



National Park Service Geologic Type Section Inventory

Sonoran Desert Inventory & Monitoring Network

Natural Resource Report NPS/SODN/NRR—2022/2453



ON THE COVER

View looking west at the type area exposures of the Oligocene Rhyolite Canyon Tuff that form the distinctive pinnacles at Chiricahua National Monument (NPS/R. STEWART).

National Park Service Geologic Type Section Inventory

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Natural Resource Report NPS/SODN/NRR—2022/2453

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Executive Summary

Type sections are one of several kinds of stratotype. A stratotype is the standard (original or subsequently designated), accessible, and specific sequence of rock for a named geologic unit that forms the basis for the definition, recognition, and comparison of that unit elsewhere. Geologists designate stratotypes for rock exposures that are illustrative and representative of the map unit being defined. Stratotypes ideally should remain accessible for examination and study by others. In this sense, geologic stratotypes are similar in concept to biological type specimens; however, they remain in situ as rock exposures rather than curated in a repository. Therefore, managing stratotypes requires inventory and monitoring like other geologic heritage resources in parks. In addition to type sections, stratotypes also include type localities, type areas, reference sections, and lithodemes, all of which are defined in this report.

The goal of this project is to consolidate information pertaining to stratotypes that occur within NPS-administered areas, in order that this information is available throughout the NPS to inform park managers and to promote the preservation and protection of these important geologic heritage resources.

This effort identified six stratotypes designated within four park units of the Sonoran Desert Inventory & Monitoring Network (SODN): Chiricahua National Monument (CHIR) has three type areas; Coronado National Memorial (CORO) has one type area; Gila Cliff Dwellings National Monument (GICL) has one type area; and Saguaro National Park (SAGU) has one type area. Table 1 provides information regarding the six stratotypes currently identified within SODN parks.

There are currently no designated stratotypes within Casa Grande Ruins National Monument (CAGR), Fort Bowie National Historic Site (FOBO), Montezuma Castle National Monument (MOCA), Organ Pipe Cactus National Monument (ORPI), Tonto National Monument (TONT), Tumacácori National Historical Park (TUMA), or Tuzigoot National Monument (TUZI). However, CHIR, MOCA, SAGU, and TUZI contain important rock exposures that could be considered for formal stratotype designation as discussed in the “Recommendations” section.

The inventory of geologic stratotypes across the NPS is an important effort in documenting these locations so that NPS staff may recognize and protect these areas for future studies. The focus adopted for completing the baseline inventories throughout the NPS has centered on the 32 inventory and monitoring (I&M) networks established during the late 1990s. Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks and was therefore adopted for the stratotype inventory. The Greater Yellowstone I&M Network (GRYN) was the pilot network for initiating this project (Henderson et al. 2020). Methodologies and reporting strategies adopted for the GRYN have been used in the development of this report for the SODN.

This report includes a recommendation section that addresses outstanding issues and future steps regarding park unit stratotypes. These recommendations will hopefully guide decision-making and

help ensure that these geoh heritage resources are properly protected and that proposed park activities or development will not adversely impact the stability and condition of these geologic exposures.

Table 1. List of SODN stratotype units sorted by park unit and geologic age, with associated reference publications and locations.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
CHIR	Rhyolite Canyon Tuff (Trco, Trcu, Trcm, Trcv, Trcl, Trca)	Pallister et al. 1994	Type area: Chiricahua National Monument, in Cochise County, Arizona. Representative sections in this area are located between Rhyolite Canyon and Sugarloaf Mountain, and at Riggs Mountain. Type area is near approximate latitude 32°0'20" N., longitude 109°19'60" W.	Oligocene
CHIR	Jesse James Canyon Tuff (Tjj, Tjjf)	Pallister et al. 1994	Type area: vicinity of Jesse James Canyon, Chiricahua National Monument and Coronado National Forest, near northern edge of Rustler Park 7.5' Quadrangle, in Cochise County, Arizona. Type area is near approximate latitude 31°59'6" N., longitude 109°20'59" W.	Oligocene
CHIR	Faraway Ranch Formation (Tfre, Tfpe, Tfrh, Tfph)	Enlows 1955; Pallister et al. 1994	Type area: near Faraway Ranch in SE/4 SE/4 SE/4 section 27, T. 16 S., R. 29 E., Cochise Head 7.5' Quadrangle, in Cochise County, Arizona. Type area is near approximate latitude 32°00'30" N., longitude 109°22'27" W.	Oligocene
CORO	Huachuca Granite (Jhb, Jhga, Jhgf, Jhgb, Jhgp, Jhgh, Jhu)	Hayes 1967	Type area: extensive exposures in southern part of Huachuca Mountains, in Cochise County, Arizona. Type area is near approximate latitude 31°21'15" N., longitude 110°15'51" W.	Jurassic
GICL	Gila Conglomerate (QTg, QTgps)	Gilbert 1875; Pye 1959	Type area: southeastern Arizona and southwestern New Mexico, in four separate valleys along Gila River east of Safford, Arizona. Type area is near approximate latitude 33°13'19" N., longitude 108°16'19" W.	Oligocene– Miocene
SAGU	Amole Arkose (Ka)	Brown 1939; Hayes 1970	Type area: exposures on western side of southern part of Tucson Mountains; extending north to Amole Peak [center section 30, T. 13 S., R. 12 E., Avra 7.5' Quadrangle], Pima County, Arizona. Type area is near approximate latitude 32°15'14" N., longitude 111°9'14" W.	Cretaceous

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections for the national parks of the Sonoran Desert Inventory & Monitoring Network. We first want to extend our sincere appreciation to Randy Orndorff, David Soller, and Nancy Stamm (U.S. Geological Survey) for their assistance with this geologic type section inventory and other important NPS projects. Randy, Dave, and Nancy manage the National Geologic Map Database and GEOLEX (the U.S. Geologic Names Lexicon, a national compilation of names and descriptions of geologic units), respectively, for the United States, critical sources of geologic map information for science, industry and the American public. We also extend our thanks to Diana Boudreau (NPS) and Andrew Zaffos (Arizona Geological Survey) for their valuable suggestions in review of this report.

We thank our colleagues and partners in the Geological Society of America (GSA) and Stewards Individual Placement Program for their continued support to the NPS with the placement of geologic interns and other ventures. Additionally, we are grateful to Rory O'Connor-Walston and Alvin Sellmer from the NPS Technical Information Center in Denver for their assistance with locating hard-to-find publications.

Thanks to our NPS colleagues in the Sonoran Desert Inventory & Monitoring Network and various network parks, especially Andy Hubbard (SODN). Andy served as peer review coordinator for this report. Additional thanks to Michael Bozek and Don Weeks (NPS retired) for continued support for this and other important geology projects in the Intermountain Region of the NPS, now known as DOI regions 6–8.

This project is possible through the support from research associates and staff in the National Park Service Geologic Resources Division and we extend our thanks to Stephanie Gaswirth, Hal Pranger, Julia Brunner, Jim Wood, Jason Kenworthy, and Rebecca Port. Finally, we want to thank the past and current members of the NPS Geologic Resource Inventory Team for more than 20 years of work to expand our understanding of the geologic features, issues, and processes in our national parks!

Dedication

We are proud to dedicate the Sonoran Desert Inventory & Monitoring Network (SODN) Geologic Type Section Inventory to Andy Hubbard, SODN Network Coordinator. Andy completed his BSc and MSc in Watershed Management at the University of Arizona and received his PhD in Rangeland Ecology at Texas A&M. Andy began his career with the National Park Service in 1995 and joined the Inventory and Monitoring Program in 1999 at Cape Cod National Seashore. We want to extend our appreciation to Andy for all his assistance and support with NPS geology and paleontology projects and publications.



Andy Hubbard, Program Manager, Sonoran Desert Inventory & Monitoring Network.

Introduction

Geologic maps show the distribution and classification of rocks, sedimentary deposits, and geologic features for a given area. The geologic classification of rocks and deposits is hierarchical with several different categories of geologic or stratigraphic units including, from regional scale to local exposure scale: supergroup, group, formation, member, and bed. The mapping of stratigraphic units involves the evaluation of lithologies, bedding properties, thickness, geographic distribution, and other factors. Mappable geologic units may be described and named through a rigorously defined process that is standardized and codified by the professional geologic community (North American Commission on Stratigraphic Nomenclature 2021). In most instances, when a new geologic unit (such as a formation) is described and named in the scientific literature, a specific and well-exposed section or exposure area of the unit is designated as the stratotype (see “Definitions” below). A type section is an important reference exposure for a named geologic unit, presenting a relatively complete and representative example of this unit. Geologic stratotypes are important geoheritage resources with historic and scientific significance, and should be available for other researchers to evaluate in the future.

The importance of stratotypes lies in the fact that they represent important comparative sites where past investigations can be built upon or re-examined and can serve as teaching sites for the next generation of geoscientists (Brocx et al. 2019). The geoheritage significance of stratotypes is analogous to libraries and museums in that they are natural repositories of Earth history and record the physical and biologic evolution of our planet. In addition, geologic formations are named after topographic or geologic features and landmarks that are recognizable to park staff and visitors. Therefore, geologic stratotypes are part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (refer to <https://www.nps.gov/articles/scientific-value.htm> for more about geologic heritage).

The goals of this project are to (1) systematically report the assigned stratotypes that occur within national parks of the Sonoran Desert Inventory & Monitoring (I&M) Network (SODN), (2) provide detailed descriptions of the stratotype exposures and their locations, and (3) reference the stratotype assignments from published literature. It is important to note that this project cannot verify a stratotype for a geologic unit if one has not been formally assigned and/or published. This effort identified six stratotypes with four SODN parks: Chiricahua National Monument (CHIR) has three type areas; Coronado National Memorial (CORO) has one type area; Gila Cliff Dwellings National Monument (GICL) has one type area; and Saguaro National Park (SAGU) has one type area. Table 1 provides information regarding the six stratotypes currently identified within SODN parks. Additionally, numerous stratotypes are located geographically outside of national park boundaries; those within 48 km (30 mi) of park boundaries are mentioned in this report.

The SODN Geologic Type Section Inventory report is part of a larger effort to document stratotypes in all 32 I&M networks and selected non-I&M parks with significant rock exposures. This report follows the standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network type section inventory (Henderson et al. 2020), which was the

pilot for this effort; refer to the “Methods” section below for detailed information. As discussed in “Methods”, the NPS Geologic Type Section Inventory Project utilizes NPS Geologic Resources Inventory (GRI) data and information, which is considered the “official” baseline geologic map and report for each park in the Inventory and Monitoring (I&M) program.

Geologic stratotypes within NPS areas have not been previously inventoried, so this report fills a void in basic geologic information compiled by the NPS at most parks. NPS staff may not be aware of the concept of geologic stratotypes nor the significance or occurrence of them in parks. Without proper documentation and awareness, the NPS cannot proactively monitor the stability, condition, or potential impacts to these locations from activities such as ground disturbance or construction. Instances where geologic stratotypes occurred within NPS areas were determined through research of published geologic literature and maps as described in “Methods” below. Sometimes the lack of specific locality information or other data limited determination of whether a particular stratotype was located within NPS administered boundaries.

Given the importance of geologic stratotypes as geologic references and geologic heritage resources, these SODN locations should be afforded some level of documentation, preservation, or protection as appropriate. This inventory can inform important conversations on whether geologic stratotypes rise to the level of national register documentation. The NPS should consider if any other legal authorities (e.g., National Historic Preservation Act), policy, or other safeguards currently in place can help protect geologic stratotypes that are established on NPS administered lands.

Through this inventory, the associated report, and close communication with park, region, and I&M Network staff, we hope there will be an increased awareness about these important geologic landmarks in parks. In turn, the awareness of these resources and their significance may be recognized in park planning and operations, to ensure that geologic stratotypes are preserved and available for future study.

Definitions

In order to clarify, standardize, and consistently reference stratigraphic concepts, principles, and definitions, the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature 2021) is recognized and adopted for this inventory. This code describes explicit practices for classifying and naming all formally defined geologic units. An important designation for a geologic unit is known as a **stratotype**—the standard exposure (original or subsequently designated) for a named geologic unit or boundary, constituting the basis for definition or recognition of that unit or boundary (North American Commission on Stratigraphic Nomenclature 2021). There are several variations of stratotype referred to in the literature and this report, and they are defined as follows:

- **Unit stratotype:** the **type section** for a stratified deposit or the **type area** for a non-stratified body that serves as the standard for recognition and definition of a geologic unit (North American Commission on Stratigraphic Nomenclature 2021). Once a unit stratotype is assigned, it is never changed, but it may be supplemented if it proves inadequate. The term “unit stratotype” is commonly referred to as “type section” and “type area” in this report.

- **Type locality:** the specific geographic locality encompassing the unit stratotype of a formally recognized and defined unit. On a broader scale, a type area is the geographic territory encompassing the type locality. Before development of the stratotype concept, only type localities and type areas were designated for many geologic units that are now long- and well-established (North American Commission on Stratigraphic Nomenclature 2021).
- **Reference sections:** for well-established geologic units for which a type section was never assigned, a reference section may serve as an invaluable standard for definitions or revisions. A principal reference section may also be designated for units whose stratotypes have been destroyed, covered, or are otherwise inaccessible (North American Commission on Stratigraphic Nomenclature 2021). Multiple reference sections can be designated for a single unit to help illustrate heterogeneity or some critical feature not found in the stratotype. Reference sections can help supplement unit stratotypes in the case where the stratotype proves inadequate (North American Commission on Stratigraphic Nomenclature 2021).
- **Lithodeme:** the term “lithodeme” is defined as a mappable unit of plutonic (igneous rock that solidified at great depth) or highly metamorphosed and pervasively deformed rock that is equivalent in rank to “formation” among stratified rocks (North American Commission on Stratigraphic Nomenclature 2021). The formal name of a lithodeme consists of a geographic name followed by a descriptive term that denotes the average modal composition of the rock (example: Cathedral Peak Granodiorite). Lithodemes are commonly assigned type localities, type areas, and reference localities.

Methods

Methodology

The process of determining whether a specific stratotype occurs within an NPS area involves multiple steps. The process begins with an evaluation of a park-specific Geologic Resources Inventory (GRI) map to prepare a full list of recognized map units (Figure 1). More information about the GRI data can be found later in this section.

Each map unit name is queried in the USGS Geologic Names Lexicon online database (“GEOLEX”, a national compilation of names and descriptions of geologic units) at <https://ngmdb.usgs.gov/Geolex/search>. Information provided by GEOLEX includes the geologic unit name, stratigraphic nomenclature usage, geologic age, and published stratotype location descriptions, and the database provides a link to significant publications as well as the USGS Geologic Names Committee Archives (Wilmarth 1938; Keroher et al. 1966). Figure 2 is taken from a search on the Oligocene Jesse James Canyon Tuff, which is mapped within CHIR.

Published GEOLEX stratotype spatial information is provided in three formats: (1) descriptive, using distance from nearby points of interest; (2) latitude and longitude coordinates; or (3) Township/Range/Section (TRS) coordinates. TRS coordinates are based upon subdivisions of a single 93.2 km² (36 mi²) township into 36 individual 2.59 km² (1 mi²) sections, and were converted into Google Earth (.kmz file) locations using Earth Point (<https://www.earthpoint.us/TownshipsSearchByDescription.aspx>). They are typically presented in an abbreviated format such as “section [#], T. [#] [N. or S.], R. [#] [E. or W.]”. The most accurate GEOLEX descriptions using TRS coordinates can help locate features within 0.1618 km² (0.0625 mi²). Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the national park is draped over it. This step serves two functions: improving accuracy in locating the stratotype and validating the geologic polygon for agreement with GEOLEX nomenclature. Geolocations in Google Earth are then converted into an ArcGIS format using a “KML to Layer” conversion tool in ArcMap.

Upon accurately identifying the stratotypes using GEOLEX or peer-reviewed literature, a Microsoft Excel spreadsheet is populated with information pertinent to the geologic unit and its stratotype attributes. Attribute data recorded in this way include: (1) whether a stratotype is officially designated; (2) whether the stratotype is on NPS land; (3) whether the stratotype location has undergone a quality control check in Google Earth; (4) reference of the publication citing the stratotype; (5) description of geospatial information; (6) coordinates of geospatial information; (7) geologic age (era, period, epoch, etc.); (8) hierarchy of nomenclature (supergroup, group, formation, member, bed, etc.); (9) whether the geologic unit was listed in GEOLEX; and (10) a generic notes field (Figure 3).

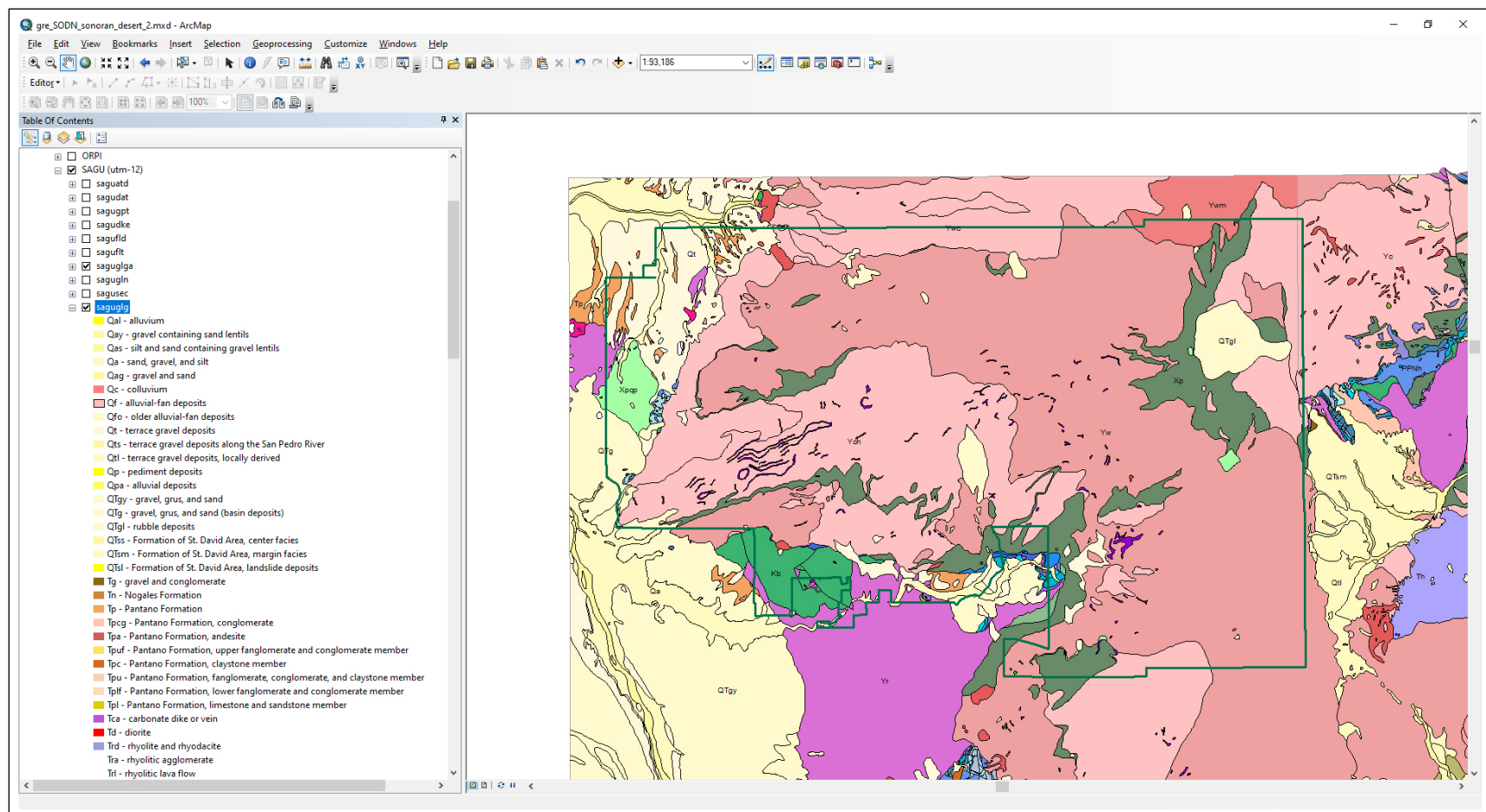



Figure 1. Screenshot of the GRI-compiled digital geologic map of Saguaro National Park showing mapped units. The NPS boundary layer has been added (green lines). Access the GIS version of the NPS boundary online:

<https://irma.nps.gov/DataStore/Reference/Profile/2224545?Inv=True>. Data modified from SAGU GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1047835>.




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National Geologic Map Database

Geolex — Unit Summary

Geologic Unit: Jesse James Canyon

Usage:

Jesse James Canyon Tuff (AZ*-recognized locally in Cochise Co.)

Geologic age:


Oligocene*

Type section, locality, area and/or origin of name:

Type area: vicinity of Jesse James Canyon, Chiricahua National Monument and Coronado National Forest, near northern edge of Rustler Park quadrangle, Cochise Co., southeastern AZ. Named from Jesse James Canyon (Pallister and others, 1994).

AAPG geologic province:

Pedregosa basin*



Significant Publications

- [Correlation charts](#)
- [GNC Archives](#)
- [N.A. Stratigraphic Code](#)
- [More Resources](#)






For more information, please contact [Nancy Stamm](#), Geologic Names Committee Secretary.

Asterisk (*) indicates published by U.S. Geological Survey authors.

"No current usage" (†) implies that a name has been abandoned or has fallen into disuse. Former usage and, if known, replacement name given in parentheses ().

Slash (/) indicates name does not conform with nomenclatural guidelines (CSN, 1933; ACSN, 1961, 1970; NACSN, 1983, 2005). This may be explained within brackets ([]).

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Figure 2. GEOLEX search result for the Jesse James Canyon Tuff.

AutoSave

Off

Save

Undo

Redo

SODN Type Section Inventory

Search

Timothy Henderson

File

Home

Insert

Page Layout

Formulas

Data

Review

View

Help

Paste

Format Painter

Cut

Copy

Calibri

11

A

A

B

I

U

Wrap Text

General

\$

%

0.00

0.00

Conditional Formatting

Format as Table

Cell Styles

Insert

Delete

Format

AutoSum

Fill

Clear

Sort & Filter

Find & Select

Analyze Data

Clipboard

Font

Alignment

Number

Styles

Cells

Editing

Analysis

Share

Comments

A44

A

B

C

D

E

F

G

H

I

J

K

L

M

N

1

Formation

Type Section Not Designated?

Type Section in NPS Boundary?

QC on GoogleEarth

Non-NPS type section locality

Publication

Desc. Geospatial Info

Coordinate Geospatial Info

Geologic Age_Era

Geologic Age_Period

Heirarchy

Geolex

Map Symbol

Notes

12

Rocks of the Turkey Creek Caldera: Dacite

X

Pallister et al. 1994

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

NO

Tdpl

13

Rocks of the Turkey Creek Caldera, Rhyolite Canyon Tuff, upper

YES - CHIR

YES

Pallister et al. 1994

Type area: Chiricahua National Monument, Cochise

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

YES

14

Rocks of the Turkey Creek Caldera, Outflow

X

Pallister et al. 1994

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

NO

Trco

15

Rocks of the Turkey Creek Caldera, Outflow

X

Pallister et al. 1994

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

NO

Trcu

16

Rocks of the Turkey Creek Caldera, Outflow

X

Pallister et al. 1994

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

NO

Trcm

17

Rocks of the Turkey Creek Caldera, Outflow

X

Pallister et al. 1994

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

NO

Trcv

18

Rocks of the Turkey Creek Caldera, Outflow

X

Pallister et al. 1994

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

NO

Trcl

19

Rocks of the Turkey Creek Caldera, Outflow

X

Pallister et al. 1994

Cenozoic

Oligocene

Rocks of the Turkey Creek Caldera

NO

Trca

20

Jesse James Canyon Tuff

YES - CHIR

YES

Pallister et al. 1994

Type area: vicinity of Jesse James Canyon, Chiricahua

Cenozoic

Oligocene

Jesse James Canyon Tuff

YES

Tjj

21

Jesse James Canyon Tuff, lithic-rich pyroclastic

X

Cenozoic

Oligocene

Jesse James Canyon Tuff

NO

Tjjf

22

Faraway Ranch Formation

YES - CHIR

YES

Principal reference locality (Far

Enlows 1955; Drewes 1982; Pallister et al. 1994

Type area: near Faraway Ranch

Cenozoic

Oligocene

Faraway Ranch Formation

YES

23

Faraway Ranch Formation, Rhyolite of El Estero

X

Pallister et al. 1994

Cenozoic

Oligocene

Faraway Ranch Formation

NO

Tfre

24

Faraway Ranch Formation, Pyroclastic flow

X

Pallister et al. 1994

Cenozoic

Oligocene

Faraway Ranch Formation

NO

Tfpe

25

Faraway Ranch Formation, Rhyolite of H

X

Pallister et al. 1994

Cenozoic

Oligocene

Faraway Ranch Formation

NO

Tfrh

26

Faraway Ranch Formation, Pyroclastic flow

X

Pallister et al. 1994

Cenozoic

Oligocene

Faraway Ranch Formation

NO

Tfph

27

Sedimentary rocks of Bonita Park

X

IN CHIR

Enlows 1955

Cenozoic

Oligocene

Sedimentary rocks of Bonita Park

YES

Tbp

Formerly

28

Welded Tuff of Joe Glen Ranch

X

Cenozoic

Oligocene

Welded Tuff of Joe Glen Ranch

NO

Tjg

29

Quartz vein

X

Cenozoic

Tertiary?

Quartz vein

NO

Tq

30

Intermediate and mafic lava flows

X

Cenozoic

Oligocene

Intermediate and mafic lava flows

NO

Tim

31

Possible pillow basalt

X

Cenozoic

Oligocene

Possible pillow basalt

NO

Timp

32

Zones of silicification

X

Cenozoic

Oligocene

Zones of silicification

NO

Tims

33

Rhyolite dikes

X

Cenozoic

Oligocene?

Rhyolite dikes

NO

Tr

34

Mural Limestone

NO

Type locality: at Mural Hill, nor Ransome 1904; Hayes 1970; Drewes 1987

Mesozoic

Lower Cretaceous

Mural Limestone

YES

Kbbs

35

Morita Formation

NO

Principal reference section: in f Hayes 1970

Mesozoic

Lower Cretaceous

Morita Formation

YES

Km

36

Glance Conglomerate

NO

Principal reference section: in f Hayes 1970

Mesozoic

Lower Cretaceous

Glance Conglomerate

YES

Kg

37

Concha Limestone

NO

Type section: on east end of Cc Gilluly et al. 1954; Mayo and Pye 1959; Bryant and McClymond

Paleozoic

Lower Permian

Concha Limestone

YES

Pcn

38

Scherrer Formation

NO

Type section: on Scherrer Ridge Gilluly et al. 1954; Wood 1959; Mayo and Pye 1959

Paleozoic

Lower Permian

Scherrer Formation

YES

Ps

39

Epitaph Dolomite

NO

Type section: on dip slope of C Gilluly et al. 1954; Mayo and Pye 1959

Paleozoic

Lower Permian

Epitaph Dolomite

YES

Pec

40

Colina Limestone

NO

Type section: on west slope of Gilluly et al. 1954; Mayo and Pye 1959

Paleozoic

Lower Permian

Colina Limestone

YES

Pec

41

Farn Formation

NO

Type section: extends from sad Gilluly et al. 1954; Mayo and Pye 1959

Paleozoic

Lower Permian

Farn Formation

YES

Pea

CAGR

CHIR

CORO

FOBO

GICL

MOCA

ORPI

SAGU

TONT

TUMA

TUZI

Ready

Display Settings

Figure 3. Stratotype inventory spreadsheet of the SODN displaying attributes appropriate for geolocation assessment.

Geologic Resources Inventory (GRI) Data

The Geologic Resources Inventory (GRI) provides digital geologic map data and pertinent geologic information on park-specific features, issues, and processes to support resource management and science-informed decision-making to the 270 parks in the I&M program. The GRI team provides three products to each park that can be useful in the determination of stratotypes: (1) a summary document from an initial scoping meeting, (2) digital geologic map data in a geographic information system (GIS) format, and (3) a GRI report.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Scoping meeting summaries serve as an interim report until the final report is delivered.

Following the scoping meeting, the GRI map team converts the geologic source maps identified in the mapping plan to GIS data in accordance with the GRI data model (<https://www.nps.gov/articles/gri-geodatabase-model.htm>). The GRI uses a unique “GMAP ID” value for each geologic source map, and all sources used to produce the GRI GIS data sets for the SODN parks can be found in Appendix A. The GRI map data is the basis for this stratotype inventory as it is considered the “official” geologic dataset for the park. The list of units present in the GRI GIS data was used to search GEOLEX.

After the digital geologic map is completed, the GRI report team uses the map data, as well as the scoping summary and additional research, to prepare the GRI report. The GRI reports were utilized for additional information about geologic resources in a given park and connections to park landscape, history, or other resources. Posters that display the GRI GIS data over imagery of the park are also created as part of the report process. They are available with the reports or separately from the GRI publications page (<https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm>).

Additional Considerations

There are several additional considerations for this inventory. The most up-to-date information available is necessary, and is either found online or in published articles and maps. Occasionally, there is a lack of specific information which limits the information contained within the final report. This inventory does not include any field work and is dependent on the existing information related to individual park geology and stratigraphy. Additionally, this inventory does not attempt to resolve any unresolved or controversial stratigraphic interpretations, which is beyond the scope of the project.

Stratigraphic nomenclature may change over time with refined stratigraphic field assessments and discovery of information through the expansion of stratigraphic mapping and measured sections. One important observation regarding stratigraphic nomenclature relates to differences in use of geologic names for units that cross state boundaries. Geologic formations and other geologic units that cross state boundaries may have different names or ranks in each of the states the units are mapped. An example is the Paleocene Fort Union Formation (as used by the Montana Bureau of Mines and

Geology and the U.S. Geological Survey), which is equivalent to the Fort Union Group of the North Dakota Geological Survey.

The lack of a designated and formal type section, or inadequate and vague geospatial information associated with a type section, limits the ability to capture precise information for this inventory. The available information related to the geologic type sections is included in this report.

This inventory report is intended for a wide audience, including NPS staff who may not have a background in geology. Therefore, this document is developed as a reference document that supports science, resource management, and a historic framework for geologic information associated with SODN parks.

All network-specific reports are peer-reviewed and submitted to the Natural Resources Stewardship and Science Publications Office for finalization.

Geology and Stratigraphy of the SODN I&M Network Parks

The Sonoran Desert Network Inventory & Monitoring Network (SODN) consists of 10 park units in central and southern Arizona and one park unit in southwestern New Mexico (Figure 4). These units are characteristic of the upper Sonoran subdivision of the Sonoran Desert Ecoregion and the Apache Highlands Ecoregion, and include Casa Grande Ruins National Monument (CAGR), Chiricahua National Monument (CHIR), Coronado National Memorial (CORO), Fort Bowie National Historic Site (FOBO), Gila Cliff Dwellings National Monument (GICL), Montezuma Castle National Monument (MOCA), Organ Pipe Cactus National Monument (ORPI), Saguaro National Park (SAGU), Tonto National Monument (TONT), Tumacácori National Monument (TUMA), and Tuzigoot National Monument (TUZI). The parks that comprise the Sonoran Desert Network protect a combined 179,801 hectares (444,299 acres) of wilderness and vary in size from 145 hectares (360 acres) in TUMA to 133,825 hectares (330,689 acres) in ORPI.

The park units of the SODN are composed of a complex assemblage of sedimentary, igneous, and metamorphic rocks with widely varying ages, from approximately 2-billion-year-old Precambrian surface exposures to relatively recent (ca. 700 CE) volcanic rocks in the Pinacate region near the international border (see Appendix B for a geologic time scale). During the Cenozoic Era, significant changes in plate motion occurred from the Eocene through the Miocene ~35–15 Ma (mega-annum, million years ago) that caused the underlying crust of western North America to stretch, thin, and break along low-angle fractures called detachment faults (Bezy 2005). During this time, numerous volcanoes were active in the Sonoran Desert, resulting in calderas (collapsed magma chambers) such as the Turkey Creek caldera of CHIR, Montezuma caldera of CORO, Gila Cliffs Dwelling caldera of GICL, and Tucson Mountains caldera of SAGU; lava vents; and cinder cones. Large-scale regional extension, coupled with intense heat from below, produced uplifts of highly sheared and metamorphosed rock called metamorphic core complexes and placed tremendous stress on the underlying crust of the Sonoran Desert region (Bezy 2005).

The modern landscape of the Basin and Range province began developing during the Miocene Epoch (~12–5 Ma) as extensive tectonic forces continued to stretch and thin the continental crust, producing large-scale normal faults (Bezy 2005; Graham 2011c). The result was roughly parallel, fault-bounded mountain ranges (horsts), many approaching elevations of 3,048 m (10,000 ft), separated by broad valleys (grabens) flanked by broad sloping “bajadas” of coalesced alluvial fans. The precipitous topographic relief of the Basin and Range landscape provides for drastic differences in climate along slopes, with the relatively cool and moist summits containing biological communities more characteristic of Canada than those of the valley bottoms below. These montane habitats are termed “sky islands”, because they rise above the desert floor to resemble islands surrounded by a sea (Graham 2011a). These “sky islands” are analogous to actual marine islands from the perspective of biogeography, speciation, and landscape connectivity (Scarborough and Brusca 2015). In combination with the bimodal precipitation regime and mid-continental position, the tremendous topographic variation over short distances helps create the amazing natural and geological diversity of the Sonoran Desert.

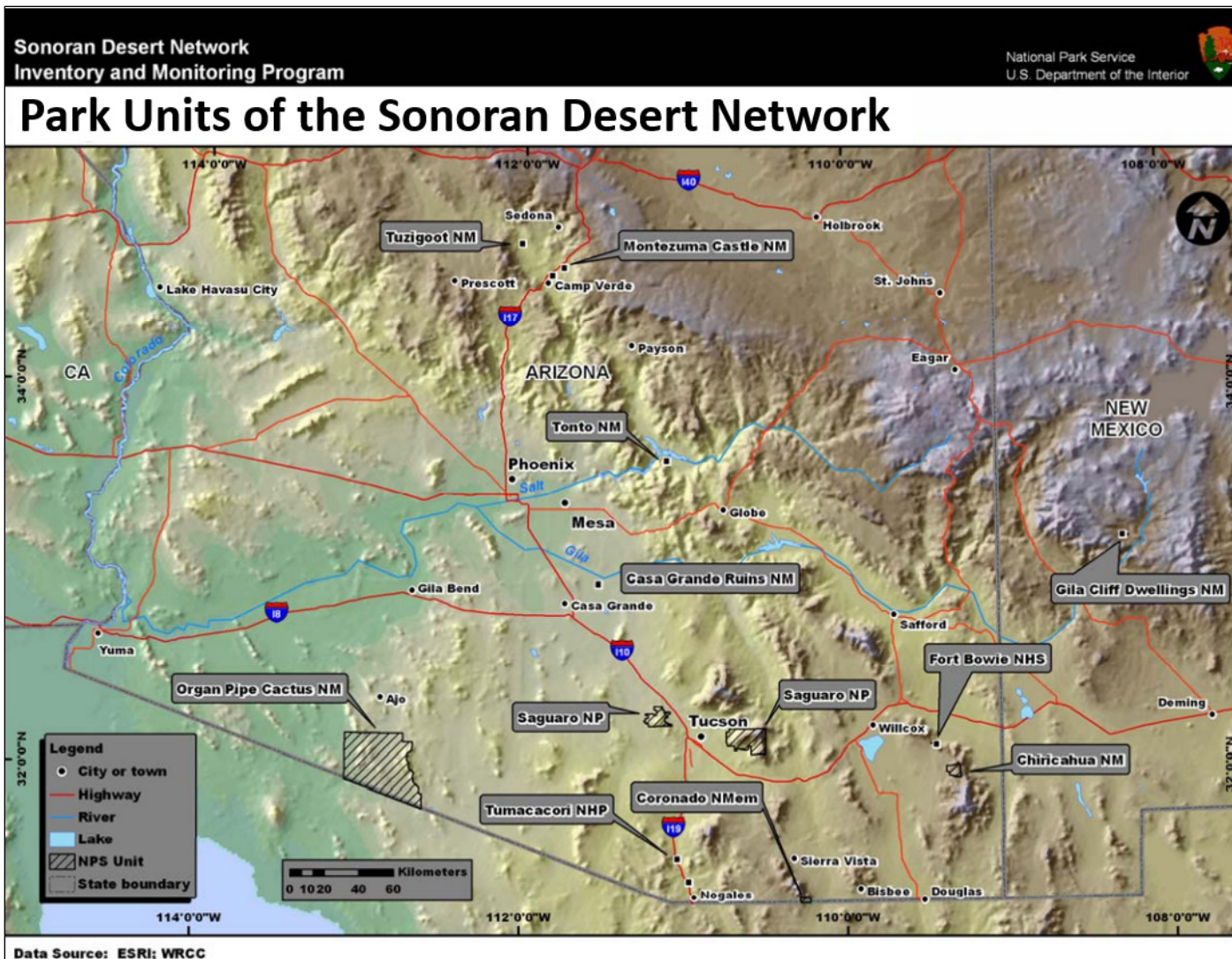


Figure 4. Map of Sonoran Desert I&M Network parks. They include Casa Grande Ruins National Monument (CAGR), Chiricahua National Monument (CHIR), Coronado National Memorial (CORO), Fort Bowie National Historic Site (FOBO), Gila Cliff Dwellings National Monument (GICL), Montezuma Castle National Monument (MOCA), Organ Pipe Cactus National Monument (ORPI), Saguaro National Park (SAGU), Tonto National Monument (TONT), Tumacacori National Monument (TUMA), and Tuzigoot National Monument (TUZI) (NPS).

Precambrian (4.6 billion to 539 million years ago)

Rocks of Precambrian age are limited to three park units of the SODN, with some of the oldest units represented by Paleoproterozoic rocks of the Pinal Schist in SAGU and granitic rocks of Cottonwood Creek in TONT. Rocks of Mesoproterozoic age include the Dripping Spring Quartzite of SAGU and TONT, the Continental Granodiorite and the granodiorite of Rincon Valley in SAGU, and the Mescal Formation in TONT. Neoproterozoic units include granodiorite stocks and aplite intrusions that underlie FOBO.

Paleozoic (539 to 252 million years ago)

Paleozoic strata are found at four of the park units of the SODN, with some of the oldest rocks represented by the Cambrian Coronado Sandstone in FOBO and Cambrian Bolsa Quartzite in SAGU. Ordovician and Devonian units in FOBO include the El Paso and Portal Formations. The Mississippian Escabrosa Limestone is mapped in both FOBO and SAGU. Sedimentary strata of the Pennsylvanian–Permian Naco Group (Horquilla Limestone, Earp Formation, Scherrer Formation, Colina Limestone, Epitaph Dolomite) are widely distributed, occurring in CHIR, CORO, FOBO, and SAGU.

Mesozoic (252 to 66 million years ago)

Mesozoic strata occur in six park units of the SODN, with some of the oldest rocks consisting of the Triassic–Jurassic Recreation Red Beds in SAGU. Jurassic units include the Huachuca Granite in CORO, rocks of La Abra and conglomerate of Scarface Mountain in ORPI, and quartz monzonite of Mount Benedict in TUMA. Strata associated with the Cretaceous Bisbee Group (Morita Formation, Glance Conglomerate, Cintura Formation, Mural Limestone) underlie CHIR, CORO, FOBO, and SAGU. Other Cretaceous formations include the Gunsight Hills Granodiorite, Aguajita Spring Granite, and Bandeja Well Granodiorite in ORPI; Cat Mountain Tuff, Wrong Mountain Quartz Monzonite, Amole Arkose, Amole plutonic rocks, and volcanics of Yuma Mine in SAGU; and the Salero Formation in TUMA.

Cenozoic (66 million years ago to the present)

Cenozoic deposits are mapped in every park unit of the SODN except FOBO. The oldest Cenozoic rocks include Oligocene igneous and volcanoclastic sedimentary rocks such as the Faraway Formation, Jesse James Canyon Tuff, and Rhyolite Canyon Tuff in CHIR; the Bloodgood Canyon Tuff, Bearwallow Mountain Andesite, and Gila Conglomerate in GICL; and the Safford Dacite and Pantano Formation in SAGU. A diverse sequence of Miocene rocks underlies ORPI and includes the Childs Latite, Batamote Andesite complex, Daniels Conglomerate, Growler Mountain Rhyolite, rhyolite of Montezuma's Head, and rhyolite of Pinkley Peak. Rocks of the Miocene–Pliocene Verde Formation are a major bedrock constituent in both MOCA and TUZI.

Quaternary surficial deposits are widely mapped in the park units of the SODN and include alluvial fan deposits (CHIR, SAGU), alluvium and colluvium (CAGR, CHIR, CORO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI), debris flows (CORO, TONT, TUMA), river terraces (CAGR, GICL, TUMA, TUZI), and terrace gravels (CORO, MOCA).

Casa Grande Ruins National Monument (CAGR)

Park Establishment

Casa Grande Ruins National Monument (CAGR) is located approximately 72 km (45 mi) southeast of downtown Phoenix in Pinal County, Arizona (Figure 5). Originally authorized as Casa Grande Ruin Reservation on March 2, 1889, the park unit was redesignated on August 3, 1918.

Encompassing about 191 hectares (473 acres), CAGR was established for the preservation and interpretation of the Casa Grande and surrounding features and objects of prehistoric interest (National Park Service 2017a). The Casa Grande (“great house” in Spanish) was named by early Spanish explorers and is a four-story, 18 m (60 ft)-long earthen-walled structure constructed by the Ancestral Sonoran Desert People (Hohokam culture) who inhabited the Gila Valley in the early 13th century. The Casa Grande is the only surviving example of a multi-story, free-standing earthen Great House structure from the Hohokam culture and was built using more than 3,000 tons of local caliche (concrete-like mixture of sand, clay, and limestone) and hundreds of juniper, pine, and other trees used as structural anchors. Besides Casa Grande, CAGR contains 62 documented prehistoric cultural sites, including a ballcourt, platform mound, and irrigation canals that embody one of the most extensive prehistoric irrigation-based agricultural desert societies in North America.

Geologic Summary

CAGR and the immediate surrounding region are part of the Sonoran Desert sub-province of the Basin and Range physiographic province (KellerLynn 2018). The province is characterized by horst and graben topography where extensional normal faults have created down-faulted structural basins (grabens) separating up-faulted mountain ranges (horsts). CAGR is situated in the down-dropped Picacho Basin. The bedrock geology of CAGR is associated with the history of the Gila River and consists entirely of Pleistocene river terrace and alluvium (unconsolidated gravel, sand, silt, and clay) deposits (Figure 6). The age of the underlying terrace indicates that the Gila River was flowing across the monument area approximately 130,000–10,000 years ago (KellerLynn 2018). Immediately surrounding CAGR are younger Holocene river deposits with localized outcrops of Proterozoic granite to the northeast of the monument.

Stratotypes

There are no designated stratotypes identified within the boundaries of CAGR. There are six identified stratotypes located within 48 km (30 mi) of CAGR boundaries that are provided in Appendix C for reference in case of future boundary expansion.



Figure 5. Park map of CAGR, Arizona (NPS).

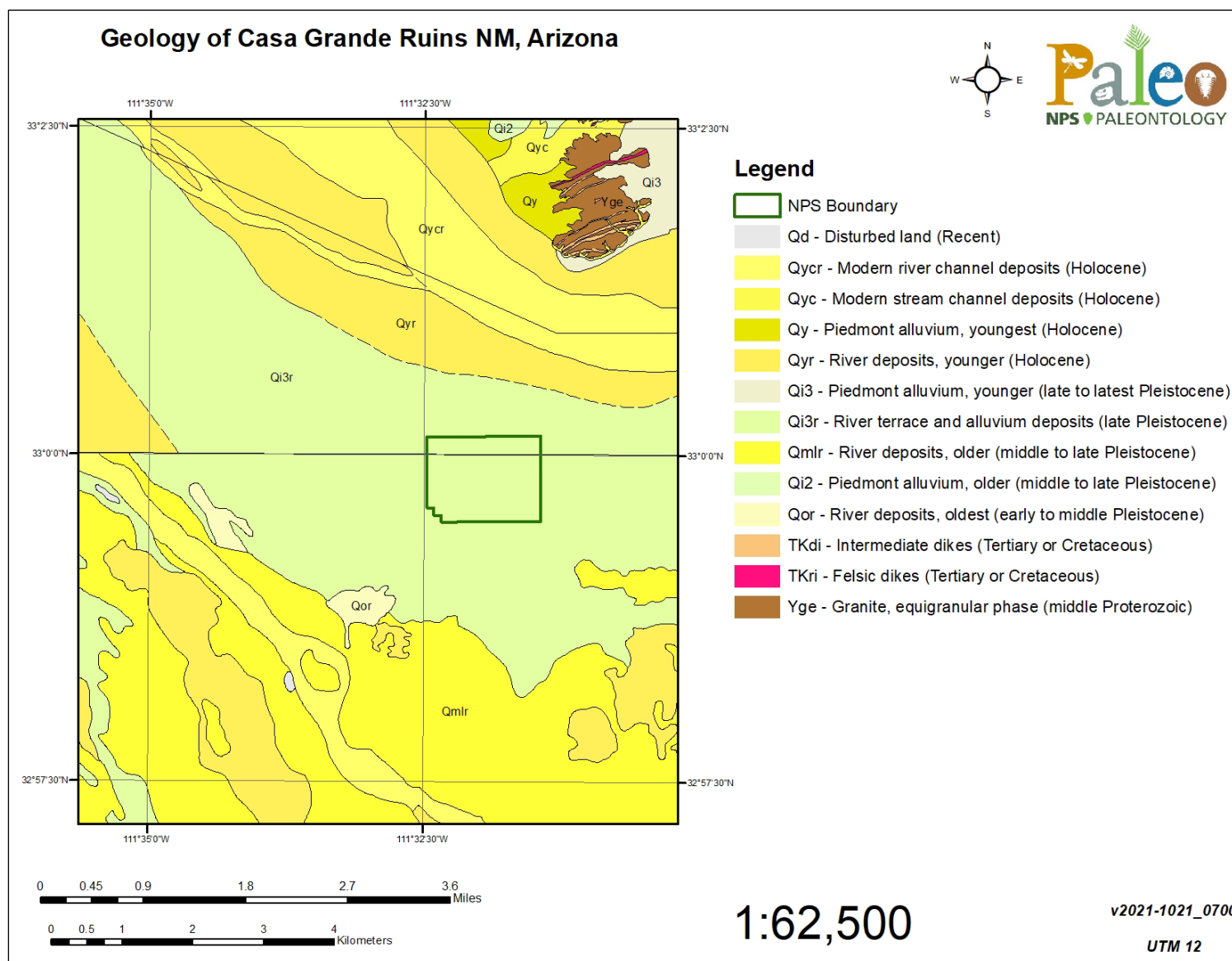


Figure 6. Geologic map of CAGR, Arizona. Data modified from CAGR GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1045749>.

Chiricahua National Monument (CHIR)

Park Establishment

Chiricahua National Monument (CHIR) is located in the Chiricahua Mountains about 153 km (95 mi) east of Tucson and 72 km (45 mi) north of the U.S.–Mexico border in Cochise County, Arizona (Figure 7). Proclaimed on April 18, 1924, CHIR encompasses approximately 4,866 hectares (12,025 acres) and preserves distinctive and abundant rhyolite rock formations known as “The Pinnacles”, which form a rugged mountain and canyon landscape. The monument’s pinnacles, columns, spires, and balanced rocks were originally deposited during the Oligocene Epoch (~27 Ma) by one of the largest known volcanic eruptions in the American Southwest. The monument also contains Faraway Ranch, a restored cattle ranch and guest house (National Park Service 2016a). Chiricahua National Monument preserves cultural resources spanning thousands of years, recording a diverse human history that includes prehistoric native peoples, Chiricahua Apaches, Buffalo Soldiers, European American pioneers and ranchers, and the Civilian Conservation Corps (National Park Service 2016b).

Geologic Summary

The bedrock geology of CHIR is dominated by the Oligocene Rhyolite Canyon Tuff, which forms the distinctive rhyolite features known as “The Pinnacles” and reveals the violent volcanic history of the region (Figure 8). The monument preserves remnants of the 19 km (12 mi) diameter Turkey Creek caldera that formed approximately 26.9 Ma (Oligocene). The formation of the caldera produced a volume of volcanic material 1,000 times larger than the 1980 eruption of Mount St. Helens and 5–10 times the volume produced by the explosion of Krakatoa in 1883 (Graham 2009). Numerous units of Oligocene age represent lava flows, pyroclastic flows, and intrusive dikes associated with the Turkey Creek caldera and include the Jesse James Canyon Tuff, Faraway Ranch Formation, welded tuff of Joe Glen Ranch, and dacite of Sugarloaf Mountain. The oldest mapped units in CHIR are in the northeastern portion of the monument and include Permian strata of the Naco Group (Horquilla Formation, Earp Formation, Epitaph Dolomite, Colina Limestone, Scherrer Formation, and Concha Limestone). Mesozoic rock units are also located in northeastern CHIR and consist of the Glance Conglomerate, Morita Formation, and unnamed volcanoclastic and volcanic rocks. Younger surficial units mapped in CHIR include Quaternary colluvium, alluvium, and alluvial fan deposits.

Stratotypes

CHIR contains three identified stratotypes that represent the Oligocene Faraway Ranch Formation, Jesse James Canyon Tuff, and Rhyolite Canyon Tuff (Table 2; Figure 9). In addition to the designated stratotypes located within CHIR, there are six identified stratotypes located within 48 km (30 mi) of CHIR boundaries that are provided in Appendix C for reference in case of future boundary expansion.

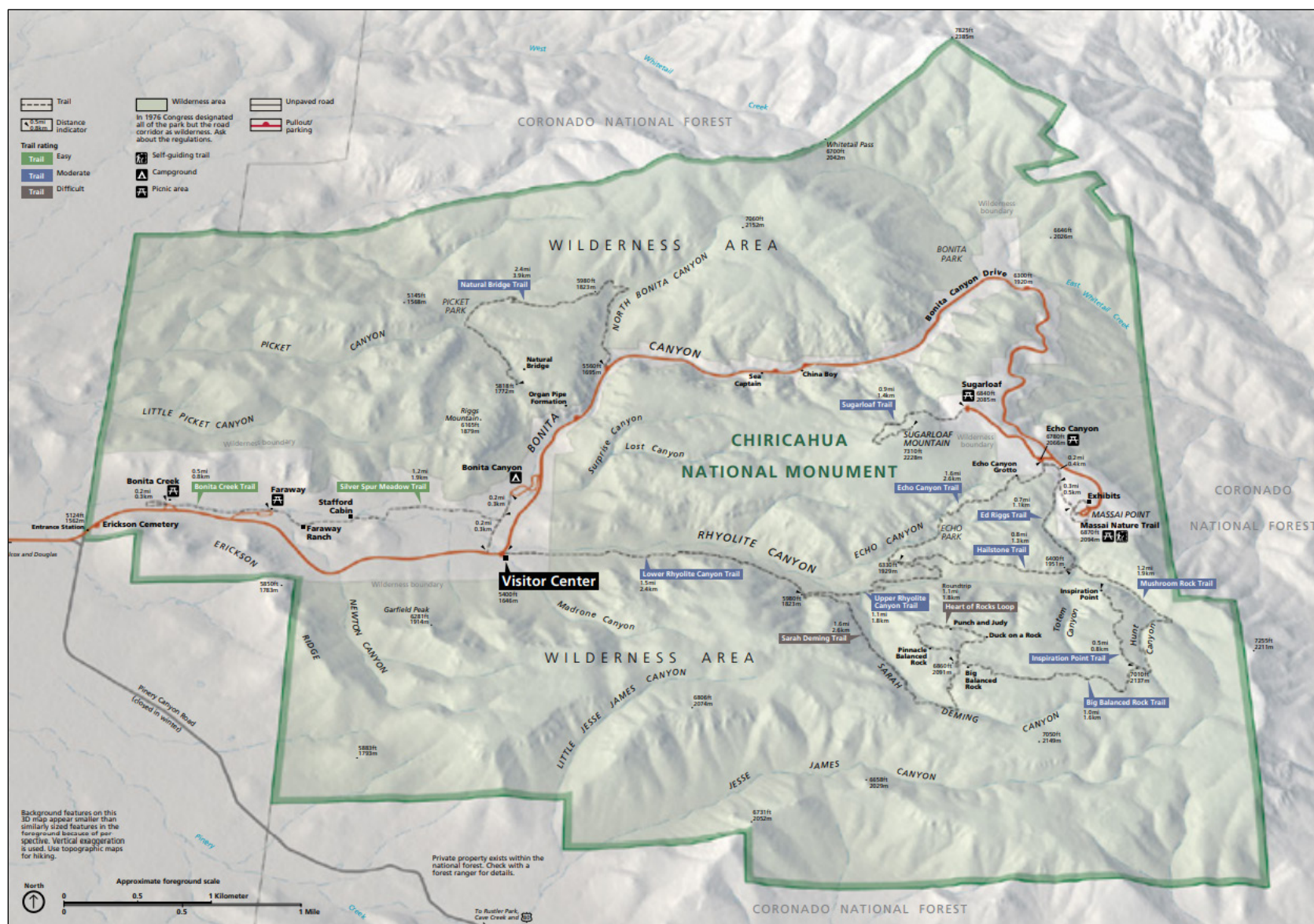


Figure 7. Park map of CHIR, Arizona (NPS).

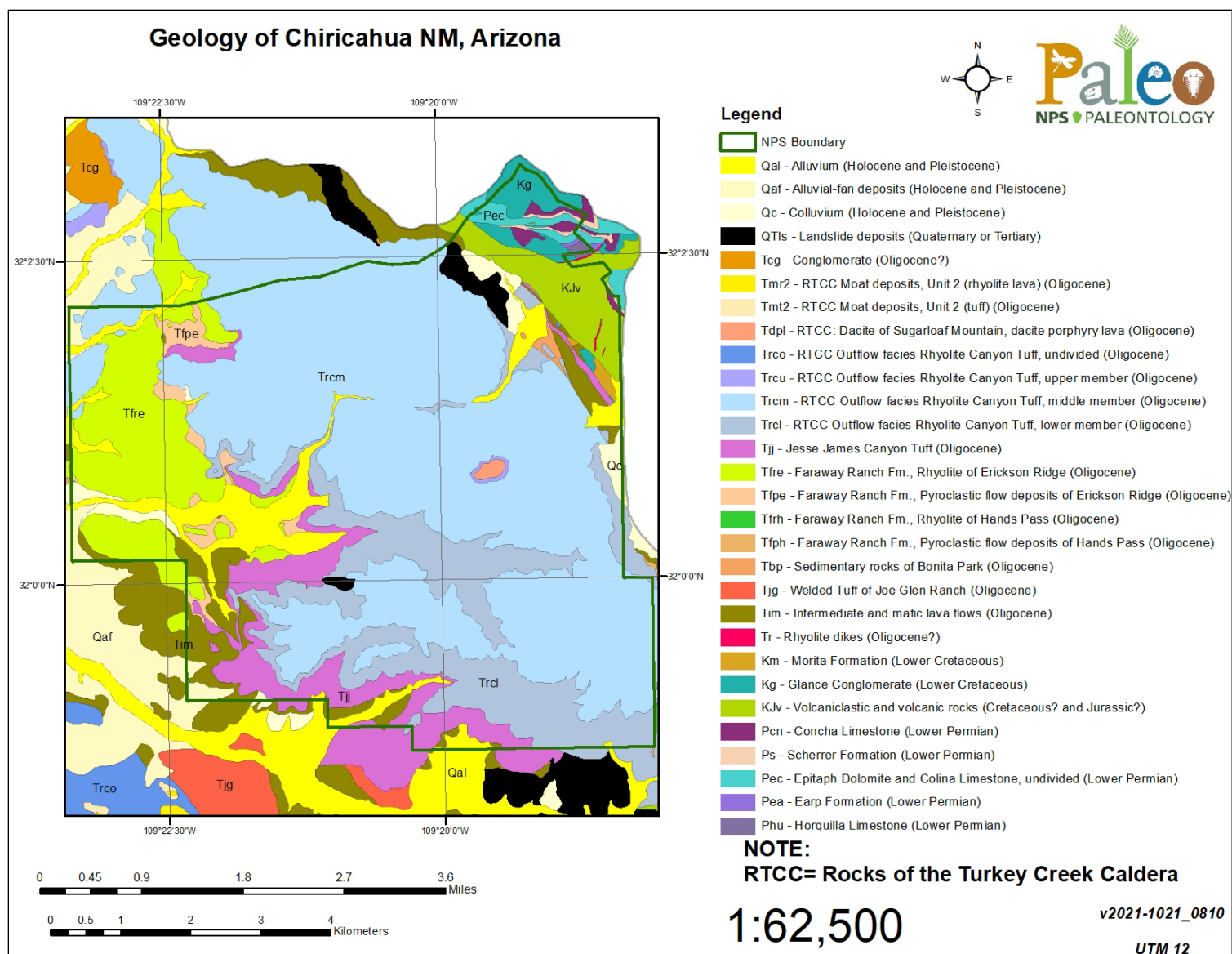


Figure 8. Geologic map of CHIR, Arizona. Data modified from CHIR GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1047295>.

Table 2. List of CHIR stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Rhyolite Canyon Tuff (Trco, Trcu, Trcm, Trcv, Trcl, Trca)	Pallister et al. 1994	Type area: Chiricahua National Monument, in Cochise County, Arizona. Representative sections in this area are located between Rhyolite Canyon and Sugarloaf Mountain, and at Riggs Mountain. Type area is near approximate latitude 32°0'20" N., longitude 109°19'60" W.	Oligocene
Jesse James Canyon Tuff (Tjj, Tjjf)	Pallister et al. 1994	Type area: vicinity of Jesse James Canyon, Chiricahua National Monument and Coronado National Forest, near northern edge of Rustler Park 7.5' Quadrangle, in Cochise County, Arizona. Type area is near approximate latitude 31°59'6" N., longitude 109°20'59" W.	Oligocene
Faraway Ranch Formation (Tfre, Tfpe, Tfrh, Tfph)	Enlows 1955; Pallister et al. 1994	Type area: near Faraway Ranch in SE/4 SE/4 SE/4 section 27, T. 16 S., R. 29 E., Cochise Head 7.5' Quadrangle, in Cochise County, Arizona. Type area is near approximate latitude 32°00'30" N., longitude 109°22'27" W.	Oligocene

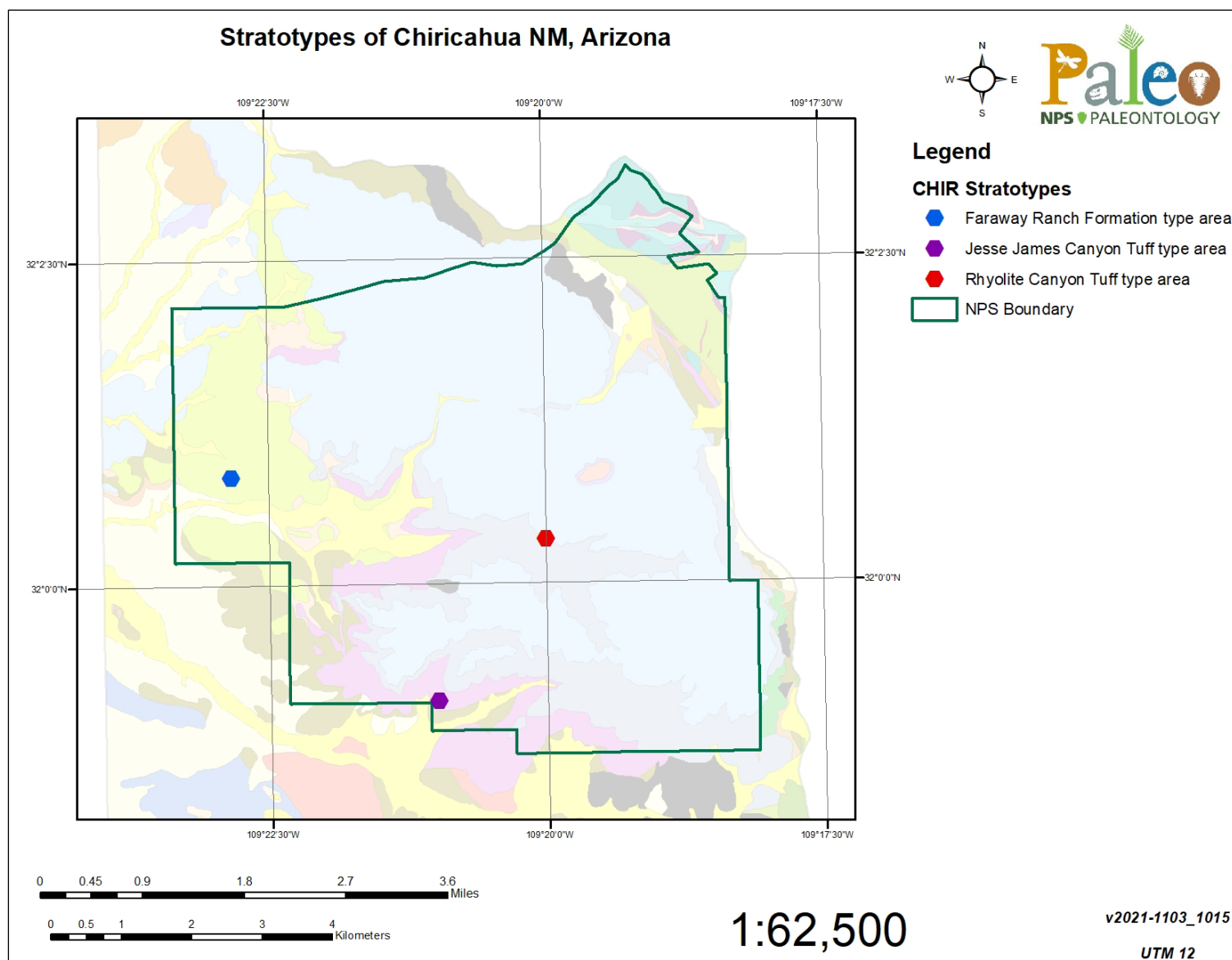


Figure 9. Modified geologic map of CHIR showing stratotype locations. The transparency of the geologic units layer has been increased.

Faraway Ranch Formation

The Oligocene Faraway Ranch Formation was originally referred to as the “Faraway Ranch series” by Enlows (1951) to describe a heterogeneous sequence of volcanic rocks in CHIR. The unit is named after its type area exposures near Faraway Ranch on lower Bonita Canyon in SE/4 SE/4 SE/4 section 27, T. 16 S., R. 29 E. (approximate latitude 32°00'30" N., longitude 109°22'27" W.) in Cochise County, Arizona (Table 2; Figures 9 and 10; Pallister et al. 1994 citing Enlows 1955). Type area exposures are approximately 244 m (800 ft) thick and consist of (in ascending order): grayish-red to brown pahoe-hoe biotite dacite flows; very coarse basalt breccia; coarse, crudely bedded lapilli tuff; and soft gray to pink rhyolite tuff (Enlows 1951, 1955). In the type area, the Faraway Ranch Formation underlies the Jesse James Canyon Tuff and overlies sedimentary rocks of Bonita Park (“Bonita Park formation” of Enlows 1955).



Figure 10. View looking north at the main house of Faraway Ranch in CHIR (NPS). The type area of the Oligocene Faraway Ranch Formation comprises the mountains in the background and in the lower Bonita Canyon area.

Jesse James Canyon Tuff

The Oligocene Jesse James Canyon Tuff was informally designated as “Member 2 of the Rhyolite Canyon Formation” by Enlows (1955), revised to the “Jesse James Canyon member of the Rhyolite Canyon Formation” by Latta (1983), and formally designated by Pallister et al. (1994). The tuff is named after its type area exposures in the vicinity of Jesse James Canyon near the northern edge of Rustler Park 7.5' Quadrangle (approximate latitude 31°59'6" N., longitude 109°20'59" W.) in Cochise County, Arizona (Table 2; Figure 9; Pallister et al. 1994). Type area exposures reach a

maximum thickness of approximately 73 m (240 ft) and consist of light gray to pinkish-gray, typically lithic poor, moderately crystal rich, biotite-bearing quartz-sanidine rhyolite ash-flow tuff (Pallister et al. 1994). The Jesse James Canyon Tuff overlies the Faraway Ranch Formation and disconformably underlies the Rhyolite Canyon Tuff.

Rhyolite Canyon Tuff

The Oligocene Rhyolite Canyon Tuff was first described by Enlows (1951, 1955) and named after exposures in Rhyolite Canyon of CHIR. Pallister et al. (1994) designated the type area of the formation in CHIR, stating that representative sections are located between Rhyolite Canyon and Sugarloaf Mountain, as well as at Riggs Mountain (Table 2; Figures 9, 11, and 12). In the type area (approximate latitude 32°0'20" N., longitude 109°19'60" W.) the formation comprises an approximately 427 m (1,400 ft) thick sequence of strata consisting of (in ascending order): 1) dark red welded rhyolite tuff with many prominent inclusions; 2) light gray to pinkish-gray tuff containing seams of strongly welded, grayish-red rhyolite and a bed of accretionary lapilli; 3) dark, glassy welded rhyolite tuff; 4) thick sequence of poor to strongly welded, light gray rhyolite tuff that exhibits vertical jointing; 5) light gray rhyolite tuff; and 6) light gray welded rhyolite tuff that forms coherent cliffs (Enlows 1955; Pallister et al. 1994). The Rhyolite Canyon Tuff disconformably overlies the Jesse James Canyon Tuff and underlies the dacite of Sugarloaf Mountain.



Figure 11. Type area exposures of the Rhyolite Canyon Tuff that form the distinctive rhyolite pinnacles of CHIR. Sugarloaf Mountain is seen in the center background (NPS/R. STEWART).



Figure 12. View looking west from Massai Point across the rhyolite pinnacles of the Rhyolite Canyon Tuff (NPS/KATY HOOPER).

Coronado National Memorial (CORO)

Park Establishment

Coronado National Memorial (CORO) is situated along the U.S.–Mexico border in Cochise County, southeastern Arizona (Figure 13). Originally authorized by Congress as an international memorial on August 18, 1941, the park unit was redesignated on July 9, 1952. The national memorial includes approximately 1,954 hectares (4,830 acres) and commemorates the first major European exploration of the American Southwest by Francisco Vázquez de Coronado in 1540–1542 and affirms the ties that bind the United States to Mexico and Spain (National Park Service 2016a). The Coronado Expedition brought to the region profound and lasting changes in areas such as language, technology, religion, livestock, agriculture, and food. CORO offers panoramic views of the U.S.–Mexico border and the San Pedro River Valley, the route believed to have been taken by the Coronado Expedition in their search for the “Seven Cities of Gold” (National Park Service 2016c).

Geologic Summary

The landscape of CORO is underlain by a complex assemblage of igneous and sedimentary rocks spanning the last 300 million years. The geology of the memorial reflects cataclysmic volcanic eruptions that occurred during the Jurassic (~201–143 Ma) and formed several calderas including the Montezuma caldera (Graham 2011a). Jurassic tuffs and associated granitic intrusions (Huachuca Granite) dominate the rugged topography in northern CORO, while the southwestern portion of the memorial contains a chaotic group of rock units that includes volcanic tuff, lava flows, limestone, sandstone, and shale (mudstone) overlain by the Jurassic Glance Conglomerate (Figures 14 and 15). The oldest bedrock mapped within CORO is in the middle of the memorial and consists of Permian strata of the Naco Group. Young surficial deposits are predominantly located in southeastern CORO and include Pleistocene–Holocene terrace gravels, alluvium, colluvium, and debris flow deposits.

Stratotypes

CORO contains one identified stratotype that represents the Jurassic Huachuca Granite (Table 3; Figure 16). In addition to the designated stratotype located within CORO, there are 21 identified stratotypes located within 48 km (30 mi) of CORO boundaries that are provided in Appendix C for reference in case of future boundary expansion.

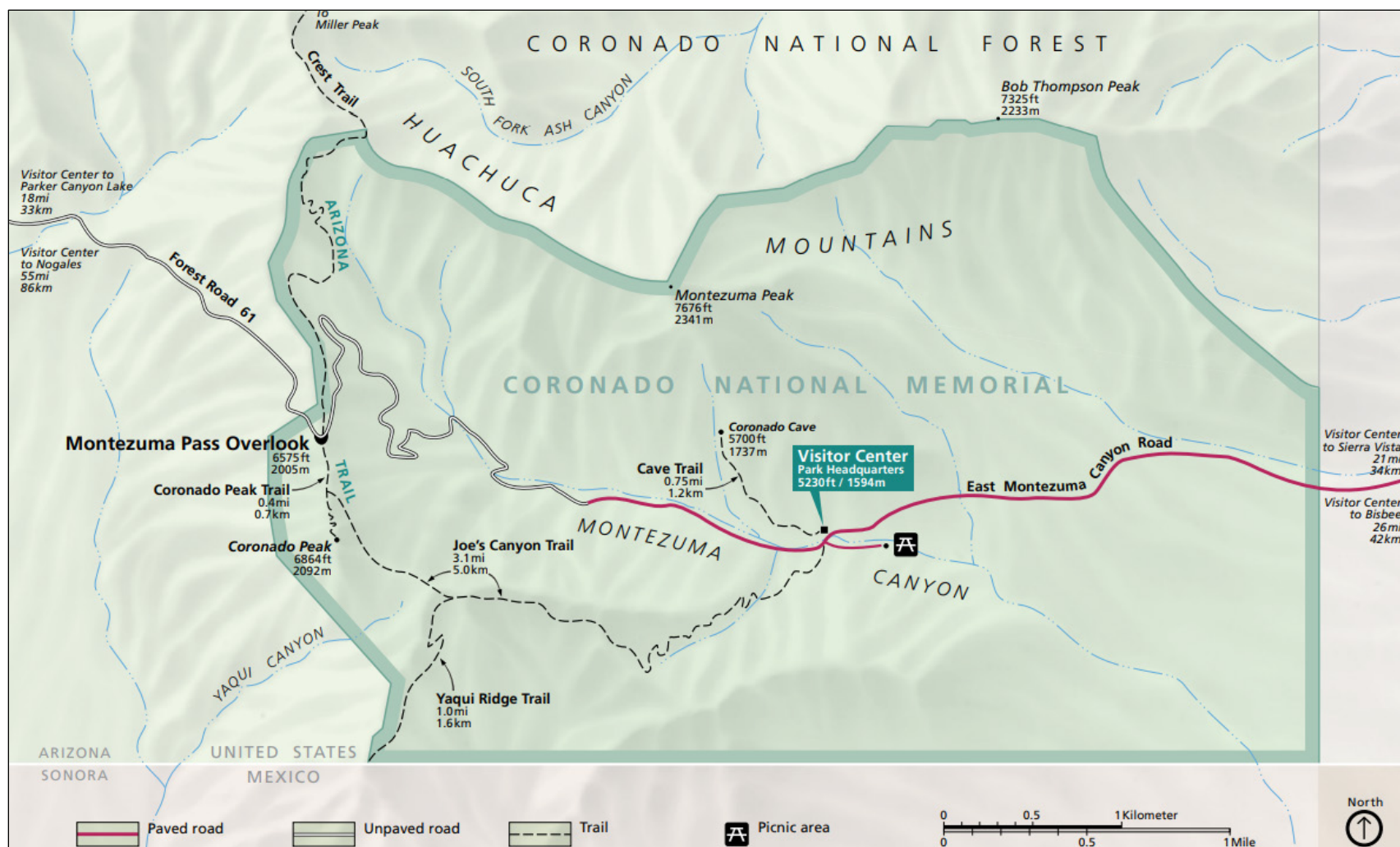


Figure 13. Park map of CORO, Arizona (NPS).

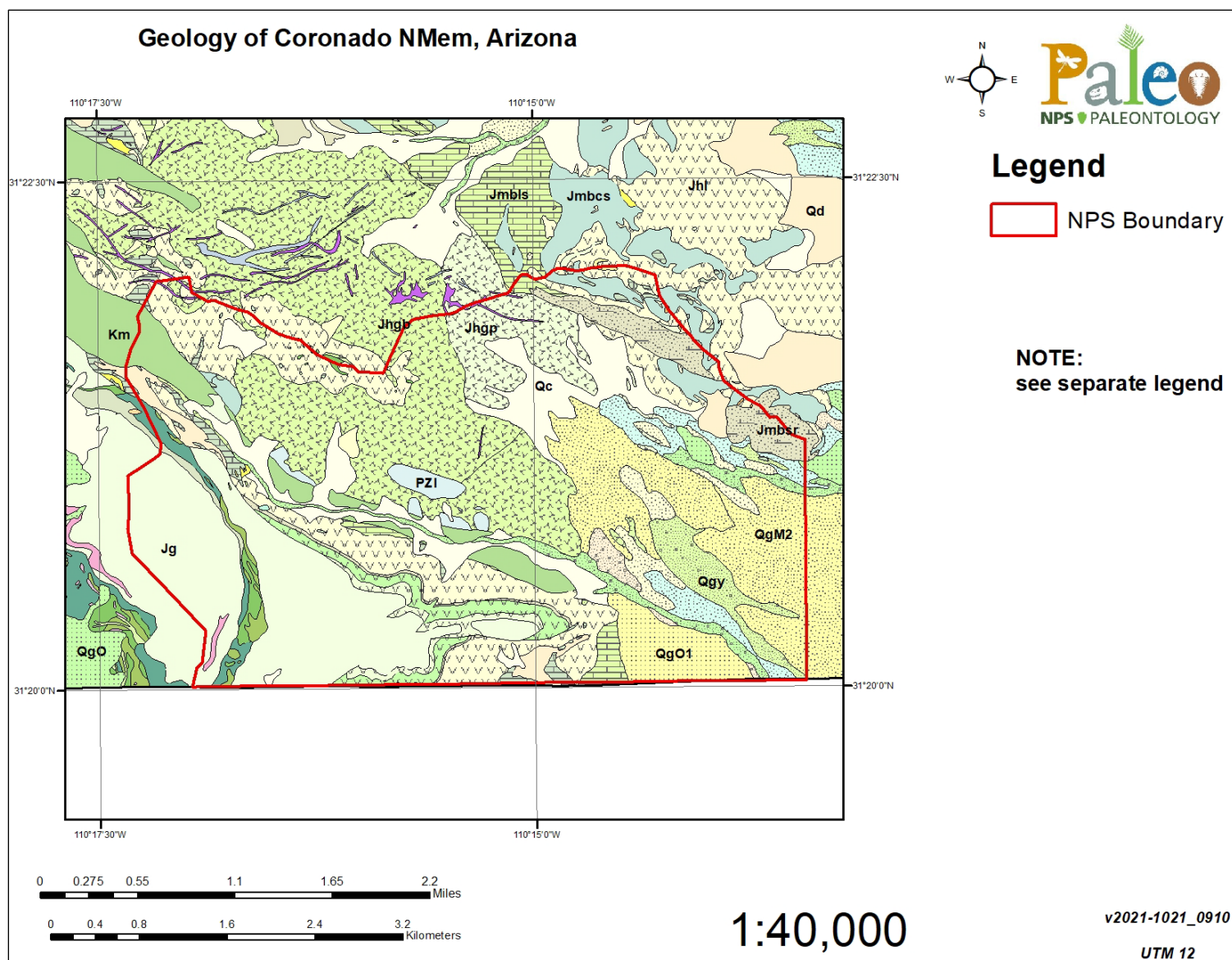


Figure 14. Geologic map of CORO, Arizona; see Figure 15 for legend. Data modified from CORO GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2166545>.

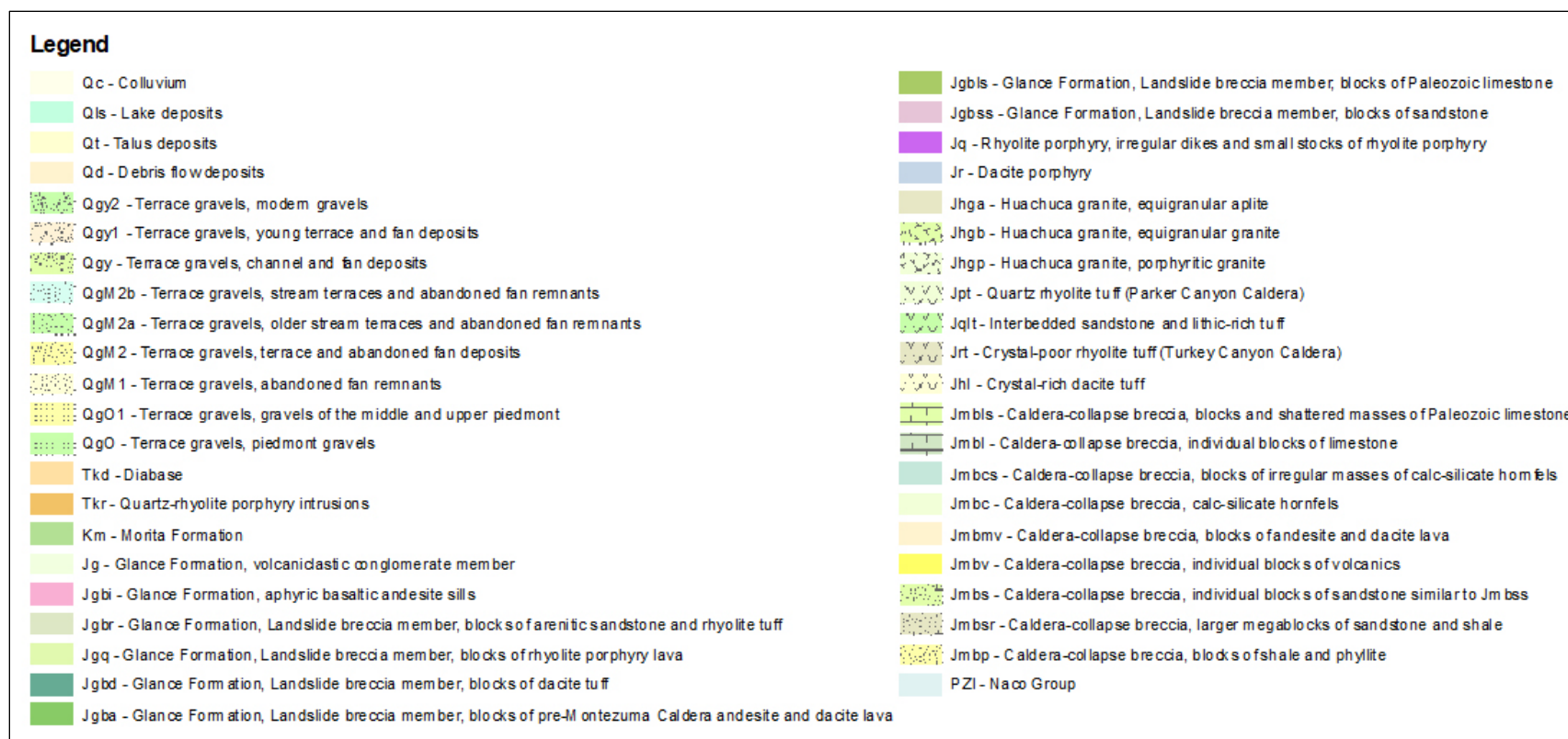


Figure 15. Geologic map legend of CORO, Arizona.

Table 3. List of CORO stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Huachuca Granite (Jhb, Jhga, Jhgf, Jhgb, Jhgp, Jhgh, Jhu)	Hayes 1967	Type area: extensive exposures in southern part of Huachuca Mountains, in Cochise County, Arizona. Type area is near approximate latitude 31°21'15" N., longitude 110°15'51" W.	Jurassic

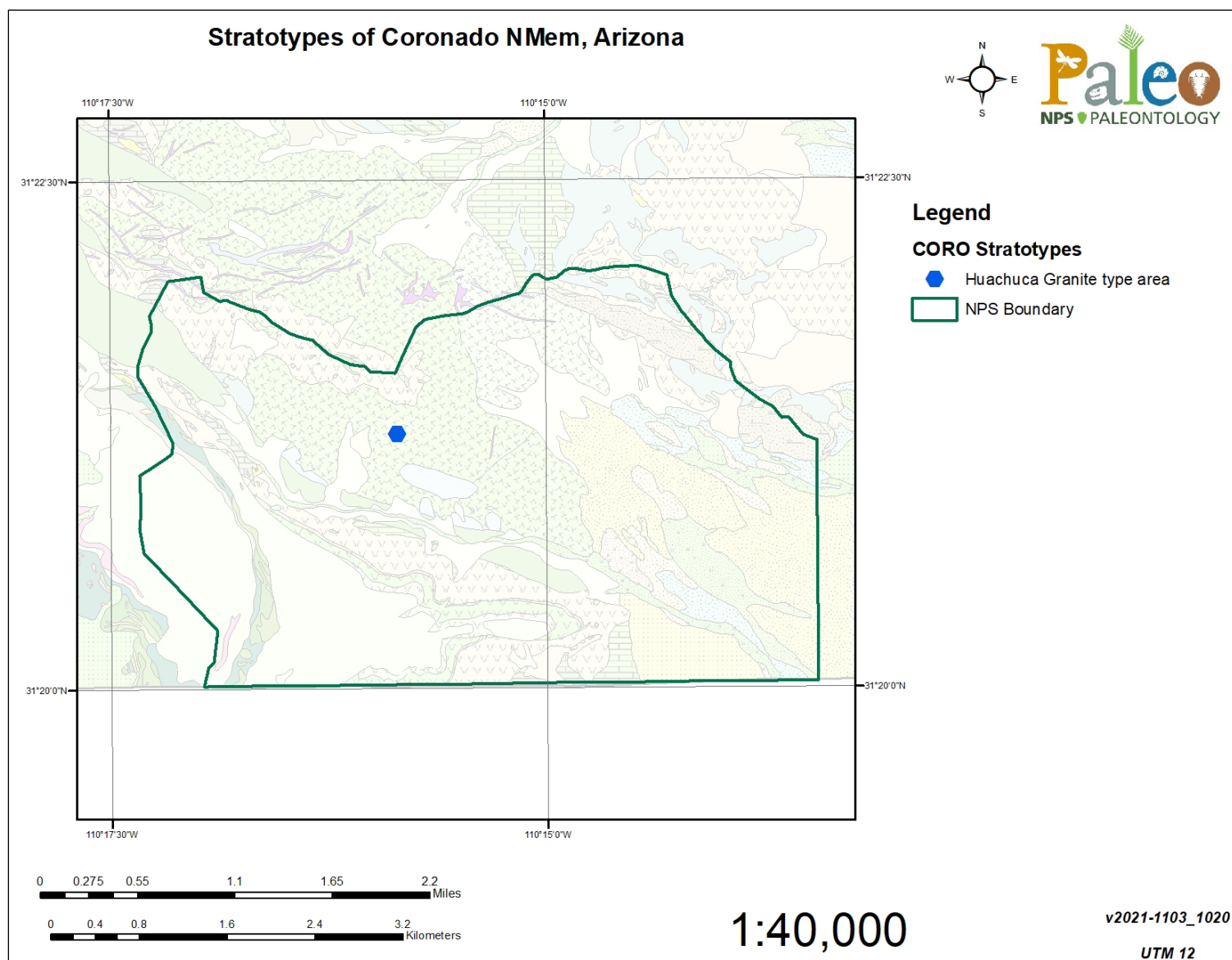


Figure 16. Modified geologic map of CORO showing stratotype locations. The transparency of the geologic units layer has been increased.

Huachuca Granite

The Jurassic Huachuca Granite was proposed by Hayes (1967) and named after its type area exposures in the southern part of the Huachuca Mountains in Cochise County, Arizona (Table 3; Figures 16 and 17; approximate latitude 31°21'15" N., longitude 110°15'51" W.). In the type area south of Montezuma Peak the formation has an estimated thickness of about 533 m (1,750 ft) (Hayes and Raup 1968). Most of the formation is comprised of medium- to coarse-grained granite with roughly equal proportions of pink orthoclase, white plagioclase, and gray quartz with biotite and hornblende usually present as varietal minerals (Hayes 1967). Many of the bounding contacts of the Huachuca are fault contacts, but the unit is overlain by the Glance Conglomerate and intrudes Permian limestones of the Naco Group as well as one or more informal units of early Mesozoic age (Hayes 1967).



Figure 17. View looking north towards Montezuma Peak, predominantly composed of the type area exposures of the Jurassic Huachuca Granite (NPS).

Fort Bowie National Historic Site (FOBO)

Park Establishment

Fort Bowie National Historic Site (FOBO) is located 19 km (12 mi) south of Bowie and 187 km (116 mi) east of Tucson in Cochise County, Arizona (Figure 18). Established on July 29, 1972, FOBO encompasses about 404 hectares (999 acres) and preserves the history, landscape, and remaining structures of Fort Bowie that are key to understanding the history of Apache Pass and the U.S. military campaign against the Chiricahua Apache from 1862 to 1886 (National Park Service 2016a). For roughly 25 years Fort Bowie was a critical army outpost that guarded the strategic Apache Pass, an important transportation corridor between the Chiricahua and Dos Cabezas ranges. Contained within the historic site are the ruins of two forts; a cemetery containing native and non-native burials; the sites of several key historical events, including the Bascom Affair, Battle of Apache Pass, and the Wagon Train Massacre; and remains of an Indian Agency building. FOBO also preserves remnants of the 1858 Butterfield Stage Station and some of the best remaining traces of the Butterfield Overland Mail Route, which provided the first reliable mail service to California from 1858 until 1861 (National Park Service 2016d).

Geologic Summary

The bedrock geology of FOBO is dominated by rounded domes of relatively erosion-resistant granodiorite that solidified during the Neoproterozoic approximately 1.4 billion years ago (Figure 19). The majority of the sedimentary and metamorphic rocks mapped within FOBO pertain to Pennsylvanian–Permian and Cretaceous formations of the Naco Group (Horquilla Limestone, Earp Formation, Colina Limestone, Scherrer Formation) and Bisbee Group (Cintura Formation, Glance Conglomerate, Mural Limestone). Some of the oldest sedimentary rocks in FOBO underlie the historic site entry road and consist of the Cambrian Coronado Sandstone, Ordovician El Paso Formation, Devonian Portal Formation, and Mississippian Escabrosa Limestone. The dominant structural feature in FOBO is the 1–2 km (0.6–1.2 mi)-wide Apache Pass fault zone that cuts diagonally across the eastern portion of the historic site and contains fault segments separated by normal, strike-slip, and reverse (thrust) faults (Graham 2011b). Rock units along the Apache Pass fault zone form a belt of fractured strata ranging from the Cambrian Period to the Cretaceous Period (~500–66 Ma).

Stratotypes

There are no designated stratotypes identified within the boundaries of FOBO. There are nine identified stratotypes located within 48 km (30 mi) of FOBO boundaries that are provided in Appendix C for reference in case of future boundary expansion.

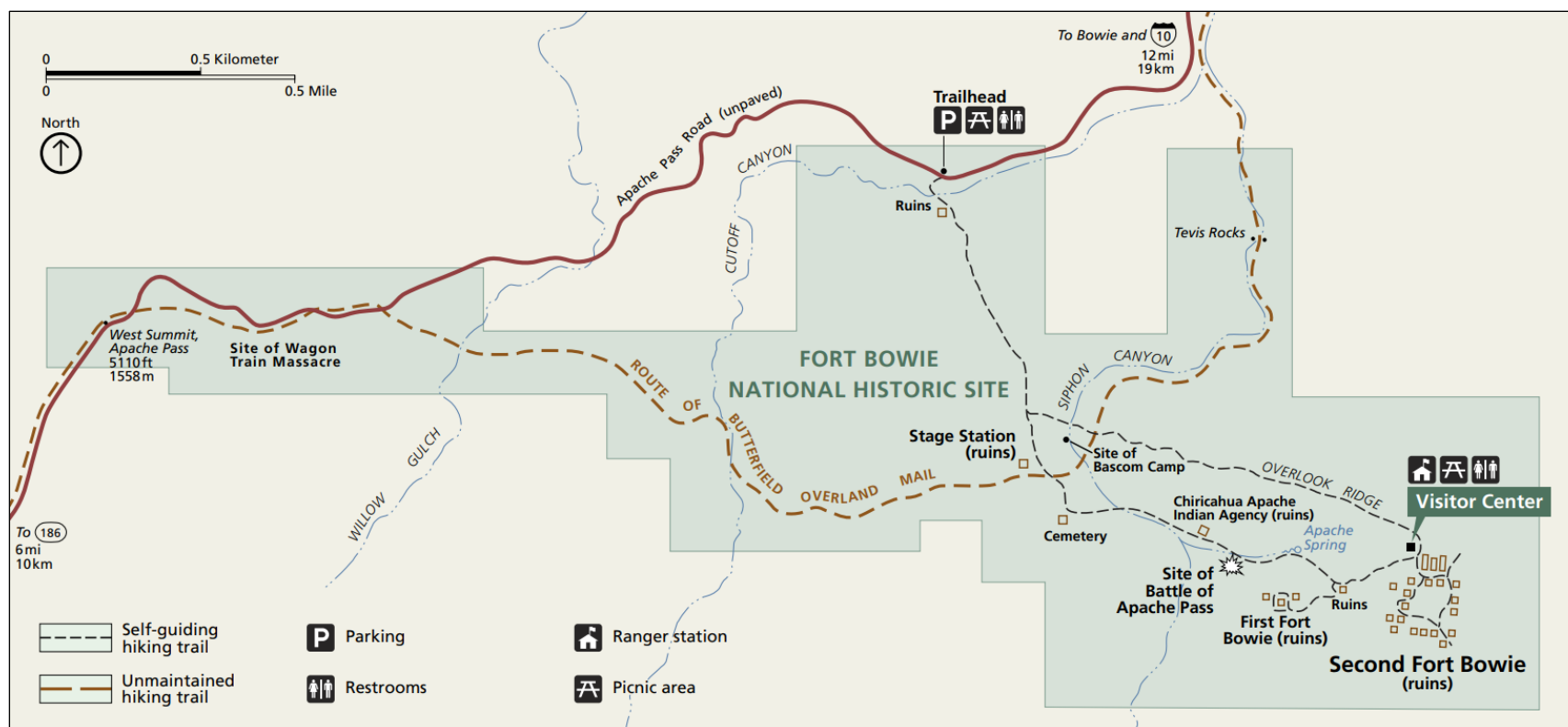
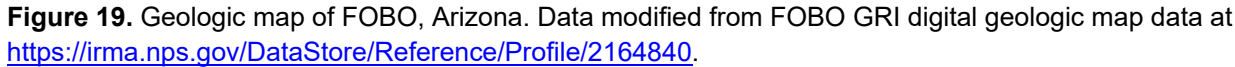


Figure 18. Park map of FOBO, Arizona (NPS).



Gila Cliff Dwellings National Monument (GICL)

Park Establishment

Gila Cliff Dwellings National Monument (GICL) is located about 50 km (31 mi) north of Silver City within Gila National Forest in the heart of the Gila Wilderness in Catron County, southwestern New Mexico (Figure 20). Proclaimed on November 16, 1907, GICL encompasses approximately 215 hectares (533 acres) and protects the remains of a well-preserved group of cliff dwellings representative of the major Southwestern culture known as the Mogollon (National Park Service 2016a). A 1.6 km (1 mi)-loop trail brings visitors through Cliff Dweller Canyon and into several natural caves containing about 40 rooms built more than 700 years ago. The monument consists of two separate units: 1) a larger main unit that includes the cliff dwellings; and 2) the smaller TJ unit that preserves one of the last unexcavated Mogollon pueblos of its size, offering outstanding research potential. The combination of springs, rivers, narrow canyons, caves, and the biodiversity in and around GICL helped sustain human cultures for thousands of years. Cultural resources in GICL comprise a collection of archeological sites that include Archaic rock shelters, Early and Late Pithouse and Classic Mimbres Pueblo period structures, cliff dwellings, Salado building foundations, and several small Apache sites that represent at least 2,000 years of human habitation of the Gila River headwaters area (National Park Service 2016e).

Geologic Summary

GICL is situated within the Mogollon-Datil volcanic field, one of Earth's great volcanic provinces. It extends from northern Mexico to Colorado and represents an extended period of volcanism from the Eocene (~40 Ma) to the Miocene (~5 Ma) (KellerLynn 2014). The Mogollon-Datil volcanic field produced numerous supervolcanoes throughout its active 35-million-year history, including volcanism that formed the Gila Cliff Dwelling caldera that contains GICL. The bedrock geology of GICL is dominated by the Oligocene–Miocene Gila Conglomerate, a volcanoclastic sedimentary unit derived from the weathered igneous rocks that comprise the surrounding highlands (Figure 21). Stream erosion and groundwater sapping slowly produced voids and caves in the Gila Conglomerate over millions of years; later, people built the namesake cliff dwellings in these caves. Some of the oldest rocks underlying GICL include the Oligocene Bloodgood Canyon Tuff and Oligocene–Miocene Bearwallow Mountain Andesite, both mapped in the main park unit along the West Fork of the Gila River. Younger surficial units mapped within GICL include Quaternary alluvial terrace deposits and Holocene alluvium.

Stratotypes

GICL contains one identified stratotype that represents the Oligocene–Miocene Gila Conglomerate (Table 4; Figure 22). In addition to the designated stratotype located within GICL, there are five identified stratotypes located within 48 km (30 mi) of GICL boundaries that are provided in Appendix C for reference in case of future boundary expansion.

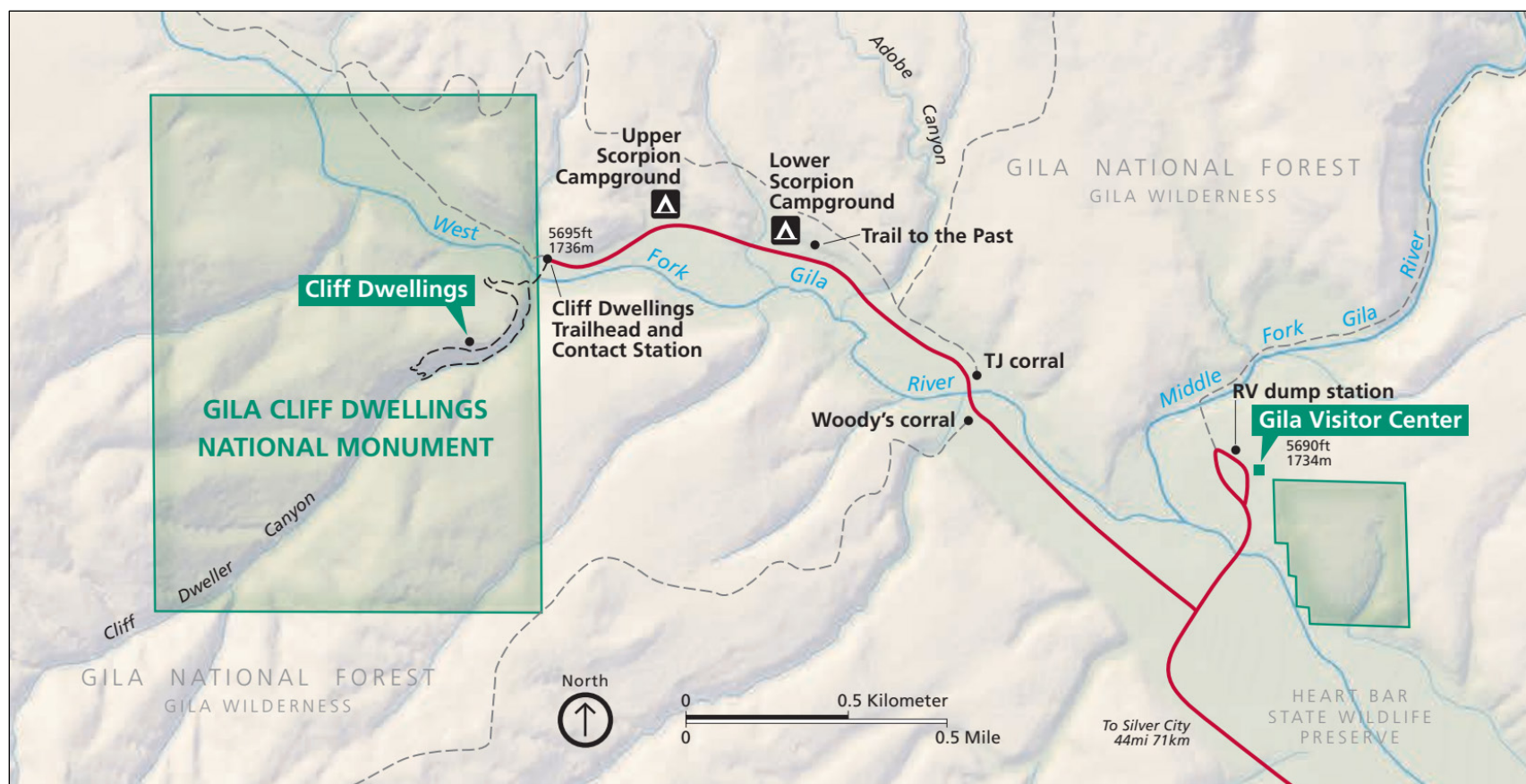


Figure 20. Park map of GICL, New Mexico (NPS).

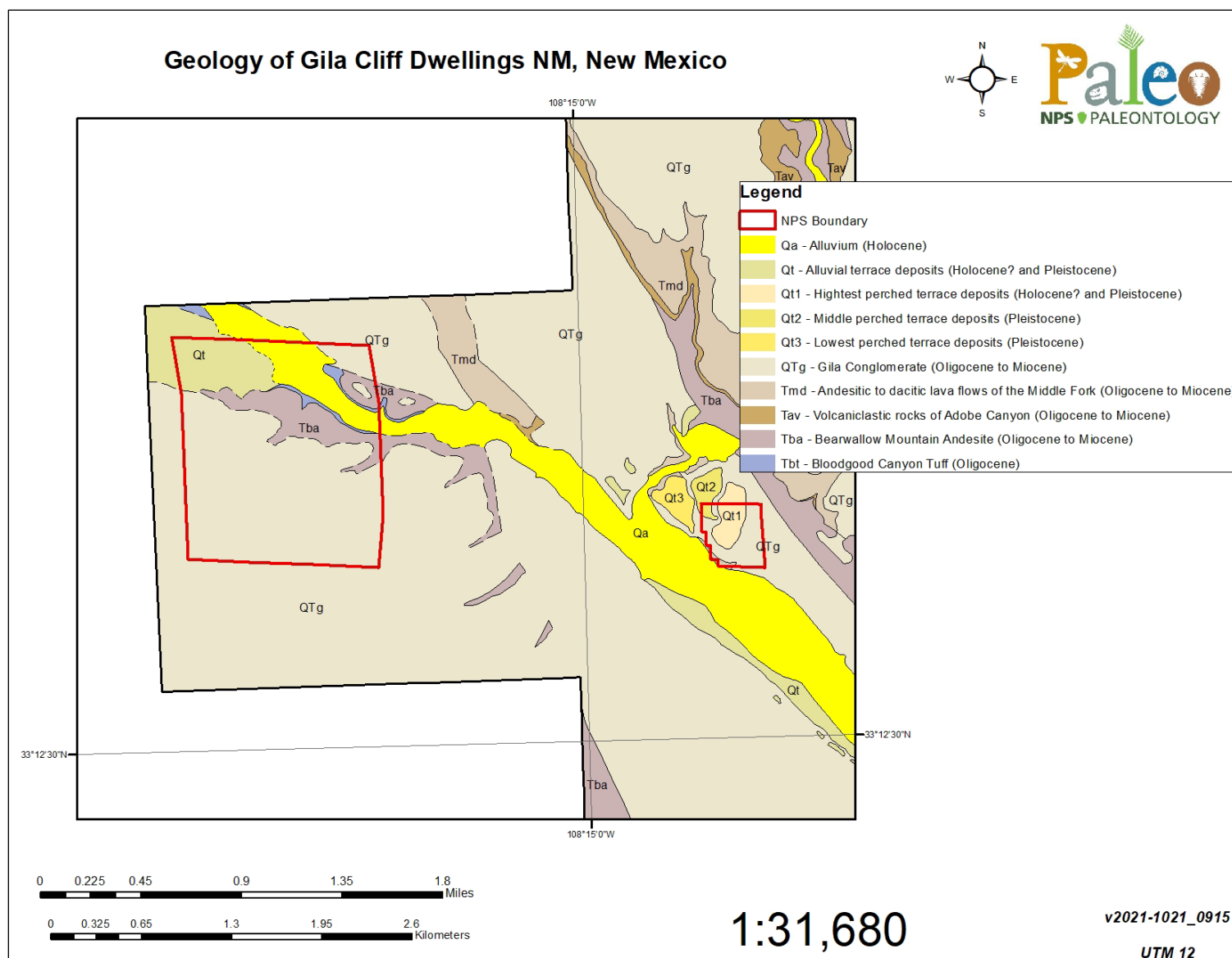


Figure 21. Geologic map of GICL, New Mexico. Data modified from GICL GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2214694>.

Table 4. List of GICL stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Gila Conglomerate (QTg, QTgps)	Gilbert 1875; Pye 1959	Type area: southeastern Arizona and southwestern New Mexico, in four separate valleys along Gila River east of Safford, Arizona. Type area is near approximate latitude 33°13'19" N., longitude 108°16'19" W.	Oligocene– Miocene

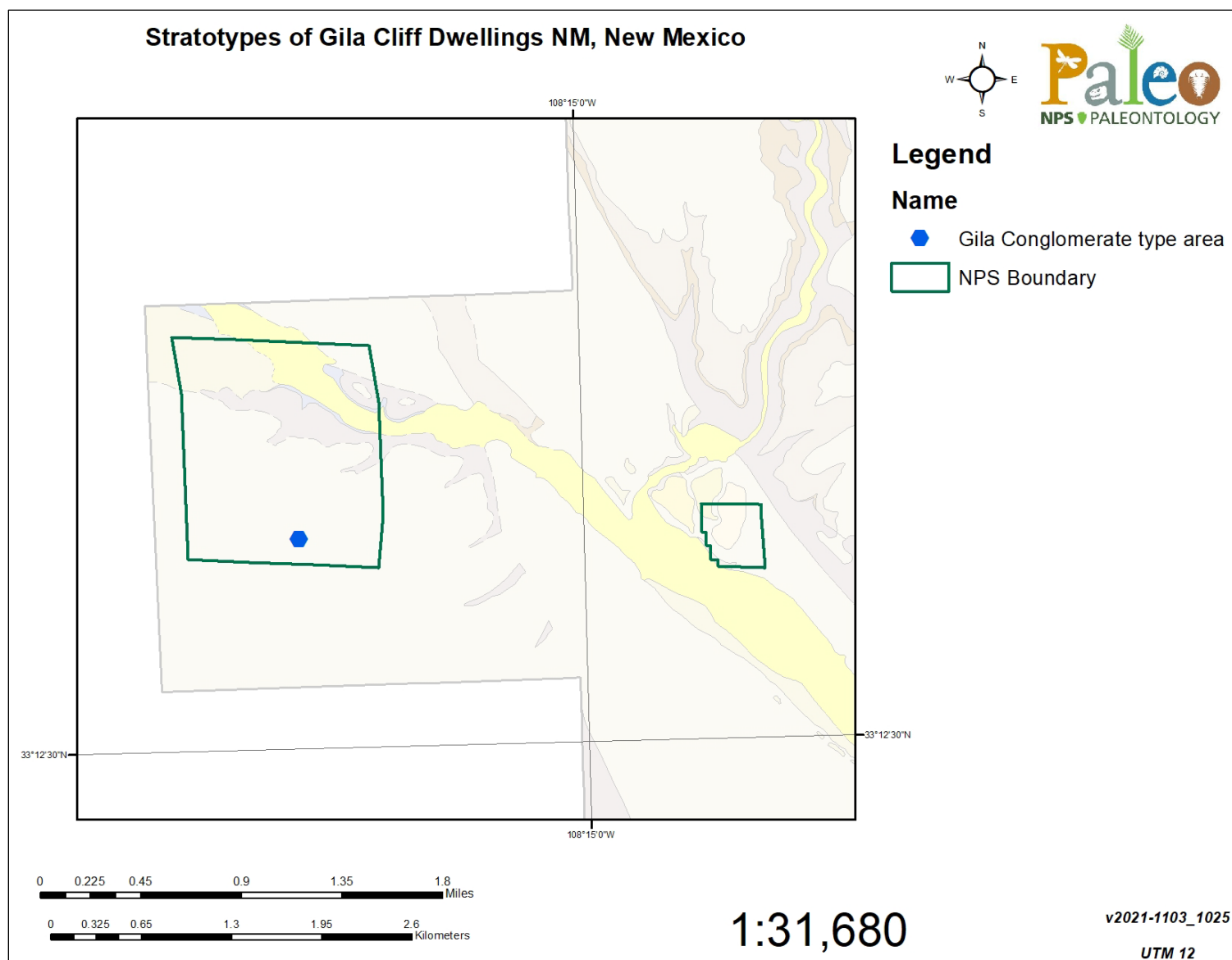


Figure 22. Modified geologic map of GICL showing stratotype locations. The transparency of the geologic units layer has been increased.

Gila Conglomerate

The Oligocene–Miocene Gila Conglomerate was named by Gilbert (1875) to describe a thick sequence of volcanoclastic sedimentary rock exposures in Arizona and southwestern New Mexico. The type area of the formation is designated as the gorges of Gila River and its tributaries in southeastern Arizona and southwestern New Mexico, in four separate valleys east of Safford, Arizona near approximate latitude 33°13'19" N., longitude 108°16'19" W. (Table 4; Figures 22–24; Pye 1959 citing Gilbert 1875). In the type area the formation has a thickness of approximately 335–366 m (1,100–1,200 ft) and consists of volcanoclastic fanglomerate, cross-bedded pumiceous sandstone, and river gravel (Gilbert 1875; Ratté et al. 2014). The Gila Conglomerate overlies the Bearwallow Mountain Andesite and underlies Quaternary alluvial terrace deposits and alluvium.



Figure 23. The Mogollon cliff dwellings in GICL, type area exposures of the Gila Conglomerate. Note the people for scale in the bottom left of the photo (NPS).



Figure 24. Volcaniclastic sedimentary strata of the Gila Conglomerate in the type area of GICL. Exposures are approximately 335–366 m (1,100–1,200 ft) and consists of volcaniclastic fanglomerate, cross-bedded pumiceous sandstone, and river gravel (NPS).

Montezuma Castle National Monument (MOCA)

Park Establishment

Montezuma Castle National Monument (MOCA) is located approximately 30 km (19 mi) south of Sedona in Yavapai County, Arizona (Figure 25). Proclaimed on December 8, 1906, MOCA encompasses about 411 hectares (1,016 acres) and was established to protect the prehistoric and historic features and natural ecosystems including iconic cliff dwellings, an artesian-fed sinkhole, and the desert riparian environment (National Park Service 2016f). The monument is composed of two non-contiguous units: the larger Castle Unit to the south and the Well Unit to the north. The most distinguishing feature of the Castle Unit is the monument namesake Montezuma Castle, a well-preserved Sinaguan cliff dwelling constructed in the 12th and 13th centuries that stands five stories tall and contains 20 rooms. Montezuma Castle is the most visible feature found within a diverse natural landscape in the Verde Valley of Arizona (KellerLynn 2019a). The most distinguishing feature of the Well Unit is Montezuma Well, an artesian-fed limestone sinkhole that hosts invertebrates found nowhere else on Earth (National Park Service 2016a).

Geologic Summary

MOCA is situated in a transition zone between the Basin and Range and Colorado Plateau physiographic provinces. Features of the transition zone include horst and graben topography indicative of the Basin and Range as well as colorful, flat-lying sedimentary strata characteristic of the Colorado Plateau (KellerLynn 2019a). The bedrock underlying MOCA predominantly consists of the Miocene–Pliocene Verde Formation and includes sedimentary lacustrine deposits, travertine (limestone precipitated around mineral springs), and limestone (Figure 26). Montezuma Castle is built into limestone of the Verde Formation, while Montezuma Well formed in the travertine sequences of the formation. The well is a natural flowing spring within an immense limestone sink created by the collapse of an underground cavern. Approximately 5.7 million liters (1.5 million gallons) of water flow through the well every day and drain through a 91 m (300 ft)-long cave where it emerges into the remains of pre-contact irrigation canals and ditches, now thickly coated with travertine (KellerLynn 2019a). Surficial deposits mapped within MOCA include Pleistocene–Holocene terrace gravels and Holocene alluvium.

Stratotypes

There are no designated stratotypes identified within the boundaries of MOCA. There are 11 identified stratotypes located within 48 km (30 mi) of MOCA boundaries that are provided in Appendix C for reference in case of future boundary expansion.

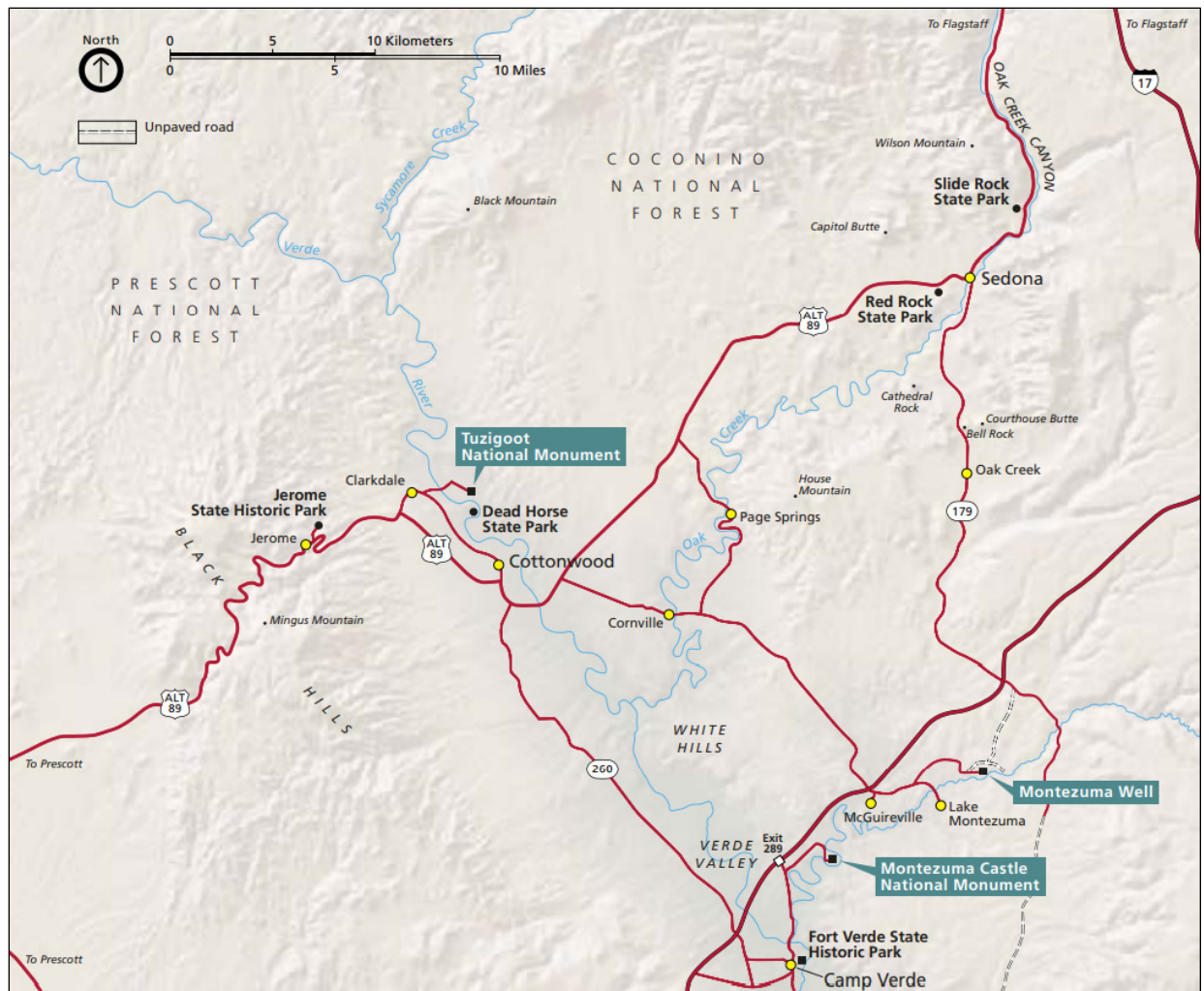


Figure 25. Regional map of MOCA, Arizona (NPS).

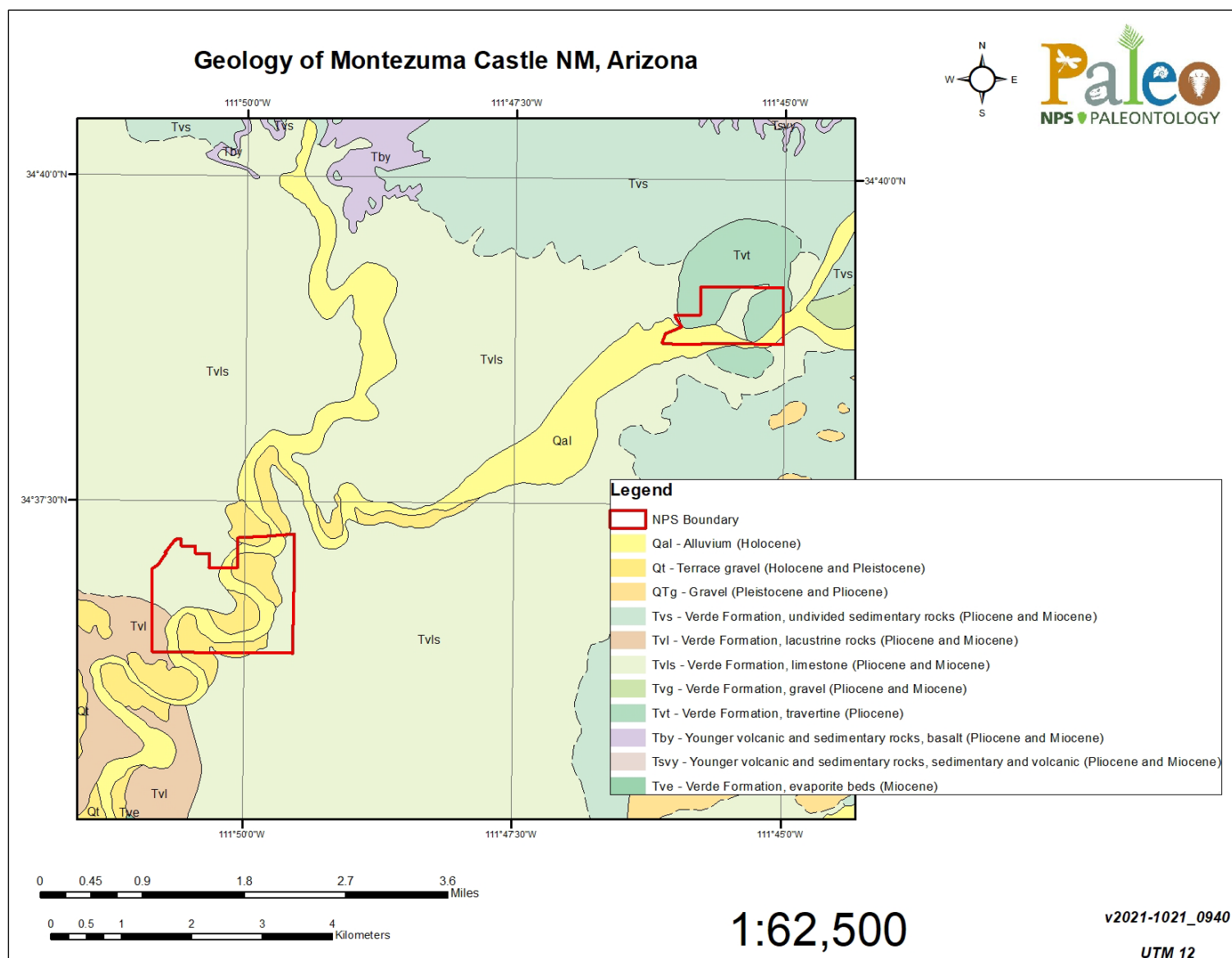


Figure 26. Geologic map of MOCA, Arizona. Data modified from MOCA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2251483>.

Organ Pipe Cactus National Monument (ORPI)

Park Establishment

Organ Pipe Cactus National Monument (ORPI) is situated along the U.S.–Mexico border about 170 km (106 mi) southwest of Phoenix and 64 km (40 mi) south of Ajo in Pima County, Arizona (Figure 27). Proclaimed on April 13, 1937, ORPI contains approximately 133,825 hectares (330,689 acres) and preserves the diverse natural resources of the Sonoran Desert, including mountains, bajadas, valleys, and washes that support unique biological communities including the namesake organ pipe cactus. The rich biological diversity of ORPI has been continuously studied since the early 1940s, serving an international role in research, conservation, and education (National Park Service 2016g). Natural communities in ORPI have adapted to the extreme temperatures, intense sunlight, and little rainfall associated with the Sonoran Desert, and include 26 species of cactus, numerous rare plants, and endangered species such as the Quitobaquito pupfish, Sonoran pronghorn, and lesser long-nosed bat. In 1976 the monument was designated a United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserve in recognition for its globally significant biological resources that are representative of the natural Sonoran Desert ecosystem (National Park Service 2016a).

Geologic Summary

ORPI encompasses a diverse suite of rock lithologies and unique morphologic features that record a complex geologic history. A simplified history of the ORPI region since the beginning of the Mesozoic can be broken down into three main geologic episodes: (1) Jurassic and Cretaceous igneous intrusions, volcanic activity, and deformation; (2) Late Cretaceous and early Cenozoic igneous intrusions accompanied by widespread metamorphism and contractional deformation; and (3) Neogene (Miocene–Quaternary) volcanism and extension that lowered the landscape elevation (Bezy et al. 2000). Widespread bedrock units mapped in ORPI include Jurassic rocks of La Abra and Miocene igneous rocks of the Childs Latite, Batamote Andesite complex, and rhyolite of Montezuma’s Head. The landscape of the monument is dominated by Cenozoic alluvium and colluvium that form broad alluvial plains typical of the Basin and Range physiographic province (Figures 28 and 29).

Stratotypes

There are no designated stratotypes identified within the boundaries of ORPI. There is one identified stratotype located within 48 km (30 mi) of ORPI boundaries that is provided in Appendix C for reference in case of future boundary expansion.



Figure 27. Park map of ORPI, Arizona (NPS).

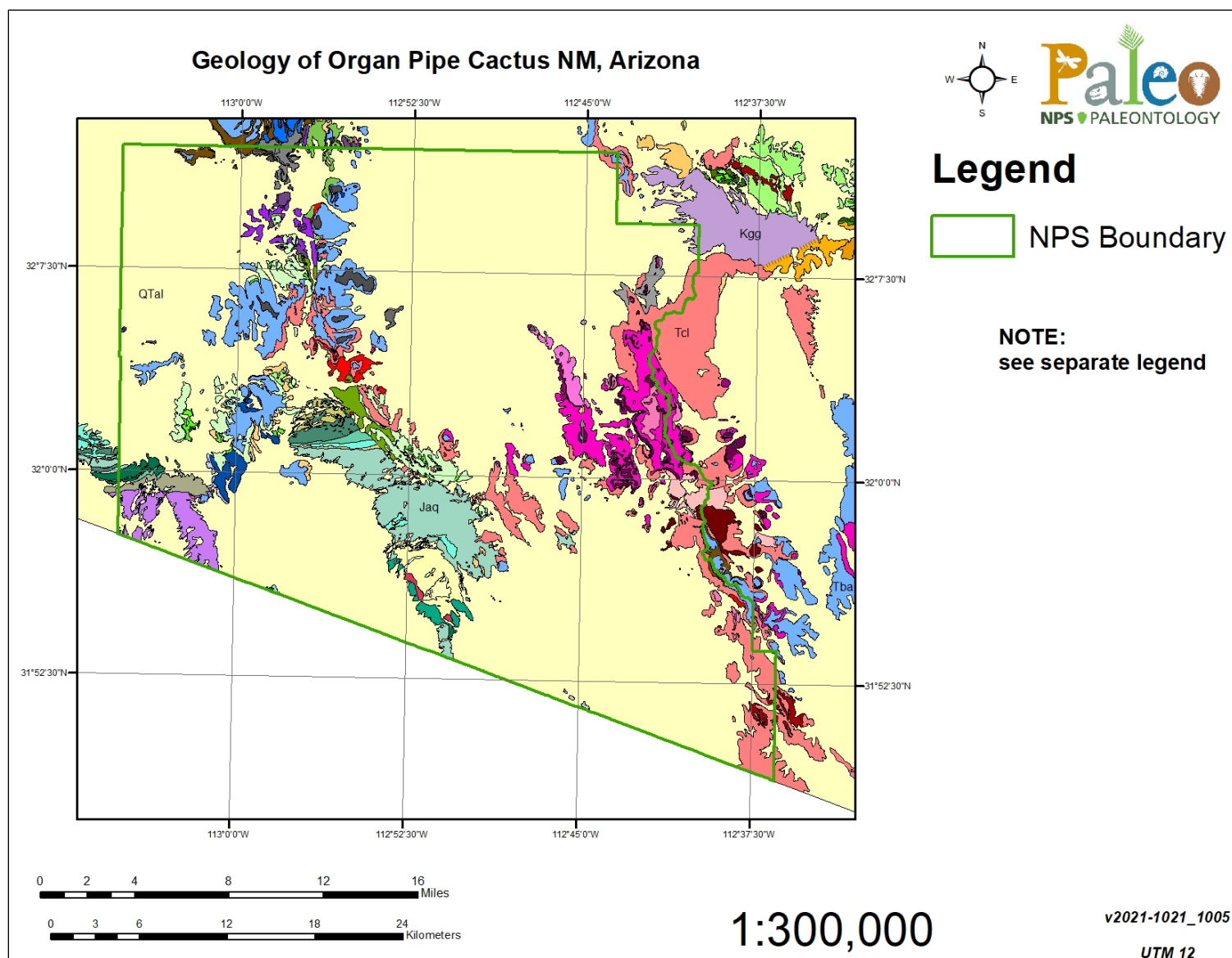


Figure 28. Geologic map of ORPI, Arizona; see Figure 29 for legend. Data modified from ORPI GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1049253>.



Figure 29. Geologic map legend of ORPI, Arizona.

Saguaro National Park (SAGU)

Park Establishment

Saguaro National Park (SAGU) consists of two non-contiguous park districts (the western Rincon Mountain District and eastern Tucson Mountain District) that flank the city of Tucson in Pima County, Arizona (Figures 30 and 31). Originally proclaimed as a national monument on March 1, 1933, the park unit was redesignated on October 4, 1994 (National Park Service 2016a).

Encompassing approximately 37,005 hectares (91,442 acres), SAGU was established to preserve and protect giant saguaro cacti, diverse biological communities of the Sonoran Desert, associated mountain ecosystems, and Rincon Creek, as well as a rich collection of cultural resources that record a continuous history of diverse human occupation in the Southwest from prehistoric to modern times (National Park Service 2014a). The saguaro cacti that are the namesake of the park are the tallest cactus species in the United States and have a distinctive morphology that is globally recognized as an iconic symbol of the American Southwest. The park contains one of the largest concentrations of rare and distinct aquatic microhabitats such as tinajas, seeps, and springs in the desert Southwest, supporting rare and special status species such as the lowland leopard frog, yellow-billed cuckoo, gray hawk, and southwestern willow flycatcher, as well as plant species uncommon to the desert, including sycamore and ash.

Geologic Summary

The geology of SAGU records a tectonic and depositional history spanning approximately 1.6 billion years and reveals several geologic episodes that include: (1) Precambrian continent development; (2) ocean inundation of southeast Arizona in the Paleozoic; (3) volcanic upheaval and mountain-building events in the Mesozoic; and (4) continental rifting in the Cenozoic (Graham 2010). Some of the oldest units in SAGU occur in the Rincon Mountain District and include Precambrian igneous and metamorphic rocks such as the Pinal Schist, Wrong Mountain Quartz Monzonite, Continental Granodiorite, Dripping Spring Formation, and granodiorite of Rincon Valley (Figures 32 and 33). The Tucson Mountain District contains markedly different geology, consisting predominantly of Cretaceous units including the Cat Mountain Tuff, Amole Arkose, Amole pluton, volcanics of Yuma Mine, and unnamed granodiorite intrusive rocks (Figures 34 and 35). Quaternary surficial deposits are mapped in both districts of SAGU and consist of alluvial fan deposits, alluvium, colluvium, terrace gravels, and rubble deposits.

Stratotypes

SAGU contains one identified stratotype that represents the Cretaceous Amole Arkose (Table 5; Figure 36). In addition to the designated stratotype located within SAGU, there are 19 identified stratotypes located within 48 km (30 mi) of SAGU boundaries that are provided in Appendix C for reference in case of future boundary expansion.

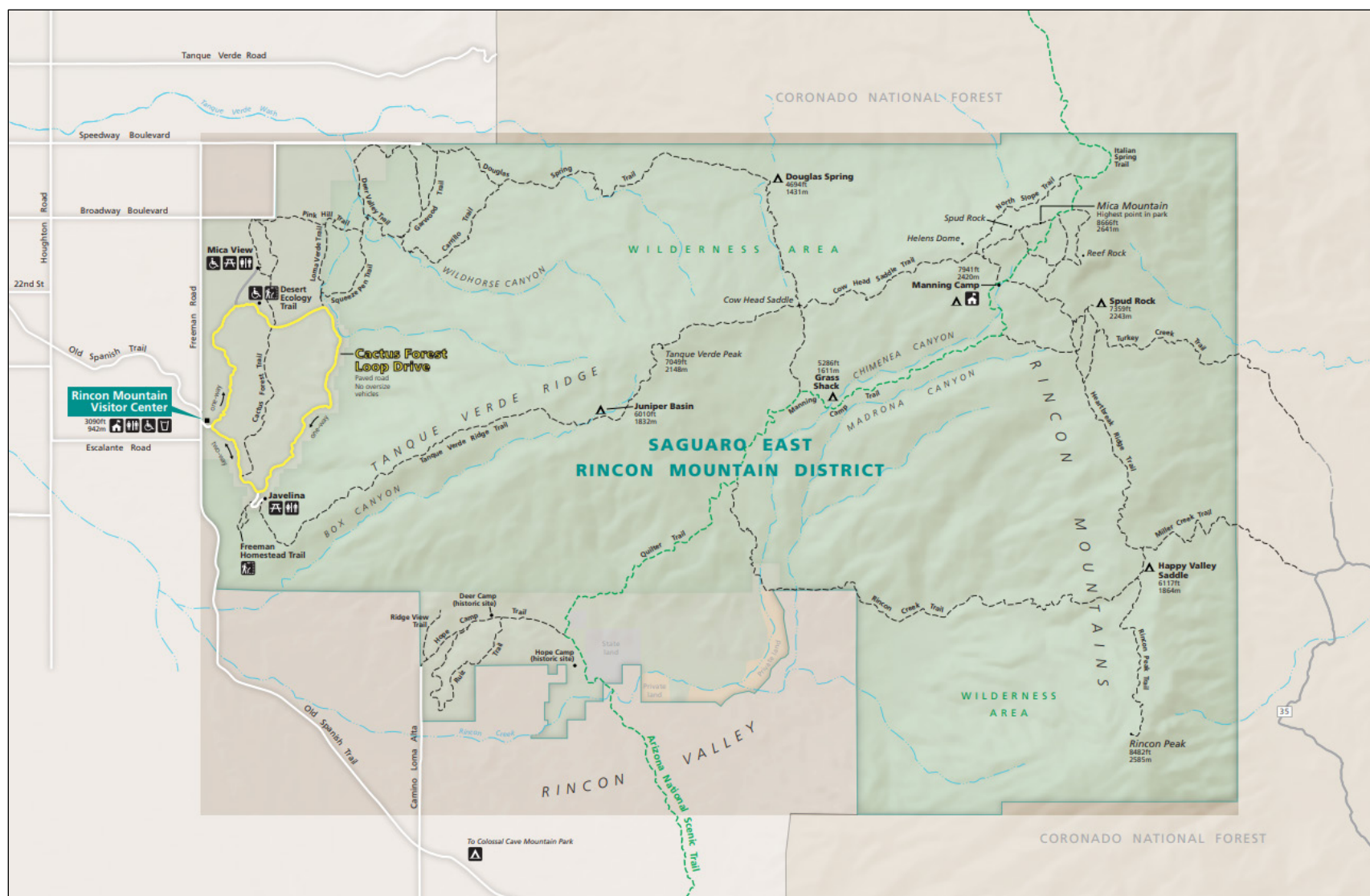


Figure 30. Park map of SAGU (Rincon Mountain District), Arizona (NPS).

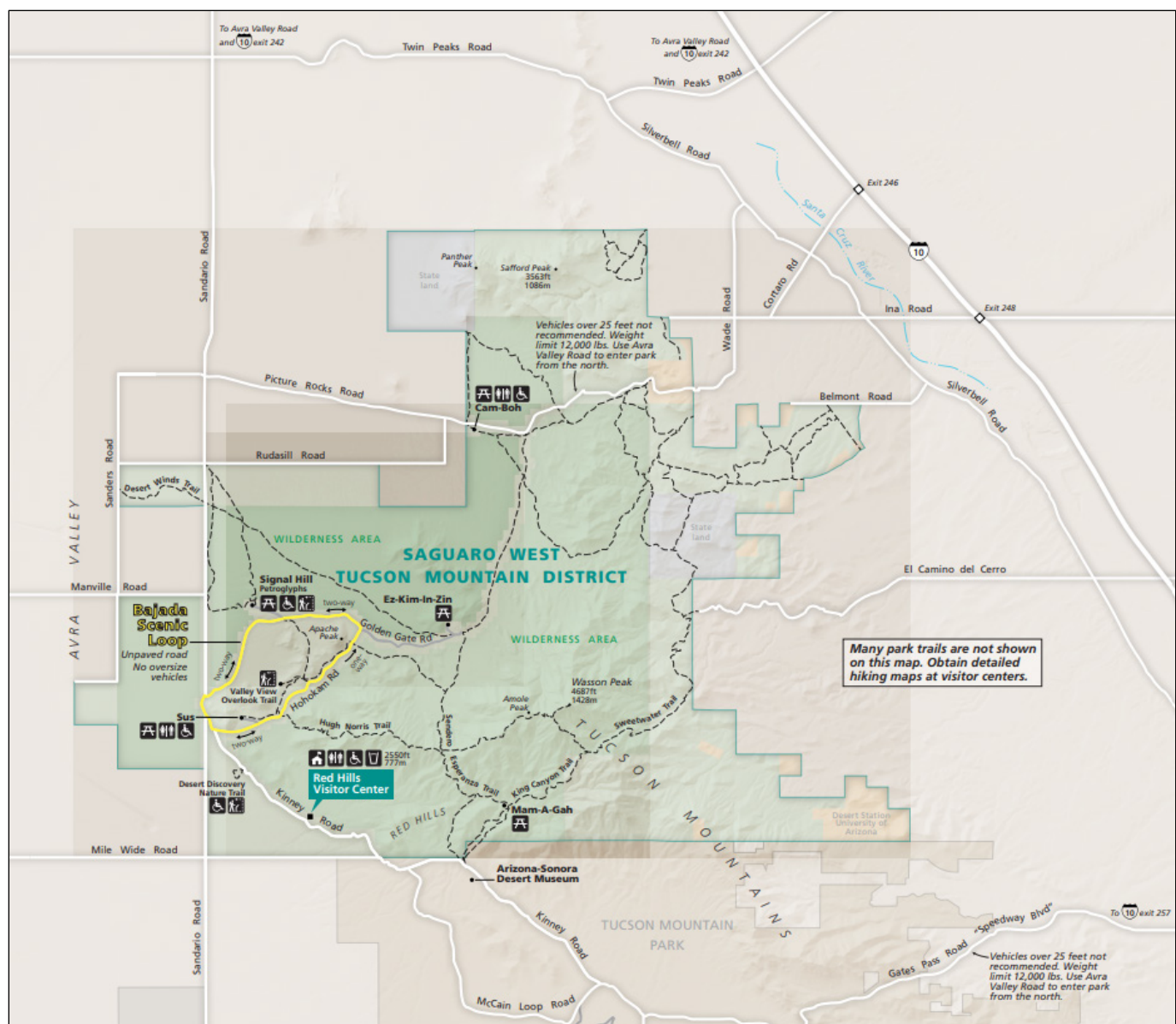


Figure 31. Park map of SAGU (Tucson Mountain District), Arizona (NPS).

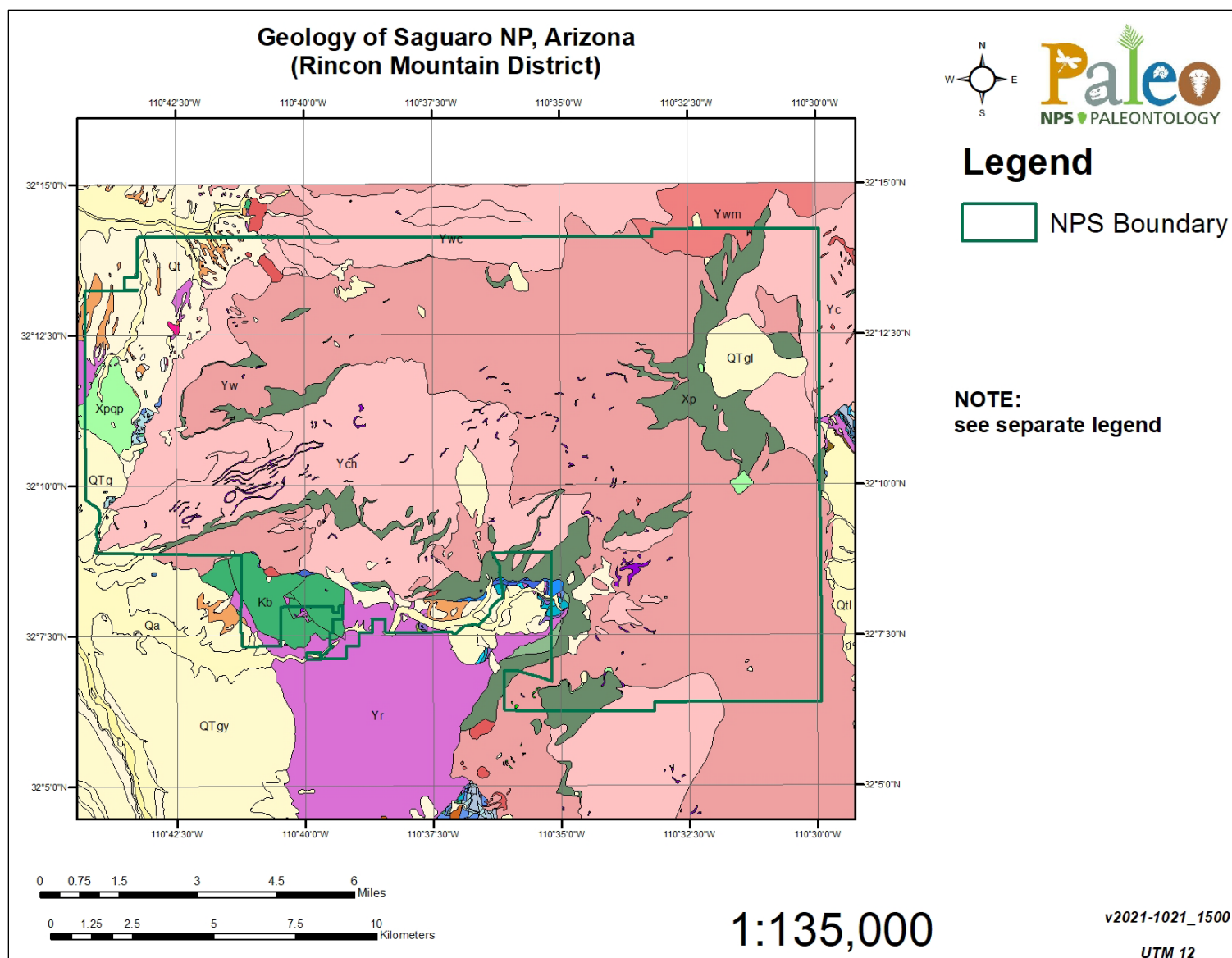


Figure 32. Geologic map of SAGU (Rincon Mountain District), Arizona; see Figure 33 for legend. Data modified from SAGU GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1047835>.



Figure 33. Geologic map legend of SAGU (Rincon Mountain District), Arizona.

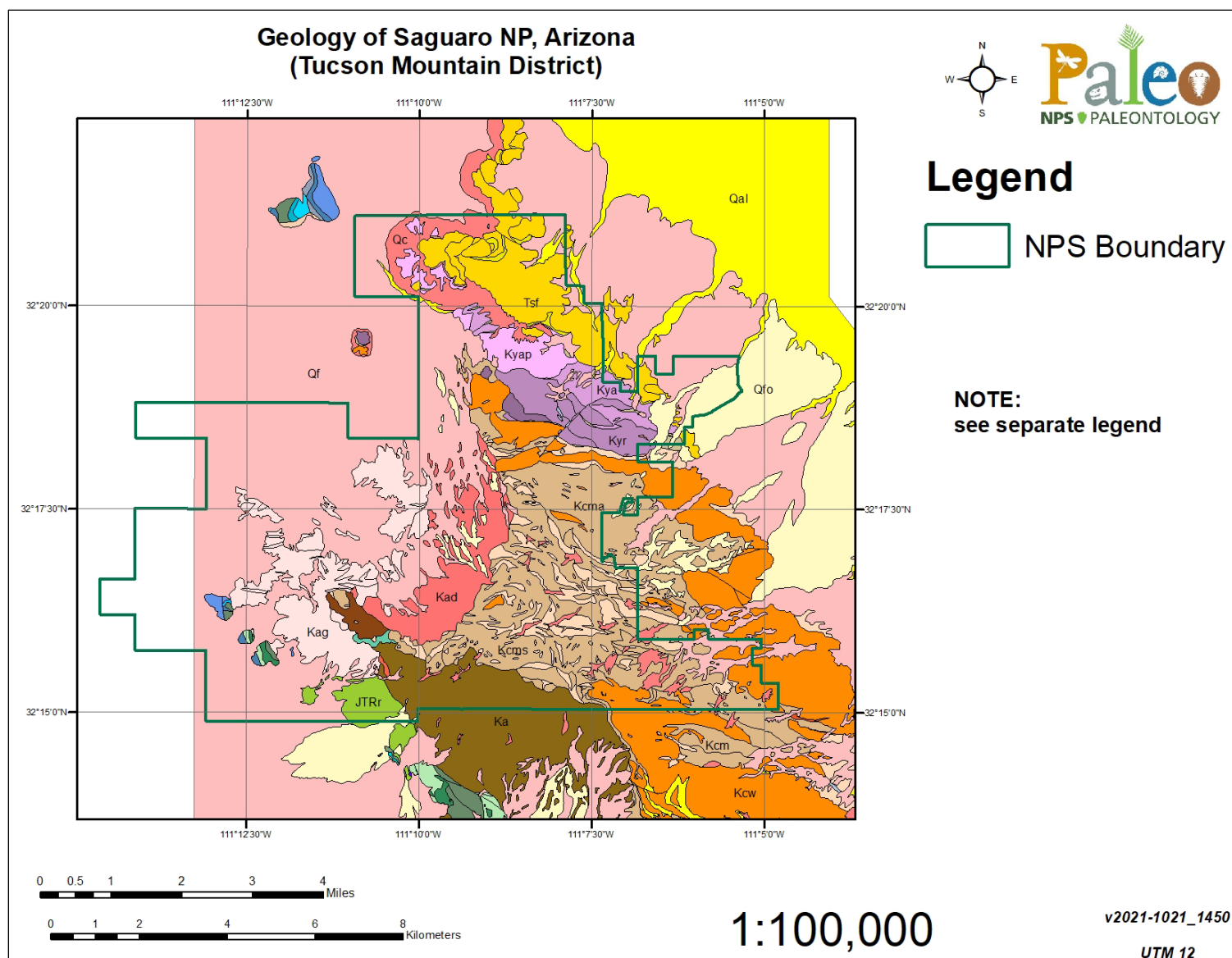


Figure 34. Geologic map of SAGU (Tucson Mountain District), Arizona; see Figure 35 for legend. Data modified from SAGU GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1047835>.

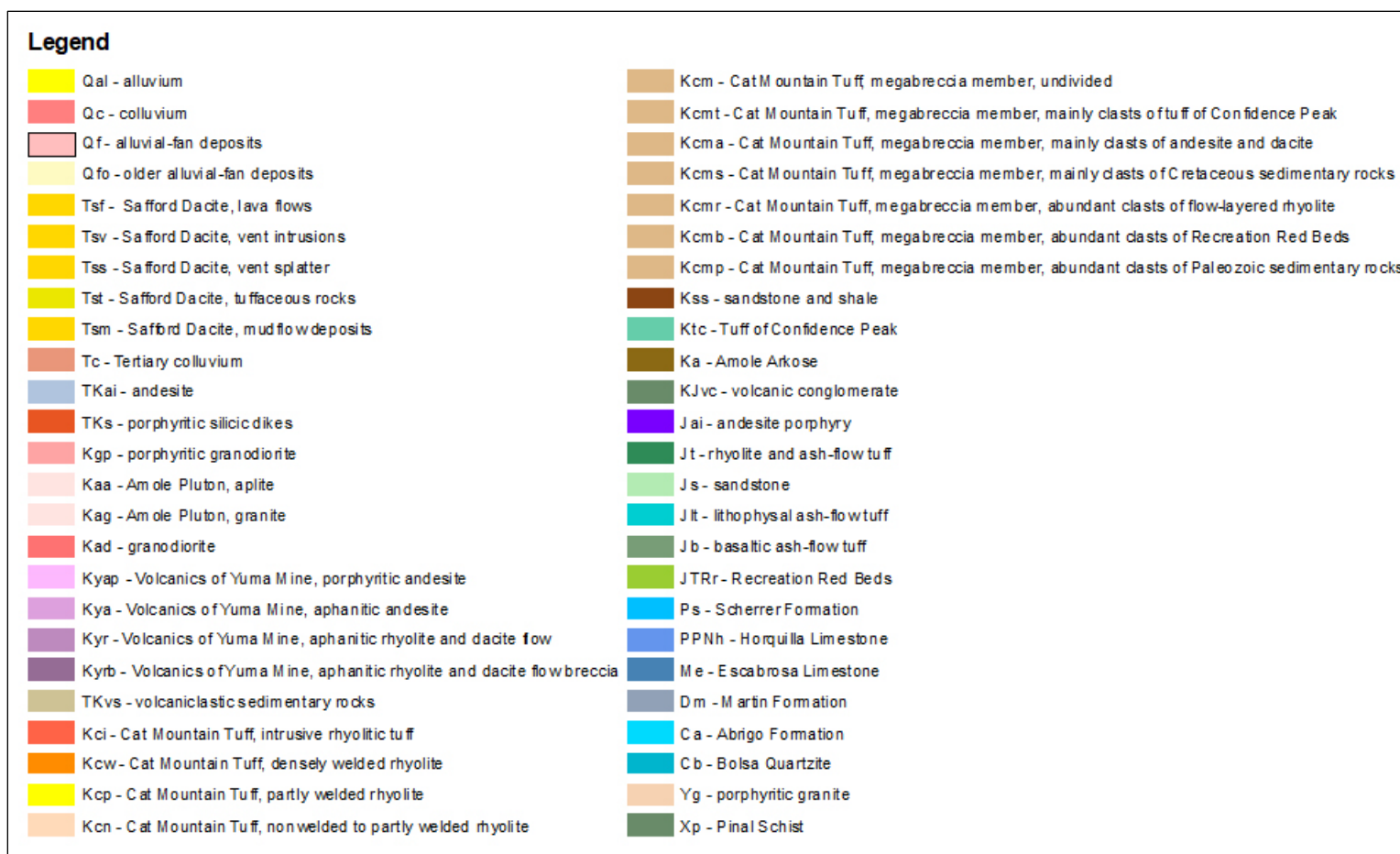


Figure 35. Geologic map legend of SAGU (Tucson Mountain District), Arizona.

Table 5. List of SAGU stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Amole Arkose (Ka)	Brown 1939; Hayes 1970	Type area: exposures on western side of southern part of Tucson Mountains; extending north to Amole Peak [center section 30, T. 13 S., R. 12 E., Avra 7.5' Quadrangle], Pima County, Arizona. Type area is near approximate latitude 32°15'14" N., longitude 111°9'14" W.	Cretaceous

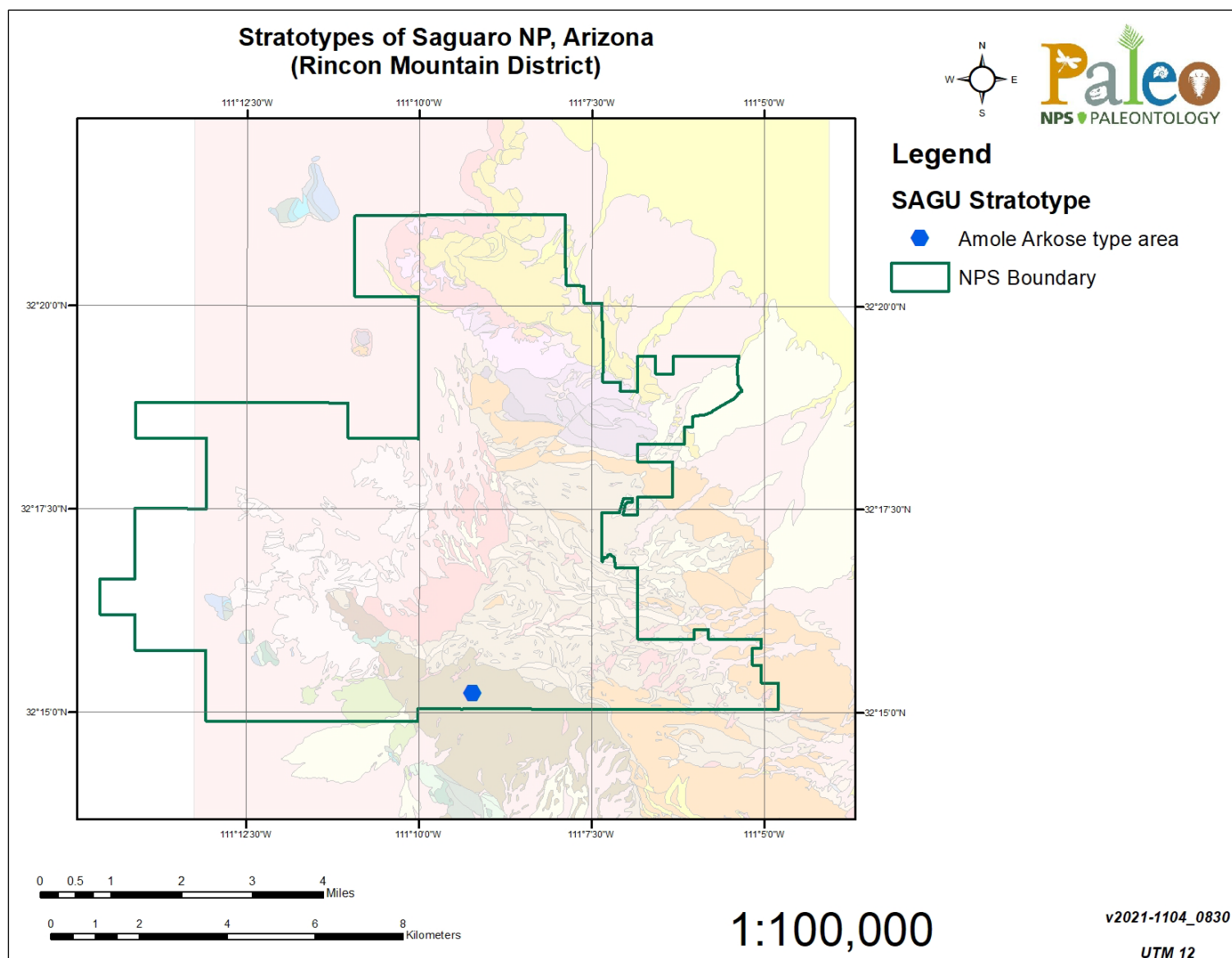


Figure 36. Modified geologic map of SAGU showing stratotype locations. The transparency of the geologic units layer has been increased.

Amole Arkose

The Cretaceous Amole Arkose was named by Brown (1939) to describe a thick sequence of arkosic (feldspar-rich) sandstone interbedded with shales (mudstones) and limestone beds in the Tucson Mountains, Arizona. The type area of the formation is located on the western side of the southern part of the Tucson Mountains and extends north to Amole Peak, in section 30, T. 13 S., R. 12 E. (approximate latitude 32°15'14" N., longitude 111°9'14" W.), Pima County, Arizona (Table 5; Figures 36 and 37; Hayes 1970 citing Brown 1939). Type area exposures of the Amole Arkose measure approximately 693 m (2,275 ft) thick and consist of massive, gray to pink, coarse-grained arkose sandstone interbedded with silvery gray shale and bluish-gray to black limestone beds that are characterized by rapid and repeated changes in lithology (Brown 1939). In the type area, the Amole Arkose unconformably overlies the Permian Rainvalley Formation and Jurassic Recreation Red Beds.



Figure 37. View from Amole Peak looking south across the type area exposures of the Cretaceous Amole Arkose in southern SAGU (NPS).

Tonto National Monument (TONT)

Park Establishment

Tonto National Monument (TONT) is situated on the southeastern flank of the Mazatzal Mountains about 90 km (60 mi) northeast of Phoenix in Gila County, Arizona (Figure 38). Proclaimed on December 19, 1907, TONT encompasses 453 hectares (1,120 acres) and preserves 700-year-old Salado cliff dwellings, archeological sites, and artifacts that represent a diverse range of cultural groups spanning more than 10,000 years (National Park Service 2017b). Colorful pottery, woven cotton cloth, and other well-preserved archeological resources tell a story of human habitation and adaptation in the northern Sonoran Desert from 1250 to 1450 CE (National Park Service 2016a). The multi-story cliff dwellings of TONT were constructed using mud, rocks, and wood in the natural recesses of the siltstone hills surrounding Tonto Basin. The Lower Cliff Dwelling consisted of 16 rooms on the ground floor (3 of which having a second story) and an adjacent 12-room annex. The Upper Cliff Dwelling was composed of 32 rooms on the ground floor, of which 8 have a second story layout. The monument contains nearly 100 archeological sites that include rock shelters, cliff dwellings, field houses, pueblos, lithic scatter, Yavapai and Apache camps, and historic ranching features (KellerLynn 2020).

Geologic Summary

The geology of TONT is part of a remarkable geologic history spanning back to the Paleoproterozoic Era (~2.5 billion to 1.6 billion years ago). The bedrock underlying the southwestern portion of the monument is predominantly composed of strata of the Mesoproterozoic Apache Group, which includes the Dripping Spring Quartzite and Mescal Limestone (Figure 39). Both cliff dwellings of TONT are built in strata of the Apache Group, with the Upper Cliff Dwelling built in the Dripping Spring Quartzite and the Lower Cliff Dwelling in the Mescal Limestone. Exposures of the Apache Group are draped by younger Quaternary talus and colluvium deposits. Some of the oldest exposures in TONT are Paleoproterozoic granitic rocks of Cottonwood Creek that occur along Deadman Canyon near the northwestern boundary of the monument. In contrast to the ancient bedrock of southwestern TONT, the northeastern part of the monument consists of Miocene and Pliocene (23–2.6 Ma) basin fill, Pleistocene (2.6 million to 11,700 years old) alluvial fan deposits, and Holocene (<11,700 years old) floodplain deposits (KellerLynn 2020).

Stratotypes

There are no designated stratotypes identified within the boundaries of TONT. There are 20 identified stratotypes located within 48 km (30 mi) of TONT boundaries that are provided in Appendix C for reference in case of future boundary expansion.

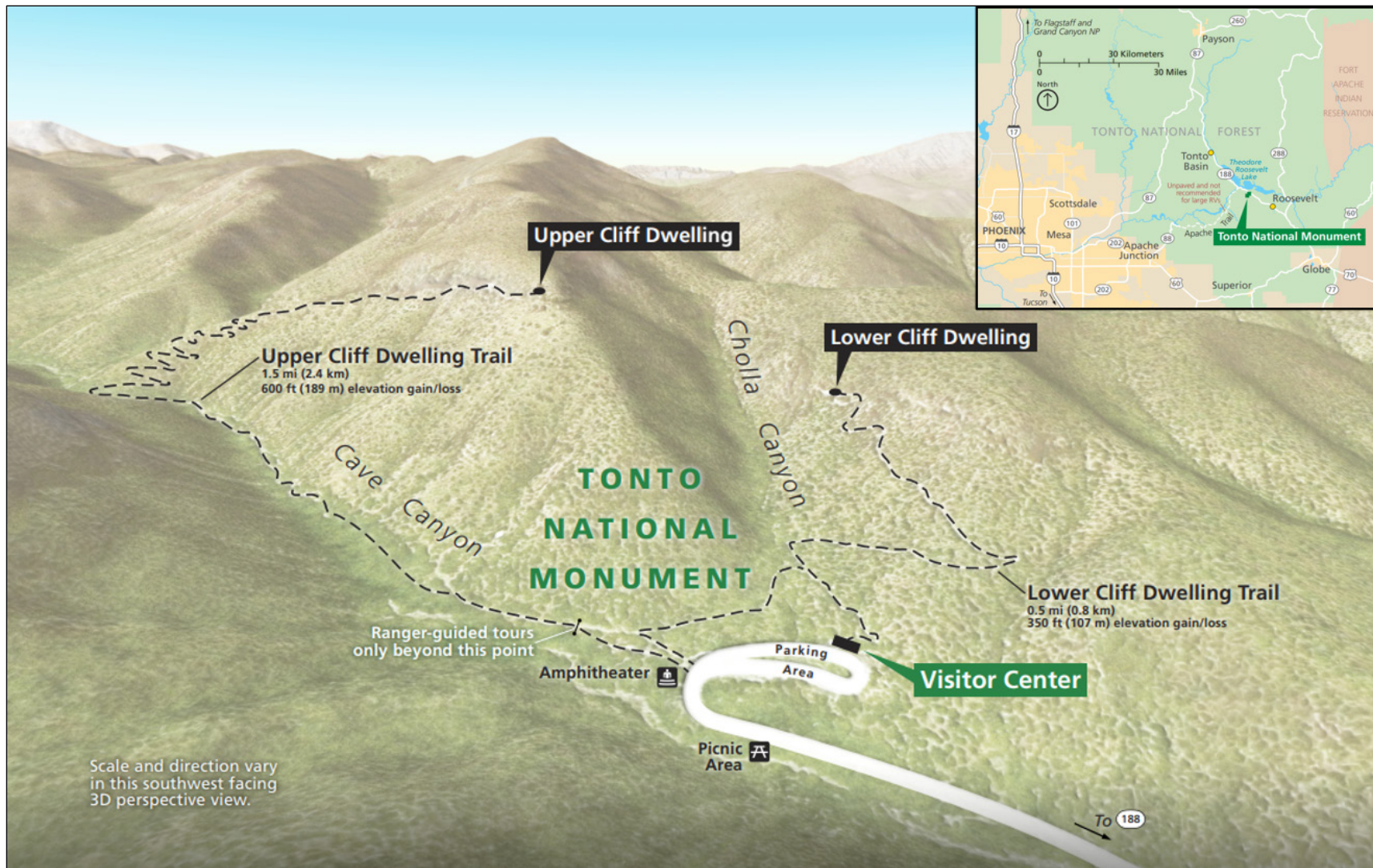


Figure 38. Park map of TONT with inset area map, Arizona (NPS).

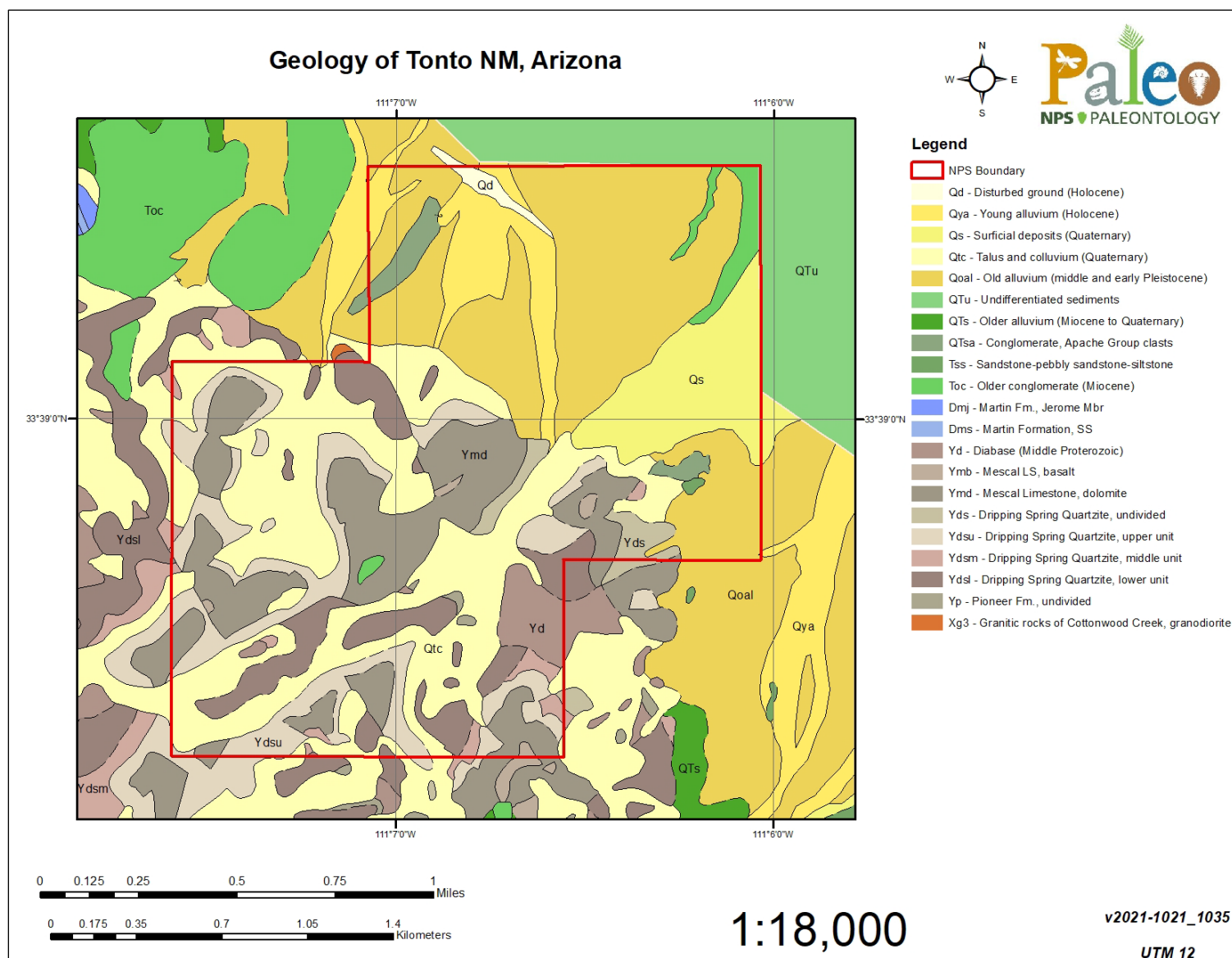


Figure 39. Geologic map of TONT, Arizona. Data modified from TONT GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2205993>.

Tumacácori National Historical Park (TUMA)

Park Establishment

Tumacácori National Historical Park (TUMA) is located 29 km (18 mi) north of the U.S.–Mexico border and 69 km (43 mi) south of Tucson in Santa Cruz County, Arizona (Figure 40). Originally proclaimed as a national monument on September 15, 1908, the park unit was redesignated on August 6, 1990. Encompassing approximately 145 hectares (360 acres), TUMA protects the ruins of the Jesuit and Franciscan missions of San José de Tumacácori (Tumacácori), San Cayetano de Calabazas (Calabazas), and Los Santos Ángeles de Guevavi (Guevavi). These three 18th and 19th century missions contain some of the best remaining examples of Spanish Mission period architectural styles and serve as an interpretive window into the rich and complex blending of cultures within the Santa Cruz River Valley from the 17th century to today (National Park Service 2016a). TUMA is the only NPS unit displaying an entire, original institutionalized Spanish mission landscape, and preserves a record of the social and political hierarchy that was emplaced on the existing Native American communities (National Park Service 2014b).

Geologic Summary

TUMA lies within the Basin and Range physiographic province, a region characterized by fault-bounded structural basins (grabens) separating uplifted mountain ranges (horsts). The horst and graben landscape of the Basin and Range province began developing during the Miocene Epoch approximately 12–5 Ma due to regionally extensive tectonic forces that stretched the continental crust (Bezy 2005; Graham 2011c). The oldest rocks underlying TUMA are Jurassic-age granitic rocks that form Mount Benedict and the southern border of the Guevavi Mission Unit. The bedrock geology of the Calabazas Mission Unit is composed entirely of sandstone, conglomerate, and volcanic tuff of the Cretaceous Salero Formation. Rocks of Quaternary age are mapped in all three units of TUMA and consist of Holocene river channel, floodplain, and terrace deposits, as well as unconsolidated alluvium (Figures 41–43).

Stratotypes

There are no designated stratotypes identified within the boundaries of TUMA. There are eight identified stratotypes located within 48 km (30 mi) of TUMA boundaries that are provided in Appendix C for reference in case of future boundary expansion.



Figure 40. Regional map of TUMA, Arizona showing the missions and presidios of the Pimería Alta. The three missions of TUMA are colored in green (NPS).

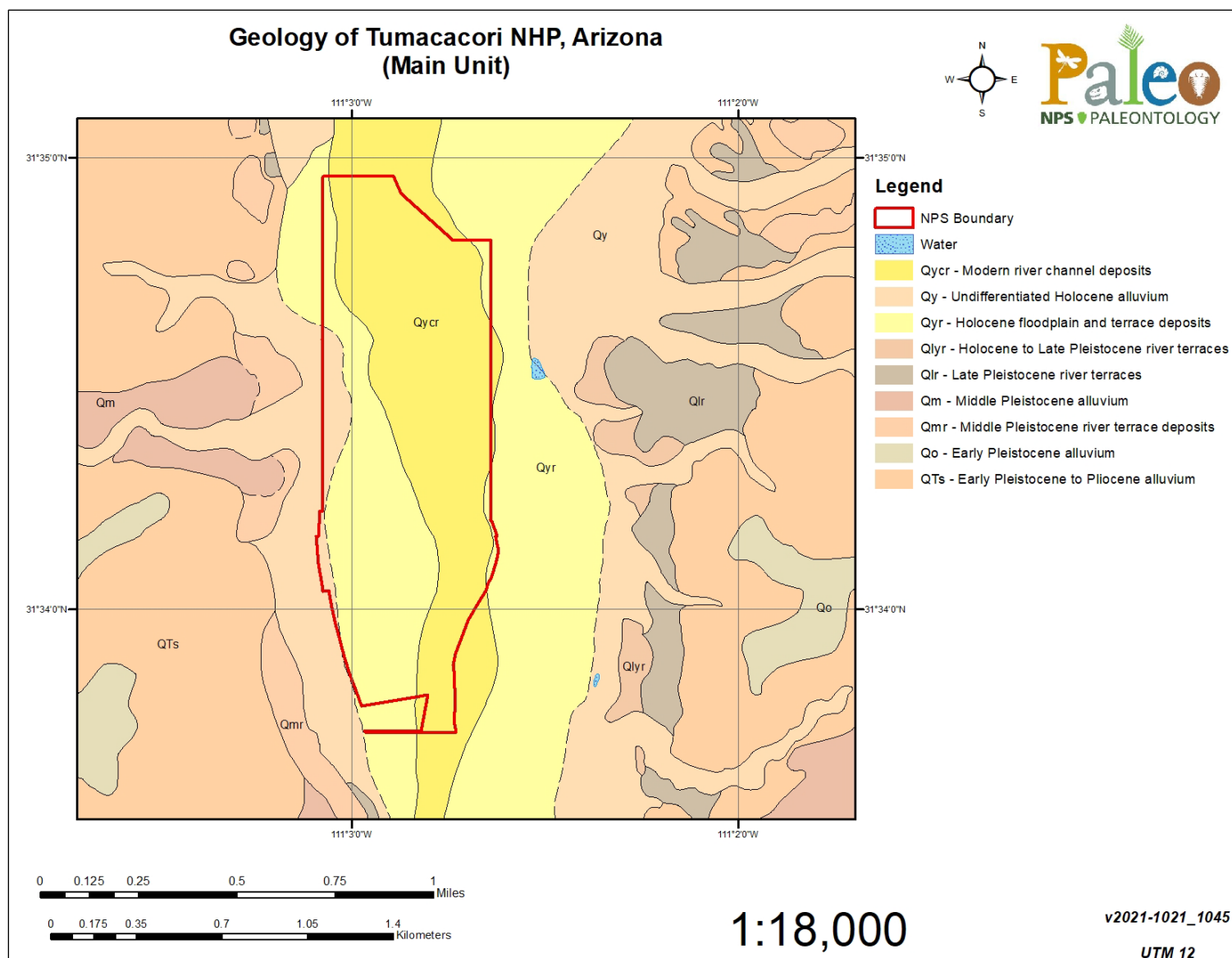


Figure 41. Geologic map of TUMA (Main Unit), Arizona. Data modified from TUMA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2164828>.

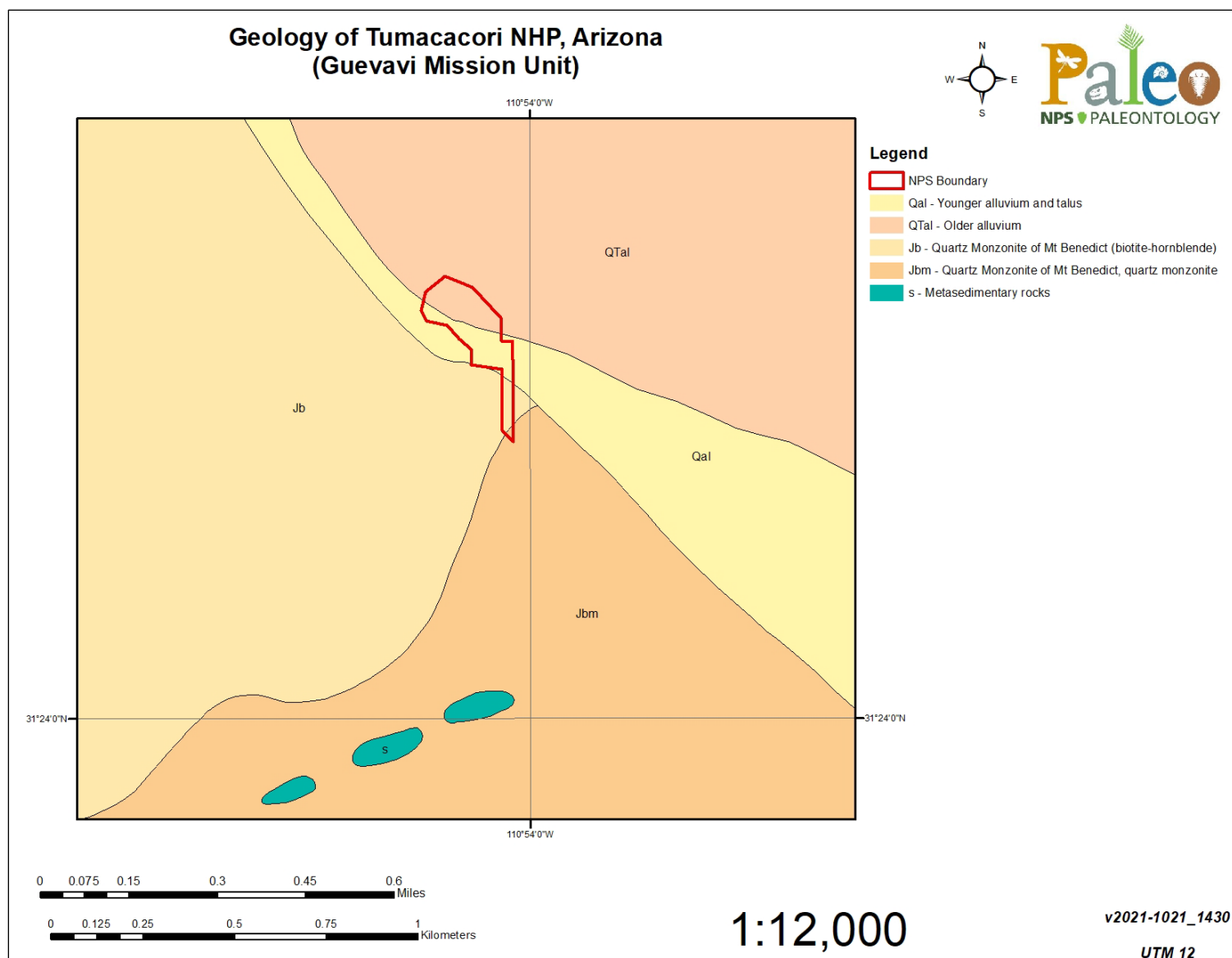


Figure 42. Geologic map of TUMA (Guevavi Unit), Arizona. Data modified from TUMA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2164828>.

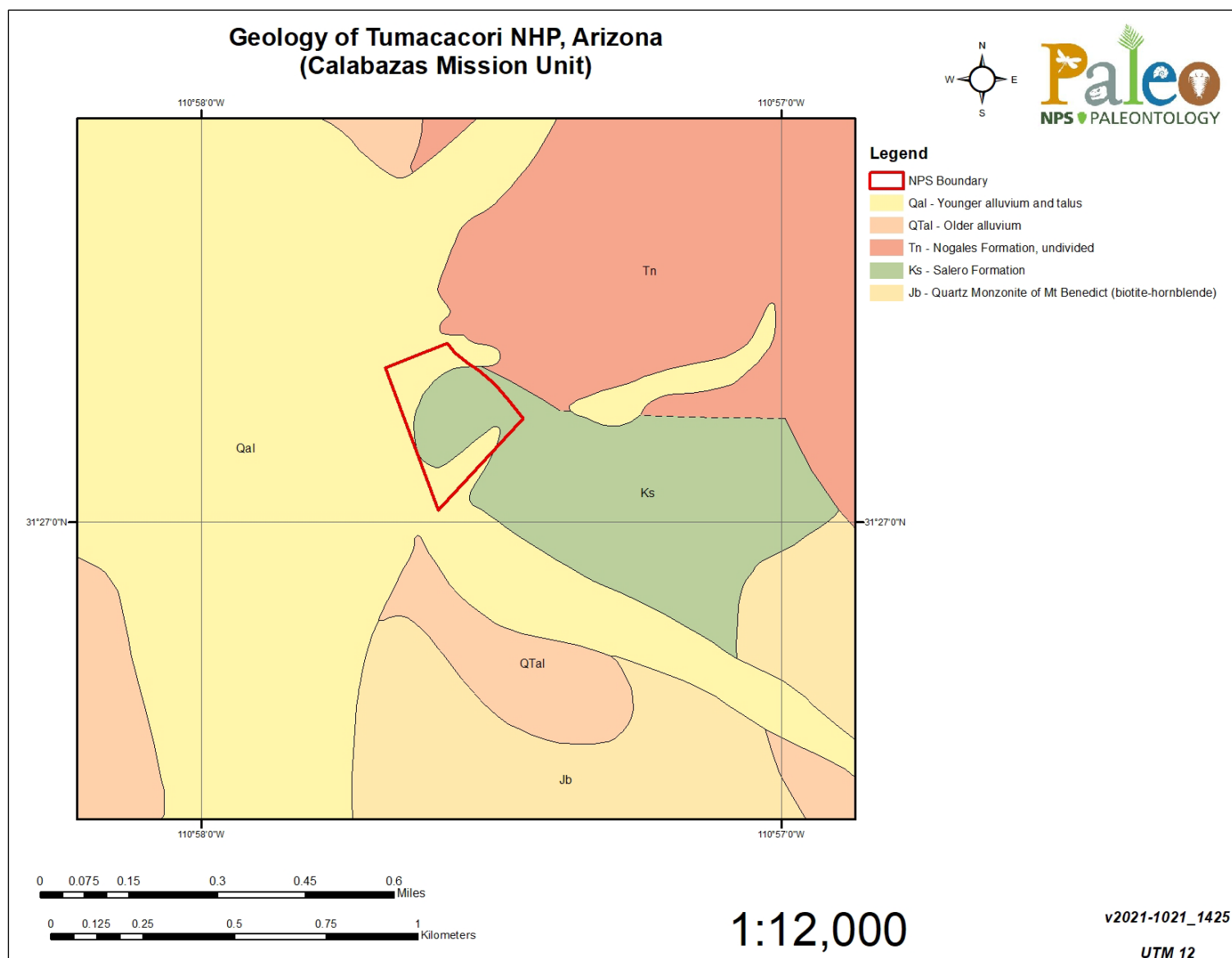


Figure 43. Geologic map of TUMA (Calabazas Mission Unit), Arizona. Data modified from TUMA GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/2164828>.

Tuzigoot National Monument (TUZI)

Park Establishment

Tuzigoot National Monument (TUZI) is located on the Verde River about 58 km (36 mi) southwest of Flagstaff in Yavapai County, Arizona (Figure 44). Proclaimed on July 25, 1939, TUZI contains approximately 328 hectares (812 acres) and was established to preserve the outstanding archeological resources of the Sinagua culture, including the ruins of a large hilltop pueblo and related historic and prehistoric sites, artifacts, and the ecologically sensitive Tavaschi Marsh (National Park Service 2016h). The Tuzigoot (Apache word meaning “crooked water”) pueblo is situated along the crest of a hill overlooking the meandering Verde River and represents the remains of a large, multi-storied village (KellerLynn 2019b). The excavation of TUZI’s hilltop pueblo has yielded some of the largest artifact assemblages of the Sinagua culture in the Verde Valley dated between 1100 and 1450 CE. Tavaschi Marsh, the largest freshwater marsh in Arizona outside of the Colorado River system, supports a diverse biological community that has provided inhabitants with plant and animal resources for edible, medicinal, and utilitarian purposes since prehistoric times.

Geologic Summary

TUZI is situated in the Verde Valley in a transition zone between the Basin and Range and Colorado Plateau physiographic provinces (KellerLynn 2019b). The bedrock geology of TUZI consists entirely of sedimentary deposits of the Miocene–Pliocene Verde Formation (Figure 45). The Tuzigoot pueblo is built upon a ridgeline composed of lacustrine deposits of the Verde Formation that topographically sits above the adjacent Verde Valley. The surrounding landscape of TUZI has been heavily impacted by the Verde River and is draped by Quaternary terrace deposits and river wash. Careful inspection of the geologic map of TUZI shows that Pecks Lake and part of Tavaschi Marsh occupy a former meander of the Verde River (marked by terrace deposits) that has since been abandoned due to continuous channel incision.

Stratotypes

There are no designated stratotypes identified within the boundaries of TUZI. There are 12 identified stratotypes located within 48 km (30 mi) of TUZI boundaries that are provided in Appendix C for reference in case of future boundary expansion.

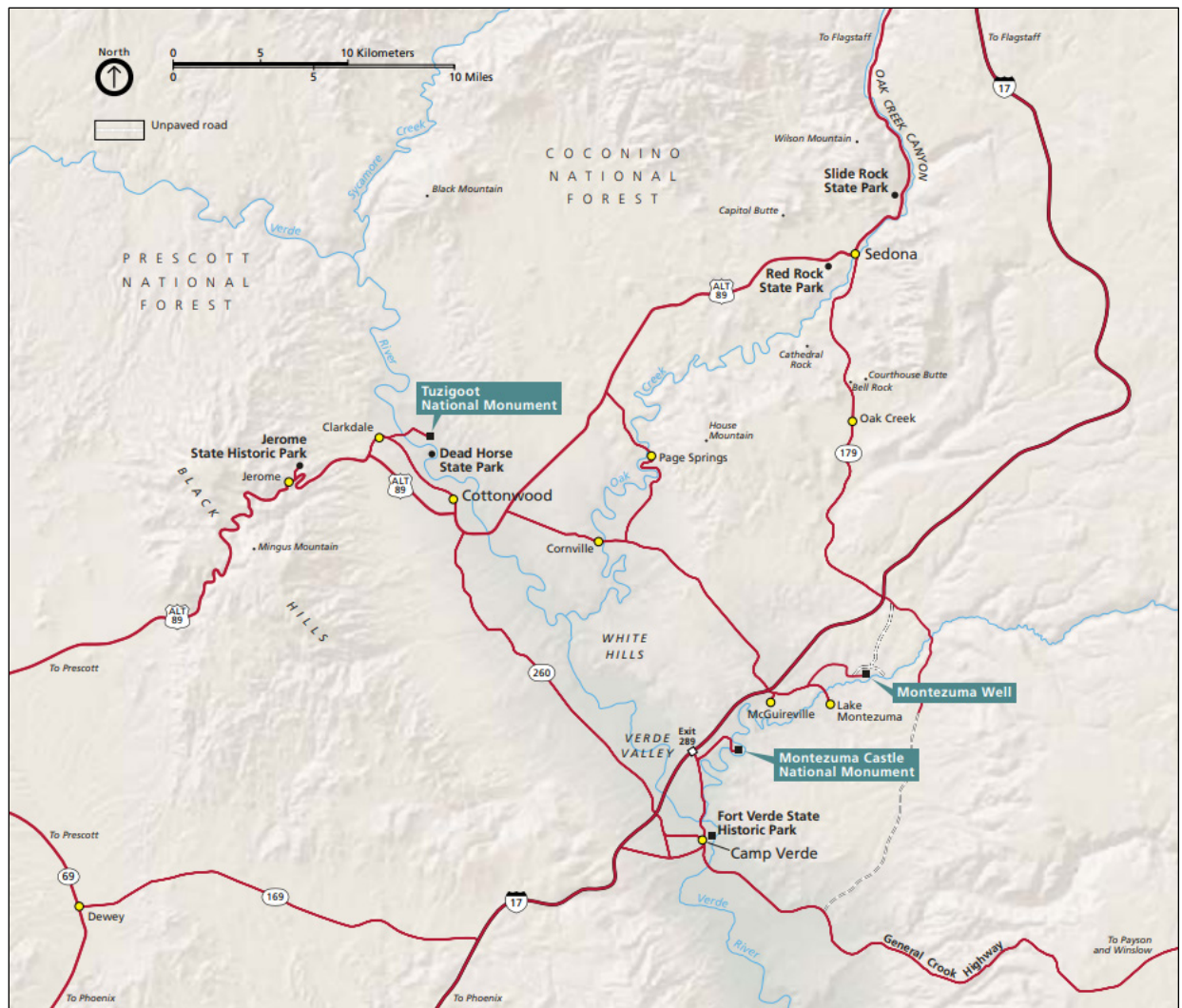


Figure 44. Regional map of TUZI, Arizona (NPS).

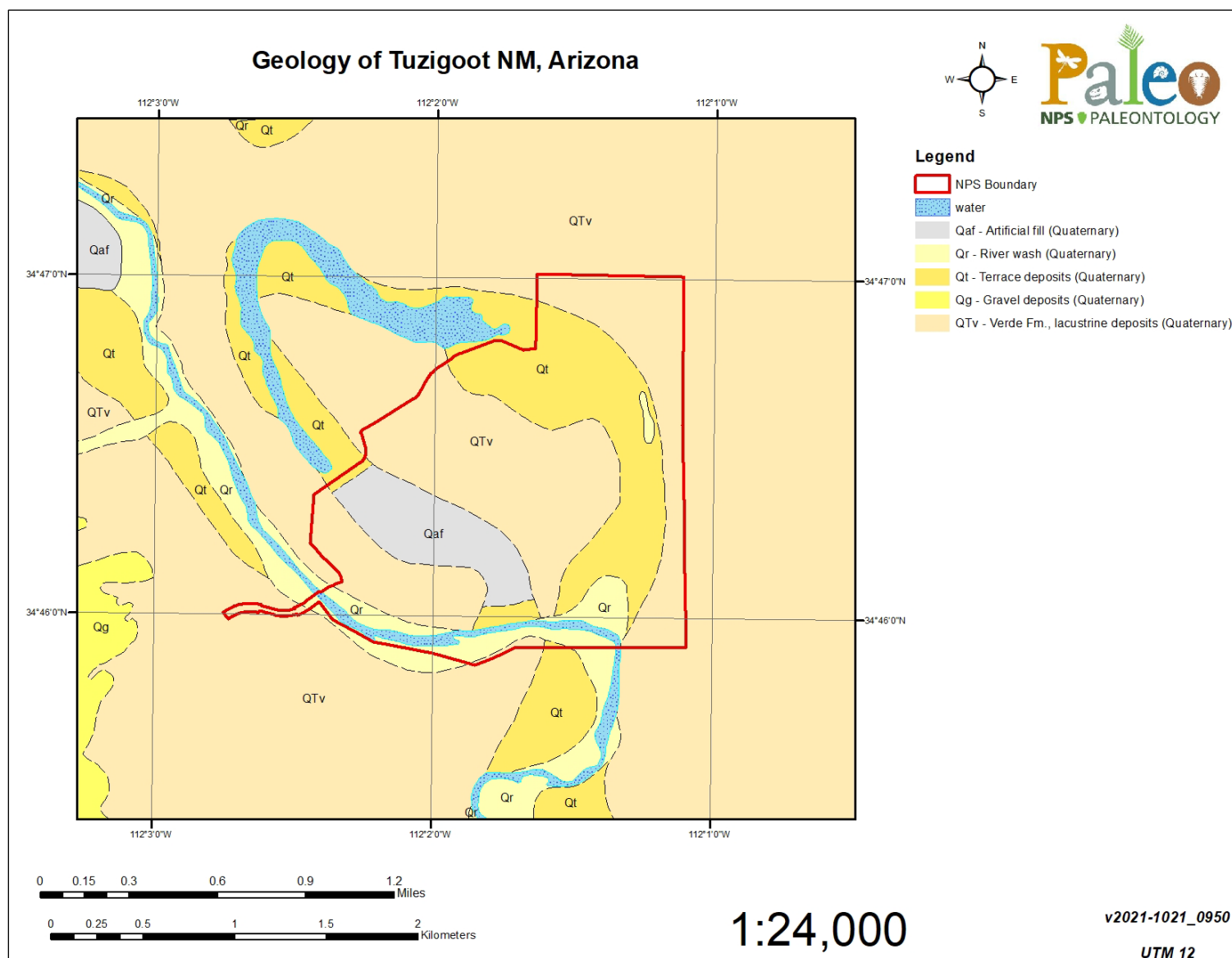


Figure 45. Geologic map of TUZI, Arizona. Although the source map identifies the Verde Formation as Quaternary, it is generally regarded as Miocene–Pliocene. Data modified from TUZI GRI digital geologic map data at <https://irma.nps.gov/DataStore/Reference/Profile/1044861>.

Recommendations

Stratotypes represent unique geologic exposures and are important to manage due to the scientific and educational values they hold for future generations. Stratotypes occur where rocks are exposed naturally (cliff face, river bluff, canyon wall, etc.) or artificially (quarry wall, road/rail/trail/canal cut, tunnel). Therefore, continued stratotype utility derives from the following three characteristics:

- **Visibility:** described rock layers remain visible and not totally or partially obscured
- **Accessibility:** the exposures at the stratotype remain reasonably accessible via road, trail, or other method
- **Unaltered Integrity:** the rock exposures are not altered significantly following description

Stratotype management strategies should focus on maintaining these characteristics to the extent practical when there are multiple management priorities at the site. The extent of the stratotype also impacts resource management considerations. For example, type areas occur over large geographic areas with less emphasis or significance placed on individual exposures, while type sections are specific localities that may warrant more focused management attention.

The recommendations below generally follow the protocol suggested by Brocx et al. (2019) with changes to fit NPS resource management framework.

- 1) The NPS Geologic Resources Division should work with park, regional, and network staff to increase their awareness and understanding about the historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes). This report is a first step toward building that awareness.
- 2) The NPS Geologic Resources Division should work with park, regional, and network staff to ensure they are aware of the locations of stratotypes in park areas. This information is necessary to ensure that proposed park activities or development do not adversely impact the stability and condition of these geologic exposures. Preservation of stratotypes should not limit accessibility for future scientific research but help safeguard these exposures from infrastructure development.
- 3) For significant sites without formal stratotype designations, GRD can provide assistance and liaison with the U.S. Geological Survey or other agencies to establish formal designations.
 - a) The Oligocene sedimentary rocks of Bonita Park were once informally described as the “Bonita Park Formation” by Enlows (1955). The unit is named after exposures in the Bonita Park region of CHIR (in SW/4 section 18, T. 16 S., R. 30 E., Cochise Head 7.5' Quadrangle) in Cochise County, Arizona. Although Enlows (1955) first proposed the unit, it currently lacks a formal designated stratotype.
 - b) The Miocene–Pliocene Verde Formation was proposed by Jenkins (1923) and named after exposures in the Verde Valley region around Clarkdale and Camp Verde, Yavapai County, Arizona. The Verde Formation is widely mapped in MOCA and TUZI and currently lacks a formal designated stratotype.

- c) The Triassic–Jurassic Recreation Red Beds were first proposed by Brown (1939) and named after its occurrence in Tucson Recreational Area (today’s SAGU). This unit is practically confined to the Red Hills region and occurs in numerous small outcrops in thrust faults east of Amole Peak in Pima County, Arizona, and currently lacks a formal designated stratotype.
- 4) For stratotypes designated external to an NPS area that may face destruction, alteration, or other significant impacts, GRD can work with park staff to potentially set up a reference section within an NPS area, which affords a baseline level of protection.
- 5) The NPS Geologic Resources Division should work with park, regional, and network staff, the U.S. Geological Survey, state geological surveys, academic geologists, and other partners to formally assess potential new stratotypes as to their significance (international, national, or statewide), based on lithology, stratigraphy, fossils or notable features using procedural code outlined by the North American Commission on Stratigraphic Nomenclature (after Brocx et al. 2019).
- 6) From the assessment in (5), the NPS Geologic Resources Division, the U.S. Geological Survey, state geologic surveys, academic geologists, and other partners should focus on registering new stratotypes at state and local government levels where current legislation allows, followed by a focus on registering at federal and state levels where current legislation allows (after Brocx et al. 2019).
- 7) The NPS Geologic Resources Division should work with park, regional and network staff to:
 - a) Compile, update, and maintain a central inventory of all designated stratotypes and potential future nominations. The USGS GEOLEX serves this function for the United States. This report is part of an effort to inventory stratotypes specific to National Park Service areas and eventually provide that data in a spatial, searchable format and integrate with GEOLEX.
 - b) Establish appropriate monitoring protocols to regularly assess stratotype locations to identify any threats or impacts to these geologic heritage features in parks. See bullet points below for potential threats. Crofts et al. (2020) provides additional details on potential threats. Brocx et al. (2019) includes examples of destroyed stratotypes and suggests protocols for conservation in Australia. Criteria to assess the stability of stratotype exposure sites should follow the guidance of the Unstable Slope Management Program (USMP) for federal land management agencies found here: <https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/federal-lands/tech-resources/31011/usmp-field-manual.pdf>.
 - c) Develop appropriate management actions based on significance of site and consideration of other resource management needs. See bullet points below for suggested management considerations.
 - d) Obtain good photographs of each geologic stratotype within the parks. Photographs of many stratotypes are rare and thus obtaining photographs of NPS stratotypes is a first step for resource management. In some cases, where there may be active geologic

processes (rock falls, landslides, coastal erosion, etc.), the use of photogrammetry may be considered for monitoring of stratotypes. GPS locations should also be recorded and kept in a database when the photographs are taken.

- e) Consider the collection and curation of geologic samples (new or extant) from stratotypes within respective NPS areas. Samples collected from stratotype exposures can be useful as reference specimens to support future studies, especially where stratotypes may be lost through natural processes or human activities.
- f) Use selected robust internationally and nationally significant stratotypes as formal teaching/interpretation sites and for geotourism so that the importance of the national- and international-level assets are more widely (and publicly) known, using wayside panels, educational sites (on site or virtual), and walkways (after Brocx et al. 2019).
- g) Develop conservation protocols of significant stratotypes, either by appropriate fencing, guard rails, trails, boardwalks, and information boards or other means (e.g., phone apps) (after Brocx et al. 2019).

Natural processes that have the potential to impact visibility, accessibility, or unaltered integrity of stratotypes include the following:

- Slope movements (e.g., rock falls, landslides)
- Erosion
- Vegetation encroachment (exotic, invasive, or native)
- Sea level rise (e.g., inundation and submersion)
- Tectonism and volcanism
- Climate change

Note that the rate, frequency, or severity of these natural processes will likely change as climate continues to change.

Human activities that have the potential to impact visibility, accessibility, or unaltered integrity of stratotypes include the following:

- Road, trail, or other infrastructure development that may remove or obscure stratotypes.
- Installation of guard rails, sprayed concrete (e.g., “Shotcrete” or gunite), wire mesh, rock bolts, or other cliff stabilization techniques.
- Restoration of a quarry or other abandoned site that was used as a stratotype location
- Graffiti, vandalism, or unauthorized fossil/mineral/rock collection
- Scientific research permits that include fossil/mineral/rock sampling or paleomagnetism coring.
- Visitor use (e.g., trails that cross stratotypes) can degrade stratotype integrity.

Potential resource management actions include the following:

- As general guidance, NPS Management Policies (section 4.8.2) states that “The Service will protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue” (National Park Service 2006).
- All stratotypes should, at minimum, be photographed at high resolution with a common object or scale bar included.
- Photogrammetry is an ideal documentation method for significant stratotypes.
- If obscuring or destruction of the outcrop is necessary for other resource management priorities (e.g., road/trail alterations, AML [Abandoned Mineral Lands] restoration [should consider stratotypes where possible], visitor safety concerns, natural rockfall or slope movement at/near the stratotype) photogrammetric documentation should be considered. Designation of a reference section at a less threatened or dangerous exposure is another possibility.
- If other geologic resources are present at the stratotype, such as fossils, significant minerals, or cave features, additional resource management and monitoring may be necessary. See for example Young and Norby (2009).
- Clear exotic or invasive vegetation from stratotypes or manage native vegetation to maximize visibility and accessibility.
- Utilize the Unstable Slope Monitoring Program (USMP) Tool to determine stability of stratotype exposure and potential hazards to human safety.
- For exceptionally significant stratotypes (international, national, or related to park fundamental purposes), consider utilizing them as formal interpretation or education sites (on site or virtual), or protecting them with fencing/guard rails, constructing boardwalks or trails to focus visitor access, or installing wayside panels.

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Appendix A: Source Information for GRI Maps of SODN Parks

GMAP = Unique identifier assigned to geologic source maps by the GRI program.

The GRI program converted these source maps to the GRI digital geologic map data for each park. GRI data sets are available at their publications page:

<https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm>. For information on how source maps are converted and what the GRI data model includes, refer to the GRI data models here: <https://irma.nps.gov/DataStore/Reference/Profile/2259192>.

CAGR

GMAP 74372: Klawon, J. E., P. A. Pearthree, S. J. Skotnicki, and C. A. Ferguson. 1998.

Geology and geologic hazards of the Casa Grande area, Pinal County, Arizona: Geologic map of the Coolidge 7.5' Quadrangle. Arizona Geological Survey, Tucson, Arizona. Open-File Report 98-23. Sheet 4 of 6. Scale 1:24,000. Available at:

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GMAP 74889: Richard, S., T. Orr, R. Moore, and C. Ferguson. 2007. Geologic data for the southeast Phoenix metropolitan area, Maricopa and Pinal Counties, Arizona. Arizona Geological Survey, Tucson, Arizona. Digital Data 24. Scale 1:24,000. Available at:

http://repository.azgs.az.gov/uri_gin/azgs/dlio/1027 (accessed August 30, 2022).

CHIR

GMAP 1120: Pallister, J. S., E. A. du Bray, and D. B. Hall. 1997. Interpretive map and guide to the volcanic geology of Chiricahua National Monument and vicinity, Cochise County, Arizona. U.S. Geological Survey, Reston, Virginia. Miscellaneous Investigations Series Map 2541. Scale 1:24,000. Available at: <https://pubs.er.usgs.gov/publication/i2541> (accessed August 30, 2022).

CORO

GMAP 4155: Hon, K. A., G. Floyd, K. S. Bolm, K. A. Dempsey, and P. A. Pearthree. 2007. A digital geologic map of the Miller Peak, Nicksville, Bob Thompson Peak, and Montezuma Pass Quadrangles, Arizona. U.S. Geological Survey, Reston, Virginia. Unpublished. Scale 1:24,000.

FOBO

GMAP 3073: Drewes, H. 1981. Geologic map and sections of the Bowie Mountain South Quadrangle, Cochise County, Arizona. U.S. Geological Survey, Washington, D.C. Miscellaneous Investigations Series Map 1363. Scale 1:24,000. Available at:

https://ngmdb.usgs.gov/Prodesc/proddesc_9172.htm (accessed August 30, 2022).

GMAP 3074: Drewes, H. 1984. Geologic map and sections of the Bowie Mountain North Quadrangle, Cochise County, Arizona. U.S. Geological Survey, Washington, D.C. Miscellaneous Investigations Series Map 1492. Scale 1:24,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_9260.htm (accessed August 30, 2022).

GICL

GMAP 3077: Ratté, J. C. and D. L. Gaskill. 1975. Reconnaissance geologic map of the Gila Wilderness Study Area, southwestern New Mexico. U.S. Geological Survey, Washington, D.C. Miscellaneous Investigations Series Map 886. Scale 1:62,500. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_9786.htm (accessed August 30, 2022).

GMAP 75624: Ratté, J. C., D. L. Gaskill, and J. R. Chappell. 2014. Geologic map of the Gila Hot Springs 7.5' Quadrangle and the Cliff Dwellings National Monument, Catron and Grant Counties, New Mexico. U.S. Geological Survey, Reston, Virginia. Open-File Report 2014-1036. Scale 1:24,000. Available at: <https://pubs.usgs.gov/of/2014/1036/> (accessed August 30, 2022).

MOCA and TUZI

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Appendix B: Geologic Time Scale

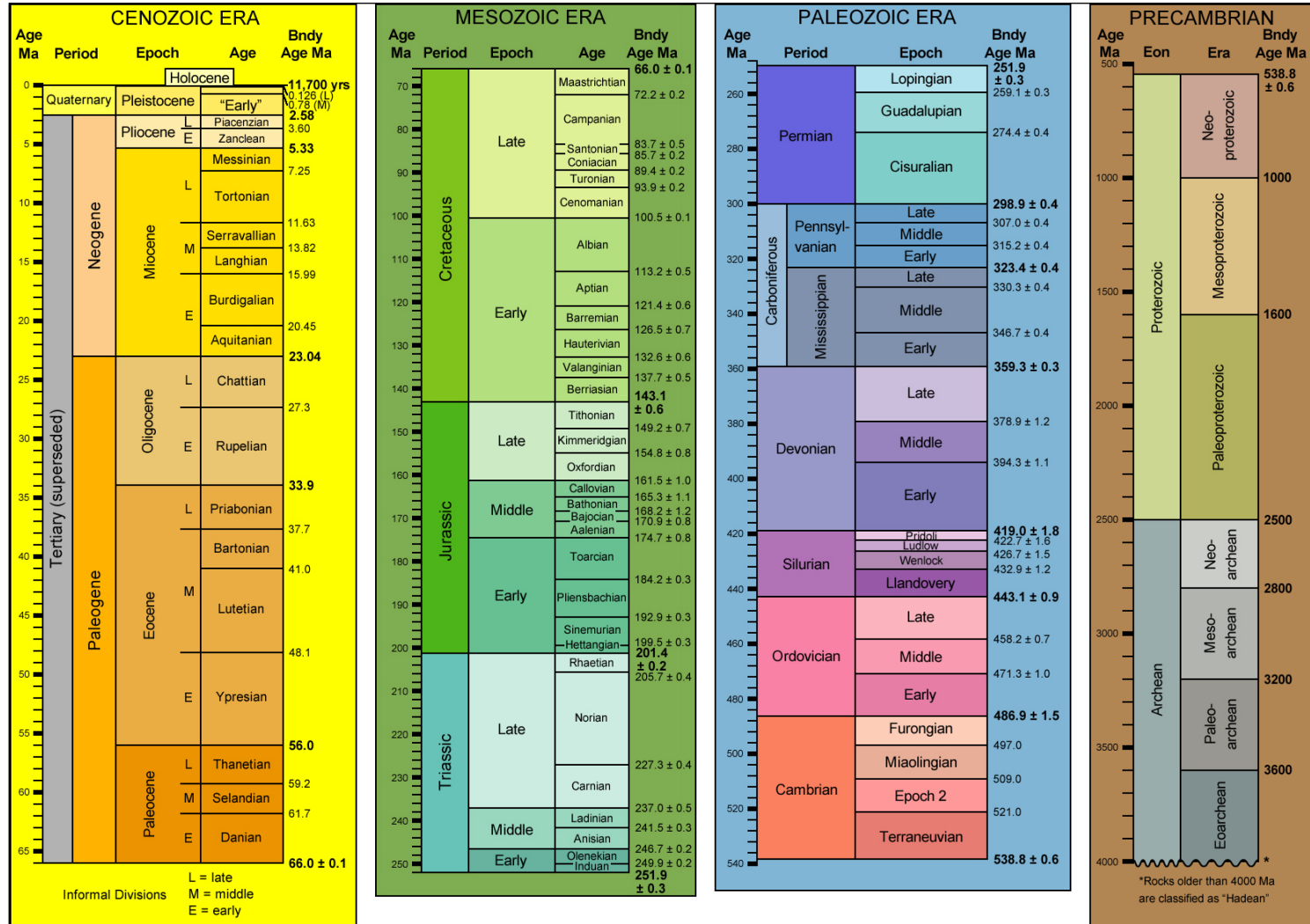


Figure B1. Geologic Time Scale. Ma=Millions of years old. Bndy Age=Boundary Age. Layout after 1999 Geological Society of America Time Scale (<https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf>). Dates after Gradstein et al. (2020).

Appendix C: Stratotypes Located Within 48 km (30 mi) of SODN Parks

CAGR

Miocene:

- Whitlow Canyon Formation (type section)
- Tule Canyon Formation (type section)
- Picketpost Mountain Formation (type section)
- Superstition Tuff, Hieroglyphic Member (type area)
- Superstition Tuff, Siphon Draw Member (type section)
- Sleeping Buffalo Rhyolite, Arnett Member (type locality)

CHIR

Devonian:

- Swisshelm Formation (type section)
- Portal Formation (type section)

Mississippian:

- Keating Formation (type section)
- Hachita Formation (type section)

Cretaceous:

- Johnny Bull Sandstone (type section)

Oligocene:

- Faraway Ranch Formation (principal reference section)

CORO

Cambrian:

- Abrigo Formation (type section)
- Bolsa Quartzite (type section)

Devonian:

- Martin Limestone (type section and principal reference section)

Mississippian:

- Escabrosa Limestone (type section and principal reference section)

Permian:

- Naco Group (type locality)
- Earp Formation (type section)
- Epitaph Dolomite (type section)
- Colina Limestone (type section)
- Horquilla Limestone (type section)
- Rainvalley Formation (type section)
- Concha Limestone (reference section)

Cretaceous:

- Bisbee Group (type locality)
- Lowell Formation (type locality)
- Cintura Formation (principal reference section)
- Mural Limestone (type locality and principal reference section)
- Morita Formation (principal reference section)
- Glance Conglomerate (principal reference section)
- Turney Ranch Formation (type section)

FOBO

Devonian:

- Portal Formation (type section)

Mississippian:

- Keating Formation (type section)
- Hachita Formation (type section)

Pennsylvanian:

- Black Prince Limestone (type section)

Permian:

- Concha Limestone (type section)
- Scherrer Formation (type section)

Triassic–Jurassic:

- Walnut Gap Formation (type section)

Cretaceous:

- Johnny Bull Sandstone (type section)

Oligocene:

- Faraway Ranch Formation (principal reference section)

GICL

Oligocene–Miocene:

- Sacaton Quartz Latite (type locality)
- Bearwallow Mountain Andesite (type locality)

Oligocene:

- Alum Mountain Formation (type locality)
- Bloodgood Canyon Tuff (type section)
- Shelly Peak Tuff (type section)

MOCA

Paleoproterozoic:

- Texas Gulch Formation (type section)
- Cherry Springs Tonalite (type locality)

Devonian:

- Martin Formation, Jerome Member (type section)

Permian:

- Schnebly Hill Formation (type section)
- Schnebly Hill Formation, Bell Rock Member (type section)
- Schnebly Hill Formation, Rancho Rojo Member (type section)
- Schnebly Hill Formation, Sycamore Pass Member (type section)
- Coconino Sandstone, Cave Spring Sandstone Member (type section)
- Coconino Sandstone, Harding Point Sandstone Member (type section)

Jurassic:

- Page Sandstone (type section)

Miocene:

- Hickey Formation (type section)

ORPI

Oligocene–Miocene:

- Ajo Volcanics (type locality)

SAGU

Precambrian–Tertiary:

- Santa Catalina Group (type locality and type area)

Mesoproterozoic:

- Continental Granodiorite (type area)
- Rincon Valley Granodiorite (type area)

Pennsylvanian:

- Black Prince Limestone (type section)

Permian:

- Snyder Hill Formation (type locality)
- Rainvalley Formation (type section)
- Concha Limestone (type section and reference section)
- Scherrer Formation (type section)

Triassic–Jurassic:

- Walnut Gap Formation (type section)

Cretaceous:

- Willow Canyon Formation (type section)
- Shellenberger Canyon Formation (type section)
- Apache Canyon Formation (type section)
- Fort Crittenden Formation (reference section)
- Turney Ranch Formation (type section)

Cretaceous–Paleocene:

- Wrong Mountain Quartz Monzonite (type area)

Oligocene–Miocene:

- Pantano Formation (type section)

Pliocene–Pleistocene:

- St. David Formation (type section)

TONT

Paleoproterozoic:

- Pinal Schist (type area)

Mesoproterozoic:

- Dripping Spring Quartzite (type section and 2 reference sections)
- Troy Quartzite (reference section)
- Mescal Limestone (reference section)

Cambrian:

- Tonto Group (type locality)

Miocene:

- Whitlow Canyon Formation (type section)
- Tule Canyon Formation (type section)
- Superstition Tuff (Superstition Group of Ferguson and Trapp 2001) (type area)
- Superstition Tuff, Canyon Lake Member (type section)
- Superstition Tuff, Dogie Spring Member (type section)
- Superstition Tuff, Hieroglyphic Member (type area)
- Superstition Tuff, Siphon Draw Member (type section)
- Government Well Formation (type section)
- Geronimo Head Formation (type section)
- Coffee Flat Mountain Formation (type area)
- Picketpost Mountain Formation (type section)
- Apache Leap Tuff (type section)
- Sleeping Buffalo Rhyolite, Arnett Member (type locality)

TUMA

Mesoproterozoic:

- Continental Granodiorite (type area)

Permian:

- Concha Limestone (reference section)
- Rainvalley Formation (type section)

Cretaceous:

- Salero Formation (type area)
- Fort Crittenden Formation (reference section)

Paleocene:

- Gringo Gulch Volcanics (type area)

Oligocene:

- Grosvenor Hill Volcanics (type area)

Miocene–Pliocene:

- Nogales Formation (type area)

TUZI

Paleoproterozoic:

- Texas Gulch Formation (type section)
- Cherry Springs Tonalite (type locality)
- Big Bug Group (type locality)

Devonian:

- Martin Formation, Jerome Member (type section)

Permian:

- Schnebly Hill Formation (type section)
- Schnebly Hill Formation, Bell Rock Member (type section)
- Schnebly Hill Formation, Rancho Rojo Member (type section)
- Schnebly Hill Formation, Sycamore Pass Member (type section)
- Coconino Sandstone, Cave Spring Sandstone Member (type section)
- Coconino Sandstone, Harding Point Sandstone Member (type section)

Oligocene–Miocene:

- Sullivan Buttes Latite (type locality)

Miocene:

- Hickey Formation (type section)

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior



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