Hackberry Mountain area, and in Mount Hope area, west of map area. Includes only those rocks that are proven to be alkali basalt. As such, percentage of outcrop defined as alkali basalt, versus basalt, is probably underestimated.

Alkali basalt and picritic rocks near base of Thirteenmile volcanics (fig. 6A) are potassic to very potassic (fig. 6C) and range from very Mg rich to very Fe rich (fig. 6D).

Trachybasalt in Mt. Hope area (fig. 7A) is average to very potassic (fig. 7C) and average to Fe rich (fig. 7D).

One sill in Martin Formation, along Chasm Creek, west of Verde River, is an alkali basalt (fig. 6A) that is moderately peraluminous (fig. 6B), very sodic to average (fig. 6C), and average in its Fe/Mg ratio (fig. 6D).

An undated, distinctive, magnetite-rich flow east of Paulden is alkalic (fig. 8A), very potassic (fig. 8C), and average in Fe/Mg ratio (fig. 8D). Flow is presumed to belong to the older volcanic rocks because of its intermediate topographic elevation between flows of Hickey Formation and flows of younger volcanic rocks, but could be of Hickey age. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tbo - Older volcanic and sedimentary rocks, basalt (Miocene)

Basalt flows, cinder cones, and minor dikes. Includes all compositions of basalt not proven to be alkali basalt. As such, percentage of outcrop defined as basalt, versus alkali basalt, is probably overestimated.

Basalt in lower part of Thirteenmile volcanic rocks (fig. 6A) has an average K/Na ratio (fig. 6C) and is very Mg rich to Mg rich (fig. 6D).

Undated flows west of Kirkland and west of Martin Mountain range in composition from basalt to andesitic basalt (fig. 8A), are sodic to average in K/Na ratio (fig. 8C), and are very Mg rich to very Fe rich (fig. 8D).

Basal part of Thirteenmile volcanic rocks may include some basalt that is equivalent to that in Hickey Formation. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tco - Older volcanic and sedimentary rocks, cinders and cinder cones (Miocene)

Cinders in beds and erosional remnants of cones. Presumed to be basaltic in composition. Exposed predominantly in Hackberry Mountain area (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tao - Older volcanic and sedimentary rocks, andesite (Miocene)

Minor, but distinctive, andesite in southern Black Hills, on either side of Interstate 17, includes distinctive gray, platy-weathering flow that is presumed to be time-correlative of youngest tuff erupted from Hackberry volcanic center (Lewis, 1983). Chemically, rock is a lati-andesite to andesite (fig. 6A) that is very sodic (fig. 6C) and has an average Fe/Mg ratio (fig. 6D). Andesite of similar composition is found in Mormon Mountain volcanic field, east of map area (Wier and others, 1989).

Other rocks referred to as andesite in Mt. Hope area range in composition from basalt to andesite, and are mostly andesitic basalt (fig. 7A) that is average to potassic (fig. 7C) and very Mg rich to Mg rich (fig. 7D). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tto - Older volcanic and sedimentary rocks, tuff (Miocene)

Rhyodacite to andesitic tuff and interbedded ash beds. In southern Verde River valley includes tuff at Towel Creek within Thirteenmile volcanic rocks near Hackberry Mountain (Lewis, 1983) north of Dugas. In Hackberry Mountain area, oldest units are most felsic; youngest units are most mafic. Eruption of tuff probably signals emptying of magma chamber, with most mafic components of tuff equivalent in composition to andesite flows (unit Tao). Ranges in composition from rhyodacite to andesite (fig. 6A) and is metaluminous to moderately peraluminous (fig. 6B), sodic to average in K/Na ratio (fig. 6C), and very Mg rich to Mg rich (fig. 6D). Other beds of tuff in older volcanics are presumed to be related to these ash beds. Tuff exposed south of Skull Valley is more rhyolitic in composition and could be, in part, older, and related to 15-Ma volcanism. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Hickey Formation (Miocene)

Basalt flows and minor, interbedded sedimentary rocks. Interbedded sedimentary rocks derived from Basin and Range province,to the south-west. Flows predominate over sedimentary rocks.Thickness of individual flows10–25m.Thickness of aggregate flows as much as 120m. Age about 10–15Ma (McKee and Anderson,1971; Wittke and others,1989). (*GRI Source Map ID 75246)* (USGS SIM-2996).

The Hickey Formation is mapped as the following units:

Thab - Hickey Formation, alkali basalt (Miocene)

Alkali basalt flows, cinder cones, and minor dikes. Includes only those rocks that are proven to be alkali basalt. As such, percentage of outcrop defined as alkali basalt, versus basalt, is probably underestimated.

In Prescott area, trachyandesite at Thumb Butte (fig. 9A) is alkalic and potassic to very potassic (fig. 9C) and has an average Fe/Mg ratio (fig. 9D). Near Mayer, most flows are alkalic, potassic to very potassic (fig. 9C), and very Mg rich to average in Fe/Mg ratio (fig. 9D). Flows north of Prescott and predominantly alkalic (fig. 9A), potassic to very potassic (fig. 9C), and very Mg rich (fig. 9D).

Along crest of Black Hills, from north of Woodchute Mountain to Cherry, alkali basalt underlies calc-alkalic to alkali-calcic basalt (Wittke and others, 1989). These rocks range in composition from basinite to alkali basalt (fig. 10A) and are average to very potassic (fig. 10C) and very Mg rich to average (fig. 10D). Map compilation did not allow differentiating the alkalic rocks from the overlying basalts; therefore all the outcrop of Hickey Formation from Woodchute Mountain to Cherry is shown as basalt (Thb).

Flows north of Woodchute Mountain, from near First View on the east to St. Matthews Mountain on the west, range in composition from trachybasalt to basinite to alkali basalt (fig. 10A) and are potassic to very potassic (fig. 10C) and very Mg rich to average (fig. 10D).

Flows and plugs at Casner Butte, just east of map area, are strongly silica-under-saturated and range in composition from phono-tephrite to ankaritrite to alkali basalt to picritic basalt (fig. 11A) and are very potassic (fig. 11C) and very Mg rich to very Fe rich (fig. 11D). Flows at top of Lee and Munds Mountains, east of Sedona, although not dated, have the chemistry of other basal flows in the Hickey Formation by being strongly silica-undersaturated basanite and alkali basalt (fig. 11A) that are very potassic (fig. 11C) and Mg rich (fig. 11D).

Distinguished from younger flows (units Taby and Tby) by percentage and provenenace of interflow sedimentary rocks. Some silica-undersaturated alkali basalt in the Hickey is difficult to distinguish fromflows in the upper part of Thirteenmile volcanic rocks. (GRI Source Map ID 75246) (USGS SIM-2996).

Thb - Hickey Formation, basalt (Miocene)

Basalt flows, cinder cones, and minor dikes. Includes all compositions of basalt not proven to be alkali basalt. As such, percentage of outcrop defined as basalt, versus alkali basalt, is probably overestimated. Ranges in composition from andesitic basalt to basalt.

Southeast of Prescott, and east of Glassford Hill, flows are basalt to andesitic basalt (fig. 9A) that are sodic to potassic (fig. 9C) and very Mg rich to Mg rich (fig. 9D).

At Big Bug Mesa and Little Mesa, flows are basalt to latitic basalt (fig. 9A) that are average in K/Na ratio (fig. 9C) and Mg rich to average (fig. 9D).

Capping flows at crest of Black Hills, from Woodchute Mountain to Cherry, are andesitic basalt (fig. 10A) that is very sodic (fig. 10C) and very Mg rich to average (fig. 10D).

The Estler volcanic field, near Estler Peak, northeast of Cordes Junction, contains basalt and minor andesitic basalt (fig. 10A) that is sodic to average (fig. 10C) and mostly average to Fe rich (fig. 10D).

Only one analysis is available for flows on flank of House Mountain, in Verde River valley. The one andesitic basalt is similar to those on crest of Black Hills (fig. 11A) and is average in K/Na ratio (fig. 11C) and Fe rich (fig. 11D).

All except one flow in Hickey Formation southwest of Hackberry Mountain are basalt to andesitic basalt (fig. 12A) that are average to very potassic (fig. 12C) and very Mg rich to very Fe rich (fig. 12D).

Distinguished with difficulty from basalt in older volcanics (unit Tbo) and from basalt in younger volcanics (unit Tby). Interflow sediments typically contain basement clasts derived from the southwest and lack basalt clasts. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tha - Hickey Formation, trachyandesite (Miocene)

Flows at base of Hickey Formation, west of Prescott at Thumb Butte; west and south of town of Chino Valley; along Verde fault in Jerome area; and south of Mayer.

At Thumb Butte, trachyandesite (fig. 9A) is potassic to very potassic (fig. 9C) and average in Fe/Mg ratio (fig. 9D). At Prescott, one flow is a latitic basalt (fig. 9A) that is very potassic (fig. 9C) and very Mg rich (fig. 9D). Flows west and southeast of town of Chino Valley are trachybasalt (fig. 9A) that is average in its K/Na ratio (fig. 9C) and Mg rich (fig. 9D).

Along Verde fault, basal flows range in composition from trachybasalt and lati-basalt to basinite and alkali basalt (fig. 10A). These rocks have K/Na and Fe/Mg ratios similar to those of basal alkali basalts on top of Black Hills.

South of Mayer, an eroded cone is trachyandesite (fig. 9A) that is sodic (fig. 9C) and average in Fe/Mg ratio (fig. 9D). A K-Ar date on hornblende of about 19 Ma has been cited as evidence that the cone may be related to the Sullivan Buttes volcanic field. Trachyandesite composition suggests that cone may be age of basalt of Hickey Formation in area.

Age at Thumb Butte about 15 Ma (Nichols Boyd, 2001). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Thbs - Hickey Formation, basalt and sedimentary rocks (Miocene)

Interbedded basalt and alkali basalt flows and sedimentary rocks. Flows predominate over sedimentary rocks. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Thsb - Hickey Formation, sedimentary rocks and basalt (Miocene)

Interbedded sedimentary rocks and basalt and alkali basalt flows. Sedimentary rocks predominate over flows. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Ths - Hickey Formation, sedimentary rocks (Miocene)

Cobble conglomerate at base of Hickey Formation. Minor interbedded sedimentary units noted higher in formation, between basalt flows. Local fresh-water limestone and travertine north of Mayer and southeast of Cordes are included within unit Ths. Clasts predominantly Paleozoic limestone and sandstone, and Early Proterozoic crystalline rocks derived from the southwest. Thickness highly variable, from 10 to 40 m, as most deposits define channels cut into Paleozoic or Early Proterozoic rocks. Thickest section along Verde fault, east of Cherry, where approximately 100 m of fluvial deposits define a northeast-flowing river system. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Lati-andesite of Sullivan Buttes and Santa Maria Mountains (Miocene? and Oligocene)

Flows, domes, agglomerate bodies, and cinder cones of andesitic basalt, latite, lati-andesite, and dacite exposed at Sullivan Buttes, Santa Maria Mountains, Juniper Mountains, and possibly south of Wilhoit. In places, contains abundant mafic to ultramafic xenoliths representative of lower continental crust (Arculus and Smith, 1979; Smith and others, 1994). An areally large gravity high extending south-southwest from town of Chino Valley may indicate a large body of mafic to ultramafic rocks of Early Proterozoic age in the upper crust (Langenheim and others, 2002, fig. 8). Characteristic chemistry of all rocks is their K- and Mg-rich nature. Intrusive centers are reversely magnetized, creating aeromagnetic lows over many bodies (Langenheim and others, 2002). Age in Sullivan Buttes area about 21–27 Ma. Age in Juniper Mountains about 22–34 Ma. Age undetermined in Santa Maria Mountains and elsewhere. (*GRI Source Map ID 75246)* (USGS SIM-2996).

The lati-andesite of Sullivan Buttes and Santa Maria Mountains is mapped as the following unit:

Tlal - Lati-andesite of Sullivan Buttes and Santa Maria Mountains, lower unit (Miocene? and Oligocene)

Flows, domes, breccia, cinder cones, and intrusive centers of lati-andesite, andesite, and dacite composition, and lesser amounts of andesitic basalt and basalt (figs. 15A, 16A). Most abundant in Sullivan Buttes volcanic field near town of Chino Valley. All rocks are average to very potassic (figs. 15C, 16C) and Mg rich to very Mg rich (figs. 15D, 16D). Thickness of domes and compound flows does not exceed 80 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Pk - Kaibab Limestone (Lower Permian)

Gray, sandy dolomitic limestone and dolomite, limestone, and minor chert. Thickness about 150 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Pkt - Kaibab Limestone and Toroweap Formation, undivided (Lower Permian)

Gray dolomite, limestone, and minor chert of the Kaibab and light-gray sandstone of the Toroweap. Combined thickness about 230 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Ptc - Toroweap Formation and Coconino Sandstone (Lower Permian)

Sandstone. Combined thickness about 240–320 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Psh - Schnebly Hill Formation (Lower Permian)

Tan to light-gray, eolian, crossbedded sandstone and minor mudstone, limestone, and evaporitic beds (Blakey, 1980; Blakey and Knepp, 1989; Blakey, 1990). Regionally, correlates with upper part of Supai Group. Thickness near Sycamore Canyon about 195 m. Thickness at Sedona about 225 m. Thickness at West Clear Creek about 275 m. Thins to the west. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Ph - Hermit Formation (Lower Permian)

Reddish-brown sandstone, mudstone, and pebble conglomerate. Uncertainty about regional correlation suggests that this unit might be equivalent to Supai PS2 of McKee (1975). Thickness in Sedona area and near Sycamore Canyon about 90 m. Thins to the northwest. (*GRI Source Map ID*

75246) (USGS SIM-2996).

PNs - Supai Formation (Upper Mississippian or Upper Pennsylvanian to Lower Permian)

Red siltstone, sandstone, silty dolomite, and minor conglomerate. Referred to as Esplanade Sandstone (Lower Permian) in Sedona area (Blakey and Knepp, 1989; Blakey and Middleton, 1998). Probably equivalent to Supai PS1 of McKee (1975; McKee, 1982). Thickness near Sedona about 55 m. Thickens to the northwest. Thickness near Sycamore Canyon about 190 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Mr - Redwall Limestone (Mississippian)

Gray limestone and minor chert. Extensive karst development and collapse features in upper and lower parts. Thickness about 75–85 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

MDrm - Redwall Limestone and Martin Formation, undivided (Middle? Devonian to Mississippian)

Limestone and dolomite. Combined thickness about 180–230 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Dm - Martin Formation (Upper and Middle? Devonian)

Dark-gray dolomite, minor limestone, and sandy siltstone. Thickness about 105–145 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

DCmt - Martin Formation and Tapeats Sandstone, undivided (Upper Devonian through Lower Cambrian)

Dolomite and sandstone. Thickness 120–230 m. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Ct - Tapeats Sandstone (Middle and Lower Cambrian)

Reddish-brown sandstone and conglomerate. Map unit includes Chino Valley Formation (Devonian? or age unknown) at top of unit. Thickness about 15–85 m. Thickens to the west. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tonalitic rocks (Early Proterozoic)

Mafic intrusive rocks, primarily hornblende bearing. Form large plutons in west-central and east-central parts of map area. Discussed from most mafic to most felsic. Most abundant in zones 5 and 6; less abundant in zone 2. Minor body in zone 1. Tonalitic rocks range in composition from gabbro-diorite to granodiorite (fig. 28A), and are average to very sodic (fig. 28C) and very Mg rich to Fe rich (fig. 28D). Tonalitic rocks are calcic in zones 5 and 6, but are calc-alkalic in zone 2 (fig. 28A). Chemistry of individual rock units summarized from west to east (figs. 29–34). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Tonalitic rocks are mapped as the following units:

Xchd - Tonalitic rocks, dikes of Cherry (Early Proterozoic)

Medium-grained, equigranular granodiorite to medium-grained, porphyritic granodiorite containing phenocrysts of feldspar and quartz in north-striking, high-angle dike swarms. Equigranular granodiorite dikes and porphyritic dikes containing quartz phenocrysts are late cogenetic bodies related to the main tonalite mass, as evidenced by immiscible igneous textures. Porphyritic granodiorite dikes may be related to Badger Spring Granodiorite (unit Xbs). All dikes undeformed. Age of cogenetic dikes probably about 1,700 Ma, as suggested by hornblende and biotite K-Ar dates of 1,690–1,709 Ma. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xch - Tonalitic rocks, Cherry Tonalite (Early Proterozoic)

Medium- to medium-coarse-grained hornblende-biotite diorite to granodiorite containing phenocrysts of hornblende (Anderson and Creasey, 1967). Includes tonalite of Cherry (DeWitt, 1989), and part of Cherry batholith (Anderson, 1989a). Newly named herein for exposures near Cherry. Type area is designated where main mass exposed from north of Cherry to far southeastern part of map area. Smaller bodies exposed along east side of Lonesome Valley. Prominent north-trending zone of high magnetic intensity along eastern Lonesome Valley probably marks western contact of Cherry Tonalite with metavolcanic rocks (Langenheim and others, 2002). Most mafic along western margin of main mass and in southern Lonesome Valley. Exposed in erosional highs beneath Tertiary basalt from Interstate 17 to southern margin of map area. Cuts Bishop Spring Granodiorite (unit Xbp) northwest of Rugged Mesa. Cuts Bland Tonalite (newly named, unit Xbl) east of Perry Mesa and south of map area, along Squaw Creek. Undeformed in most outcrops, but mildly to strongly flow foliated in places. Strongly deformed along Shylock fault and Shylock high-strain zone in southwestern Black Hills. Hosts gold-bearing quartz veins in Cherry district that are genetically related to the tonalite (Clements, 1991).

Chemically is calc-alkalic (fig. 34A), sodic to very sodic (fig. 34C), and very Mg rich to Fe rich (fig. 34D).
Age of sample from near Cherry, from U-Pb zircon analyses, is 1,740 Ma (Anderson and others, 1971). K-Ar hornblende dates of 1,694 and 1,690 Ma obtained from samples near Cherry (Lanphere, 1968; Dalrymple and Lanphere, 1971). 40Ar/39Ar total fusion date of 1,709 Ma obtained from one hornblende (Dalrymple and Lanphere, 1971). K-Ar biotite dates of 1,689–1,693 Ma also obtained from same samples. Conflicting age (cuts 1,720-Ma Bland Tonalite but has U-Pb zircon age of 1,740 Ma) may be due to more than one tonalite body within a composite pluton (Anderson, 1989a). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xtgr - Texas Gulch Formation, rhyolitic meta-tuffaceous rocks (Early Proterozoic)

Tan rhyolitic metatuff and interbedded phyllite. Exposed north of Dewey. Thickness undetermined. Age about 1,715 Ma and younger (S.A. Bowring, unpub. U-Pb zircon data, cited in Karlstrom and Bowring, 1991). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xtgs - Texas Gulch Formation, purple slate (Early Proterozoic)

Metamorphosed purple shale and fine-grained tuffaceous metasedimentary rocks. Exposed north of Dewey. Interbedded with rhyolitic meta-tuffaceous rocks (unit Xtgr) on a regional scale. Thickness undetermined. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Gabbroic rocks (Early Proterozoic)

Mafic to ultramafic intrusive rocks. Gabbro and gabbro-norite are the most common rock types (fig. 22A) and are found in all zones in the Prescott-Jerome area (fig. 21). Significant exposures of ultramafic rocks are present only in zone 2, in the Prescott area. Evolved rocks, such as diorite and monzodiorite (fig. 22A), are present only in central part of map area, in zones 2, 3, and 4. Many gabbros in zone 6 (Jerome area) are Al rich and plot above the field of unaltered rocks (fig. 22B); rocks are not altered, but are rich in Ca-plagioclase. High-Al rocks are noted in zones 2, 3, and 5, but are especially abundant in zone 6. Gabbros have a wide range of K/Na and Fe/Mg ratios (figs. 22C, D); no spatial variations are evident. Only the evolved rocks in zone 3 are Ti rich. Age undetermined, but cross-cutting relations indicate that gabbros are the oldest plutonic rocks in map area. Discussed from most mafic to most felsic, and portrayed in chemical diagrams from west (zone 1) to east (zone 6) (figs. 23–27). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Gabbroic rocks are mapped as the following unit:

Xgb - Gabbroic rocks, gabbro (Early Proterozoic)

Medium- to coarse-grained, equigranular, hornblende-rich gabbro-norite, gabbro, and gabbro-diorite. Exposed as large bodies throughout central Bradshaw Mountains (zones 2–5). Smaller bodies exposed near Jerome, in the Black Hills (zone 6), especially within Grapevine Gulch Volcanics. Mildly to strongly deformed and metamorphosed in central Bradshaw Mountains. Larger bodies have only localized zones of high strain; smaller bodies are more thoroughly deformed. Undeformed and only mildly metamorphosed in Black Hills.

Largest gabbro mass is exposed in zone 2, west of Prescott, and is centered on Sugarloaf Mountain. Compositions range from gabbro-norite to diorite (fig. 23A), and include abundant leucogabbro bodies too small to show on map. Zone 2 contains a higher percentage of gabbro-norite than most other zones (fig. 23A), and has some of the most primitive chondrite-normalized rare-earth-element (REE) profiles.

Zone 3 contains three large gabbro masses. One extends north from Longfellow Ridge to west edge of Big Bug Mesa, and is referred to as the Dandrea Ranch mass, for a locality west of Big Bug Mesa. Another, possibly related to the first, is centered on Bodie mine, west of Crooks Canyon. The last is centered on Salida Spring, east of Prescott. A prominent aeromagnetic high east of Prescott is spatially associated with this mass (Langenheim and others, 2002, fig. 5b). Chemistry of first two bodies is similar, ranging from gabbro-norite, through gabbro, to gabbro-diorite (fig. 24A). Wide range in both K/Na and Fe/Mg ratios (figs. 24C, D) and no obvious systematic pattern may suggest complex intrusive mixtures in the two bodies. Salida Spring body contains small-scale igneous layers defined by east-striking flow foliation. Both the Salida Spring gabbroic body and the Badger Mountain ultramafic body have distinctive REE patterns with pronounced positive Eu anomalies, suggestive of crystal accumulation of plagioclase.

Many small gabbro bodies are exposed in zone 4, the largest of which is at the Blue Bell mine. Chemistry of most bodies is similar (fig. 25A) and shows little variation (figs. 25C, D).

Many gabbro bodies in Jerome area (zones 6A and 6B) are distinctive by being high Al and plagioclase rich (fig. 27B), similar to those in zone 5 (fig. 26).
Underground samples of gabbro at United Verde mine are notably Al rich, and could represent plagioclase cumulates of leucogabbro, as suggested by their sodic nature (fig. 27C) and Fe- to very Fe-rich nature (fig. 27D). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xb - Basaltic flows (Early Proterozoic)

Fine- to medium-grained metamorphosed tholeiite, basalt, and minor ultramafic rocks. Includes some basaltic andesite where flows are interbedded with tholeiite and basalt. Mafic phenocrysts minor, but where present are converted to amphibole and opaque oxide minerals. Plagioclase phenocrysts minor, but present in metabasalt at head of Munds Draw (zone 6). Exposed in zones 2 through 5; minor basalt in southern part of zone 6.

In zone 2, flows are exposed north of Kirkland, west and north of Granite Mountain, in Sugarloaf Mountain area, and in area from Maverick Mountain to Mount Tritle. Flows in zone 2 are predominantly calcic to calc-alkalic tholeiite, basalt, and basaltic andesite (fig. 37A) that are very sodic to average in K/Na ratio (fig. 37C) and average to very Fe rich (fig. 37D). Some andesite is present. Flat chondrite-normalized REE patterns indicate that flows in zone 2 are among the most primitive in Bradshaw Mountains (Ed DeWitt, unpub. data, 2002).

Zone 3A contains abundant flows from south of Spruce Mountain to Charcoal Gulch. From Bigelow Peak to north of Walker, flows are mostly calc-alkalic andesitic basalt (fig. 38A). Bigelow Peak area contains some of the most Mg-rich tholeiite in Bradshaw Mountains (fig. 38D). All flows have chondrite-normalized REE patterns that have a slight light-rare-earth-element (LREE) enrichment and a minor negative Eu anomaly (Vance, 1989; this study).

Zone 4A contains abundant flows from Towers Mountain to the northern contact of the Minnehaha Granodiorite (newly named unit Xmh).

Flows and breccias in zones 4B and 4C extend from south of Humboldt area on the north to Silver Mountain on the south. Flows west of the Iron King mine, extending from Spud Mountain to past the McCabe mine along Galena Gulch, are largely calc-alkalic to calcic basaltic andesite (fig. 41A) that are sodic to average in K/Na ratio (fig.41C) and very Fe rich (fig. 41D). Breccia bodies contained within the flows also are andesitic basalt that ranges from alkali-calcic to calcic (fig. 41A) and that are very sodic to sodic (fig. 41C) and very Fe rich (fig. 41D). All these flows, except those that are high Ti, have chondrite-normalized REE patterns that have slight LREE enrichment and little to no Eu anomalies (Vance, 1989; this study).

Some flows east of Iron King mine are calc-alkalic to alkali-calcic andesitic basalt, but more are andesitic (fig. 41A). Andesitic basalt is very sodic (fig. 41C) and Fe rich (fig. 41D), similar to flows at Spud Mountain.

Flows at Huron mine and east of Humboldt are calcic tholeiite to calc-alkalic basalt (fig. 41A) that is very sodic (fig. 41C) and average to very Fe rich (fig. 41D). Chondrite-normalized REE patterns of these flows are similar to those on Spud
Mountain.

Most flows in zone 4C are calc-alkalic basalt to calcic tholeiite (fig. 42A) that are very sodic (fig. 42C) and Mg rich to very Fe rich (fig. 42D). REE patterns of such rocks in northern and central parts of zone have typical LREE enrichment and little or no Eu anomaly (Vance, 1989; this study). Mafic rocks in southern part of zone, however, have relatively flat REE patterns, similar to those of basaltic rocks in zone 2.

Zones 5A and 5B contain minor basalt, principally along east side of Crazy Basin Granite, from southeast of Mayer to south edge of map area, and in Yarber Wash area. In Townsend Butte and Bland Hill areas (zone 5A), basalt to tholeiite is most common, but minor ultramafic rocks are noted (fig. 43A). Flows are predominantly very sodic to average in K/Na ratio (fig. 43C) and range widely in Fe/Mg ratio (fig. 43D). Calc-alkalic basalt and calcic tholeiite are also the most common flows in zone 5B (fig. 44A). Flows near contact with granophyre of Cherry are enriched in potassium (fig. 44C). Most flows in zone 5B are average in Fe/Mg ratio (fig. 44D). Flows near Cordes and Bland Hill have low concentrations of REE and relatively flat chondrite-normalized patterns.

The only basaltic flows in zone 6A are at far northwest end of Black Hills, near head of Munds Draw, and north of Squaw Peak, along south margin of Verde River valley. Flows at Munds Draw are distinctly porphyritic, containing plagioclase phenocrysts. Flows are calc-alkalic basalt to calcic tholeiite (fig. 45A) that is sodic to potassic (fig. 45C) and very Fe rich (fig. 45D). REE abundances are among lowest of all basalts. Chondrite-normalized pattern is flat. Flows in Squaw Creek Canyon are alkali-calcic to calc-alkalic basalt (fig. 45A) that range widely in K/Na ratio (fig. 45C) and are very Fe rich (fig. 45D). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xa - Andesitic flows (Early Proterozoic)

Fine- to medium-grained, metamorphosed andesite and minor andesitic basalt and dacite containing altered phenocrysts of feldspar. Exposed in zones 2, 4, and 5 in Bradshaw Mountains and in zone 6 in Black Hills and Dugas areas. Body along Slate Creek (zone 2) contains some breccia fragments. Andesitic rocks along Little Copper Creek and near Potato Patch included in andesitic basalt (unit Xab).

Body in zone 4B that extends from Iron King mine on the north to Little Bug Mesa on the south is predominantly calc-alkalic to alkali-calcic andesite (fig. 41A) that is very sodic (fig. 41C) and Fe rich to very Fe rich (fig. 41D). Alkali-calcic basaltic andesite (fig. 41A) is interbedded with the andesite. Included with this normal andesite are flows of high-Ti andesite to lati-andesite that are enriched in REE and form chondrite-normalized patterns that slope gently down from the LREE to the heavy rare-earth-element (HREE) and that have minor to no negative Eu anomalies (Vance, 1989; this study).

A large area of andesite flows, tuffs, and interbedded chert and iron-formation crops out from Mayer to Crown King in zone 4C. Andesite from near the Swastika mine is representative of the flows, which are calc-alkalic (fig. 42A), very sodic (fig. 42C), and very Fe rich (fig. 42D). Smaller areas of andesite are found east of Cordes to Mayer in zone 5A.

In the Black Hills (zone 6A), andesites are noted as bombs within tuffaceous rocks in Grapevine Gulch Formation along Yaeger Canyon (Vance, 1989). Bombs are calc-alkalic (fig. 46A), very sodic to sodic (fig. 46C), and very Fe rich (fig. 46D).

The Shea Basalt (Anderson and Creasey, 1967), which crops out south of Jerome in zone 6B, is a distinctive high-Ti andesite to lati-andesite that is alkali-calcic to calc-alkalic (figs. 47A, 48A). The Shea, which is very sodic (figs. 47C, 48C) and very Fe rich (figs. 47D, 48D), is cut by gabbro sills and dikes too small to be shown at map scale. Limited data from altered samples of dikes and sills suggest an alkalic syenogabbro to syenodioritic composition that is Mg rich. Gabbros of this composition are unknown from Early Proterozoic rocks (units Xgb, Xlgb, Xdi) in map area, but are present in Middle Proterozoic gabbro (unit Ygb). A genetic relationship of the Shea to the gabbro bodies is possible, but unproven at present.

Along Squaw Creek Canyon and to the south, along Verde River (zone 6A), calc-alkalic to alkali-calcic andesite (fig. 45A) is exposed that is sodic to very potassic (fig. 45C) and average to Fe rich (fig. 45D). (GRI Source Map ID 75246) (USGS SIM-2996).

Xd - Dacitic flows (Early Proterozoic)

Fine-grained, porphyritic dacite containing phenocrysts of plagioclase. Flows and breccias exposed east of Climax mine in zone 2 and west of Lynx Lake in zone 3. Minor dacite interbedded with basaltic andesite breccia north of Big Bug Mesa in zone 4B is calc-alkalic (fig. 39A), very sodic (fig. 39C), and very Fe rich (fig. 39D). Dacite interbedded with basalt and rhyolite at Blue Bell mine (zone 4C) is calcic to calc-alkalic (fig. 42A), very sodic (fig. 42C), and Mg rich (fig. 42D). At Copper Mountain, in zone 5A, dacite composition is inferred from minor-element chemistry.

Flows in Grapevine Gulch Formation in southern Black Hills (zone 6A) range from calcic dacite or rhyodacite to calc-alkalic andesite, and include minor rhyolite (fig. 46A). An average composition is

dacite, but some flows may be rhyodacite. Andesite and dacite or rhyodacite are sodic to average in K/Na ratio (fig. 46C) and very Fe rich (fig. 46D).

The Brindle Pup Andesite is a series of vesicular flows that have a fine-grained groundmass and conspicuous plagioclase phenocrysts. Flows range in composition from calc-alkalic andesite to calcic rhyodacite (fig. 46A), and have an average composition of dacite. Overall, flows are metaluminous to strongly peraluminous (fig. 46B), predominantly very sodic (fig. 46C), and predominantly Fe rich to very Fe rich (fig. 46D). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xrd - Rhyodacitic flows (Early Proterozoic)

Fine-grained, porphyritic rhyodacite containing phenocrysts of quartz and feldspar. Includes minor crystal-rich tuff and fragmental rhyodacite. Exposed only in small bodies in zones 3A and 3B in Bradshaw Mountains, but widely exposed in southern Black Hills, north of Cherry.

Small bodies near the Poland-Walker Tunnel and along Big Bug Creek north of Big Bug Mesa are calc-alkalic (figs. 39A, 41A), predominantly very sodic (fig. 41C), and average to Fe rich (figs. 39D, 41D). Similar bodies along Benjamin Gulch in zone 3A are presumed to be calc-alkalic rhyodacite that is strongly peraluminous, very sodic, and very Fe rich.

In southern Black Hills, three major rock units have rhyodacitic composition. Dacite of Burnt Canyon contains vesicular flows having a fine-grained groundmass and phenocrysts of plagioclase and fine-grained quartz. Flows range from alkali-calcic rhyodacite to calc-alkalic rhyodacite (fig. 46A), and are metaluminous to mildly peraluminous (fig. 46B), very sodic (fig. 46C), and Fe rich to very Fe rich (fig. 46D). Relict phenocryst assemblage may indicate an overall andesitic composition (Vance, 1989). Felsic parts of Burnt Canyon flows are calcic rhyodacite (fig. 46A), strongly peraluminous (fig. 46B), very sodic (fig. 46C), and predominantly average in Fe/Mg ratio (fig. 46D). Similarly, relict phenocryst assemblage may indicate an overall andesitic composition (Vance, 1989).

The Deception Rhyolite south of Brindle Pup mine has a fine-grained to aphanitic groundmass and phenocrysts of plagioclase and quartz. Limited samples suggest that flows are calc-alkalic rhyodacite (fig. 48A) that is strongly peraluminous (fig. 48B), very sodic (fig. 48C), and average in Fe/Mg ratio (fig. 48D). This rhyodacitic composition is slightly more mafic than that of least altered rocks in the Deception(?) Rhyolite near Jerome.

Rocks mapped as Gaddes Basalt are very heterogeneous and contain little to no basalt. Major rock types consist of fine-grained, dark rhyodacite, dacite, spilitized andesite, and very minor basalt. Most sampled units are calc-alkalic to calcic rhyodacite (fig. 48A) that is metaluminous (fig. 48B), very sodic (fig. 48C), and Fe rich to very Fe rich (fig. 48D).

Rhyodacite flows are exposed on Marlow Mesa and along Gap Creek in zone 6A. Flows are calc-alkalic rhyodacite (fig. 45A) that is mildly peraluminous (fig. 45B), has a wide range in K/Na ratio (fig. 45C), and is average to very Fe rich (fig. 45D).

Age of Deception Rhyolite near Jerome was suggested to be about 1,770 Ma (Anderson and others, 1971), but that age was questioned by L.T. Silver in Conway and Karlstrom (1986). Age of about 1,740 Ma (S.A. Bowring, unpub. U-Pb zircon data cited in Karlstrom and Bowring, 1991) may be more accurate. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xr - Rhyolitic flows and pyroclastic rocks (Early Proterozoic)

Fine-grained, porphyritic rhyolite containing phenocrysts of quartz and minor feldspar. Includes small bodies of breccia and tuff, as well as silicified and veined rhyolite that is not included in the hydrothermally altered rhyolite related to massive sulfide mineralization (unit Xrh). Some flows have extensively brecciated flow tops and margins, and are difficult to distinguish from bodies of breccia. Exposed throughout zones 1 through 6. Particularly abundant in zone 5A along eastern margin of

Crazy Basin Granite and in zone 6B in southern Black Hills.

Flows and minor tuff east of Climax mine in zone 2 are interbedded with dacite and more mafic rocks. Bodies north of Spruce Mountain in zone 3A are mostly flows, but include some hypabyssal intrusive masses that cut basaltic andesite. Limited data suggest that flows and hypabyssal bodies are calc-alkalic rhyolite to rhyodacite that is mildly peraluminous, very sodic, and Mg rich.

Thin flows and minor bodies of tuff north of Chaparral high-strain zone and near Lynx Creek in zone 3A range from calcic rhyolite to rhyodacite that is strongly peraluminous, very sodic, and very Mg rich to alkali-calcic rhyolite that is mildly peraluminous, very sodic, and Fe rich (Vance, 1989; this study).

South of Chaparral high-strain zone, along Big Bug Creek, in zone 4B, bodies of rhyolite are interbedded with rhyodacite and minor tuff. Least altered bodies of rhyolite range in composition from calcic rhyodacite to alkali-calcic rhyolite that is mildly peraluminous, ranges widely in K/Na ratio, and is average to Fe rich (Vance, 1989). North of Big Bug Creek, near Mt. Elliott, limited data suggest presence of alkali-calcic rhyolite to alkali rhyolite that is mildly peraluminous, average in K/Na ratio, and Fe rich.

Large bodies of rhyolite, breccia, and tuff are exposed from north of Crown King stock to southeast of Humboldt in zone 4C. The largest bodies, near DeSoto mine and southeast of Round Hill, are silicified. Limited data from smaller bodies north and west of Mayer suggest rhyolite is alkali-calcic, mildly peraluminous, sodic, and average in Fe/Mg ratio.

Largest concentration of rhyolite flows, tuffs, and variably silicified rhyolite in map area is along Black Canyon and within the Black Canyon high-strain zone, from near Cordes to past southern boundary of map area (Jerome, 1956; Anderson and Blacet, 1972c). Silicification and loss of alkali metals make original composition of rhyolites difficult to ascertain.

Bodies of rhyolite near Cordes in zone 5A are fine-grained flows interbedded with andesite and basaltic andesite. Rhyolite is calc-alkalic, mildly peraluminous, very sodic, and average to Fe rich. Numerous bodies of rhyolite from southeast of Round Hill to west of Yarber Wash in zone 5B range from flows to hypabyssal intrusive masses. Data are too limited to assess the chemistry of these rhyolite bodies.

Fine-grained to aphanitic flows and hypabyssal bodies are interbedded with tuff west of northern Black Hills, along Coyote Wash (zone 6A). Limited data suggest that high-silica rhyolite is calc-alkalic, mildly peraluminous, very sodic, and Fe rich.

Porphyritic rhyolite containing quartz and minor plagioclase phenocrysts at Willow Spring, east of Dugas in zone 6A, is alkali-calcic (fig. 46A), mildly peraluminous (fig. 46B), very sodic (fig. 46C), and average to very Fe rich (fig. 46D).
The Buzzard Rhyolite in southern Black Hills (zone 6B) is a flow-banded rock that contains phenocrysts of plagioclase and quartz. Fragments of felsic volcanics are common in rhyolite, and breccia beds that lack matrix material are noted (Anderson and Creasey, 1958). This high-silica rhyolite ranges from calcic to alkali-calcic (fig. 48A) and is mildly to strongly peraluminous (fig. 48B), very sodic (fig. 48C), and Mg rich to Fe rich (fig. 48D).

Cleopatra Formation (previously referred to as Cleopatra Quartz Porphyry) and Deception Rhyolite at Jerome are suggested to be as old as 1.76 Ga (Anderson and others, 1971). Newer determination of 1,738±0.5 Ma (S.A. Bowring, supplementary data in Slack and others, 2007) is preferred age of rhyolite. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xah - Altered andesitic rocks (Early Proterozoic)

Chloritized rock exposed in lenticular to irregularly shaped areas. Exposed west of Mayer in zone 4C, southwest of Cordes Junction in zone 5A, and near Copper Mountain in zone 5B. Altered rocks west

of Mayer grade upward into silicified andesite and rhyolite. South of Jerome, in zone 6B, chloritized rocks are either altered andesite or altered rhyolite (Lindberg and Jacobson, 1974; Lindberg, 1989; Anderson, 1989b). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xrh - Altered rhyolitic and pyroclastic rocks (Early Proterozoic)

Chlorite-rich rocks having extensive iron stain caused by oxidation of sulfide minerals. Includes chloritized rhyolite at DeSoto and Blue Bell mines in zone 4C and chloritized rhyolite at Binghampton mine south of Round Hill in zone 5B (fig. 49).

South of Jerome, in zone 6B, includes chloritized Deception Rhyolite beneath United Verde massive sulfide deposit (Anderson and Nash, 1972; DeWitt, 1989; Lindberg, 1989). Least altered Deception Rhyolite (A/CNK ratio of 1.1; fig. 49B) is progressively converted into strongly peraluminous (A/CNK ratio of 2–4) in distal zone; into Mg-rich rock (A/CNK ratio of 4–20) in proximal zone; and into chlorite schist (A/CNK ratio of 45–300) beneath massive sulfide ore body (Vance and Condie, 1987; Gustin, 1990). Deception Rhyolite that originally was calc-alkalic (fig. 49A) becomes strongly calcic in distal zone; plots to right of the classification diagram in proximal zone; and returns to a composition of trachybasalt to latitic basalt in chlorite schist (fig. 49A). Deception Rhyolite that was very sodic becomes very potassic in distal and proximal zones; and remains in very potassic field in the chlorite schist (fig. 49C). Rhyolite that was very Fe rich becomes very Mg rich with progressive alteration (fig. 49D). Chlorite schist shows apparent REE, Y, and Zr enrichment, which is probably due to volume reduction of Deception Rhyolite during hydrothermal alteration (Vance and Condie, 1987). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xmv - Mafic rocks (Early Proterozoic)

Includes probable andesite, basaltic andesite, and basalt flows and minor breccias. Primarily basalt flows are exposed along west side of Mint Wash Granodiorite in zone 2. Basalt and andesite flows and inferred andesitic breccias are exposed along west side of large gabbro on Sugarloaf Mountain in zone 2. Basalt to andesite flows are exposed south of Pine Mountain, in far southeast corner of map area. Basalt flows and minor dacite bodies are exposed in a large area north of Squaw Peak on south rim of Verde River valley. Basalt and andesite exposed in canyon of Agua Fria River, south of Richinbar mine, near southern boundary of map area. In northern part of that area, extensive metagabbro bodies cut the basalt and are locally more abundant than the mafic metavolcanic rocks. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xt - Tuffaceous metasedimentary rocks (Early Proterozoic)

Fine-grained felsic to intermediate-composition tuff and interbedded metasedimentary rocks. Numerous exposures in zones 2–6; particularly abundant in zone 4 where referred to as part of Spud Mountain Formation (Anderson and Blacet, 1972a) and in zone 6 as part of Grapevine Gulch Formation (Anderson and Creasey, 1967). Thickness difficult to estimate because of variable intensity of folding.

South of Slate Creek in zone 2, unit contains much tuff of dacitic composition and discontinuous beds of iron-formation. Tuff extends past west edge of map into Zonia mine area, where it is interbedded with felsic to intermediate-composition flows.

West of Lynx Creek in zone 3A, unit is a mixture of andesitic to rhyolitic tuff and minor chemically precipitated metasedimentary rocks.

Along and south of Chaparral high-strain zone, from Spud Mountain on the north to past Big Bug Mesa on the south, in zone 4A, dacitic tuff is interbedded with minor andesitic tuff. Farther south, west of Battle Flat, this tuff is present on the side of dacite crystal tuff (unit Xd2). Southeast of Iron King mine, and extending between Big Bug Mesa and Little Mesa, in zone 4A, dacitic to rhyodacitic tuff

contains minor andesitic material. On west side of southern part of Brady Butte Granodiorite in zone 4A, dacitic to rhyodacitic tuff is interbedded with minor sedimentary rocks. South of Crown King to Silver Mountain in zone 4C, tuff contains much sedimentary material and thin beds of iron-formation and chert.

A large exposure of tuff extends from east of Humboldt on the north to east of Mayer on the south (zones 4C and 5B). Predominantly volcanic in the north, the tuff contains an increasing percentage of wacke material to the south. Apparently, tuff grades into wacke (unit Xw) southeast of Blue Bell mine.

Much of Grapevine Gulch Formation in southwestern Black Hills (zone 6A) is fine-grained siliceous sedimentary rocks and tuff. Fine-grained siliceous tuff is exposed along east side of Lonesome Valley. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xa1 - Andesitic breccia (Early Proterozoic)

Fine- to medium-grained, metamorphosed andesitic matrix and angular clasts of andesite and more felsic volcanic rocks (Anderson and Blacet, 1972b, c). Small body north of Mt. Elliott in zone 3A has matrix of calcic andesite to dacite (fig. 38A) that has an average K/Na ratio (fig. 38C) and is average to Fe rich (fig. 38D). Small bodies of andesite breccia are exposed from Big Bug Mesa to west of Brady Butte in zones 4A and 4B. Although rocks are altered, their minor-element composition indicates an andesitic composition. A large mass of andesitic breccia extends from east of Humboldt to near Copper Mountain, east of Mayer. Minor-element chemistry of rocks suggests a basaltic andesite to andesite. Andesitic breccia in Grapevine Gulch Formation exposed north of Shylock mine in zone 6A has a matrix that is calc-alkalic (figs. 45A, 46A), predominantly very sodic to sodic (figs. 45C, 46C), and average to very Fe rich (figs. 45D, 46D). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xr1 - Rhyolitic breccia (Early Proterozoic)

Fine-grained to aphanitic rhyolite breccia and quartz-veined rhyolite. Exposed north of Blue Bell mine in zone 4C. Other breccia bodies too small to be shown at map scale are at DeSoto mine, in zone 4C; southwest of Round Hill, in zone 4C; at Copper Queen mine, to the southeast of Round Hill in zone 5B; and at Copper Mountain, east of Mayer in zone 5B. Hydrothermally altered equivalent of similar breccia is extensively exposed south of United Verde mine at Jerome, where it is part of Deception Rhyolite and Cleopatra Formation (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xd1h - Altered dacitic breccia (Early Proterozoic)

Chlorite-rich breccia beds in Deception Rhyolite south of Jerome in zone 6B. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xr1h - Altered rhyolitic breccia (Early Proterozoic)

Chlorite-rich breccia beds in Deception Rhyolite south of Jerome in zone 6B. Similar pattern of chemical alteration as in altered rhyolite. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xd2 - Dacitic tuff (Early Proterozoic)

Fine-grained matrix and abundant feldspar and quartz phenocrysts in crystal-rich tuff. Contains variable concentrations of felsic to intermediate-composition clasts. Has both welded and nonwelded characteristics where metamorphism has not destroyed original textures.

Largest mass exposed west of Battle Flat, on west side of Brady Butte Granodiorite, in zone 4A. Contains abundant plagioclase phenocrysts and lesser partially resorbed quartz phenocrysts (Blacet,

1985). Lithic fragments mostly of dacitic to andesitic composition. Probably intertongues with andesitic material to the north. Composition ranges from calcic rhyodacite to calc-alkalic dacite (fig. 40A) that is metaluminous to slightly peraluminous (fig. 40B), very sodic to sodic (fig. 40C), and very Mg rich to average in Fe/Mg ratio (fig. 40D). Mg-rich nature of dacite is atypical for unaltered rocks in Bradshaw Mountains and Black Hills, as most rocks are average to Fe rich (fig. 35D). REE pattern has flat HREE segment and slightly enriched LREE and minor negative Eu anomaly (Vance, 1989; this study). Major- and minor-element chemistry of dacite closely resemble that of Minnehaha Granodiorite (newly named), suggesting that granodiorite may be subvolcanic equivalent of dacite.

Smaller bodies exposed north of Chaparral fault in zones 3A and 4B contain fewer phenocrysts of plagioclase and more lithic fragments (Krieger, 1965). Tuff interbedded with breccia beds.

Crystal- and lithic-rich tuff exposed along Tule Canyon, east of Dugas in zone 6A, retains variable compaction and welding textures. Tuff is a calc-alkalic dacite to rhyodacite (fig. 46A), and is more mafic toward the base. Tuff is metaluminous to mildly peraluminous (fig. 46B), very sodic (fig. 46C), and Fe rich to very Fe rich (fig. 46D).

Tuffaceous rocks in Grapevine Gulch Formation in southeastern Black Hills (zone 6A) contain mixed sedimentary units and contain clasts of rhyolite, dacite, and dark andesite. Along Yaeger Canyon, on west side of Mingus Mountain, tuff contains mafic lithic material and hyaloclastite (Vance, 1989). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xr2 - Rhyolitic tuff (Early Proterozoic)

Fine-grained, porphyritic rhyolite containing abundant phenocrysts of partially embayed quartz. Particularly abundant in zones 5 and 6. Silicified and leached of alkali metals in many outcrops. Described as quartz porphyry in places (Anderson and Blacet, 1972c).

At Hackberry mine, south of Poland Junction in zone 4B, and extending to the north, crystal-poor tuff contains fragments of felsic volcanic rocks and minor andesite.

Along Black Canyon, from Townsend Butte on the north to past southern boundary of map area, thick sequences of crystal-rich tuff are interbedded with rhyolite flows and flows of felsic composition. Some bodies of tuff could be hypabyssal intrusive rocks. Silicified and leached of alkali metals in many outcrops, as are similar rocks north of Townsend Butte (O'Hara, 1987b). Alteration to clay-rich protolith in Early Proterozoic facilitated development of high-strain zone along thick sequence of tuff during regional metamorphism and deformation. Least altered tuff is calc-alkalic rhyolite that is strongly peraluminous, very sodic, and very Fe rich.

Largest body of tuff is exposed northeast of Mayer, from near Round Hill to west of Copper Mountain. This tuff is less altered than those along Black Canyon; therefore, high-strain zones not developed here as opposed to zones along Black Canyon. Least altered tuff northwest of Copper Mountain is strongly peraluminous, calc-alkalic to calcic, average to potassic, and average in Fe/Mg ratio.

Bodies of tuff interbedded with Shea Basalt south of Jerome, near Copper Chief mine, were referred to as quartz porphyry (Anderson and Creasey, 1958). Least altered rocks are alkali-calcic to calc-alkalic rhyolite that is slightly peraluminous, very sodic, and average to Fe rich.

South of United Verde mine, along Hull Canyon, relatively unaltered tuff is interbedded with breccia beds. Some of this tuff is part of Cleopatra Quartz Porphyry or Cleopatra Formation (Anderson and Creasey, 1958; Anderson and Nash, 1972) that hosts the massive sulfide ore at the mine. Other tuff is stratigraphically above beds that host massive sulfide ore (Gustin, 1990). Least altered tuff in the Cleopatra that hosts ore is calc-alkalic rhyolite that is mildly to strongly peraluminous, very sodic, and average to very Fe rich (Vance and Condie, 1987). Deception Rhyolite has moderate negative Eu anomaly, similar to that in Buzzard Rhyolite (Vance, 1989). Least altered tuff in beds above the Cleopatra is silicified and strongly peraluminous, very sodic, and very Mg rich (Gustin, 1990).

Age of rhyolite tuff along Big Bug Creek north of Big Bug Mesa in zone 3B about 1,750 Ma (Anderson and others, 1971). (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xr2h - Altered rhyolitic tuff (Early Proterozoic)

Chlorite-rich crystal tuff of Cleopatra Formation south of Jerome in zone 6B. Similar pattern of chemical alteration as in altered rhyolite. Also includes muscovite- and quartz-rich rocks derived from tuff and crystal-rich rhyolite tuff. Crops out as elongate to circular areas zoned from muscovite-rich margins to quartz-rich core. Exposed east and southeast of Townsend Butte. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xd3 - Dacitic intrusive rocks (Early Proterozoic)

Fine-grained, porphyritic to equigranular dacite containing phenocrysts of plagioclase. Exposed only in Grapevine Gulch Formation in southeastern Black Hills (zone 6A). May grade into flows. (*GRI Source Map ID 75246)* (USGS SIM-2996).

Xr3 - Rhyolitic intrusive rocks (Early Proterozoic)

Fine-grained, equigranular to slightly porphyritic, irregularly shaped masses containing quartz phenocrysts. Includes large discordant mass west of Yarber Wash in zone 5B and smaller discordant bodies in Grapevine Gulch Formation in southern Black Hills of zone 6A. Intrusive rhyolitic rocks have large negative Eu anomalies, which distinguish them from other rhyolitic rocks, such as Buzzard and Deception Rhyolites (Vance, 1989). (*GRI Source Map ID 75246)* (USGS SIM-2996).

USGS SIM-2996 Source Information

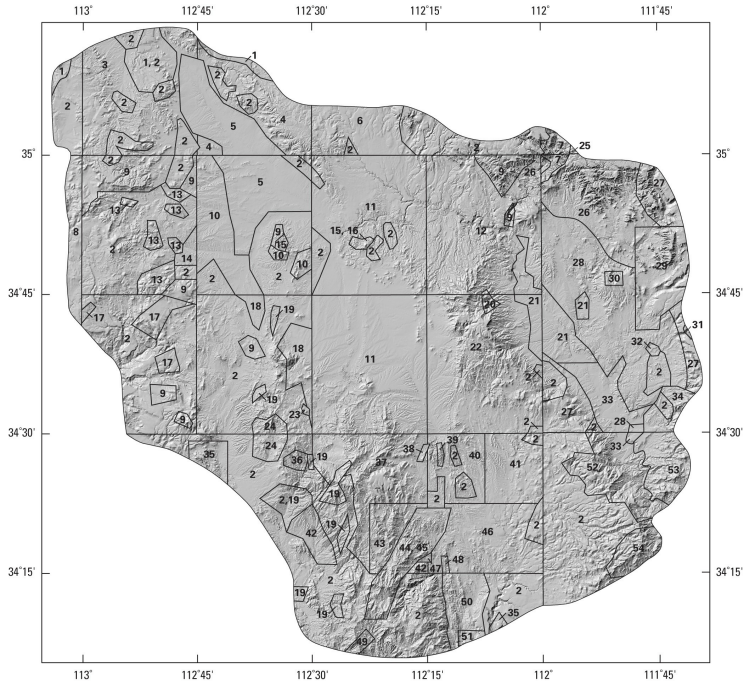
DeWitt, E., et. al., 2008, Geologic Map of the Prescott National Forest and the Headwaters of the Verde River, Yavapai and Coconino Counties, Arizona: U.S. Geological Survey, Scientific Investigations Map, SIM-2996, scale 1:100,000 (*GRI Source Map ID 75246*).

Location Map



Extracted from: (USGS SIM-2996).

Index to Sources of Geologic Mapping



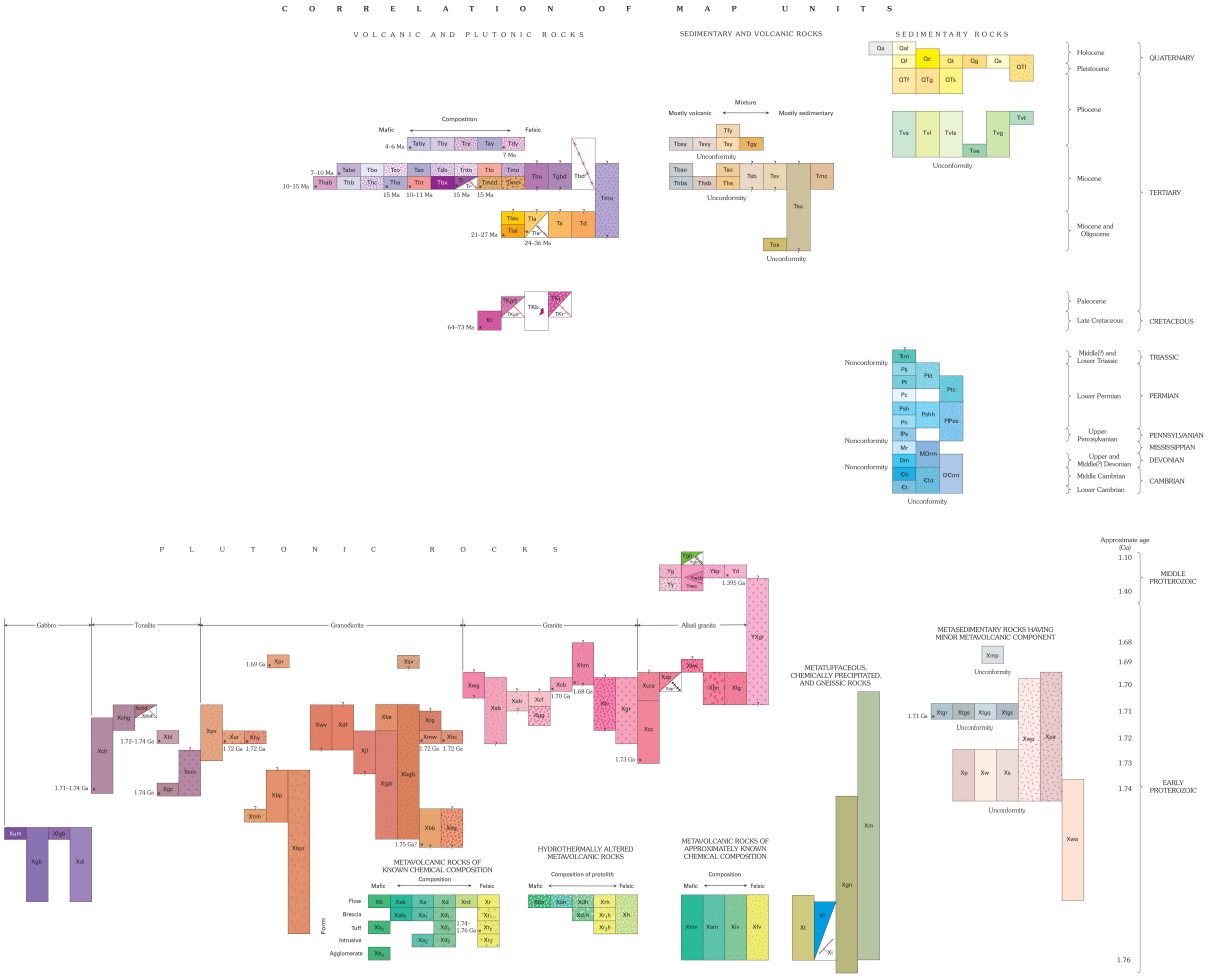
SOURCES OF GEOLOGIC MAPPING

1. Goff and others (1983)
2. DeWitt (this report)
3. Krieger (1967a)
4. Krieger (1967b)
5. Ostenaa and others (1993)
6. Krieger (1967c)
7. Huff and others (1966)
8. Simmons and Ward (1992)
9. Billingsley and others (1988)
10. Krieger (1967d)
11. Krieger (1965)
12. Lehner (1958)
13. Ash (1997)
14. Krieger (1967e)
15. Tyner (1984)
16. Ward (1993)
17. Krieger (1967f)
18. Krieger (1967g)
19. Force (this report)
20. Lindberg and Jacobson (1974)
21. House and Pearthree (1993)
22. Anderson and Creasey (1967)
23. Nichols-Boyd (2001)
24. Johnston and Lowell (1961)
25. Ulrich and others (1984)
26. Levings (1980)
27. Weir and others (1989)
28. Twenter and Metzger (1963)
29. Karlstrom and others (1983)
30. Holm and others (1998)
31. Ulrich and others (1983)
32. Lindberg (this report); Donchin (1983)
33. House (1994)
34. Ulrich and Bielski (1983)
35. DeWitt (1987)
36. Light (1975)
37. Anderson and Blacet (1972a)
38. O'Hara (1987a)
39. Swan (1987)
40. Anderson and Blacet (1972b)
41. Anderson and Blacet (1972b)
42. Hook (1956)
43. Blacet (1985)
44. DeWitt (1976)
45. DeWitt (1979)
46. Anderson and Blacet (1972c)
47. Argenbright (1986)
48. Darrach (1988)
49. Winegar and others (1978)
50. Jerome (1956)
51. Winn (1982)
52. Wolfe (1983)
53. Lewis (1983)
54. Canney and others (1967)

INDEX TO SOURCES OF GEOLOGIC MAPPING

Extracted from: (USGS SIM-2996).

Correlation of Units



Extracted from: (USGS SIM-2996).

List of Map Units



Extracted from: (USGS SIM-2996).

Map Legend

Contact—Dashed where approximately located; queried where uncertain

Fault—Dashed where approximately located; dotted where concealed by younger units; queried where uncertain. Bar and ball on downthrown side where relative movement known

Landslide scarp—Double tic on downthrown block

Marker bed

Quartz vein—Queried where uncertain

Fracture—Dashed where approximately located

PHANEROZOIC AND PROTEROZOIC STRUCTURAL FEATURES

Folds—Showing trace of axial surface and plunge where known. Dotted where concealed; queried where uncertain. Phanerozoic folds shown in black; Proterozoic F_1 structures shown in magenta; Proterozoic F_2 structures shown in purple; Proterozoic F_3 structures in cyan. Note: In this legend, black used for all folds

Monocline—Both axes shown where possible

Top of flexure

Bottom of flexure

Anticline

Syncline

Overturned anticline

Overturned syncline

PROTEROZOIC STRUCTURAL FEATURES

High-strain zone

Lineament—Determined from aerial photographs

PHANEROZOIC AND PROTEROZOIC PLANAR STRUCTURES

Strike and dip of beds

Inclined

Horizontal

Inclined, dip 45°–89°

Overturned

PROTEROZOIC PLANAR STRUCTURES

Strike and dip of tectonic S_1 foliation—Spaced cleavage in crystalline rocks and low-grade phyllosilicate-bearing foliation in tuffaceous and sedimentary protoliths. Common strike northeast in eastern part of map area. Developed east of Shylock and Black Canyon high-strain zones, but also present northwest of Shylock high-strain zone, west of Black Hills. May have been developed in western part of map area during folding predating deposition of sedimentary protoliths (units Xp, Xw, and Xa), but has been strongly overprinted by S_2 surface

Inclined

Vertical

Inclined, dip 45°–89°

Strike and dip of tectonic S_2 foliation—Prograde metamorphic foliation containing mica- and amphibole-bearing minerals. Well developed in western part of map area, west of Shylock and Black Canyon high-strain zones. Developed in isolated areas in eastern part of map area, especially south of map area on east side of Shylock high-strain zone. Common strike to northeast in much of map area, but is north in northernmost part of area. Common dip to northwest, except north of Brady Butte Granodiorite, where southeast-dipping foliation results in local refolding of F_2 folds in Texas Gulch Formation. Surface folded and deformed by F_3 event, especially around northern part of Crazy Basin Granite

Inclined

Vertical

Inclined, dip 45°–89°

Strike and dip of tectonic S_3 foliation—Retrograde metamorphic foliation containing phyllosilicate mineral assemblages. Preferential development in tuffaceous and hydrothermally altered protoliths. Well developed within high-strain zones. Common strike north in Shylock, Black Canyon, and Oro Flame high-strain zones, but northeast in Chaparral high-strain zone

Inclined

Vertical

Strike and dip of tectonic S_4 foliation—Destructive, poorly developed cleavage and phyllosilicate-bearing surface that deforms pre-existing surfaces. Poorly developed in northwestern part of map area. Common strike northeast

Inclined

Vertical

Inclined, dip 45°–89°

Strike and dip of igneous flow foliation

Inclined

Vertical

Inclined, dip 45°–89°

Strike and dip of joints

Inclined

Vertical

OTHER FEATURES

Volcanic center

Buried volcanic center—Determined from aeromagnetic lows

Buried ring dike—Approximately located where determined from circular pattern of connected aeromagnetic lows

Sinkhole—Subcircular structure due to dissolution of Redwall Limestone at depth. Names shown where known

Collapse structure—Irregularly shaped structure due to dissolution of evaporitic material in Verde Formation or subcircular structure formed during creation of travertine mound in Verde Formation

SAMPLE LOCALITIES

FT ap 8 Ma **Radiometric date**—Method, material analyzed, and age. Details in table 1

Multiple samples

Single sample

Major- and minor-element geochemistry of unaltered rock—Analyses determined for this study and many published analyses in databases included with this map

Location accurate, single sample

Location accurate, multiple samples

Location approximate, single sample

Location approximate, multiple samples

Selected-element geochemistry of possible economic importance

Location accurate, single sample

Location accurate, multiple samples

Location approximate, multiple samples

526489
Gts
MS
Xpw
Wb

Selected water well—Black symbol shows Arizona Department of Water Resources registry number and simplified map units encountered; abbreviations of units as in Description of Map Units; depths in feet indicate top and bottom of units encountered. Registry number and map units omitted for gray symbols. See table 2. Data from Arizona Department of Water Resources CD-ROM, Spring 2007. Complete listing of all water wells in Excel file included with this map, but file contains only original information from driller, not interpretation of geology based on this study

Extracted from: (USGS SIM-2996).

Geochemistry Data

Geochemistry data for the Geologic Map of the Prescott National Forest and the Headwaters of the Verde River, Yavapai and Coconino Counties, Arizona is presented below.

Geochemistry Data

Explanatory notes for geochemistry spreadsheet

Lines 1-20 in the spreadsheet are descriptive information for the samples:

1) Decimal latitude in degrees.

2) Decimal longitude in degrees.

3) 30 by 60 minute quadrangle location

4) 7 ½ minute quadrangle location

5) Township location

6) Range location

7) Section location

8) Elevation in feet above sea level

9) Magnetic susceptibility in cgs units (times 10^{-6})

10) Scintillometer reading in counts per second

11) Age in map unit subdivisions: X, Early Proterozoic; Y, Middle Proterozoic; K, Cretaceous; T, Tertiary

12) Source of data. Abbreviated format includes first author; +, secondary authors; 1985, year of publication.

13) Location information, if available

14) Map unit on geologic map, if available

15) Field number of sample, if available; USGS publications that lacked field numbers are given a number utilizing an abbreviation for the Professional Paper of Bulletin, the table that contains the analysis, and the number of the sample in the table. As an example, B1336-8 (7) is from Bulletin 1336, table 8, analysis 7.

16) Laboratory number of sample analyzed by USGS.

17) Notes about alteration of sample

18) Notes about mineralization of sample.

19) Field name for sample

20) Suite in which sample has been grouped by this author. Suites discussed in text and in figures.

Lines 21-44 include data for major elements and major oxides.

Lines 46-53 include calculations for figures in the text.

Lines 56-167 include data for minor elements determined by various analytical procedures. XRF, energy-dispersive x-ray fluorescence; ICP-MS, induction-coupled plasma mass spectrometry; INAA, instrumental neutron activation analysis; other, any technique other than the three described above.

The spreadsheet contains nine tabs or data sheets labeled as follows:

X gr plut – Early Proterozoic granitic to dioritic rocks. Data arranged in suites, generally from mafic to felsic.

X gb plut – Early Proterozoic gabbroic rocks. Data arranged in suites from west to east.

Y plut – Middle Proterozoic plutonic rocks. Data arranged in suites from west to east.

X mv1 – Early Proterozoic metavolcanic rocks. Data from published and unpublished USGS sources arranged in suites from west to east.

X mv2 – Early Proterozoic metavolcanic rocks. Data from non-USGS sources arranges in suites from west to east.

X alt – Early Proterozoic hydrothermally altered rocks. Data arranged in subgroups of suites from west to east.

TK plut – Tertiary-Cretaceous plutonic and hypabyssal rocks. Data arranged in suites from west to east. Data from Ball (1983) recalculated because of analytical problems with Al_2O_3 and Na_2O

T v1 – Tertiary volcanic rocks. Data from published and unpublished USGS sources arranged in suites either alphabetically or from west to east.

Tv2 – Tertiary volcanic rocks in and near the Hackberry volcanic center. Data arranged alphabetically in suites.

Pamphlet

The pamphlet for the Geologic Map of the Prescott National Forest and the Headwaters of the Verde River, Yavapai and Coconino Counties, Arizona is presented below.

Pamphlet to accompany Scientific Investigations Map 2996

The pamphlet contains the following sections:

Contents
Figures
Tables
Conversion Factors

Photographs

Travertine vent in Tertiary Verde Formation



Travertine vent in Tertiary Verde Formation (map unit Tvt), Montezuma Well National Monument, Verde Valley. Vertical water-escape tubes and structures on right side of image define vent area. Sediments deposited by the vent decrease in dip toward the geologist and flatten to horizontal on cliff in background on left side of image. Photograph by Raymond Johnson, 2007.

Extracted from: (USGS SIM-2996).

Metamorphosed basaltic agglomerate



Metamorphosed basaltic agglomerate (map unit Xb_4) southeast of Blue Bell mine. Lightest-colored clasts are rhyolite tuff. Large light clast above hammer is dacite. Green-gray clasts are andesite and basalt. Brownish-gray matrix is carbonate-rich andesite. Darkest greenish-gray clast in upper left corner is basalt. Hammer and pencil for scale.

Extracted from: (USGS SIM-2996).

Massive sulfide ore



Massive sulfide ore from the Iron King mine. Dull yellow grains and fragments are pyrite. Large mudball clast is broken into smaller fragments below center near right margin of slab. Minor chalcopyrite coats sides of pyrite grains but is difficult to see. Fine-grained galena is present within dark-gray to black beds that consist of quartz and minor chlorite. Scanned image of polished slab from dump of mine. Seventy-two percent of natural size.

Extracted from: (USGS SIM-2996).

GRI Digital Data Credits

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

The information in this document was compiled from GRI source maps, and intended to accompany the digital geologic-GIS map(s) and other digital data for Montezuma Castle National Monument and Tuzigoot National Monument, Arizona (MOCA and TUZI) developed by James Winter and Dalton Meyer (Colorado State University) using earlier GRI digital geologic-GIS data in ESRI coverage and shapefile formats. This earlier GRI digital data was produced by David Plume, Jim Chappell, Phillip Reiker, Georgia Hybels, Andrea Croskrey, Heather Stanton, John Gilbert and Jason Isherwood (Colorado State University and NPS GRD).

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 data review and finalization by Stephanie O'Meara.

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