# The National Park Service Stratotype Inventory

By Tim C. Henderson, Vincent L. Santucci, Justin S. Tweet, Tim Connors, Nancy R. Stamm, Randall C. Orndorff, David R. Soller, and Cullen Scheland

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# Abbreviations

| | |
|---|---|
| Geolex | U.S. Geological Survey Geologic Names Lexicon |
| GSRI | Geologic and Soil Resources Inventory |
| GSSP | global boundary stratotype section and point |
| I&M | Inventory and Monitoring |
| NACSN | North American Commission on Stratigraphic Nomenclature |
| NPS | National Park Service |
| PLSS | Public Land Survey System |
| USGS | U.S. Geological Survey |

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## Chapter B

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By Tim C. Henderson,[1,2] Vincent L. Santucci,[2] Justin S. Tweet,[2] Tim Connors,[3] Nancy R. Stamm,[4] Randall C. Orndorff,[4] David R. Soller,[4] and Cullen Scheland[2]

## Introduction

### An Inventory of Stratigraphic Origins within the National Park Service

The geologic history of Earth is recorded in layers or bodies of rock that are classified in a hierarchical order with several different categories of geologic units, including: supergroup, group, formation, member, bed, supersuite, suite, or complex. Geologists analyze and classify rock types based on properties that include lithology, texture, thickness, sedimentary structures, fossils, geographic or geospatial distribution, and age. In instances where new geologic units are proposed, a stratotype is assigned to a designated section, locality, or area of well-exposed rock that displays diagnostic characteristics for identification and correlation. Stratotypes are also namesakes, in that formally recognized rock units are named for the places where they were first described, measured, and mapped. Thus, a vast majority of the stratigraphic nomenclature alludes to geographic or geologic features. Some particularly recognizable examples (and their stratotype assignments) include the Paleoproterozoic Vishnu Schist (Vishnu Canyon in Grand Canyon National Park, Arizona), the Early Cambrian Harpers Formation (Harpers Ferry National Historical Park, West Virginia), and the Late Cretaceous Whitney Granodiorite (Mount Whitney in Sequoia and Kings Canyon National Parks, California).

Beginning in 2020, the National Park Service (NPS) began a systematic effort to document the occurrence of stratotypes exposed within, partially within, and near NPS administrative boundaries. The NPS stratotype inventory project represents an important component of a geologic resource inventory, as these designations are vital to our national geologic heritage (herein referred to as "geoheritage") and possess significant scientific, historic, educational, cultural, and aesthetic values. The geoheritage significance of stratotypes is analogous to libraries and museums, in that they are geologic landmarks of Earth history and record the prodigious forces and evolving life forms that define our understanding of the planet. These designated exposures preserve knowledge, represent comparative geologic references where previous observations can be re-examined or reinterpreted, and can serve as valuable educational tools for future geoscientists (Brocx and others, 2019).

The NPS stratotype inventory includes the following:

- Documentation of designated stratotype exposures to confirm their geospatial occurrence within, partially within, and near NPS administrative boundaries, compiled from published reports and maps;
- Compilation and visualization of the precise geographic locations of the stratotype exposures; and
- Recommendations that address potential land and resource management issues associated with NPS stratotypes.

By achieving these goals, this project helps to raise awareness of stratotypes as a geologic resource by educating NPS staff and the public so that they may better understand, recognize, and protect these important park resources. The focused approach adopted for conducting the stratotype inventories throughout the NPS has centered on the 32 Inventory and Monitoring (I&M) networks established by the NPS during the late 1990s (for more information on each network, see https://www.nps.gov/im/networks.htm). The I&M networks represent groups or clusters of park units that are based on shared geography and natural resource characteristics. The Greater Yellowstone I&M Network, encompassing Bighorn Canyon National Recreation Area, Grand Teton National Park, John D. Rockefeller Jr. Memorial Parkway, and Yellowstone National Park, was used as the pilot network for initiating this stratotype inventory and was first published in November 2020 (Henderson and others, 2020). The 32d and final report on the Northeast Temperate I&M Network was published in October 2022 (Henderson and others, 2022). Currently, the NPS stratotype inventory project has identified more than 700 stratotypes within NPS administrative boundaries.

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## Stratotypes Come in Many (Land)Forms

An important designation for any newly proposed geologic unit is a stratotype, as it is the standard constituting the basis for definition or recognition of that unit. Stratotypes are not limited to any particular rock type and can occur in both natural (river bluff, mountain peak, coastal cliff, volcanic edifice, and so forth) and anthropogenic (that is, road-, rail-, trail-, and canal cuts, quarry walls, tunnels, and so forth) exposures. For clarity and consistency in reporting, the NPS stratotype inventory follows the definition of stratotypes outlined in article 8 of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature [NACSN], 2021). The North American Stratigraphic Code standardizes stratigraphic concepts, principles, and definitions, which provides a common language that outlines explicit practices for classifying and naming formally defined geologic units. However, there are several variations of stratotype assigned by geologists that differ based on function (chronostratigraphy versus lithostratigraphy), lithology, and geographic extent. These are described here:

1. **Type section:** A stratified deposit that serves as the standard for recognition and definition of a geologic unit. Once a type section is designated, it is never abandoned nor changed. However, if it proves inadequate, it may be supplemented by a reference section(s) (NACSN, 2021). Typically, type sections are geographically restricted to one or two well-defined exposure locations.

2. **Type locality:** The specific geographic locality encompassing the type section of a formally recognized and defined unit. In many early reports, type localities (and type areas) were stated to be the exposures at and near the geographic feature from which the unit was named. Today, with advances in geographic positioning systems, the methodology of proposing stratotypes is a rigorously defined process that is standardized and codified by the professional geologic community (see NACSN, 2021; Stamm, 2023).

3. **Type area:** For sedimentary rocks, the type area is a broader geographic territory that encompasses the type locality. For mappable units of crystalline igneous and high-grade metamorphic rock known as "lithodemes," the type area is equivalent to a type section (NACSN, 2021).

4. **Reference section:** A reference section serves as an invaluable designation that helps define, refine, and supplement other stratotypes, especially for geologic units that are extremely heterogeneous, containing a diverse suite of diagnostic features not found in a single location. Of particular significance are principal reference sections, such as (1) lectostratotypes, designated to serve as type sections for well-established geologic units that were proposed prior to the modern system of classification and nomenclature and lack a type section, locality, or area, and (2) neostratotypes, designated to serve as replacement type sections for geologic units whose types have been destroyed, covered, or otherwise made inaccessible (NACSN, 2021).

5. **Chronostratigraphic global boundary stratotype section and point (GSSP; also referred to as a "golden spike"):** a geologic section that serves as the material reference for the lower boundary of an internationally recognized stage (Remané and others, 1996; Cohen and others, 2013). The base of the Roadian, Wordian, and Capitanian Stages of the Guadalupian Series (middle Permian) are recognized at Guadalupe Mountains National Park, Texas (Henderson and Shen, 2020; Wu and others, 2020; Shen and others, 2022).

## Methods

Determining whether a stratotype occurs within an NPS administrative boundary involves multiple steps. The process begins with an evaluation of existing geologic maps and reports to prepare a full list of recognized geologic units present in a park-specific region. Each geologic unit name is queried in the U.S. Geological Survey (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, age, stratigraphic nomenclature history, strata relationships (formations comprising a group, and so forth), and published stratotype location descriptions. The Geolex database also provides links to relevant scientific publications as well as previously published geologic names lexicons (for example, Wilmarth, 1938; Keroher and others, 1966) and the USGS Geologic Names Committee archives (for example, https://ngmdb.usgs.gov/Geolex/stratres/cards).

Historically, geologists have typically published stratotype geospatial information in three common formats: (1) descriptive, using distance measurements from prominent, nearby geographic or topographic features; (2) latitude and longitude coordinates or Universal Transverse Mercator coordinates; or (3) Public Land Survey System (PLSS) locations using township/range/section coordinates. A detailed procedural outline for describing stratotype locations is provided in Stamm (2023). In order to pinpoint stratotype locations, a degree of geologic detective work is necessary that utilizes a number of applications and services including Earth Point (https://www.earthpoint.us/), Google Earth (https://earth.google.com/), and USGS MapView (beta) by the National Geologic Map Database (https://ngmdb.usgs.gov/mapview/). USGS MapView (beta) provides geologic bedrock and surficial maps at multiple scales, topographic maps, aerial imagery, various coordinate systems, and a map overlay opacity function that allows users to quicky navigate

and locate geographic or geologic features. Individual stratotype sites are mapped as points in Google Earth, using a NPS Geologic and Soil Resources Inventory (GSRI) digital geologic map layer draped over the data. The GSRI digital maps help improve accuracy, justify stratotype location points within NPS boundaries, and validate the points against published descriptions. Stratotype exposures described using PLSS coordinates can be converted into Google Earth-compatible KML files (.kml) using Earth Point's "Township & Range – Search By Description" feature (https://www.earthpoint.us/TownshipsSearchByDescription.aspx). Plotted stratotype locations in Google Earth are then converted into an ArcGIS-compatible shapefile format (including .cpg, .dbf, .prj, .sbn, .sbx, .shp, and .shx files) to generate park-specific stratotype maps.

In addition to mapping published stratotype locations, a digital inventory spreadsheet was created for each I&M network that contains detailed information from published journals and maps. The inventory spreadsheets are populated with the following data considered pertinent to the geologic units and their stratotype attributes: (1) whether a stratotype is formally designated; (2) whether the stratotype is within NPS administrative boundaries; (3) whether the stratotype location has undergone a quality control check in Google Earth using the GSRI digital geologic map; (4) reference publication(s) citing the stratotype; (5) description of geospatial information; (6) geospatial coordinates; (7) geologic age (era, period, epoch, and so forth); (8) hierarchical rank (supergroup, group, formation, member, bed, and so forth); and (9) a generic notes field.

There are several considerations to keep in mind. 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 network stratotype reports. The NPS stratotype inventory does not include any field work and is dependent on existing published information related to individual park geology and stratigraphy. Additionally, the NPS stratotype inventory project does not attempt to resolve any unresolved or controversial stratigraphic interpretations, as this 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 or other jurisdictional boundaries. Geologic formations and their stratigraphic equivalents that cross these boundaries may have different names or ranks in each of the states the units are mapped. For example, the Jurassic Aztec Sandstone in Nevada and California is equivalent to the Navajo Sandstone in Utah and Arizona, which is also equivalent to the Nugget Sandstone in Wyoming.

# Results

## Abundance and Distribution of NPS Stratotypes

Since summer 2020, the NPS stratotype inventory team has worked closely with the USGS, State Geological Surveys, academic institutions, and NPS staff to publish technical reports for all 32 I&M networks (fig. 1). The entire report series is available online at the NPS stratotype inventory website (NPS, 2024) and the Integrated Resource Management Applications portal (https://irma.nps.gov/DataStore/Search/Quick). Included in each report are tables, maps, photographs, and descriptions of stratotypes confirmed within NPS boundaries, as well as a recommendation section that addresses outstanding issues, management considerations, and future steps regarding stratotype monitoring. These recommendations can be used to inform and guide decision-making to help protect geoheritage resources and avoid adverse impacts on the stability and condition of these geologic exposures from proposed park activities or development (see section "National Park Service Stratotypes, Geoheritage, and Geoconservation" below). Additionally, digital inventory spreadsheets were produced for each set of network parks that address the various geologic units mapped within NPS administrative boundaries as well as their detailed stratotype location descriptions (see "Methods" section above).

As of 2025, the NPS stratotype inventory project has confirmed more than 700 stratotypes located across more than 100 individual parks. These resources span the continental United States but also include Alaska, Hawai'i, Guam, American Samoa, and the U.S. Virgin Islands (fig. 2). The NPS has recently published a geospatial dataset that maps stratotype locations across the National Park System (Henderson and others, 2024). In order to protect sensitive stratotype locality information, both a public and restricted (NPS-only) version of the dataset have been published. The geospatial product contains various stratotype-related attributes (for example, geologic unit name, geologic age, NPS park site, stratotype variation, stratotype designation descriptions [restricted version only], references, lithology, state, and county) that may help in the monitoring or protection of these resources.

The stratotype attribute data can be sorted and analyzed geographically by individual park site, I&M network, and state, in addition to other factors such as geologic age (figs. 2–3; tables 1–4). Most of the ten NPS parks with the greatest numbers of stratotypes are concentrated in the western United States in some of the most popular parks of the country (table 1). Factors that heavily influence the overall number of stratotypes in a given park include the accessibility (including geographic controls on vegetative cover), complexity, and diversity of the regional geology combined with the duration of scientific exploration and research. Many of the remarkable geologic landscapes of the top ten national parks have a demonstrated research history and have been studied by geologists since the early 19th century.

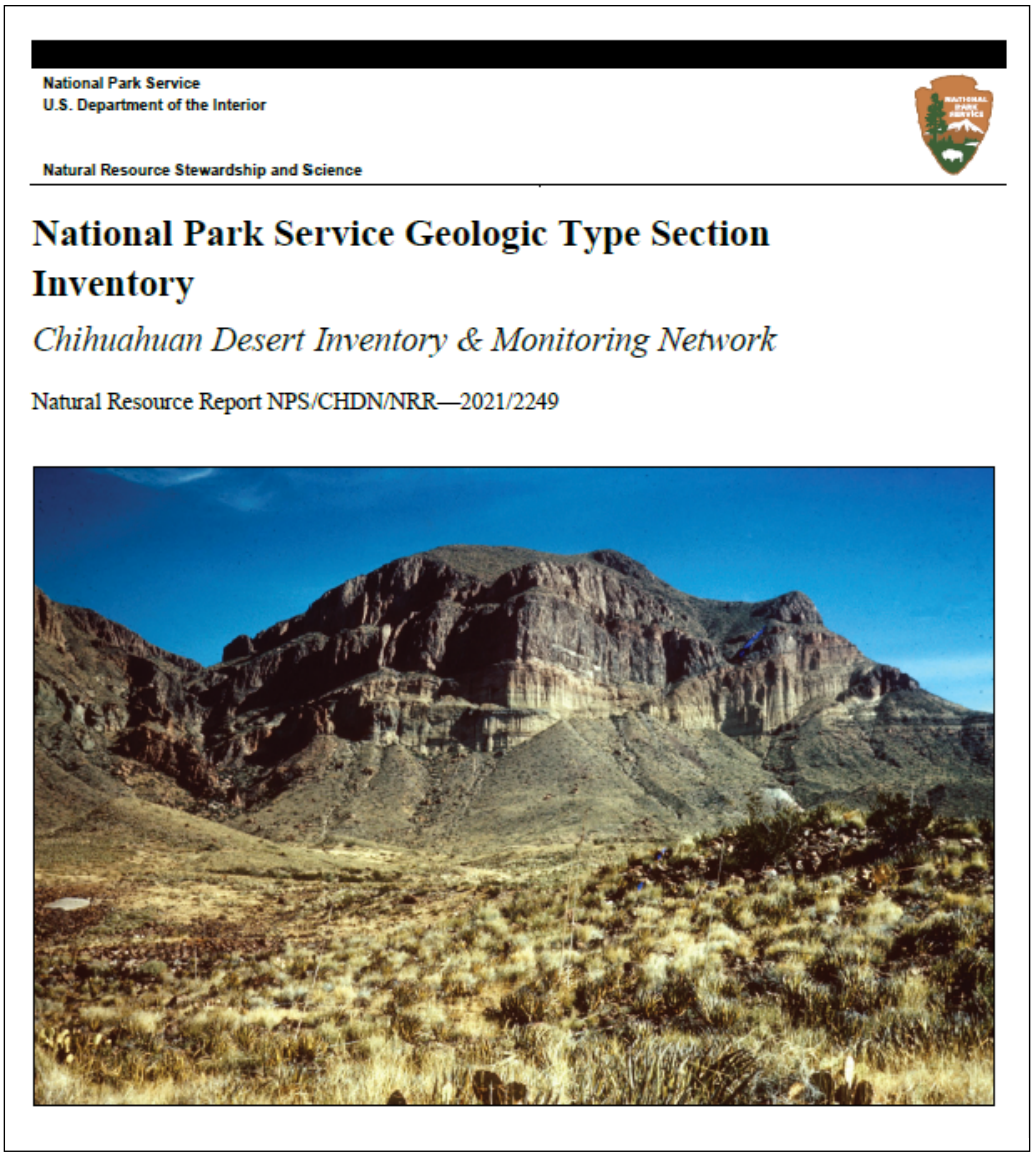
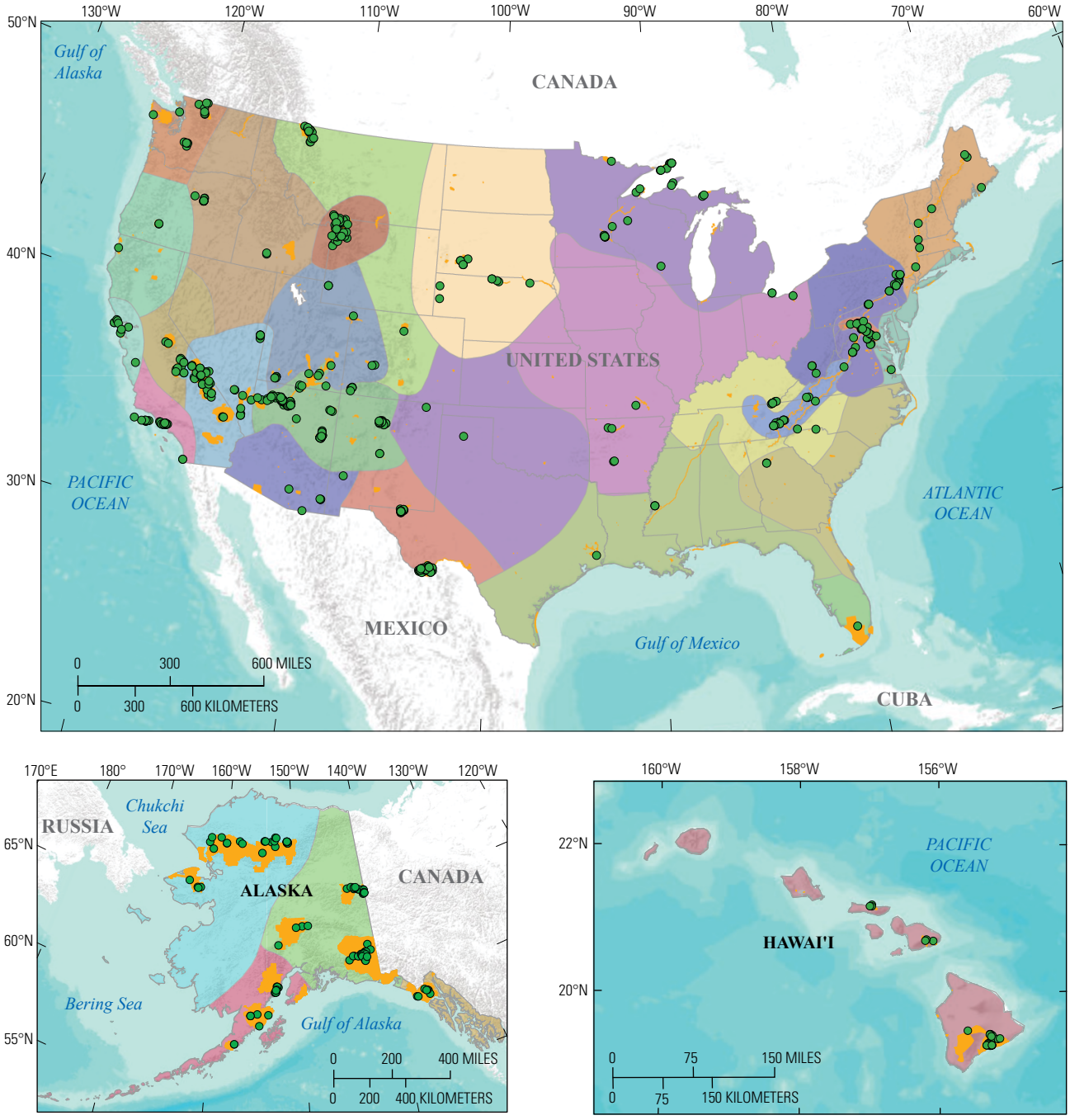



**Figure 1.** Image showing an example National Park Service stratotype inventory report for the Chihuahuan Desert Inventory and Monitoring Network. The entire 32 report series can be found at the National Park Service stratotype inventory website (National Park Service, 2024) and the Integrated Resource Management Applications portal (https://irma.nps.gov/DataStore/Search/Quick).

**Figure 2. (page 5)** Map showing stratotype distribution across the National Park System broken down by individual park, state, and Inventory and Monitoring network. Currently more than 700 stratotypes have been documented from 100 individual parks of the National Park System. The distribution (and number of stratotypes) includes the continental United States (567), Alaska (101), and Hawai'i (35); not shown in the figure are stratotypes located in American Samoa (1), Guam (1), and the U.S. Virgin Islands (1).




Base maps from Esri and its licensors, 2024
Contiguous USA Albers projection
World Geodetic System of 1984

## EXPLANATION

- **National Park Service unit**
- **Inventory and Monitoring networks**
- Appalachian Highlands
- Arctic
- Central Alaska
- Chihuahuan Desert
- Cumberland Piedmont
- Eastern Rivers and Mountains
- Great Lakes
- Greater Yellowstone
- Gulf Coast
- Heartland
- Klamath
- Mediterranean Coast
- Mid-Atlantic
- Mojave Desert
- National Capital Region
- North Coast and Cascades
- Northeast Coastal and Barrier
- Northeast Temperate
- Northern Colorado Plateau
- Northern Great Plains
- Pacific Islands
- Rocky Mountain
- San Francisco Bay Area
- Sierra Nevada
- Sonoran Desert
- South Florida/Caribbean
- Southeast Alaska
- Southeast Coast
- Southern Colorado Plateau
- Southern Plains
- Southwest Alaska
- Upper Columbia Basin
- **National Park Service stratotype**

**Table 1.** National Park Service parks with the greatest number of stratotypes.

[NPS, National Park Service]

| NPS park unit (NPS code) | Number of stratotypes |
|---|---|
| Grand Canyon National Park (GRCA) | 54 |
| Death Valley National Park (DEVA) | 45 |
| Petrified Forest National Park (PEFO) | 39 |
| Yellowstone National Park (YELL) | 33 |
| Big Bend National Park (BIBE) | 31 |
| Hawai‘i Volcanoes National Park (HAVO) | 29 |
| Appalachian National Scenic Trail (APPA) | 28 |
| Wrangell-St. Elias National Park and Preserve (WRST) | 26 |
| Santa Monica Mountains National Recreation Area (SAMO) | 25 |
| Guadalupe Mountains National Park (GUMO) | 24 |

**Table 2.** National Park Service Inventory and Monitoring networks with the greatest number of stratotypes.

[NPS, National Park Service]

| Inventory and Monitoring network (NPS code) | Number of stratotypes |
|---|---|
| Southern Colorado Plateau Network (SCPN) | 127 |
| Mojave Desert Network (MOJN) | 63 |
| Chihuahuan Desert Network (CHDN) | 55 |
| Central Alaska Network (CAKN) | 47 |
| Greater Yellowstone Network (GRYN) | 39 |

**Table 3.** The top five states with the greatest number of National Park Service stratotypes.

| State | Number of stratotypes |
|---|---|
| Arizona | 113 |
| California | 111 |
| Alaska | 101 |
| Texas | 57 |
| Hawai‘i | 35 |

**Table 4.** Total number of stratotypes within the National Park System categorized by geologic age.

| Geologic age | Number of stratotypes |
|---|---|
| Quaternary | 101 |
| Neogene | 87 |
| Cretaceous | 70 |
| Paleogene | 63 |
| Cambrian | 57 |
| Triassic | 57 |
| Neoproterozoic | 52 |
| Carboniferous | 49 |
| Mesoproterozoic | 47 |
| Permian | 43 |
| Devonian | 42 |
| Jurassic | 30 |
| Ordovician | 21 |
| Silurian | 15 |
| Paleoproterozoic | 8 |
| Archean | 2 |

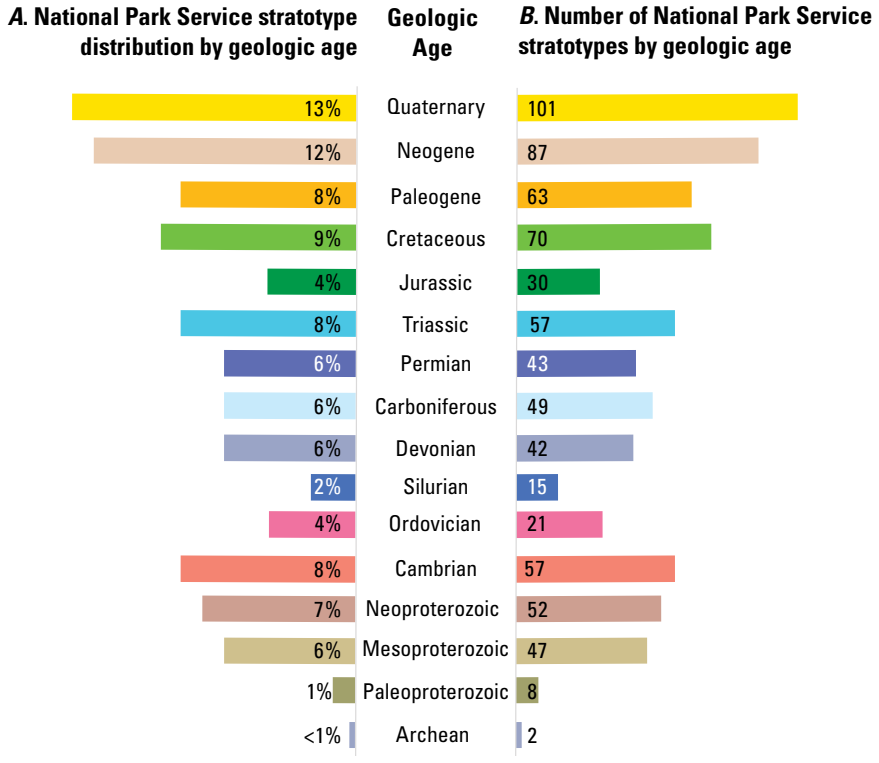



**Figure 3.** Diagrams showing National Park Service stratotypes broken down by geologic age. *A*, Bar graph showing the geologic age distribution as a percentage (%), in order from oldest (Archean) to youngest (Quaternary). *B*, Bar graph showing number of stratotypes by geologic age in order from oldest to youngest using recorded totals.

## NPS Stratotypes, Geoheritage, and Geoconservation

Although stratotypes are geologic reference exposures and are inherently scientific in nature, these geoheritage resources also provide aesthetic, cultural, educational, and historical values. Across the country, stratotypes can be identified in many of the popular landscape features within the National Park System. For example, the iconic layer-cake stratigraphy at Grand Canyon National Park, Arizona, provides some of the most beautiful scenic views in the country. The extensive, well-exposed nature of the rocks, combined with a long history of geologic research, has resulted in the largest documented number of stratotypes amongst all other national parks (fig. 4). At Guadalupe Mountains National Park, Texas, the middle Permian reef complex records an exceptional depositional succession of strata that are internationally renowned. In fact, for this reason, the International Commission on Stratigraphy selected this section of rocks to be the exemplar of the middle Permian and hence named the series the Guadalupian (Henderson and Shen, 2020; Wu and others, 2020). Additionally, the three named stages of the Guadalupian Series, the Roadian, Wordian, and Capitanian in ascending order, have GSSPs that are located within the park (fig. 5). At Mesa

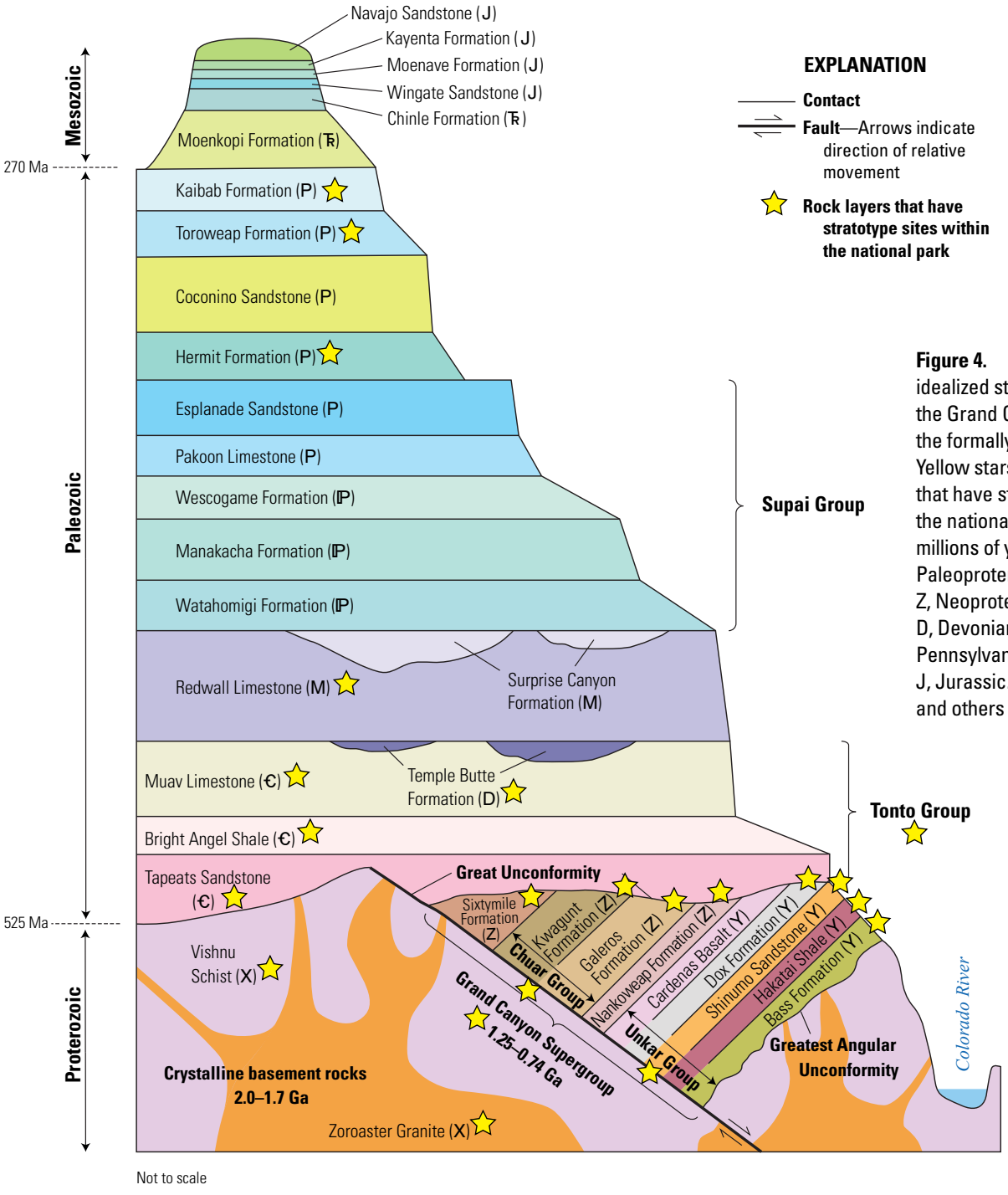
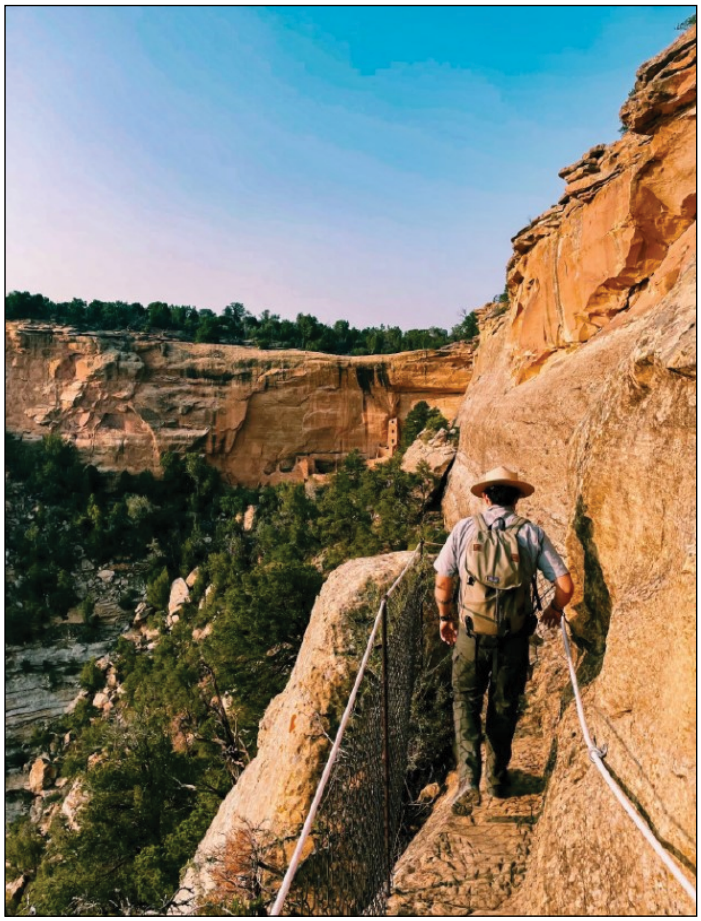



**Figure 4.** Illustration showing the idealized stratigraphic column of the Grand Canyon, showing all of the formally named rock formations. Yellow stars indicate rock layers that have stratotype sites within the national park. "Ma" refers to millions of years before present. X, Paleoproterozoic; Y, Mesoproterozoic; Z, Neoproterozoic; Є, Cambrian; D, Devonian; M, Mississippian; ℙ, Pennsylvanian; P, Permian; Ŧr, Triassic; J, Jurassic. Modified from Billingsley and others (2019).




**Figure 5.** Photograph showing the global boundary stratotype section and point (GSSP) golden spike marker for the base of the Wordian Stage of the Guadalupian Series (middle Permian) at Guadalupe Mountains National Park, Texas. This is one of three GSSP markers within the park that define the bases of the three stages of the middle Permian. Photograph by National Park Service.



Verde National Park, Colorado, stratotype designations for Cretaceous rocks comprise some of the sheer sandstone cliffs that surround the Indigenous cliff dwellings considered integral to the park's cultural and regional history (fig. 6). The famous Specimen Ridge in Yellowstone National Park, Wyoming, is part of an assigned stratotype area containing what are referred to as "fossil forests" of excellently preserved, Eocene petrified tree stumps in their original upright growth positions (fig. 7). On a historical note, many of the stratotypes assigned at Big Bend National Park, Texas, were designated by the first park superintendent (and geologist) Ross Maxwell. The previous examples are just a small representation of the diverse geoheritage stories associated with stratotypes across the National Park System.

**Figure 6.** Photograph showing exposures of the Upper Cretaceous Cliff House Sandstone in Mesa Verde National Park, Colorado. The stratotype is designated in the Echo Cliffs in the southern part of the park, where the formation consists of compact sandstone that forms the sheer canyon cliffs into which the Indigenous cliff dwellings were constructed. Photograph by National Park Service.



**Figure 7.** Photograph showing stratotype exposures of the Eocene Lamar River Formation at Specimen Ridge, Yellowstone National Park, Wyoming. Volcanic conglomerates, breccias, and tuffs of the Lamar River Formation are known to contain some of the most impressive and best-preserved fossil forests in the park. Photograph by National Park Service.

Given the importance of stratotypes as geoheritage resources, these locations merit some degree of preservation or protection within NPS administered areas. The following three characteristics, important to the utility of these resources, are considerations for potential stratotype monitoring:

1. **Visibility:** the described rock exposures remain visible and are not totally or partially obscured;
2. **Accessibility:** the exposures at the stratotype designation remain safely and reasonably accessible via road, trail, or other method; and
3. **Unaltered integrity:** the rock exposures are not altered significantly following description.

Stratotype management strategies could 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 commonly occur over large geographic areas with less emphasis or significance placed on individual exposures. Alternatively, type sections are specific localities that may warrant more focused management attention. More detailed information about NPS stratotype management is included within the report series (see NPS, 2022).

The visibility, accessibility, and unaltered integrity of stratotype exposures are susceptible to both natural processes (that is, climate change, erosion, slope movements, tectonism and (or) volcanism, vegetation encroachment) and human activities (that is, infrastructure development, graffiti, vandalism, theft, scientific research sampling, visitor use). Regarding management considerations, the protection of geoheritage sites such as stratotypes is a challenging task as nature is an unstoppable erosive agent—it is inevitable that stratotype designations will degrade and (or) be lost through time. In fact, multiple incidents of stratotype loss have already been documented within the NPS, stemming from various natural and human disturbances including urban development (the Pleistocene Las Vegas Formation at Tule Springs Fossil Beds National Monument, Nevada), road construction projects (the Neoproterozoic Swift Run Formation at Shenandoah National Park, Virginia), and burial by volcanic activity (the Holocene Uēkahuna Ash [Fiske and others, 2009; therein spelled “Uwēkahuna Ash”] at Hawai‘i Volcanoes National Park). However, this inventory of NPS stratotypes fills a void in basic geologic resource information documented by most park units and can be used to educate NPS staff, the public, and scientific community so they are aware of the abundance, importance, location, and condition of these resources.

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