National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

Upper Columbia Basin Inventory & Monitoring Network

Natural Resource Report NPS/UCBN/NRR—2022/2377

ON THE COVER
The steep canyon walls of Picture Gorge in John Day Fossil Beds National Monument, type locality of the Miocene Picture Gorge Basalt and Dayville Basalt of the Columbia River Basalt Group. Photo taken by the US Forest Service (Pacific Northwest Region).

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Contents

Contents (continued)

Figures

Figures (continued)

Page

Tables

Page

Photographs

Page

Executive Summary

A fundamental responsibility of the National Park Service (NPS) is to ensure that the resources of the National Park System are preserved, protected, and managed in consideration of the resources themselves and for the benefit and enjoyment by the public. Through the inventory, monitoring, and study of park resources, we gain a greater understanding of the scope, significance, distribution, and management issues associated with these resources and their use. This baseline of natural resource information is available to inform park managers, scientists, stakeholders, and the public about the conditions of these resources and the factors or activities that may threaten or influence their stability and preservation.

There are several different categories of geologic or stratigraphic units (supergroup, group, formation, member, bed) that form a hierarchical system of classification. The mapping of stratigraphic units involves the evaluation of lithologies (rock types), 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). The type section is an important reference exposure for a named geologic unit that presents a relatively complete and representative example for this unit. Geologic stratotypes are important both historically and scientifically, and should be available for other researchers to evaluate in the future.

The inventory of all geologic stratotypes throughout the 423 units of the NPS is an important effort in documenting these locations in order that NPS staff recognize and protect these areas for future studies. The focus adopted for completing the baseline inventories throughout the NPS is centered on the 32 inventory and monitoring networks (I&M) established during the late 1990s. The I&M networks are clusters of parks within a defined geographic area based on the ecoregions of North America (Fenneman 1946; Bailey 1976; Omernik 1987). These networks share similar physical resources (geology, hydrology, climate), biological resources (flora, fauna), and ecological characteristics. Specialists familiar with the resources and ecological parameters of the network, and associated parks, work with park staff to support network-level activities (inventory, monitoring, research, data management).

Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks. The planning team from the NPS Geologic Resources Division who proposed and designed this inventory selected the Greater Yellowstone Inventory & Monitoring Network (GRYN) as the pilot network for initiating this project (Henderson et al. 2020). Through the research undertaken to identify the geologic stratotypes within the parks of the GRYN, methodologies for data mining and reporting on these resources were established. Methodologies and reporting adopted for the GRYN have been used in the development of this report for the Upper Columbia Basin Inventory & Monitoring Network (UCBN).

The goal of this project is to consolidate information pertaining to geologic type sections 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 landmarks and geologic heritage resources. The review of stratotype occurrences for the UCBN shows there are currently no designated stratotypes for Big Hole National Battlefield (BIHO), City of Rocks National Reserve (CIRO), Craters of the Moon National Monument and Preserve (CRMO), Lake Roosevelt National Recreation Area (LARO), Minidoka National Historic Site (MIIN), Nez Perce National Historical Park (NEPE), and Whitman Mission National Historic Site (WHMI). Hagerman Fossil Beds National Monument (HAFO) has one type locality and one reference section; and John Day Fossil Beds National Monument (JODA) has two type sections, five type localities, two type areas, and two reference localities (Table 1).

This report concludes with 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 geoheritage 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 UCBN stratotype units sorted by park unit and geologic age, with associated reference publications and locations. Units without GRI map symbols are not currently included on a GRI map.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
HAFO	Yahoo Clay (Qy)	Malde 1982	**Type locality**: exposures ~6.4 km (4 mi) south-southwest of Hagerman, ID, near mouth of Yahoo Creek, where it joins with Snake River, along boundary of Hagerman Fossil Beds National Monument, in secs. 3, 4, and 5, T. 8 S., R. 13 E. [Hagerman 7.5′ Quadrangle], Twin Falls County, ID. **Reference section**: Canyon wall of the Snake River, west and southwest of Hagerman, Falls Co, ID.	Pleistocene
JODA	Rattlesnake Formation (Qtr)	Merriam et al. 1925; Enlows 1973, 1976	**Type section** (composite): 1. exposures in the butte west of Picture Gorge on Rattlesnake Creek, in SW/4 sec. 19, T. 12 S., R. 26. E.; and 2) exposures on the east side of Cottonwood Creek, in SW/4 sec. 33, T. 12 S., R. 26 E., Grant County, OR. **Type locality**: exposures along the John Day River where the river enters Picture Gorge, approximately 8.8 km (5.5 mi) west of Dayville, Grant County, OR.	Miocene
JODA	Rattlesnake Ash-Flow Tuff, Rattlesnake Formation (Qtr)	Enlows 1976; Walker 1979	**Reference locality** (former type locality): on Rattlesnake Creek about 1.6 km (1 mi) west of Cottonwood Creek, Grant County, OR.	Miocene
JODA	Mascall Formation (Tm)	Merriam et al. 1925	**Type locality**: exposures along the John Day River where the river enters Picture Gorge, approximately 8.8 km (5.5 mi) west of Dayville, Grant County, OR.	Miocene
JODA	Picture Gorge Basalt, Columbia River Basalt Group (Tcrbp)	Waters 1961; Swanson et al. 1979	**Type section**: roadcuts along U.S. Highway 26 near junction with State Highway 19, in SW/4 sec. 17, NE/4 sec. 18, and NW/4 sec. 20, T. 12 S., R. 26 E., Picture Gorge West 7.5′ Quadrangle, Grant County, OR. **Type locality**: exposures in Picture Gorge, Grant County, OR.	Miocene
JODA	Dayville Basalt, Columbia River Basalt Group (Tcrbu)	Bailey 1989	**Type locality**: Picture Gorge, in S/2 sec. 18 and N/2 sec. 19, T. 12 S., R. 26 E., Grant County, OR.	Miocene
JODA	Camas Creek Member, Monument Mountain Basalt, Columbia River Basalt Group	Bailey 1989	**Reference locality**: Picture Gorge, in E/2 sec. 18, T. 12 S., R. 26 E., Grant County, OR.	Miocene
JODA	John Day Formation (Tjd)	Merriam 1901; Hunt and Stepleton 2004	**Type area**: exposures located north (downstream) along the John Day River from Picture Gorge towards Kimberly, Grant County, OR.	Eocene–Miocene

Table 1 (continued). List of UCBN stratotype units sorted by park unit and geologic age, with associated reference publications and locations. Units without GRI map symbols are not currently included on a GRI map.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
JODA	Turtle Cove Member, John Day Formation (Tjut, Tjlt)	Fisher and Rensberger 1972	**Type area**: exposures in sec. 32, T. 10 S., R. 26 E., Foree State Park, Picture Gorge Quadrangle, Grant County, OR.	Oligocene–Miocene
JODA	Overlook Tuff of Big Basin Member, John Day Formation	Bestland et al. 1997; Graham 2014a	**Type locality**: exposures west of the visitor overlook that outcrop at the base of "Rainbow Hill" in the Painted Hills unit, Wheeler County, OR.	Oligocene

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections of the national parks of the Upper Columbia Basin Inventory & Monitoring Network (UCBN). 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 (https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl?glx=1) and GEOLEX (https://ngmdb.usgs.gov/Geolex/search, the U.S. Geologic Names Lexicon, a national compilation of names and descriptions of geologic units), critical sources of geologic information for science, industry, and the American public.

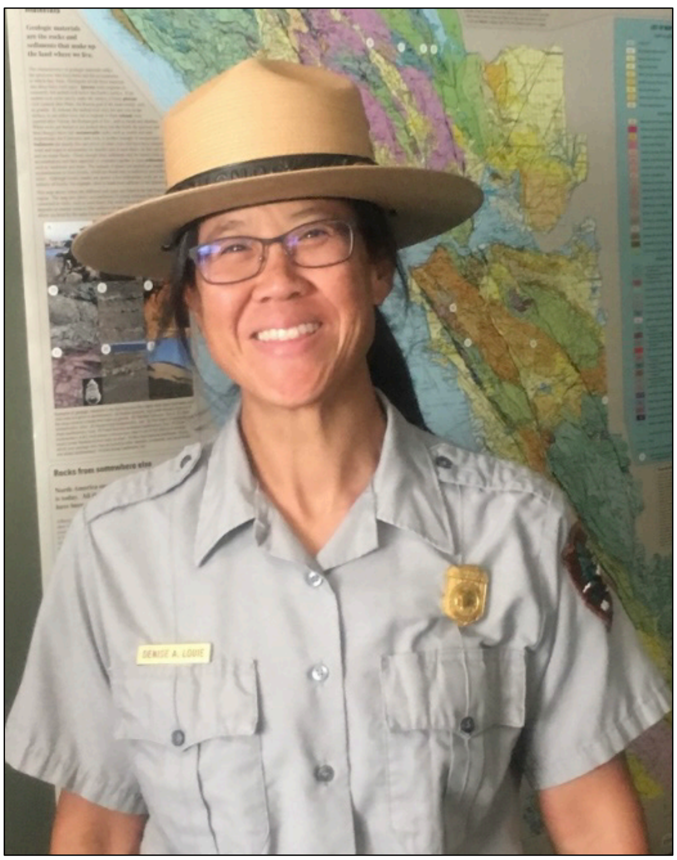
We thank our colleagues and partners in the Geological Society of America (GSA) and Stewards Individual Placement Program for their continued support to the NPS with the placement of geologic interns and other ventures. We thank also the Oregon Department of Geology and Mineral Industries for the permission to reuse Figure 2 from Enlows (1976) as Figure 27. 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 UCBN and various network parks including: Gordon Dicus and Jeff Lonneker (UCBN), Kari Prassack (HAFO), and Nick Famoso (JODA). Additional thanks to Denise Louie, Jalyn Cummings and Ted Fremd (NPS retired) for continued support for this and other important geology projects in the Pacific West Region of the NPS. Jalyn served as peer review coordinator for this report. We also extend our gratitude to geologist Erick Bestland (Flinders University of South Australia) for his important contributions to the stratigraphic interpretation of the geology at JODA.

This project is made 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, Jason Kenworthy, Rebecca Port, and Jim Wood. 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 pleased to dedicate the Upper Columbia Basin Inventory & Monitoring Network Geologic Type Section Inventory report to Denise Louie, the Pacific West Region Natural Resources and Stewardship Program Lead. Denise joined the National Park Service in 1993 as a student trainee at Big Bend National Park, Texas, and was subsequently hired as the park's Vegetation Management Program Manager which she served from 1993 to 2000. Denise was hired as the Vegetation Management Program Manager at Zion National Park, Utah, in 2000 and served in this position until 2006. Between 2006 and 2015 Denise served as the Integrated Resources Program Lead at Pinnacles National Park, California. In 2015, Denise accepted the Assistant Team Lead in the Pacific West Region's Natural Resources & Stewardship Program and served in this position until 2020. Currently, Denise serves as the Program Lead for the Pacific West Region's Natural Resource Stewardship and Science, which she has served since 2020. We recognize the outstanding leadership consistently demonstrated by Denise for all NPS resources, including geologic and paleontologic resources. Thank you Denise!



Denise Louie, National Park Service Pacific West Region's Natural Resources and Science Program Lead (NPS).

Introduction

The NPS Geologic Type Section Inventory Project ("Stratotype Inventory Project") is a continuation of and complements the work performed by the Geologic Resources Inventory (GRI). The GRI is funded by the NPS Inventory & Monitoring Program and administered by the Geologic Resources Division (GRD). The GRI is designed to compile and present baseline geologic resource information available to park managers, and advance science-informed management of natural resources in the national parks. The goals of the GRI are to increase understanding and appreciation of the geologic features and processes in parks and provide robust geologic information for use in park planning, decision making, public education, and resource stewardship. Additional GRI information and products can be accessed on IRMA or the GRI publication page (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm).

Documentation of stratotypes (i.e., type sections/type localities/type areas; see "Definitions" below) that occur within national park boundaries represents a significant component of a geologic resource inventory, as these designations serve as the standard for defining and recognizing geologic units (North American Commission on Stratigraphic Nomenclature 2021). 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 students (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.

The goals of this project are to 1) systematically report the assigned stratotypes that occur within national park boundaries, 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. Additionally, numerous stratotypes are located geographically outside of national park boundaries; those within 48 km (30 mi) of park boundaries are mentioned briefly in this report because of their proximity to parks.

This geologic type section inventory for the parks of the Upper Columbia Basin Inventory & Monitoring Network (UCBN) follows standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network stratotype inventory (Henderson et al. 2020). All network-specific reports are prepared, peer-reviewed, and submitted to the Natural Resources Stewardship and Science Publications Office for finalization. A small team of geologists and paleontologists from the NPS Geologic Resources Division and the NPS Paleontology Program has taken responsibility for this important inventory for the NPS.

This inventory fills a void in basic geologic information compiled by the NPS at most parks. Instances where geologic stratotypes occur within NPS areas were determined through research of published geologic literature and maps. Sometimes the lack of specific locality or other data limited determination of whether a particular stratotype was located within NPS administered boundaries. Below are the primary justifications that warrant this inventory of NPS geologic stratotypes.

- Geologic stratotypes are a part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (https://www.nps.gov/articles/scientific-value.htm);
- Geologic stratotypes are important geologic landmarks and reference locations that define important scientific information associated with geologic strata. Geologic formations are frequently named after topographic or geologic features and landmarks that are recognizable to park staff;
- Geologic stratotypes are both historically and scientifically important components of earth science investigations and mapping;
- Understanding and interpreting the geologic record depends on the stratigraphic occurrences of mappable lithologic units (formations, members). These geologic units are the foundational attributes of geologic maps;
- Geologic maps are important tools for science, resource management, land use planning, and other areas and disciplines;
- Geologic stratotypes are similar in nature to type specimens in biology and paleontology, serving as the primary reference for defining distinctive characteristics and establishing accurate comparisons;
- Geologic stratotypes within NPS areas have not been previously inventoried and there is a general absence of baseline information for this geologic resource category;
- NPS staff may not be aware of the concept of geologic stratotypes and therefore would not understand the significance or occurrence of these natural references in the parks;
- Given the importance of geologic stratotypes as geologic references and geologic heritage resources, these locations should be afforded some level of preservation or protection when they occur within NPS areas;
- If NPS staff are unaware of geologic stratotypes within parks, the NPS cannot proactively monitor the stability, condition, or potential impacts to these locations during normal park operations or planning. This lack of information also hinders the protection of these localities from activities that may involve ground disturbance or construction.
- 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 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.

Geology and Stratigraphy of the UCBN I&M Network Parks

The Upper Columbia Basin Inventory and Monitoring Network (UCBN) consists of nine National Park Service (NPS) units in Idaho, western Montana, central and eastern Oregon, and eastern Washington (Figure 1). The network parks include: Big Hole National Battlefield (BIHO; Montana); City of Rocks National Reserve (CIRO; Idaho); Craters of the Moon National Monument and Preserve (CRMO; Idaho); Hagerman Fossil Beds National Monument (HAFO; Idaho); John Day Fossil Beds National Monument (JODA; Oregon); Lake Roosevelt National Recreation Area (LARO; Washington); Minidoka National Historic Site (MIIN; Idaho); Nez Perce National Historical Park (NEPE; Idaho, Montana, Oregon, Washington); and Whitman Mission National Historical Site (WHMI; Washington). The UCBN parks occupy more than 344,00 hectares (850,000 acres) of the Columbia Plateau and Snake River Plane geographic regions and preserve a rich diversity of both natural and cultural resources.

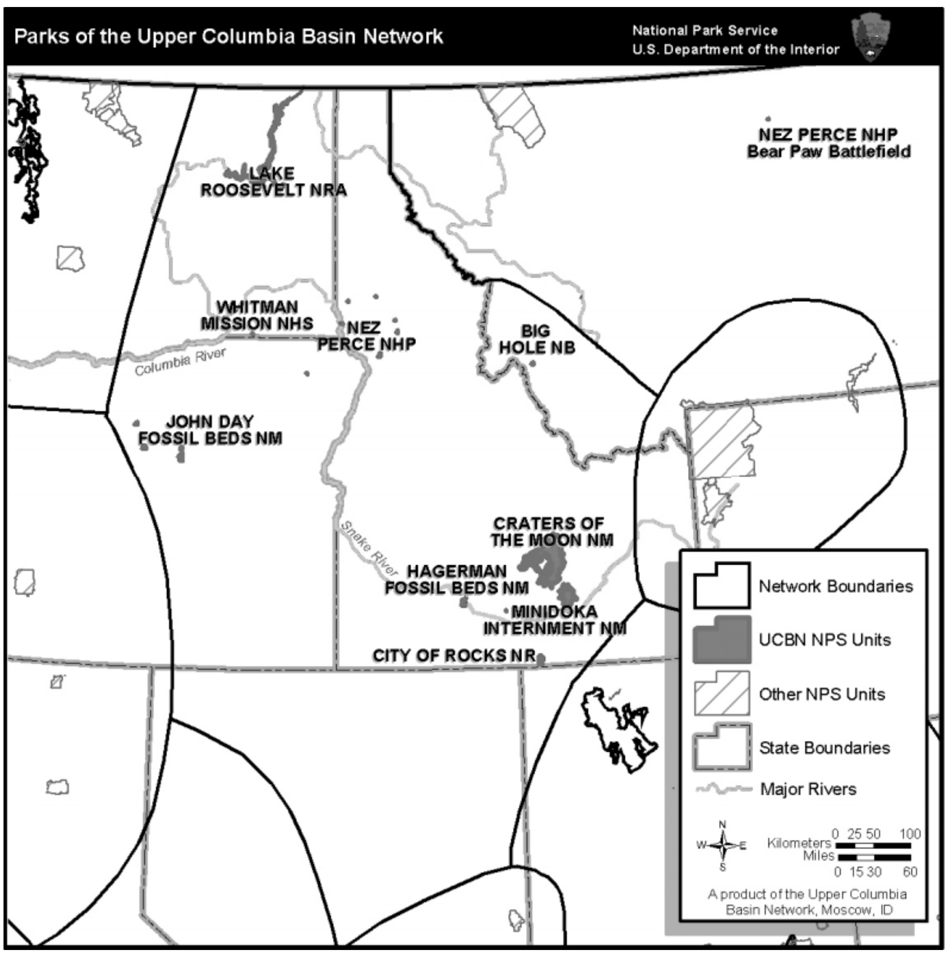


Figure 1. Map of Upper Columbia Basin I&M Network parks, including: Big Hole National Battlefield (BIHO), City of Rocks National Reserve (CIRO), Craters of the Moon National Monument and Preserve (CRMO), Hagerman Fossil Beds National Monument (HAFO), John Day Fossil Beds National Monument (JODA), Lake Roosevelt National Recreation Area (LARO), Minidoka National Historic Site (MIIN), Nez Perce National Historical Park (NEPE), and Whitman Mission National Historic Site (WHMI) (NPS).

Several UCBN parks include notable geologic resources. CIRO preserves very old Precambrian rocks including the granitic Almo Pluton and Green River Complex (see Appendix B for a geologic time scale). The reserve provides opportunities to study and learn about a variety of geologic features and processes such as arches, joints, panholes, and tafone formed through weathering, erosion, mass wasting and other geologic processes. CRMO hosts the largest basaltic lava field in the continental United States. At least 60 different lava flows have been mapped, ranging in age from the late Pleistocene into the Holocene. These volcanic sequences in CRMO include more than two dozen volcanic cones and are part of the larger Snake River Plain volcanic province. HAFO and JODA were both established primarily to preserve globally significant Cenozoic paleontological resources.

Precambrian

The oldest known rocks in UCBN parks are Archean granite, granite gneiss, schist, and amphibolite within CIRO. A sequence of Neoproterozoic units is mapped within CIRO, including: Elba Quartzite of Armstrong, Schist of the Upper Narrows, Quartzite of Yost, Schist of Stevens Springs, Quartzite of Clarks Basin, and Schist of Mahogany Peaks. The Neoproterozoic–early Cambrian Addy Quartzite is exposed in LARO.

Paleozoic

Extensive Paleozoic rocks occur in LARO, spanning from the early Cambrian through Permian. The oldest Paleozoic unit in LARO is the early Cambrian Gypsy Quartzite, which is overlain by the Maitlen Phyllite, including the Reeves Limestone Member, which is early–middle Cambrian in age. The Metaline Formation (Cambrian–Ordovician), Ledbetter Slate (Early–Middle Ordovician), Covada Group (Ordovician), a series of metasedimentary rocks (Devonian–Carboniferous), and the Mission Argillite (Permian) are also documented in LARO. Within CRMO the metamorphosed Pogonip Group is mapped, and the Mississippian Copper Basin Formation is also exposed.

Mesozoic

The only Triassic rocks in the network parks pertain to an unnamed Early Triassic limestone mapped in LARO. The Early Cretaceous Mitchell Group is exposed at JODA. The Late Cretaceous Judith River Formation occurs in the Bear Paw Battlefield unit of NEPE.

Cenozoic

The oldest known Cenozoic unit in the UCBN parks is the early–middle Eocene Clarno Formation at JODA. The John Day Formation spans from the middle Eocene into the Miocene at JODA. The Eocene–Miocene Bozeman Group is mapped at BIHO. The Miocene is well represented at JODA, including the upper John Day Formation, Picture Gorge Basalt (early Miocene), Mascall Formation (early–middle Miocene), and Rattlesnake Formation (late Miocene). The Miocene Columbia River Basalt Group and Latah Formation are exposed at several units of BIHO. The Upper Banbury Basalt is a late Miocene–early Pliocene unit present beneath the Pliocene Glenns Ferry Formation at HAFO. Pleistocene–Holocene sediments and alluvium are documented at all of the UCBN parks. The Tuana Gravel (early Pleistocene), Yahoo Clay (middle Pleistocene), and Crowsnest Gravel (late Pleistocene) are documented at HAFO. Quaternary glacial deposits including Vashon Drift and pre-Vashon deposits underlie portions of MIIN in Washington. Late Pleistocene and Holocene basalts are mapped at CRMO and MIIN (Snake River Basalt). The Touchet Beds are mapped at WHMI.

National Park Service Geologic Resource Inventory

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 in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division (GRD) of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The GRI team consists of a partnership between the GRD and the Colorado State University Department of Geosciences to produce GRI products.

GRI Products

The GRI team undertakes four tasks for each park in the Inventory and Monitoring program: 1) conduct a scoping meeting and provide a summary document; 2) provide digital geologic map data in a geographic information system (GIS) format; 3) create posters to display the GRI GIS data; and 4) provide a GRI report. These products are designed and written for non-geoscientists.

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 sessions were held on the following dates for the UCBN parks: CRMO on May 12–13, 1999; CIRO on June 16–17, 1999; LARO on September 10–11, 2002; HAFO on September 18, 2003; BIHO, NEPE, and WHMI on March 8–10, 2004; and JODA on April 27–28, 2004.

Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. As of 2022 GRI reports have been completed for CIRO, CRMO, HAFO, JODA, and WHMI; outstanding reports still include BIHO, LARO, and NEPE. The GRI team conducts no new field work in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). Additional information regarding the GRI, including contact information, is available at https://www.nps.gov/subjects/geology/gri.htm.

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the UCBN parks follows the selected source maps and includes components such as: faults, mine area features, mine point features, geologic contacts, geologic units (bedrock, surficial, glacial), geologic line features, structure contours, and so forth. These are commonly acceptable geologic features to include in a geologic map.

Posters display the data over imagery of the park and surrounding area. Complete GIS data are available at the GRI publications website: https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at, or beneath the land surface (Evans 2016). Color and sometimes symbols on geologic maps are used to distinguish geologic map units. The unit labels consist of an uppercase letter (or symbol for some ages) indicating the geologic age and lowercase letters indicating the formation's name. Other symbols depict structures such as faults or folds, locations of past geologic hazards that may be susceptible to future activity, and other geologic features. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) and work by Bernknopf et al. (1993) provide more information about geologic maps and their uses.

Geologic maps are typically one of three types: surficial, bedrock, or a combination of both. Surficial geologic maps typically encompass deposits that are unconsolidated and which formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type, geologic processes, and/or depositional environment. The GRI team has produced various maps for the UCBN parks.

Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and compiles and converts digital data to conform to the GRI GIS data model. The GRI GIS dataset includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are typically included in an ancillary map information document (PDF) for a specific park. The GRI team uses a unique "GMAP ID" value for each geologic source map, and all sources to produce the GRI GIS datasets for the UCBN parks can be found in Appendix A.

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The most recent GRI GIS data for HAFO was compiled using data model version 2.3, which is available at https://www.nps.gov/articles/gri-geodatabase-model.htm; the BIHO, CIRO, CRMO, JODA, LARO, NEPE, and WHMI data are based on older data models and need to be upgraded to the most recent version. The data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI website (https://www.nps.gov/subjects/geology/gri.htm) provides more information about the program's products.

GRI GIS data are available on the GRI publications website (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm) and through the NPS Integrated Resource Management Applications (IRMA) Data Store portal (https://irma.nps.gov/DataStore/Search/Quick). Enter "GRI" as the search text and select BIHO, CIRO, CRMO, HAFO, JODA, LARO, MIIN, NEPE, or WHMI from the unit list.

The following components are part of the dataset:

- A GIS readme file that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology;
- Federal Geographic Data Committee (FGDC)-compliant metadata;
- An ancillary map information document that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross-sections, and figures;
- ESRI map documents that display the GRI GIS data; and
- A version of the data viewable in Google Earth (.kml / .kmz file).

GRI Map Posters

Posters of the GRI GIS draped over shaded relief images of the park and surrounding area are included in GRI reports. Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data, but are available online from a variety of sources. Contact GRI for assistance locating these data.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based on the information provided. Please contact GRI with any questions.

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the posters. Based on the source map scales (1:100,000, 1:62,500, and 1:24,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 51 m (167 ft), 32 m (104 ft), and 12 m (40 ft), respectively, of their true locations.

Methods

Described here are the methods employed and definitions adopted during this inventory of geologic stratotypes located within the administrative boundaries of the parks in the UCBN. This report is part of an inventory of geologic stratotypes throughout the National Park System. Therefore, the methods, definitions, and challenges identified here pertain not only to the parks of the UCBN, but also to other inventory and monitoring networks and parks.

There are several considerations for this inventory. The most up-to-date information available is necessary, 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 new 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 transcend state boundaries. Geologic formations and other units that cross state boundaries may be referenced with different names in each of the states the units are mapped. An example is the Triassic Chugwater Formation in Wyoming, which is equivalent to the Spearfish Formation in the Black Hills of South Dakota.

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.

Finally, 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 NPS areas.

Methodology

The process of determining whether a specific stratotype occurs in an NPS area involves multiple steps. The process begins with an evaluation of the existing park-specific GRI map to prepare a full list of recognized map units (Figure 2).

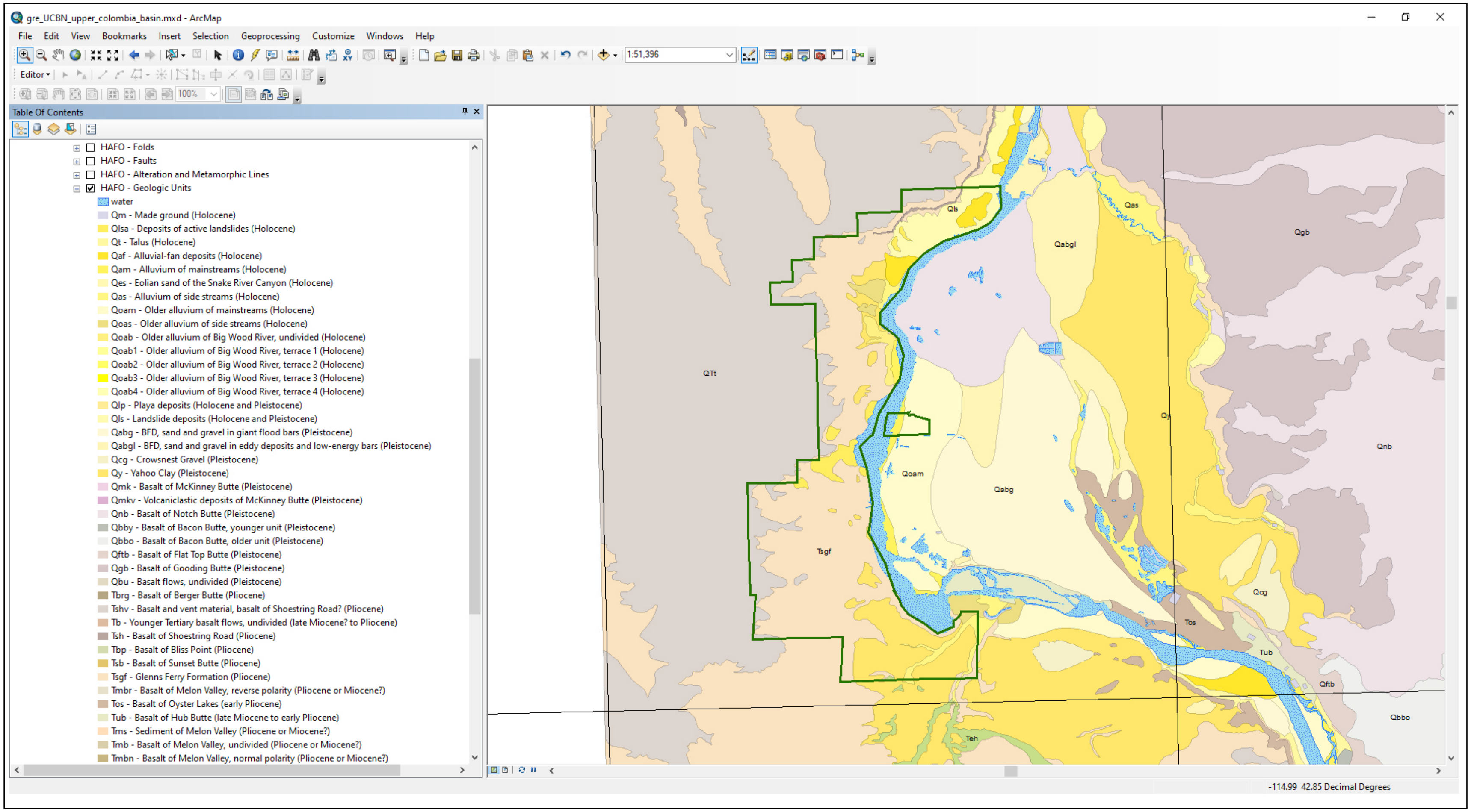


Figure 2. Screenshot of digital geologic map of Hagerman Fossil Beds National Monument showing mapped units.

Each map unit name is then 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 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 3 below is taken from a search on the Picture Gorge Basalt of the Columbia River Basalt Group.

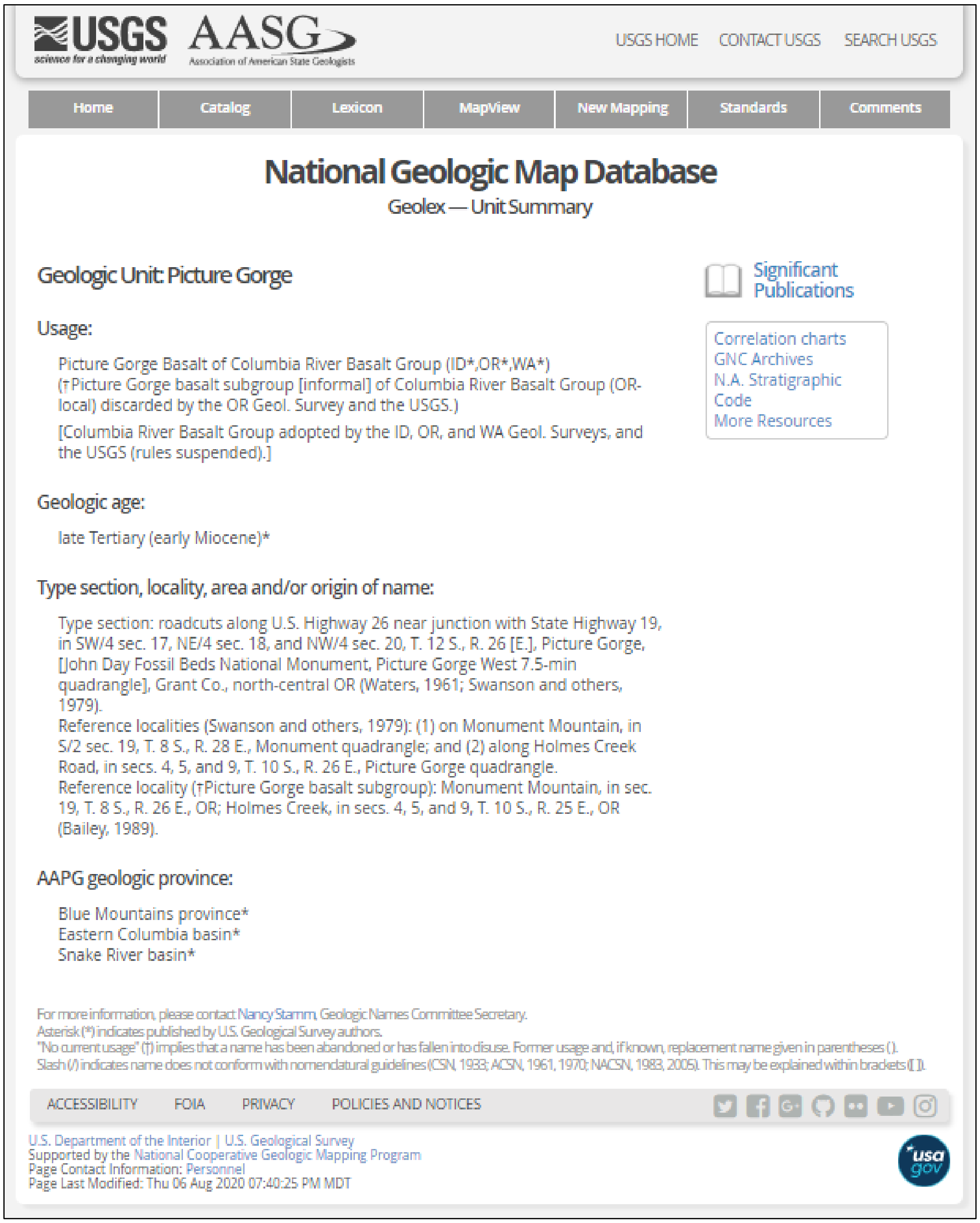
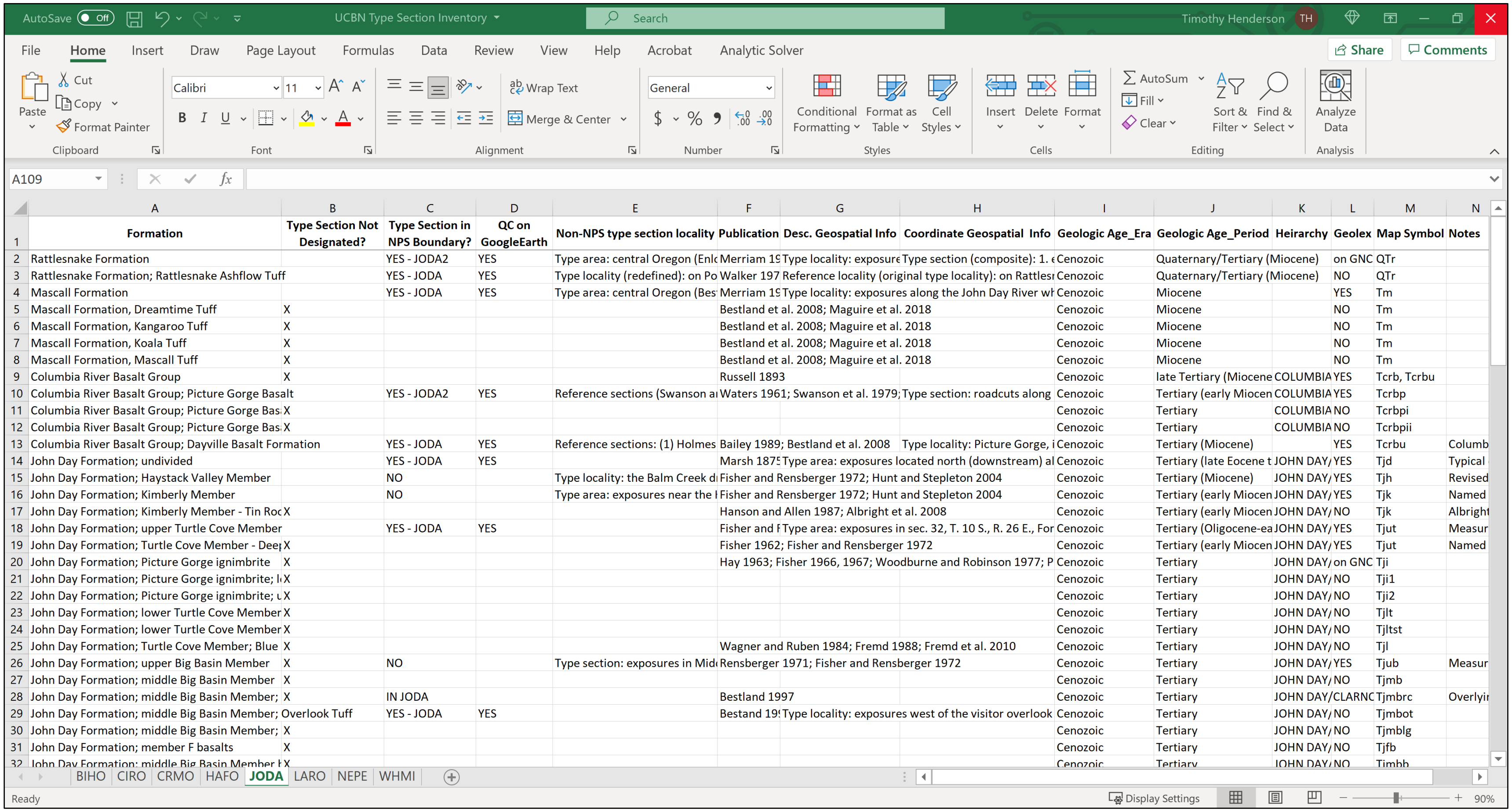


Figure 3. GEOLEX search result for the Picture Gorge Basalt unit of the Columbia River Basalt Group.

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 km^2 (36 mi^2) township into 36 individual 2.59 km^2 (1 mi^2) sections, and were converted into Google Earth (.kmz file) locations using Earth Point (https://www.earthpoint.us/TownshipsSearchByDescription.aspx). Coordinates are typically presented in an abbreviated format such as "sec. [#], T. [#] [N. or S.], R. [#] [E. or W.]". The most accurate GEOLEX descriptions using TRS coordinates can help locate features within 0.1618 km^2 (0.0625 mi^2). Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the national park area is draped over it. This step serves two functions: to improve 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, 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 is listed in GEOLEX; and 10) a generic notes field (Figure 4).



	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
2	Rattlesnake Formation		YES - JODA2	YES	Type area: central Oregon (Enlc	Merriam 19	Type locality: exposure	Type section (composite): 1. e	Cenozoic	Quaternary/Tertiary (Miocene)		on GNC	QTr	
3	Rattlesnake Formation; Rattlesnake Ashflow Tuff		YES - JODA	YES	Type locality (redefined): on Po	Walker 197	Reference locality (original type locality): on Rattles		Cenozoic	Quaternary/Tertiary (Miocene)		NO	QTr	
4	Mascall Formation		YES - JODA	YES	Type area: central Oregon (Bes	Merriam 19	Type locality: exposures along the John Day River wh		Cenozoic	Miocene		YES	Tm	
5	Mascall Formation, Dreamtime Tuff	X				Bestland et al. 2008; Maguire et al. 2018			Cenozoic	Miocene		NO	Tm	
6	Mascall Formation, Kangaroo Tuff	X				Bestland et al. 2008; Maguire et al. 2018			Cenozoic	Miocene		NO	Tm	
7	Mascall Formation, Koala Tuff	X				Bestland et al. 2008; Maguire et al. 2018			Cenozoic	Miocene		NO	Tm	
8	Mascall Formation, Mascall Tuff	X				Bestland et al. 2008; Maguire et al. 2018			Cenozoic	Miocene		NO	Tm	
9	Columbia River Basalt Group	X				Russell 1893			Cenozoic	late Tertiary (Miocene	COLUMBIA	YES	Tcrb, Tcrbu	
10	Columbia River Basalt Group; Picture Gorge Basalt		YES - JODA2	YES	Reference sections (Swanson ar	Waters 1961; Swanson et al. 1979;		Type section: roadcuts along	Cenozoic	Tertiary (early Miocen	COLUMBIA	YES	Tcrbp	
11	Columbia River Basalt Group; Picture Gorge Bas	X							Cenozoic	Tertiary	COLUMBIA	NO	Tcrbpi	
12	Columbia River Basalt Group; Picture Gorge Bas	X							Cenozoic	Tertiary	COLUMBIA	NO	Tcrbpii	
13	Columbia River Basalt Group; Dayville Basalt Formation		YES - JODA	YES	Reference sections: (1) Holmes	Bailey 1989; Bestland et al. 2008		Type locality: Picture Gorge, i	Cenozoic	Tertiary (Miocene)		YES	Tcrbu	Columb
14	John Day Formation; undivided		YES - JODA	YES		Marsh 1875	Type area: exposures located north (downstream) al		Cenozoic	Tertiary (late Eocene t	JOHN DAY/	YES	Tjd	Typical
15	John Day Formation; Haystack Valley Member		NO		Type locality: the Balm Creek di	Fisher and Rensberger 1972; Hunt and Stepleton 2004			Cenozoic	Tertiary (Miocene)	JOHN DAY/	YES	Tjh	Revised
16	John Day Formation; Kimberly Member		NO		Type area: exposures near the I	Fisher and Rensberger 1972; Hunt and Stepleton 2004			Cenozoic	Tertiary (early Miocen	JOHN DAY/	YES	Tjk	Named
17	John Day Formation; Kimberly Member - Tin Roc	X				Hanson and Allen 1987; Albright et al. 2008			Cenozoic	Tertiary (early Miocen	JOHN DAY/	NO	Tjk	Albright
18	John Day Formation; upper Turtle Cove Member		YES - JODA	YES		Fisher and F	Type area: exposures in sec. 32, T. 10 S., R. 26 E., For		Cenozoic	Tertiary (Oligocene-ea	JOHN DAY/	YES	Tjut	Measur
19	John Day Formation; Turtle Cove Member - Deep	X				Fisher 1962; Fisher and Rensberger 1972			Cenozoic	Tertiary (early Miocen	JOHN DAY/	YES	Tjut	Named
20	John Day Formation; Picture Gorge ignimbrite	X				Hay 1963; Fisher 1966, 1967; Woodburne and Robinson 1977; P			Cenozoic	Tertiary	JOHN DAY/	on GNC	Tji	
21	John Day Formation; Picture Gorge ignimbrite; l	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tji1	
22	John Day Formation; Picture Gorge ignimbrite; u	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tji2	
23	John Day Formation; lower Turtle Cove Member	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tjlt	
24	John Day Formation; lower Turtle Cove Member	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tjltst	
25	John Day Formation; Turtle Cove Member; Blue	X				Wagner and Ruben 1984; Fremd 1988; Fremd et al. 2010			Cenozoic	Tertiary	JOHN DAY/	NO	Tjl	
26	John Day Formation; upper Big Basin Member	X	NO		Type section: exposures in Mid	Rensberger 1971; Fisher and Rensberger 1972			Cenozoic	Tertiary	JOHN DAY/	YES	Tjub	Measur
27	John Day Formation; middle Big Basin Member	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tjmb	
28	John Day Formation; middle Big Basin Member;	X	IN JODA			Bestland 1997			Cenozoic	Tertiary	JOHN DAY/CLARN		Tjmbrc	Overlyi
29	John Day Formation; middle Big Basin Member; Overlook Tuff		YES - JODA	YES		Bestand 19	Type locality: exposures west of the visitor overlook		Cenozoic	Tertiary	JOHN DAY/	NO	Tjmbot	
30	John Day Formation; middle Big Basin Member;	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tjmblg	
31	John Day Formation; member F basalts	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tjfb	
32	John Day Formation; middle Big Basin Member I	X							Cenozoic	Tertiary	JOHN DAY/	NO	Tjmbb	

Figure 4. Stratotype inventory spreadsheet of the UCBN displaying attributes appropriate for geolocation assessment.

Definitions

In order to clarify, standardize, and consistently reference stratigraphic concepts, principles, and definitions, the North American Stratigraphic Code is recognized and adopted for this inventory. This code seeks to describe 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 and constitutes 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:

1) **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. The term “unit stratotype” is commonly referred to as “type section” and “type area” in this report.

2) **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).

3) **Reference sections**: for well-established geologic units for which a type section was never assigned, a reference section may serve as an invaluable standard in 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).

4) **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 and is a term 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.

Big Hole National Battlefield (BIHO)

Big Hole National Battlefield (BIHO) is located about 160 km (100 mi) southwest of Helena, Montana along the eastern Bitterroot Range in Beaverhead County, southwestern Montana (Figure 5). Established as a military preserve in 1883, BIHO was designated a national monument on June 23, 1910 and redesignated a national battlefield on May 17, 1963 (National Park Service 2016a). In 1992, BIHO was legislatively added as an administrative unit of Nez Perce National Historical Park (NEPE, covered in its own section below). Encompassing approximately 409 hectares (1,011 acres), BIHO pays tribute to the battle between the Nez Perce and the 7th U.S. Infantry forces with Montana citizen volunteers on August 9–10, 1877. The battle is considered a key event within a five-month conflict in which the army was intent on moving the Nez Perce to the Lapwai Reservation in Idaho. Along the way, a series of confrontations between the two sides would lead to the death of 90 Nez Perce and 31 soldiers.

BIHO is named after Big Hole Valley, one of the highest and widest mountain valleys of western Montana. The valley separates the Pioneer Mountains along its eastern margin from the Bitterroot Range on the west and contains a thick fill of sedimentary material such as sand, clay, mud, and gravel that overlie deeply buried volcanic rocks. The bedrock geology of BIHO is predominantly composed of rocks associated with the Eocene–Miocene Bozeman Group and related valley-fill deposits. Younger Quaternary alluvium (unconsolidated deposits of gravel, sand, silt, or mud) are mapped within BIHO along the transect of the North Fork of the Big Hole River and its tributaries (Figure 6).

There are no designated stratotypes identified within the boundaries of BIHO. There are also no identified stratotypes located within 48 km (30 mi) of BIHO boundaries.

Figure 5. Park map of BIHO, Montana (NPS).

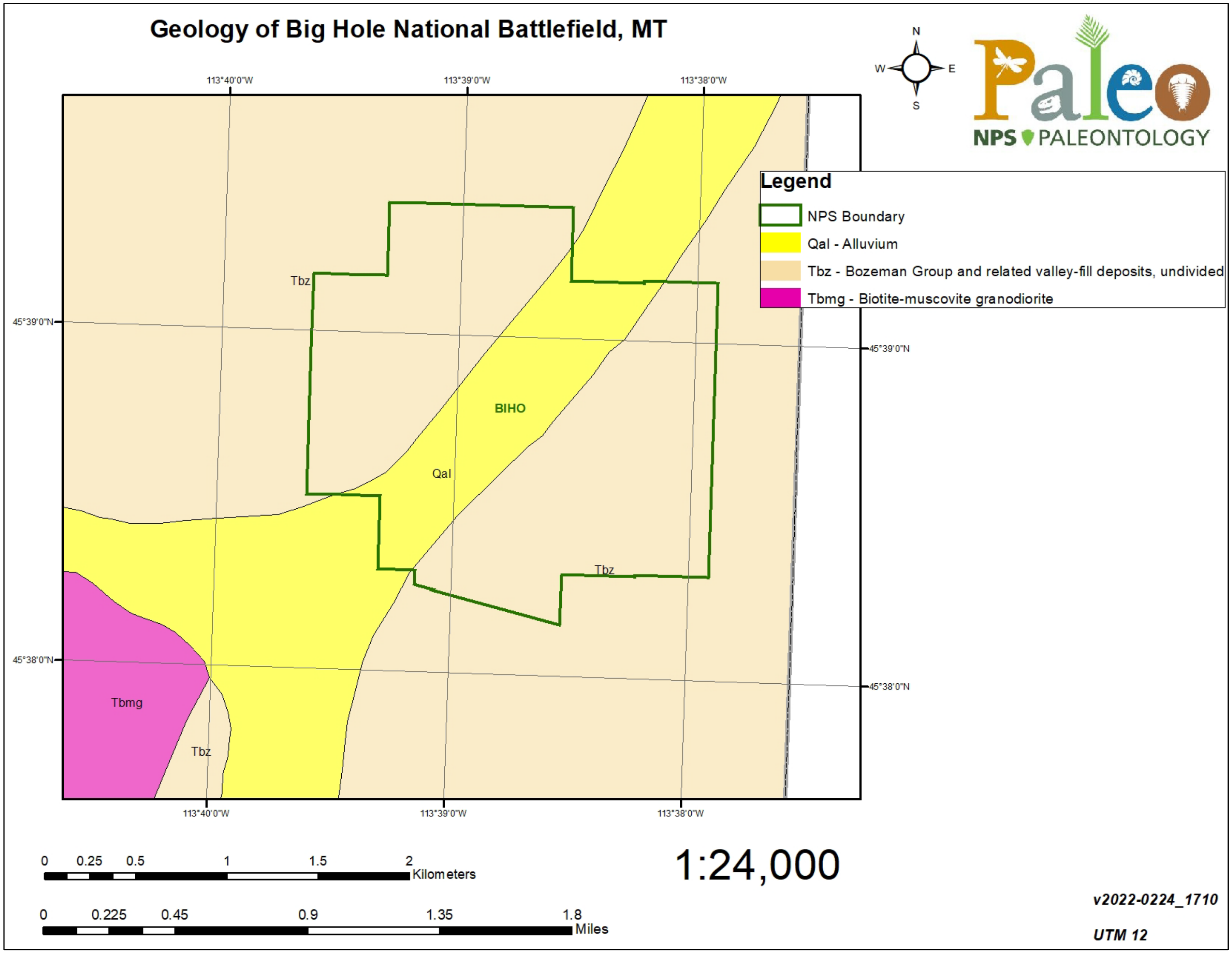


Figure 6. Geologic map of BIHO, Montana. Data modified from BIHO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047475.

City of Rocks National Reserve (CIRO)

City of Rocks National Reserve (CIRO) is located in the southern part of the Albion Mountains in Cassia County, south-central Idaho (Figure 7). Established on November 18, 1988, CIRO encompasses approximately 5,830 hectares (14,407 acres) of scenic geologic landscape containing naturally sculpted granitic spires and domes considered significant to the Northern Shoshone people. The reserve centers on three upland valleys or basins (Circle Creek Basin, Twin Sisters Basin, and Emigrant Basin) that are underlain by broad erosional plains cut into the granite and surrounded by high mountains to the east and west that are carved by narrow canyons (Thornberry-Ehrlich 2010). CIRO was created to preserve and protect the scenic qualities and attributes of the California Trail landscape, historic rural setting, and granite features, while interpreting its values and managing recreation (National Park Service 2018).

The geologic features of CIRO are world-renowned, both for rock-climbing enthusiasts and academic research purposes. The landscape of the reserve is home to rare, densely spaced granite spires and domes that led to the designation of its national natural landmark status. The geologic formations and landforms at CIRO provide opportunities for scientists to observe and understand 1) ancient and recent tectonic events that uplifted the mountainous interior of the western United States; and 2) surficial weathering processes that shape the landscape and reveal buried rocks and structures (National Park Service 2018). The bedrock geology of CIRO predominantly consists of igneous and metamorphic units (Figure 8), including some of the oldest rocks in North America: metamorphosed igneous rocks associated with the Archean Green Creek Complex are more than 2.5 billion years old (Thornberry-Ehrlich 2010). Juxtaposed against the Green Creek Complex is the Oligocene-age Almo pluton (~28 million years old), a contact that represents an age gap of billions of years.

There are no designated stratotypes identified within the boundaries of CIRO. There are two identified stratotypes located within 48 km (30 mi) of CIRO boundaries, for the Neoproterozoic(?) Elba Quartzite (type section) and the Permian Badger Gulch Formation (type section).

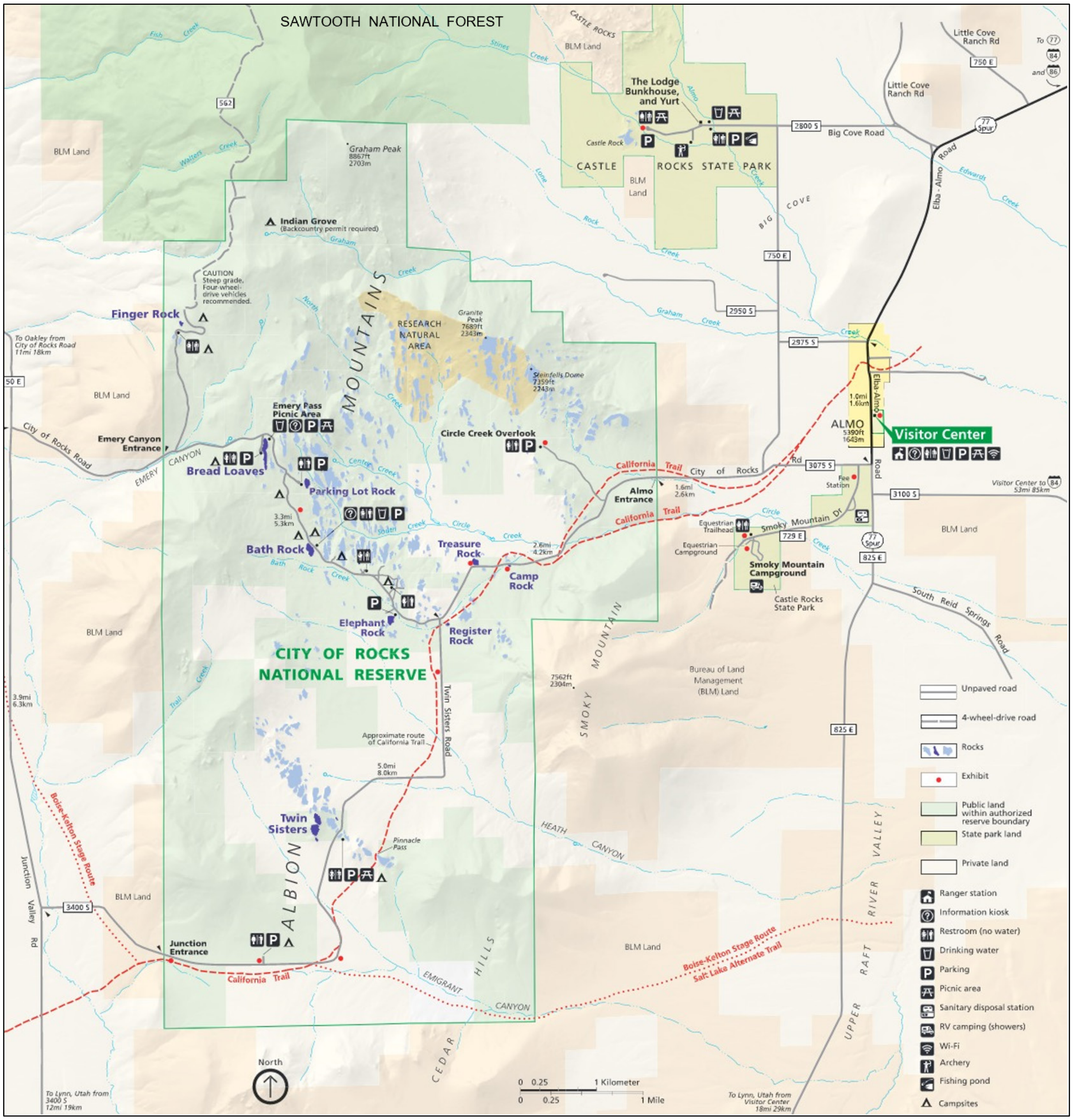


Figure 7. Park map of CIRO, Idaho (NPS).

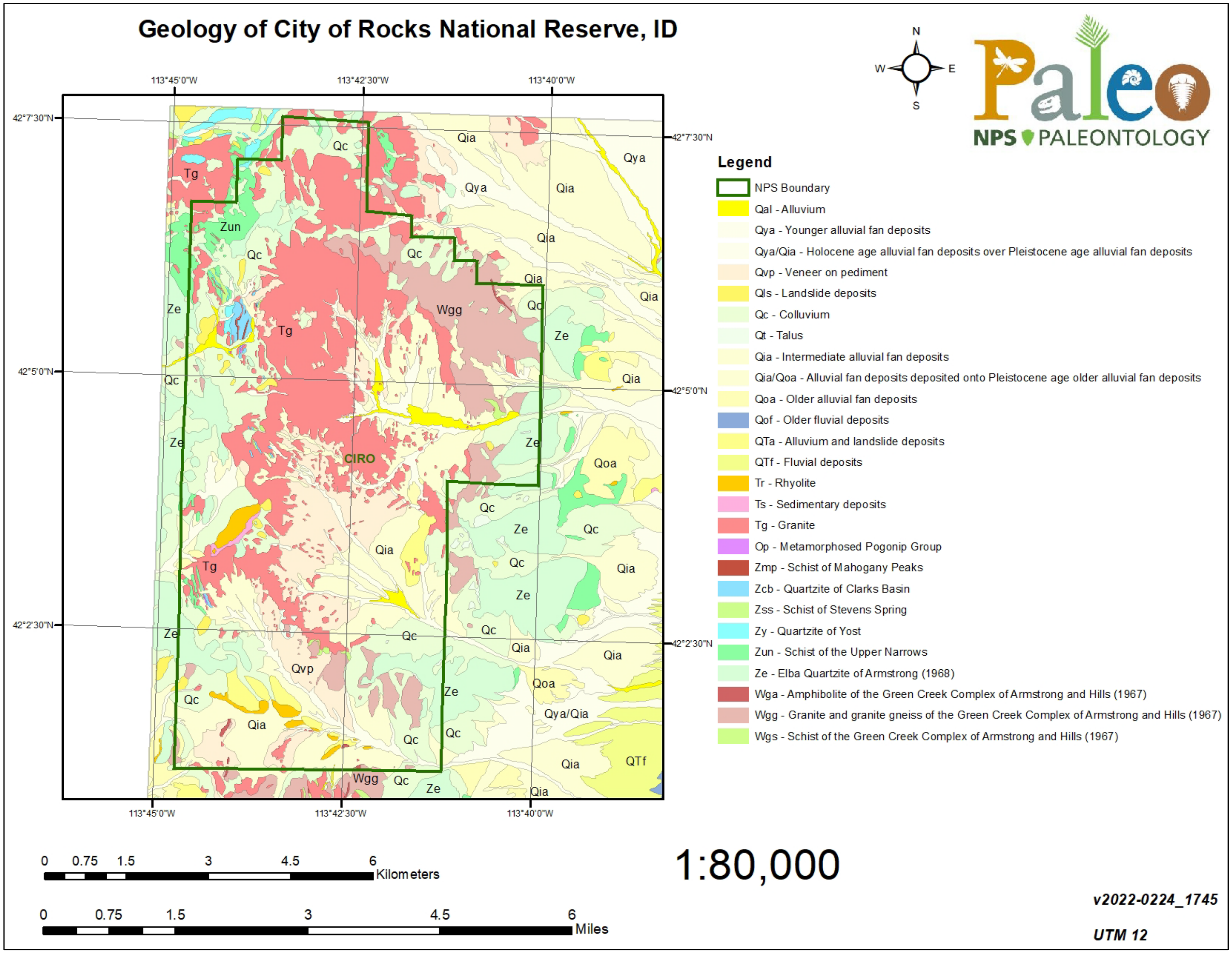


Figure 8. Geologic map of CIRO, Idaho. Data modified from CIRO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1045691.

Craters of the Moon National Monument and Preserve (CRMO)

Craters of the Moon National Monument and Preserve (CRMO) is located about 200 km (125 mi) east of Boise, Idaho in Butte, Blaine, Lincoln, Minidoka, and Power Counties, south-central Idaho (Figure 9). Established as a national monument on May 2, 1924, the national preserve was later designated on August 21, 2002 (National Park Service 2016a). Encompassing approximately 187,897 hectares (464,304 acres), CRMO is cooperatively administered by the National Park Service and the Bureau of Land Management. Craters of the Moon National Monument and Preserve protects a vast "weird and scenic landscape" with remarkable and diverse volcanic features, sagebrush steppe ecosystems, and wilderness, which provides opportunities to explore, understand, and value the rugged and remote high desert landscape of the Great Rift region (National Park Service 2014). The landscape of the CRMO contains lava flows, steep cinder cones, and lava tubes once thought to resemble that of the moon. The name "Craters of the Moon" was popularized by R. W. Limbert in The National Geographic Magazine (Limbert 1924) and remained even after the first lunar landing in 1969 revealed that most lunar craters formed by meteoroid impacts, not volcanic activity (KellerLynn 2018).

CRMO encompasses three lava fields (Craters of the Moon, Wapi, and Kings Bowl lava fields) and most of the Great Rift volcanic rift zone. The Great Rift system represents a tensional (pull-apart) fracture in the Earth's crust that extends for more than 80 km (50 mi) and is marked by short cracks typically less than 2 km (1 mi) long but extending below the surface to an estimated depth of 200 m (650 ft) (KellerLynn 2018). Lava flows in CRMO are geologically young (Pleistocene–Holocene) and range in age from about 15,000–2,000 years old (Figures 10 and 11). Craters of the Moon lava field is the largest and northernmost of the three fields and is composed of approximately 60 lava flows and 25 volcanic cones that cover an area of 1,600 km^2 (618 mi^2) (KellerLynn 2018). Lava flows in CRMO have a variety of textures that developed due to different cooling rates combined with varying amounts of dissolved gases. A diverse assemblage of volcanic features is found within CRMO, reflecting many geologic processes. These features include lava tubes, tumuli (domed structures), pressure ridges (elongate ridges), cinder cones, spatter cones, hornitos (small, upright mounds of cooled lava), and pit craters.

There are no designated stratotypes identified within the boundaries of CRMO. There are 36 identified stratotypes located within 48 km (30 mi) of CRMO boundaries, for the Cambrian Tyler Peak Formation (type section); Ordovician Kinnikinic Quartzite (reference section); Devonian Carey Dolomite (type section), Picabo Formation (type section), and Milligen Formation (principal reference section and reference section); Mississippian Bluebird Mountain Formation (four reference sections), Arco Hills Formation (type section and two reference sections), Middle Canyon Formation (type section), Surrett Canyon Formation (type section), Scott Peak Formation (type section), Drummond Mine Limestone (type section), Copper Basin Group (type locality), South Creek Formation (type section), Argosy Creek Formation (type section), Brockie Lake Conglomerate Member of the Argosy Creek Formation (type section), Iron Bog Creek Member of the Argosy Creek

Formation (type section), Muldoon Canyon Member of the Argosy Creek Formation (type section), Green Lake Limestone Bed of the Muldoon Canyon Member of the Argosy Creek Formation (type section), and Little Copper Formation (type section and reference section); Pennsylvanian Eagle Creek Member of the Wood River Formation (type section) and Hailey Member of the Wood River Formation (type section and principal reference section); Permian Wilson Creek Member of the Wood River Formation (type section); Miocene Blacktail Creek Tuff (reference section) and Walcott Tuff (type locality and reference section); Miocene–Pliocene Heise Group (type area); and Pleistocene Big Hole Basalt (type locality), and Cedar Butte Basalt (type locality).

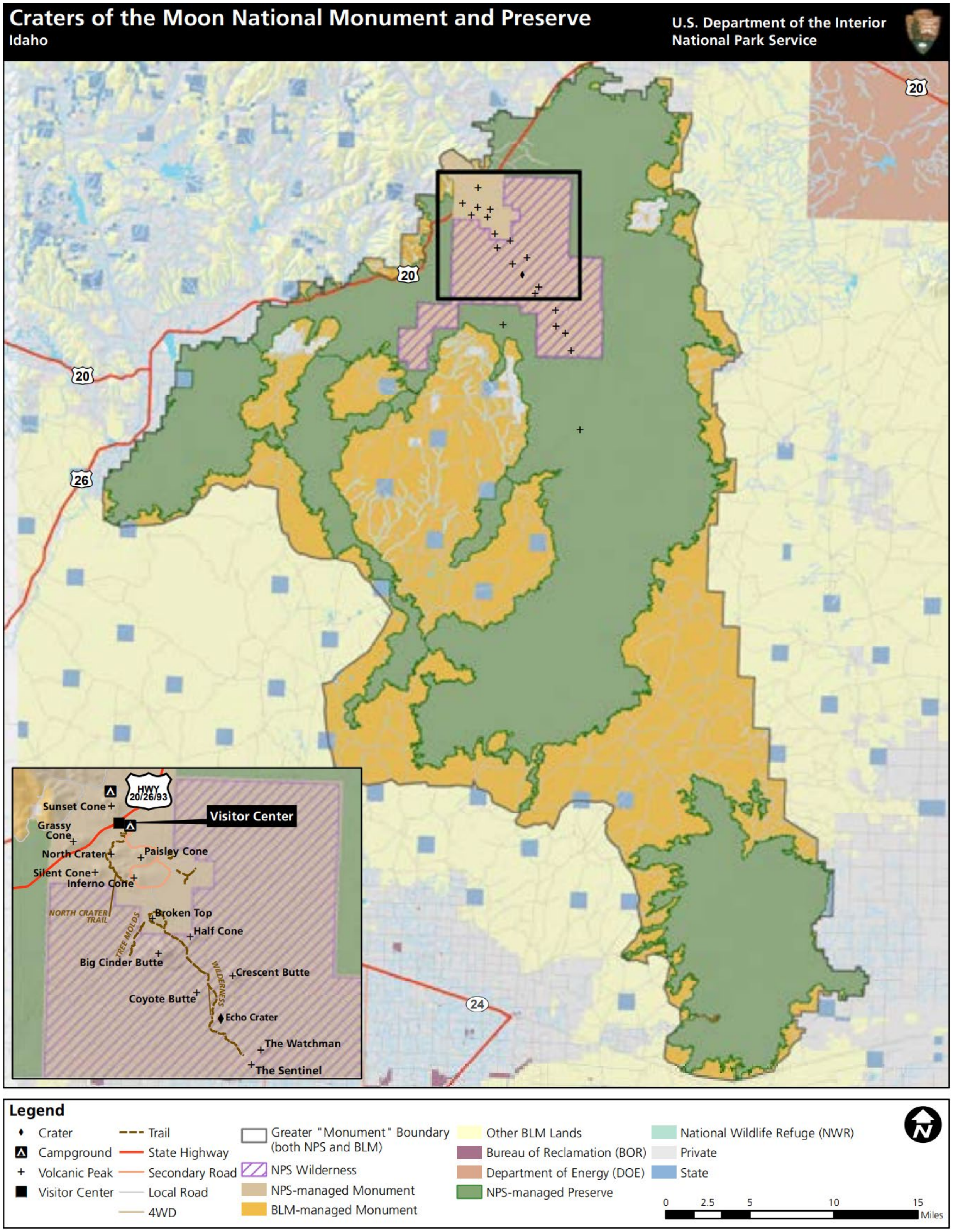


Figure 9. Park map of CRMO, Idaho (NPS).

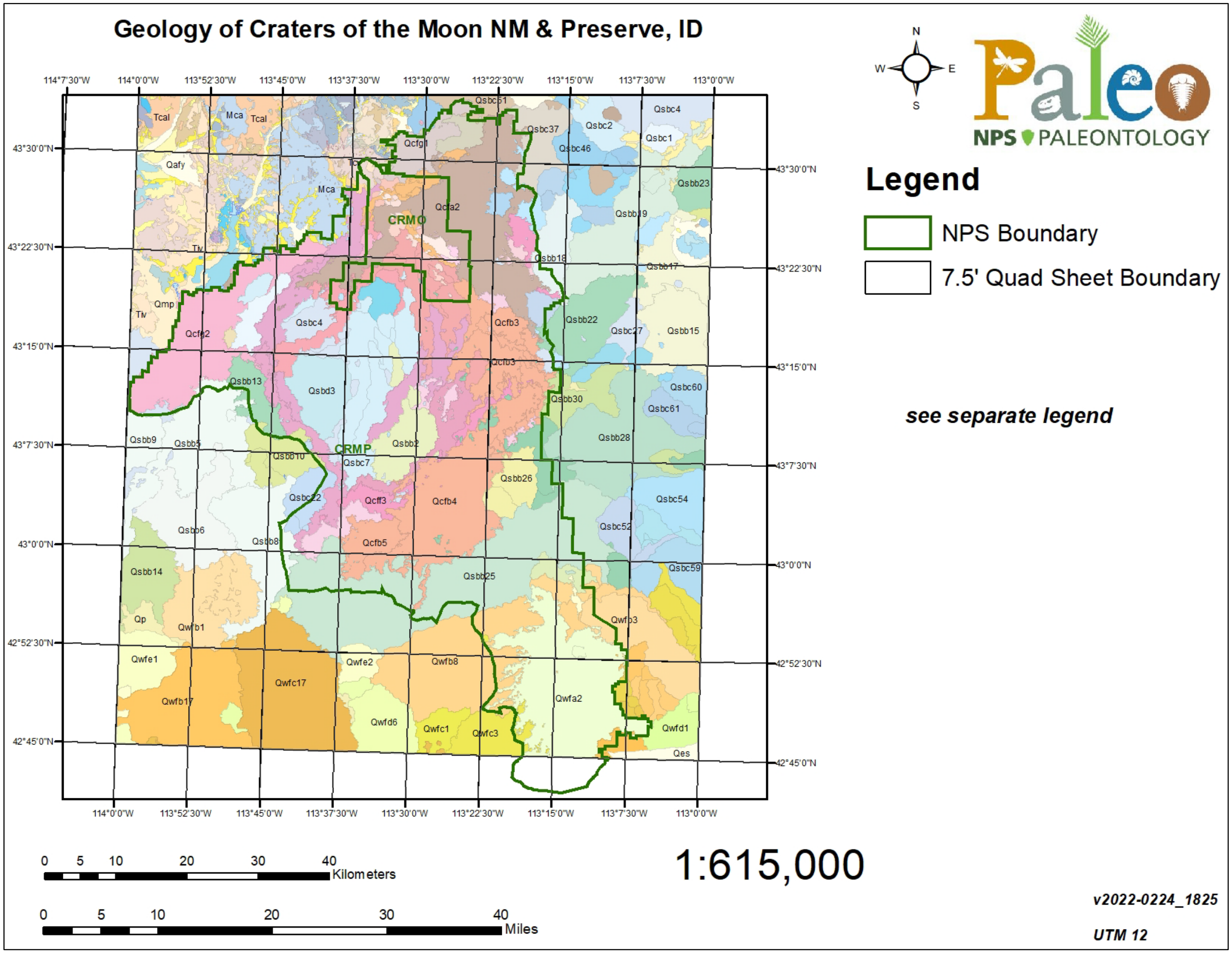


Figure 10. Geologic map of CRMO, Idaho. Data modified from CRMO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2223530. See Figure 11 for legend.

Figure 11. Geologic map legend of CRMO, Idaho.

Hagerman Fossil Beds National Monument (HAFO)

Hagerman Fossil Beds National Monument (HAFO) lies just west of the town of Hagerman, Idaho within a scenic landscape of sandy bluffs, basalt canyons, waterfalls, and hot springs in Gooding and Twin Falls Counties, southern Idaho (Figure 12). Established November 18, 1988, HAFO encompasses approximately 1,760 hectares (4,351 acres) and contains important Blancan Land Mammal Age fossils, including the Hagerman Horse Quarry, from the Pliocene Epoch (5.3 to 2.6 million years ago) (National Park Service 2016a). HAFO has yielded more than 200 fossilized plant and animal species and is recognized as one of North America's most important localities concerning the evolution of the horse. The purpose of HAFO is to preserve the outstanding paleontological resources, to serve as a center for furthering scientific research, and to broaden public understanding of geology, paleontology and the significance of the Hagerman fossil record (National Park Service 2015a). The monument is also designated as the Hagerman Fauna Sites National Natural Landmark.

The geology of HAFO consists of layers of sedimentary and volcanic rock that compose bluffs that have been deeply incised by arroyos to form steep slopes. The formations exposed in the monument fall into either the Idaho Group or the Snake River Group and include the Pliocene Glenns Ferry Formation and the Pleistocene Tuana Gravel and Yahoo Clay (Figure 13). The Glenns Ferry Formation is the source of the majority of the fossils found the monument and records a variety of ancient depositional environments including wetland, riparian, lacustrine and grassland ecosystems (Graham 2009). The diversity and richness of species preserved in the fossil sites provide an important opportunity to conduct research to reconstruct the ancient Pliocene paleoenvironment. Some of the fossil species collected from the Glenns Ferry Formation in HAFO have been found nowhere else on Earth.

HAFO contains two identified stratotypes that represent the Pleistocene Yahoo Clay (type locality and reference section; Table 2; Figure 14). In addition to the designated stratotypes located within HAFO, stratotypes located within 48 km (30 mi) of the monument's boundaries include: the Miocene Banbury Basalt (type locality); Pliocene Glenns Ferry Formation (type area); Pliocene–Pleistocene Tuana Gravel (type locality); Pleistocene Yahoo Clay (10 reference sections), Melon Gravel (type locality), Sand Springs Basalt (type locality), Thousand Springs Basalt (type locality), Crowsnest Gravel (type locality), Wendell Grade Basalt (type locality), Malad Basalt (type locality), Black Mesa Gravel (type area), Bancroft Springs Gravel (type area), Sugar Bowl Gravel (type locality), and McKinney Basalt (type locality); and the Pleistocene–Holocene Snake River Group (type area).

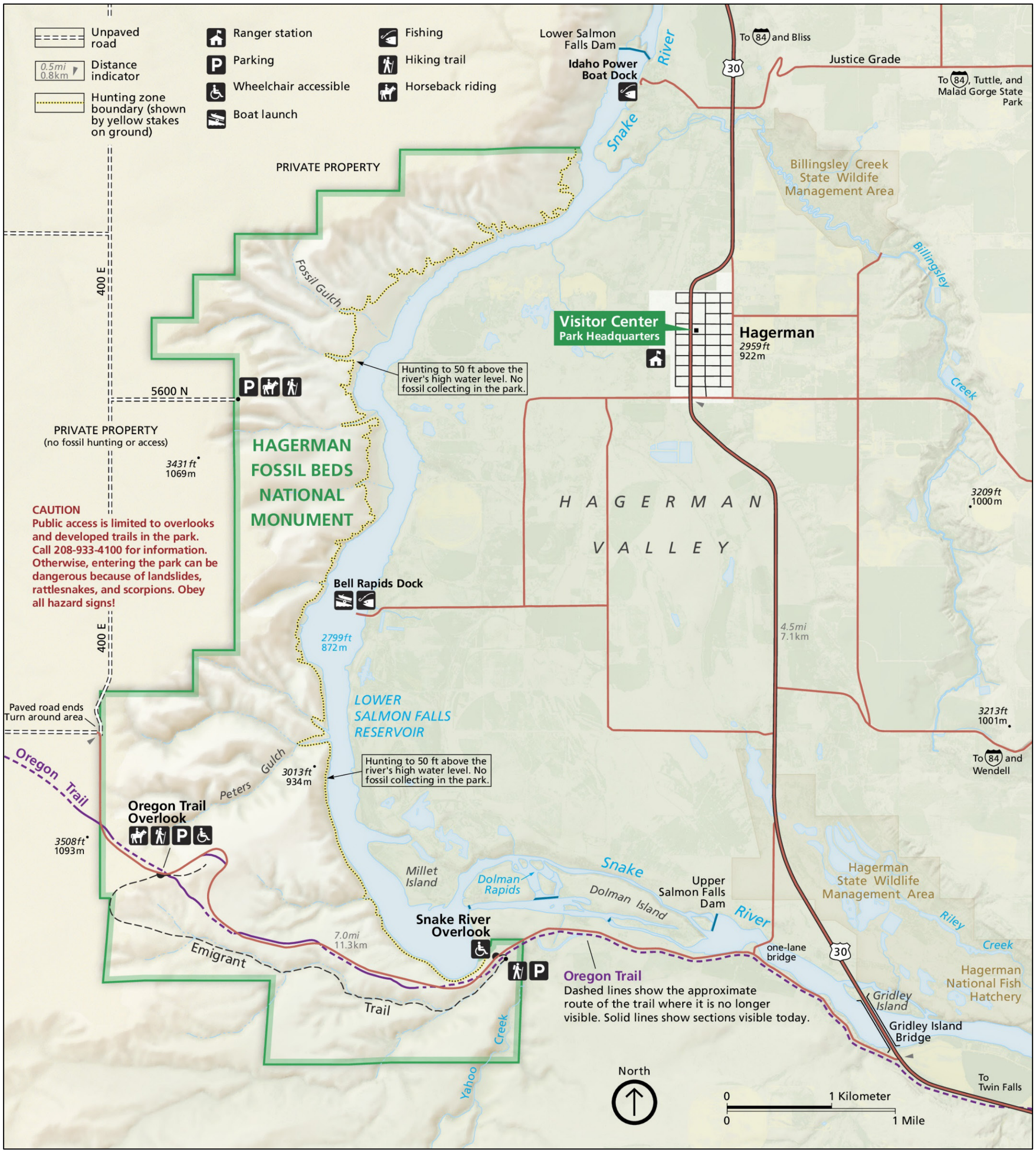


Figure 12. Park map of HAFO, Idaho (NPS).

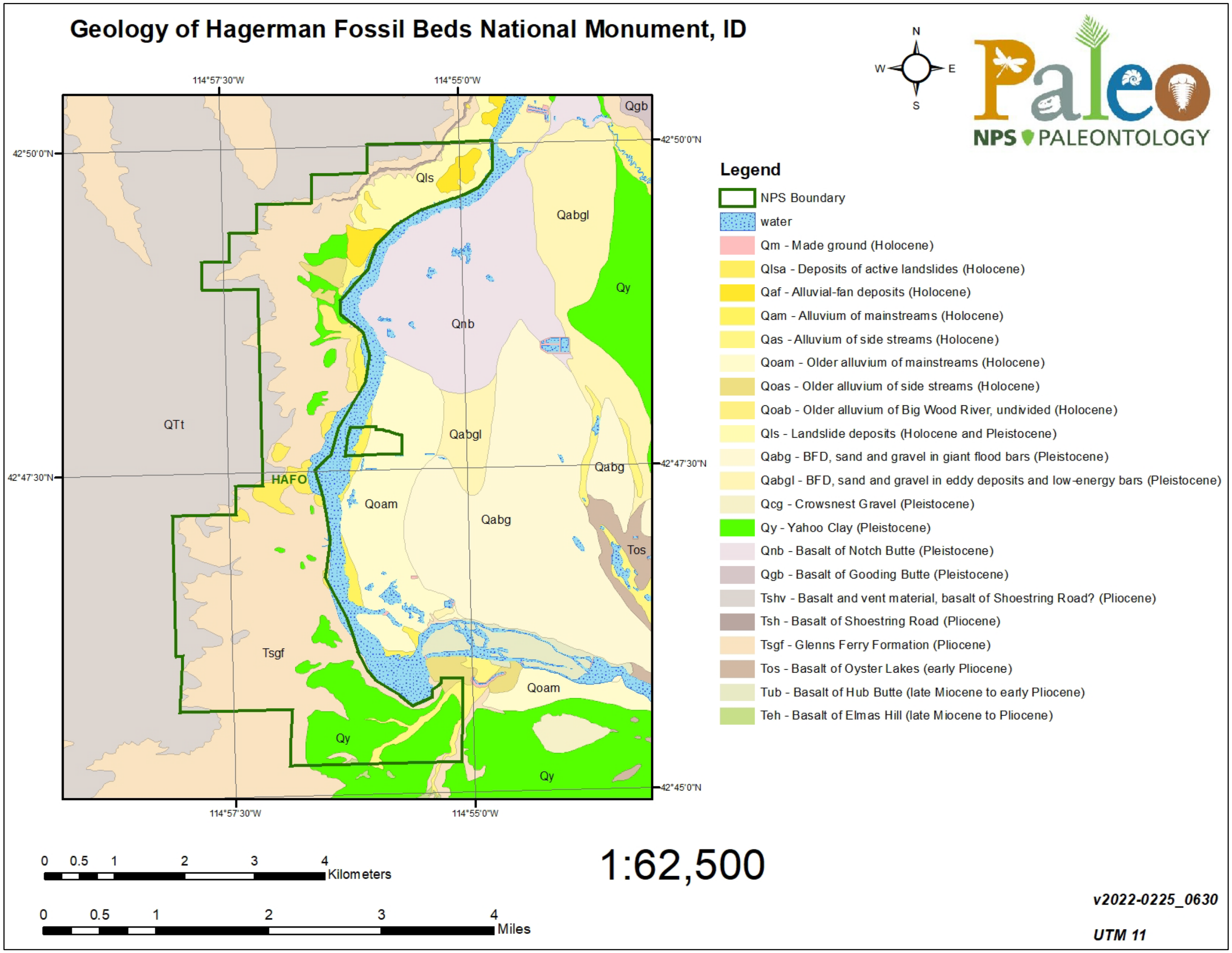


Figure 13. Geologic map of HAFO, Idaho. Data modified from HAFO GRI digital geologic map at https://irma.nps.gov/DataStore/Reference/Profile/2265301.

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

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Yahoo Clay (Qy)	Malde 1982	**<u>Type locality</u>**: exposures approx. 6.4 km (4 mi) south-southwest of Hagerman, ID, near mouth of Yahoo Creek, where it joins with Snake River, along boundary of Hagerman Fossil Beds National Monument, in secs. 3, 4, and 5, T. 8 S., R. 13 E. [Hagerman 7.5′ Quadrangle], Twin Falls County, ID. Reference section: canyon wall of the Snake River, west and southwest of Hagerman, Falls County, ID.	Pleistocene

Yahoo Clay

The Pleistocene Yahoo Clay of the Snake River Group was named by Malde (1982) for deposits found near the mouth of Yahoo Creek southwest of Hagerman, Idaho. Malde (1982) designated the type locality of the formation in the left wall of a former canyon of the Snake River approximately 6.4 km (4 mi) southwest of Hagerman, in sections 3, 4, and 5, T. 8 S., R. 13. The Yahoo Clay overlies the Glenns Ferry Formation here and in the adjacent parts of sections 8, 9, and 10 to the south (Table 2; Figure 14; see also map of Malde and Powers 1972). In the type locality the Yahoo Clay measures about 27 m (90 ft) thick and is uniform in lithology, consisting of pinkish-white to yellowish-brown laminated clay with sparse amounts of silty clay (Malde 1982). The eroded surface of the unit forms a loose, “popcorn” textured layer typically 0.3 m (1 ft) or more thick, possibly due to the presence of shrink-swell clays (Malde 1982). A reference section for the formation is located in the cliffs above the Snake River west and southwest of Hagerman in HAFO (Table 2; Figure 14; Malde 1982).

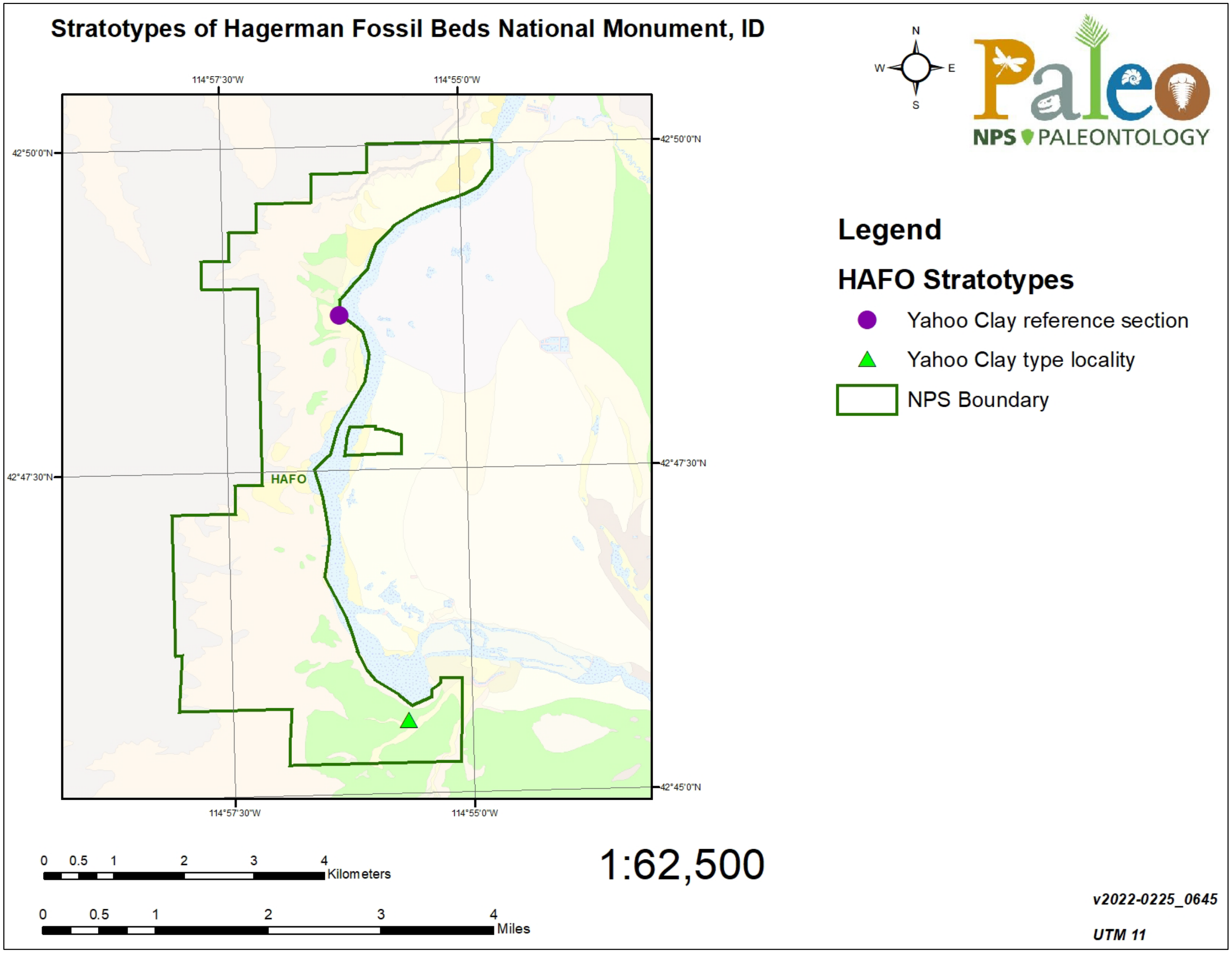


Figure 14. Modified geologic map of HAFO showing stratotype locations. The transparency of the geologic units layer has been increased.

John Day Fossil Beds National Monument (JODA)

John Day Fossil Beds National Monument (JODA) is located within the John Day River valley in Grant and Wheeler Counties, north-central Oregon (Figure 15). Authorized on October 26, 1974, JODA encompasses approximately 5,690 hectares (14,062 acres) and preserves a remarkably complete fossil record spanning nearly 50 million years of the "*Age of Mammals and Flowering Plants*", from ~50 million to 7.5 million years ago (Albright et al. 2008; National Park Service 2016a). John Day Fossil Beds National Monument and the surrounding badlands contain a diverse assemblage of fossil plants and vertebrates. The notable fossil species from JODA include early horses, rhinoceroses, canids, and members of more than 30 other mammalian families entombed in reworked volcanic sediments. The monument is geographically dispersed among three widely separated units (Sheep Rock, Painted Hills, and Clarno units) and includes significant natural features such as the towering Clarno Palisades, Picture Gorge, Sheep Rock, Goose Rock, Blue Basin, and Cathedral Rock.

The geology of JODA include lava flows, lahars, ash beds, tuff layers, and interbedded sedimentary rocks that record ancient depositional environments that include alluvial fan, floodplain, stream, and lacustrine ecosystems. Rock units within JODA are primarily Paleogene–Neogene in age and include the Clarno Formation, John Day Formation, igneous units associated with the Columbia River Basalt Group, Mascall Formation, and Rattlesnake Formation (Figures 16–18). Some of the oldest rocks mapped within the monument are conglomerates and sandstone lenses of the Cretaceous Mitchell Group (Gable Creek Formation) found in the Sheep Rock Unit. The greatest diversity and abundance of fossil specimens are found in the John Day Formation. Museum collections from JODA include nearly 54,000 specimens of plant and animal fossils that encompass most of the Cenozoic Era (Graham 2014a; N. Famoso, JODA Paleontology Program Manager and Museum Curator, pers. comm., 2022). These well-preserved fossil collections document evolutionary change and extinction through time and provide evidence of complex biological responses to changing climate and geologic events (Graham 2014a).

JODA contains 11 identified stratotypes that are subdivided into two type sections, five type localities, two type areas, and two reference localities (Table 3; Figures 19 and 20). In addition to the designated stratotypes located within JODA, stratotypes located within 48 km (30 mi) of the monument's boundaries include: the Eocene–Oligocene Clarno Formation (type locality); Oligocene Big Basin Member of the John Day Formation (type section); and the Miocene Haystack Valley Member of the John Day Formation (type locality), Johnson Canyon Member of the John Day Formation (type area), Kimberly Member of the John Day Formation (type area), Rose Creek Member of the John Day Formation (type locality), Picture Gorge Basalt (two reference localities), Twickenham Basalt (type locality and two reference localities), Bologna Creek Member of the Twickenham Basalt (type locality and reference locality), Donnely Basin Member of the Twickenham Basalt (type locality and reference locality), Muleshoe Creek Member of the Twickenham Basalt (type locality and reference locality), Monument Mountain Basalt (type locality and reference locality), Holmes Creek Member of the Monument Mountain Basalt (type locality and reference locality), Franklin Mountain Member of the Monument Mountain Basalt (type locality and reference locality), Dayville Basalt (two reference localities), Alder Mountain Member of the Dayville Basalt (type locality and reference locality), Branson Creek Member of the Dayville Basalt (type locality and reference locality), Hamilton Member of the Dayville Basalt (type locality), Horse Canyon Member of the Dayville Basalt (reference locality), Johnny Cake Member of the Dayville Basalt (type locality and reference locality), Little Tamarack Member of the Dayville Basalt (type locality and reference locality), Monument Lookout Member of the Dayville Basalt (type locality and reference locality), Tamarack Member of the Dayville Basalt (type locality and reference locality), Windy Canyon Member of the Dayville Basalt (type locality and reference locality), Mascall Formation (type locality?), and the Rattlesnake Formation (part of composite type section).

Figure 15. Regional map of JODA, Oregon (NPS).

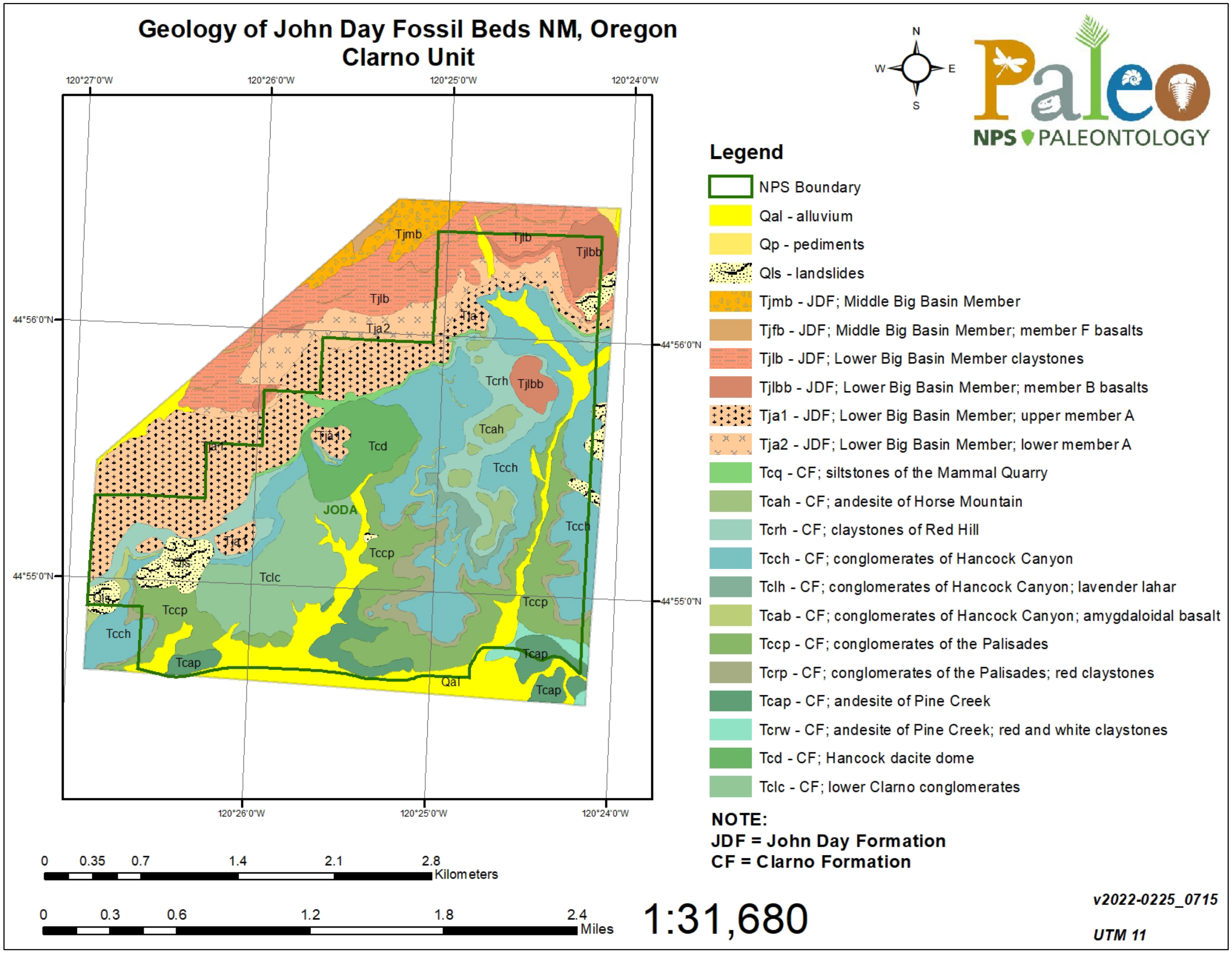


Figure 16. Geologic map of JODA (Clarno Unit), Oregon. Data modified from JODA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1045725.

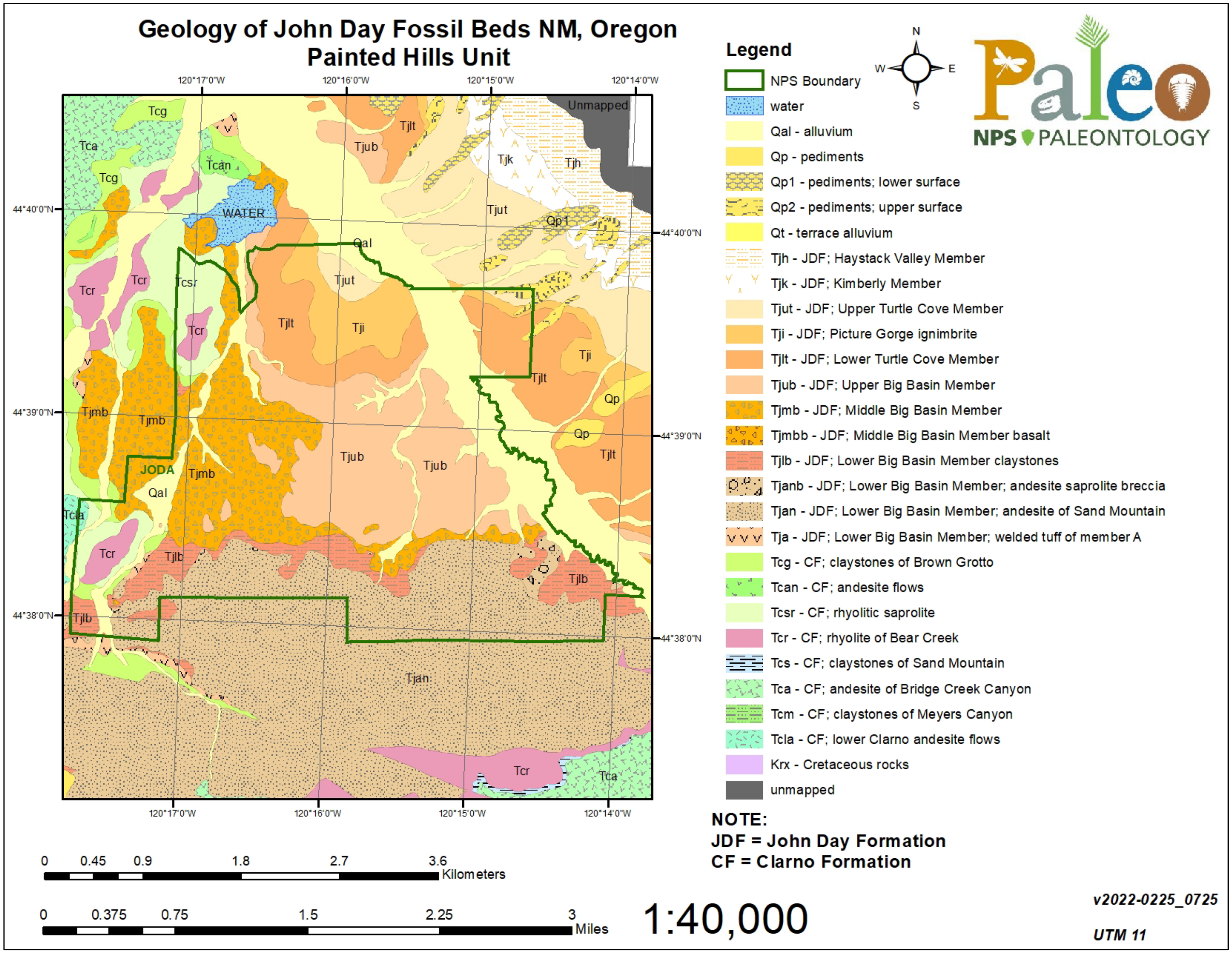


Figure 17. Geologic map of JODA (Painted Hills Unit), Oregon. Data modified from JODA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1045727.

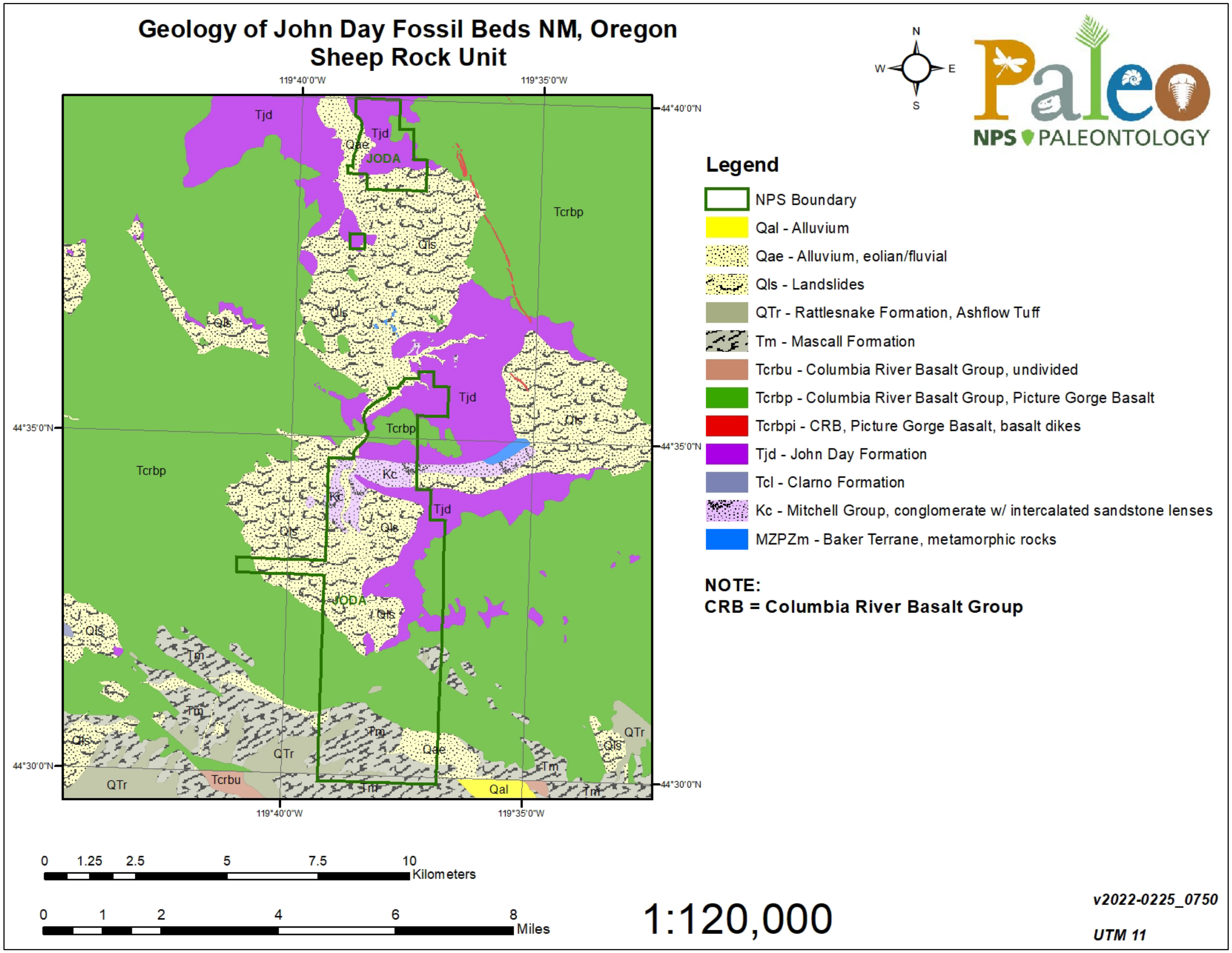


Figure 18. Geologic map of JODA (Sheep Rock Unit), Oregon. Data modified from JODA GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1045730.

Table 3. List of JODA stratotype units sorted by age with associated reference publications and locations. Units without GRI map symbols are not currently included on a GRI map.

Unit Name (GRI map symbol)	**Reference**	**Stratotype Location**	**Age**
Rattlesnake Formation (Qtr)	Merriam et al. 1925; Enlows 1973, 1976	**Type section** (composite): 1. exposures in the butte west of Picture Gorge on Rattlesnake Creek [SW/4 sec. 19, T. 12 S., R. 26. E.]; and 2) exposures on the east side of Cottonwood Creek [SW/4 sec. 33, T. 12 S., R. 26 E.], Grant County, OR. **Type locality**: exposures along the John Day River where the East Fork of the river enters Picture Gorge, approximately 8.8 km (5.5 mi) west of Dayville, Grant County, OR.	Miocene
Rattlesnake Ash-Flow Tuff, Rattlesnake Formation (Qtr)	Enlows 1976; Walker 1979	**Reference locality** (original type locality): on Rattlesnake Creek about 1.6 km (1 mi) west of Cottonwood Creek, Grant County, OR.	Miocene
Mascall Formation (Tm)	Merriam et al. 1925	**Type locality**: exposures along the John Day River where the East Fork of the river enters Picture Gorge, approximately 8.8 km (5.5 mi) west of Dayville, Grant County, OR.	Miocene
Picture Gorge Basalt, Columbia River Basalt Group (Tcrbp)	Waters 1961; Swanson et al. 1979	**Type section**: roadcuts along U.S. Highway 26 near junction with State Highway 19, in SW/4 sec. 17, NE/4 sec. 18, and NW/4 sec. 20, T. 12 S., R. 26 E., Picture Gorge West 7.5′ Quadrangle, Grant County, OR. **Type locality**: exposures in Picture Gorge, Grant County, OR.	Miocene
Dayville Basalt, Columbia River Basalt Group (Tcrbu)	Bailey 1989	**Type locality**: Picture Gorge, in southern half sec. 18 and N/2 sec. 19, T. 12 S., R. 26 E., Grant County, OR.	Miocene
Camas Creek Member, Monument Mountain Basalt, Columbia River Basalt Group	Bailey 1989	**Reference locality**: Picture Gorge, in E/2 sec. 18, T. 12 S., R. 26 E., Grant County, OR.	Miocene
John Day Formation (Tjd)	Merriam 1901; Hunt and Stepleton 2004	**Type area**: exposures located north (downstream) along the John Day River from Picture Gorge towards Kimberly, Grant County, OR.	Eocene–Miocene
Turtle Cove Member, John Day Formation (Tjut, Tjlt)	Fisher and Rensberger 1972	**Type area**: exposures in sec. 32, T. 10 S., R. 26 E., Foree State Park, Picture Gorge Quadrangle, Grant County, OR.	Oligocene–Miocene
Overlook Tuff of Big Basin Member, John Day Formation	Bestland et al. 1997; Graham 2014a	**Type locality**: exposures west of the visitor overlook that outcrop at the base of "Rainbow Hill" in the Painted Hills unit, Wheeler County, OR.	Oligocene

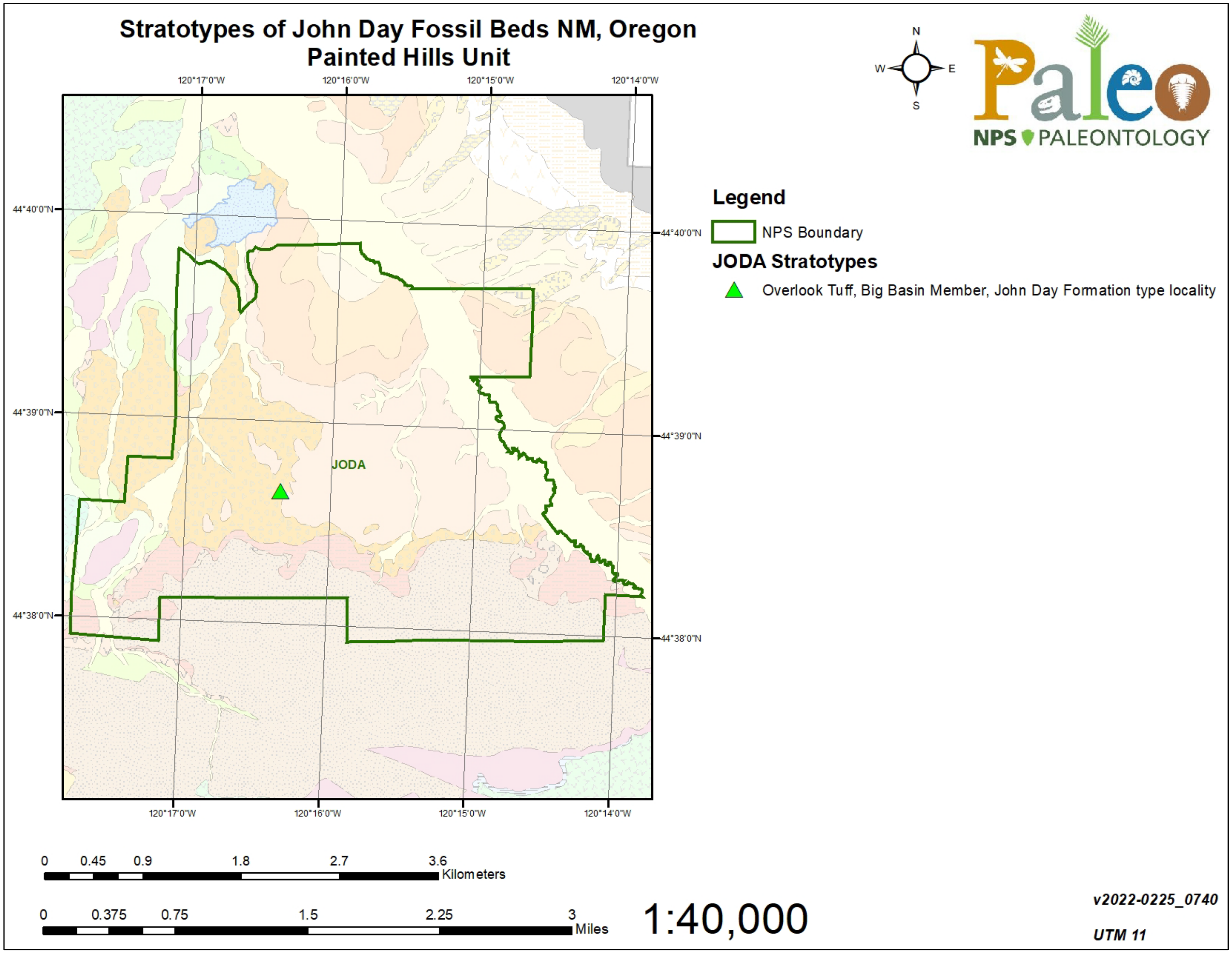


Figure 19. Modified geologic map of JODA (Painted Hills Unit) showing stratotype locations. The transparency of the geologic units layer has been increased.

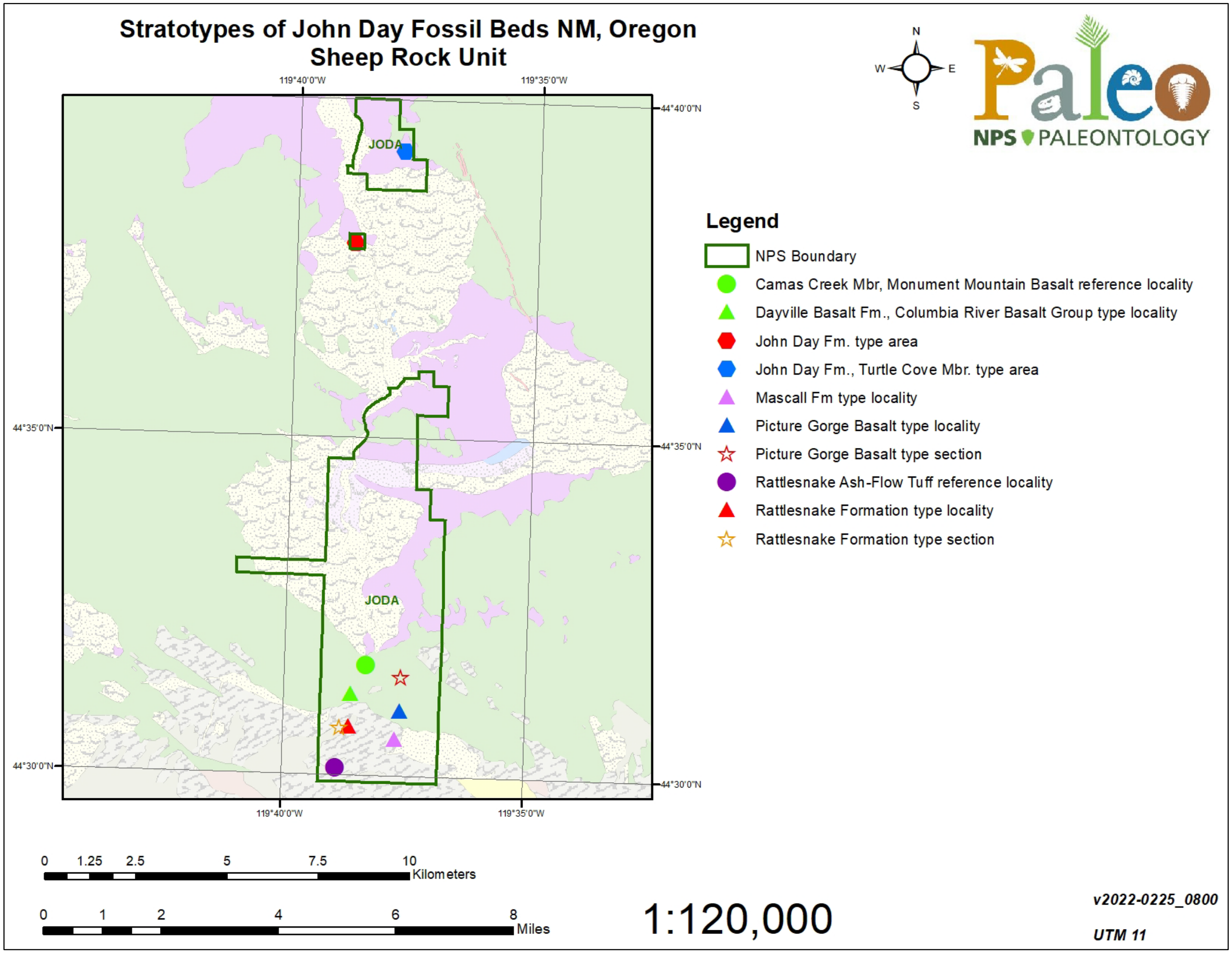


Figure 20. Modified geologic map of JODA (Sheep Rock Unit) showing stratotype locations. The transparency of the geologic units layer has been increased.

John Day Formation

The Eocene–Miocene John Day Formation was first mentioned by Marsh (1875) and Cope (1888) before Merriam (1901) formally described the unit in detail. The type area of the formation is designated in exposures located north (downstream) along the John Day River from Picture Gorge towards the town of Kimberly, Oregon (Table 3; Figure 20; Hunt and Stepleton 2004 citing Merriam 1901). The John Day Formation is a complex series of strata predominantly composed of volcaniclastic rocks, claystones, siltstones, tuffs, rhyolitic plugs, and localized mafic lava flows that are scattered across three major depositional basins and represent different depositional facies (rock types deposited in different environments) (Figures 21 and 22; Fisher and Rensberger 1972; Fremd et al. 2010). In the type area (eastern facies), Merriam (1901) estimated the thickness of the formation between 320–518 m (1,050–1,700 ft), but Fisher and Rensberger (1972) reported a composite thickness of 762 m (2,500 ft) within the Picture Gorge and Kimberly Quadrangles. In general, the eastern facies of the John Day Formation is a thinner, finer-grained, more fossiliferous sequence of strata compared to the western and southern facies (Fisher 1967; Fisher and Rensberger 1972). The John Day Formation overlies the Clarno Formation and underlies the Picture Gorge Basalt of the Columbia River Basalt Group.

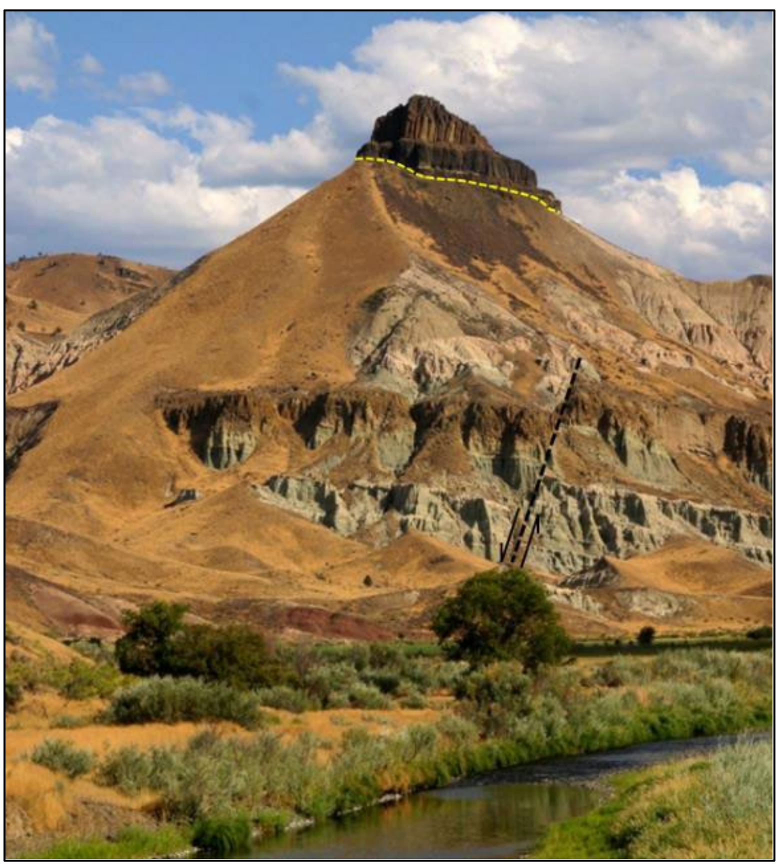


Figure 21. Type area exposure of the John Day Formation at Sheep Rock in the Sheep Rock unit. Fossiliferous claystones, siltstones, and tuffs of the John Day Formation form the slopes. The top of Sheep Rock is capped by the Picture Gorge Basalt (above dashed yellow line). Offset fault shown by black dashed line with arrows showing relative displacement. Annotated NPS photograph.

Figure 22. Cathedral Rock as seen along the John Day River, a prominent type area exposure of the John Day Formation (NPS).

Overlook Tuff, Big Basin Member, John Day Formation

The Oligocene Overlook Tuff of the Big Basin Member of the John Day Formation was named by Bestland et al. (1993, 1994, 1997) for its type locality exposures west of the visitor overlook that outcrop at the base of "Rainbow Hill" in the Painted Hills unit in Wheeler County, Oregon (Table 3; Figure 19). In the type locality of the Painted Hills area, the Overlook Tuff is an important stratigraphic marker measuring several meters thick that commonly shows reworking, graded beds, and crystal concentrations. The presence of the tuff marks a significant break in the stratigraphic sequence, with an abrupt contact with underlying claystones that approximates the Eocene–Oligocene boundary (Bestland et al. 1999; Graham 2014a). The Overlook Tuff overlies lignite beds of the Big Basin Member and gradationally underlies the "Red Cap" beds of the Big Basin Member.

Turtle Cove Member, John Day Formation

The Oligocene–Miocene Turtle Cove Member of the John Day Formation was proposed by Fisher and Rensberger (1972) and named after excellent exposures in the area originally called Turtle Cove by Merriam (1901). Type area exposures are designated in sec. 32, T. 10 S., R. 26 E., Foree State

Park, Picture Gorge Quadrangle, Grant County, Oregon (Table 3; Figure 20; Fisher and Rensberger 1972). In the type area the Turtle Cove Member measures about 366 m (1,200 ft) thick and consists of fine-grained, diagenetically altered, variegated tuffs with conspicuous marker beds of the Picture Gorge ignimbrite and other air-fall tuff layers (Figure 23; Fisher and Rensberger 1972). The Turtle Cove Member stratigraphically occurs between the overlying Kimberly Member and underlying Big Basin Member of the John Day Formation.

Figure 23. Badlands topography of Turtle Cove, type area of the Turtle Cove Member of the John Day Formation (NPS/GLENNA LANGE).

Camas Creek Member, Monument Mountain Basalt

The Miocene Camas Creek Member of the Monument Mountain Basalt (Columbia River Basalt Group) was named by Bailey (1989) for its type locality exposures near the junction of Camas Creek and the North Fork of the John Day River. Although the type locality is located outside the administrative boundary of JODA, a reference locality for the member is designated in Picture Gorge, in E/2 sec. 18, T. 12 S., R. 26 E., Grant County, Oregon (Table 3; Figures 20, 24; Bailey 1989). The unit generally consists of two lava flows that are characterized as aphyric (lack of large mineral crystals) to sparsely plagioclase- and olivine-phyric (bimodal crystal size distribution) (Bailey 1989). Near the reference locality, the Camas Creek Member directly overlies the John Day Formation and underlies the Holmes Creek Member of the Monument Mountain Basalt.

Figure 24. Steep canyon walls of Picture Gorge, type locality of the Picture Gorge Basalt and Dayville Basalt and reference locality of the Camas Creek Member of the Monument Mountain Basalt (NPS/NICK FAMOSO).

Dayville Basalt

The Miocene Dayville Basalt of the Columbia River Basalt Group was named by Bailey (1989) after its type locality exposures approximately 10 km (6 mi) northwest of Dayville in Picture Gorge, in S/2 sec. 18 and N/2 sec. 19, T. 12 S., R. 26 E., Grant County, Oregon (Table 3; Figures 20, 24). The formation consists of at least 22 lava flows of small areal extents that have variable composition, ranging from abundantly phyric- to aphyric flows with different phenocryst (large mineral crystal set in a fine matrix) assemblages (Bailey 1989). At the type locality, the formation reaches a maximum thickness of about 160 m (525 ft). The Dayville Basalt overlies the Monument Mountain Basalt and underlies the Grande Ronde Basalt.

Picture Gorge Basalt

The Miocene Picture Gorge Basalt was named by Waters (1961) after its type locality exposures at Picture Gorge in Grant County, Oregon (Table 3; Figures 20, 24, and 25). Swanson et al. (1979) outlined a more detailed description of the type section location in the roadcuts along U.S. Highway 26 near the junction with State Highway 19, in SW/4 sec. 17, NE/4 sec. 18, and NW/4 sec. 20, T. 12 S., R. 26 E., in the Picture Gorge West 7.5′ Quadrangle (Table 3; Figure 20). The Picture Gorge Basalt consists of a sequence of aphyric flows underlain and overlain by plagioclase-phyric flows that Bailey (1989) would later designate the Dayville Basalt, Monument Mountain Basalt, and Twickenham Basalt. The type section of the formation consists of 17 flows that measure approximately 430 m (1,410 ft) thick (Swanson et al. 1979). At the type section the Picture Gorge Basalt conformably underlies the Mascall Formation and unconformably overlies the John Day Formation.

Figure 25. Columnar basalt of the Picture Gorge Basalt in the type locality at Picture Gorge (NPS/B. LILLIE).

Mascall Formation

The Miocene Mascall Formation was named by Merriam (1901) for exposures near Mascall Ranch approximately 6.4 km (4 mi) from Dayville, Oregon. The type locality of the formation is designated along the John Day River where it enters Picture Gorge, approximately 8.8 km (5.5 mi) west of Dayville (Table 3; Figure 20; Merriam et al. 1925). The unit consists of yellowish-white- to gray interbedded tuffs, tuffaceous shale (mudstone), pumiceous sandstone, and blocks of basalt (Merriam et al. 1925; Enlows 1976; Fremd et al. 2010). A columnar section measured at the type locality by Merriam et al. (1925) is about 637 m (2,090 ft) thick. At the type locality, the Mascall Formation unconformably underlies the Rattlesnake Formation and overlies rocks of the Columbia River Basalt Group (Figure 26).

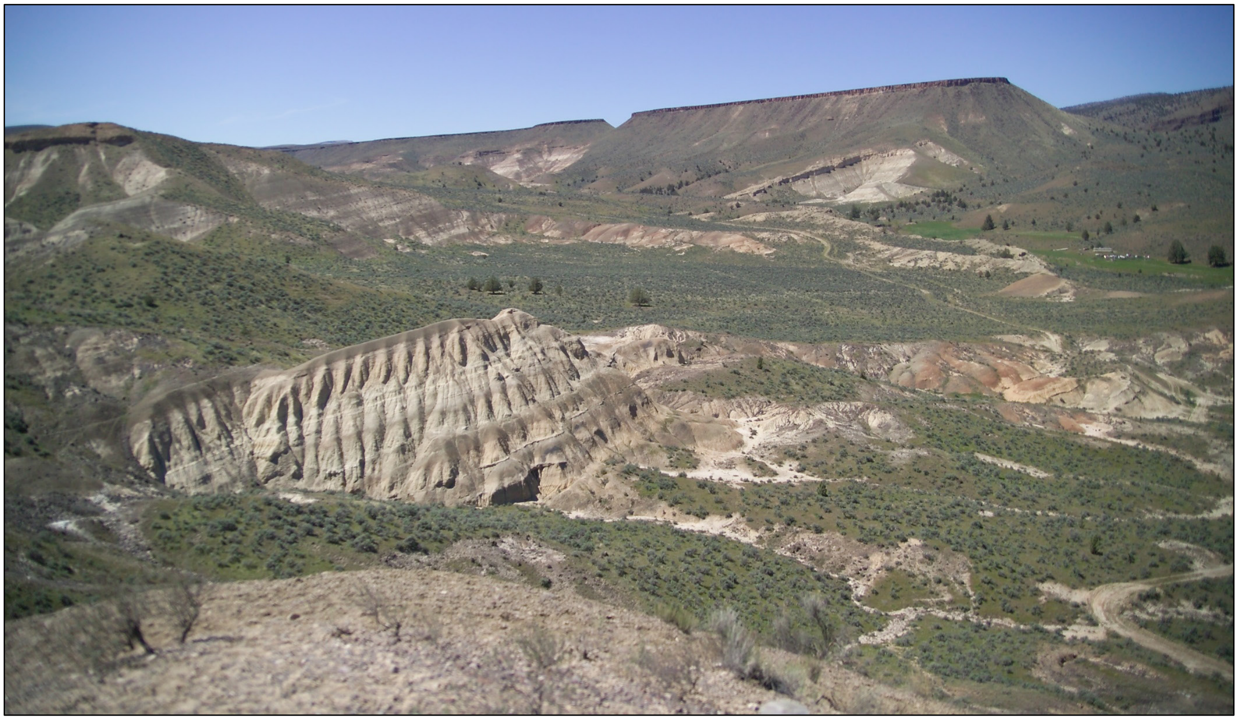


Figure 26. View from the Mascall Overlook towards the type locality exposures of the Mascall Formation and Rattlesnake Formation (NPS). The Rattlesnake Formation unconformably caps the Mascall Formation, with the resistant Rattlesnake Air-Fall Tuff capping the hills in the distance.

Rattlesnake Formation

The Miocene Rattlesnake Formation was first described by Merriam (1901) in the John Day region near Rattlesnake Creek about 1.6 km (1 mi) west of Cottonwood Creek, Oregon. A composite type section of the formation is designated at the following locations: 1) exposures in the butte west of Picture Gorge on Rattlesnake Creek [SW/4 sec. 19, T. 12 S., R. 26. E.]; and 2) exposures on the east side of Cottonwood Creek [SW/4 sec. 33, T. 12 S., R. 26 E.] in Grant County, Oregon (Table 3; Figures 20 and 27; Enlows 1973, 1976). Enlows (1976) subdivided the formation at the type section into three members: 1) a Lower Fanglomerate Member with thick interbeds of yellowish-gray volcanic wacke and grayish-orange volcanic mudstone; 2) the Rattlesnake Ignimbrite Tongue, a single flow unit separated into three zones (see Rattlesnake Ash-Flow Tuff section below); and 3) an Upper Fanglomerate Member composed of small boulders, cobbles, and pebbles (Enlows 1976). The type locality of the formation is along the John Day River where it enters Picture Gorge, approximately 8.8 km (5.5 mi) west of Dayville (Table 3; Figure 20; Merriam et al. 1925). In the type locality the Rattlesnake Formation unconformably overlies the Mascall Formation and consists of about 120 m (394 ft) of soft siltstones and conglomerates punctuated by several more resistant tuff beds (Prothero et al. 2006).

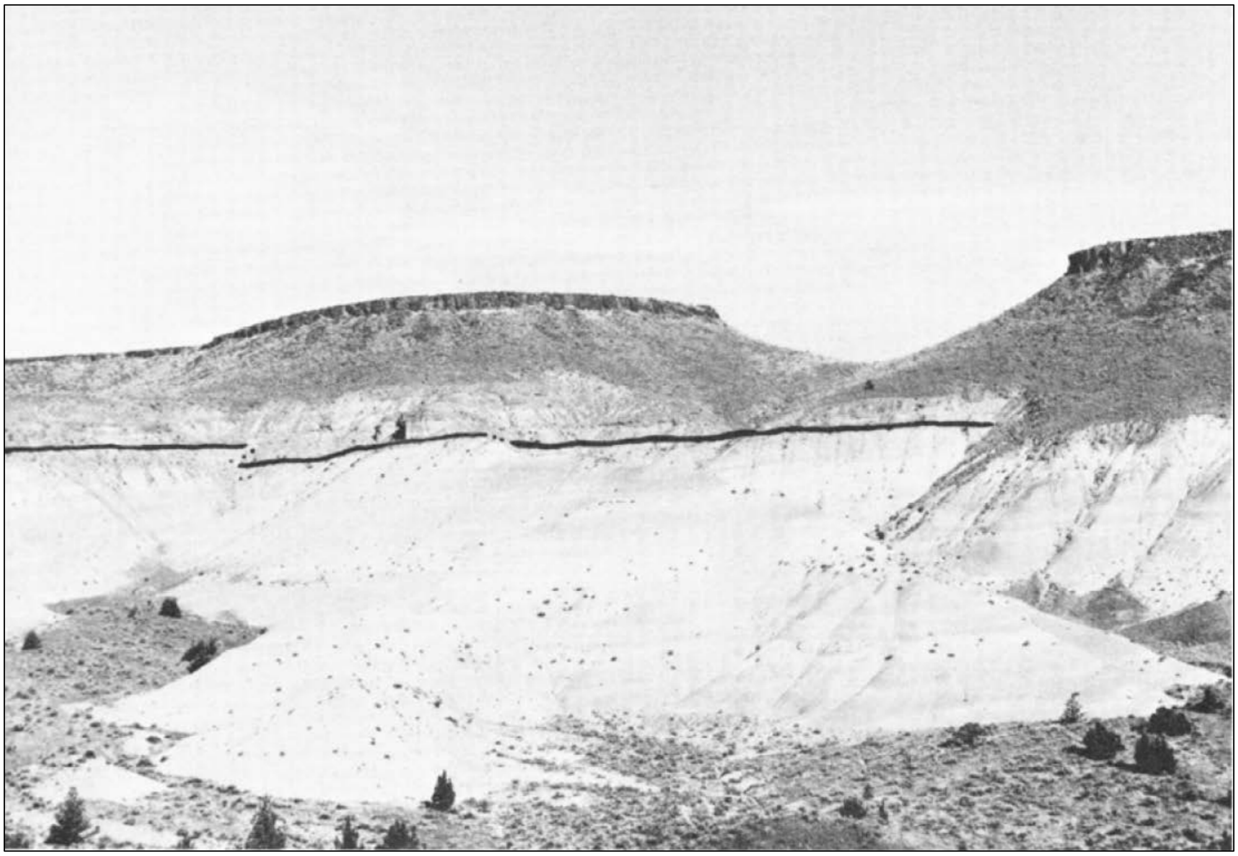


Figure 27. Type section exposure of the Rattlesnake Formation on Rattlesnake Creek. The Lower Fanglomerate Member of the Rattlesnake Formation overlies the Mascall Formation (contact represented by solid black line) and is capped by the Rattlesnake Ash-Flow Tuff (“Rattlesnake Ignimbrite Tongue”). Figure 2 from Enlows (1976), courtesy of Oregon Department of Geology and Mineral Industries.

Rattlesnake Ash-Flow Tuff

The Miocene Rattlesnake Ash-Flow Tuff of the Rattlesnake Formation was originally identified by Merriam (1901) and referred to as the “Rattlesnake Ignimbrite Tongue” by Enlows (1976) before the unit was redesignated by Walker (1979). A reference locality (the original type locality) of the tuff is located on Rattlesnake Creek about 1.6 km (1 mi) west of Cottonwood Creek in Grant County, Oregon (Table 3; Figure 20; Enlows 1976; Walker 1979). The ash-flow tuff is about 12 m (39 ft) thick at the reference locality, consisting of a single flow and cooling unit of poorly to moderately welded pumiceous tuff (Walker 1979). At the reference locality, the unit forms a prominent cap over the badland topography of the Mascall Formation (Figure 28).

Figure 28. The Rattlesnake Ash-Flow Tuff as seen from the Mascall Overlook (NPS). The tuff forms a resistant marker bed approximately 12 m (29 ft) thick that caps the hill.

Lake Roosevelt National Recreation Area (LARO)

Lake Roosevelt National Recreation Area (LARO) is the largest reservoir in the Pacific Northwest and stretches 214 km (133 mi) from Grand Coulee Dam to Onion Creek in Ferry, Grant, Lincoln, and Stevens Counties, northeastern Washington (Figure 29). Originally established as Coulee Dam Recreational Area on December 18, 1946, the park unit was renamed on January 1, 1997 (National Park Service 2016a). Encompassing approximately 40,626 hectares (100,390 acres), LARO protects, conserves, and preserves the natural and cultural resources of the Upper Columbia River Basin behind Grand Coulee Dam and provides for diverse recreational opportunities (National Park Service 2015b). Formed by the construction of the Grand Coulee Dam in 1941, the Franklin D. Roosevelt Lake is situated along the convergence of the Okanogan Highlands and Columbia Basin physiographic provinces. LARO includes more than 483 km (300 mi) of publicly accessible shoreline and provides visitors a variety of recreational options that include boating, fishing, camping, picnicking, and sightseeing.

LARO is situated in a landscape sculpted by a rare combination of sequential geologic processes that include 1) tectonic plate convergence, 2) volcanism, 3) continental glaciation, and 4) cataclysmic Ice Age floods. An assemblage of metamorphic, igneous, and sedimentary rocks can be found around Lake Roosevelt that record ancient plate tectonic processes (Figure 30). The northern area of LARO around Kettle Falls contains meta-sedimentary rocks that were once part of an ancient seafloor. To the south, the Grand Coulee Dam is built upon granite bedrock that formed due to subduction-related volcanism. During the Miocene, extensive lava flows were deposited over the landscape of LARO and formed the layers of rock associated with the Columbia River Basalt Group. The dark, layered basalt of the Columbia River Basalt Group borders the southern edge of Lake Roosevelt, from Fort Spokane to the Grand Coulee Dam area. The effect of Pleistocene glaciation scoured the mountains in the northern LARO region while the southern half was subjected to catastrophic flooding as glacially dammed lakes were weakened and burst. The broad, box-like canyons of the Channeled Scabland were formed during multiple episodes of immense flooding. Evidence of Ice Age flooding can be found everywhere around Lake Roosevelt and are recorded in carved channels (“coulees”) and layered sedimentary deposits called rhythmites.

There are no designated stratotypes identified within the boundaries of LARO. There are six identified stratotypes located within 48 km (30 mi) of LARO boundaries, for the Eocene Scatter Creek Rhyodacite (type locality), Sanpoil Volcanics (type locality), O’Brien Creek Formation (type locality), and Klondike Mountain Formation (type locality), and the Miocene Roza Member of the Wanapum Basalt (reference section) and Latah Formation (type locality).

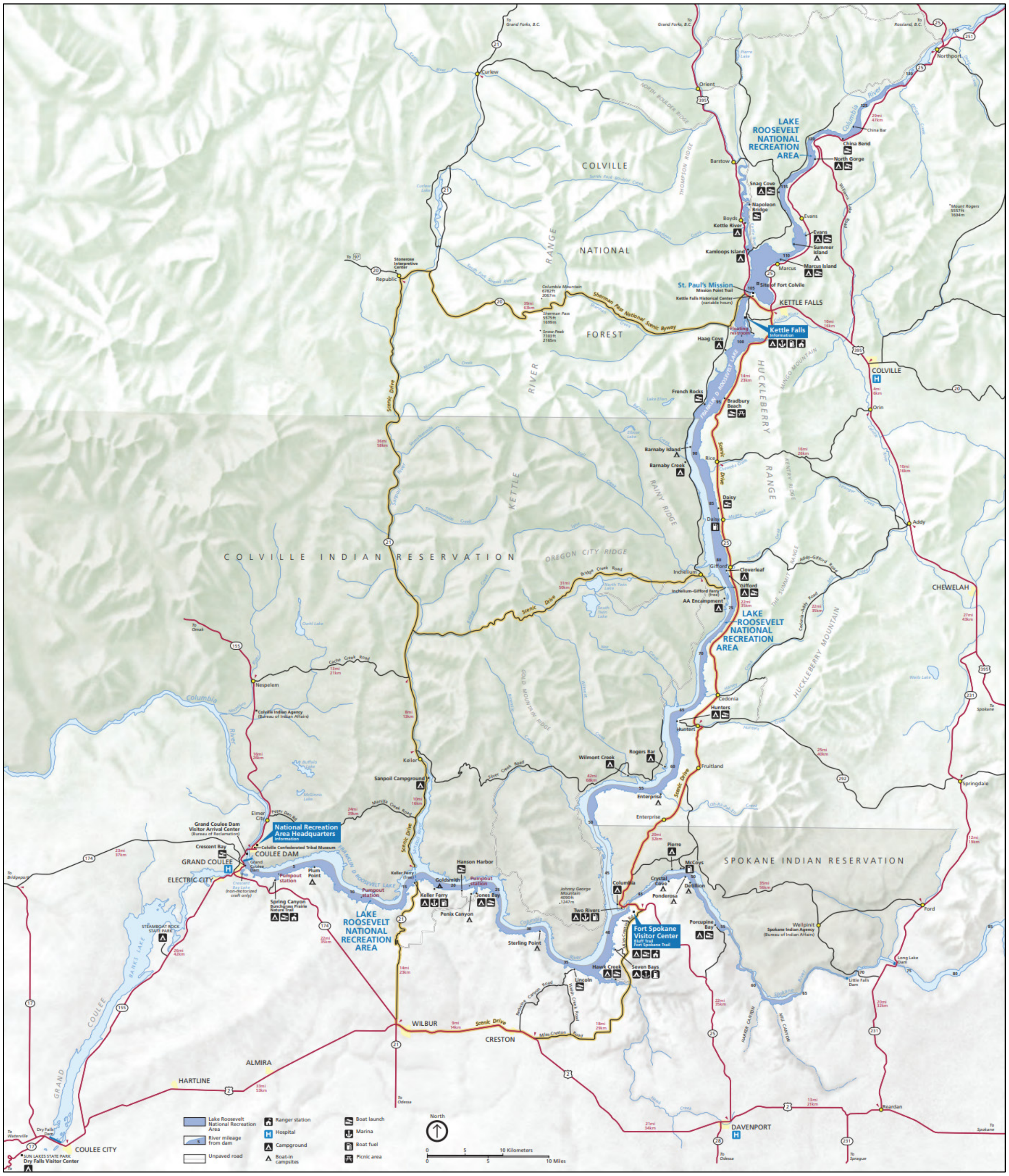


Figure 29. Park map of LARO, Washington (NPS).

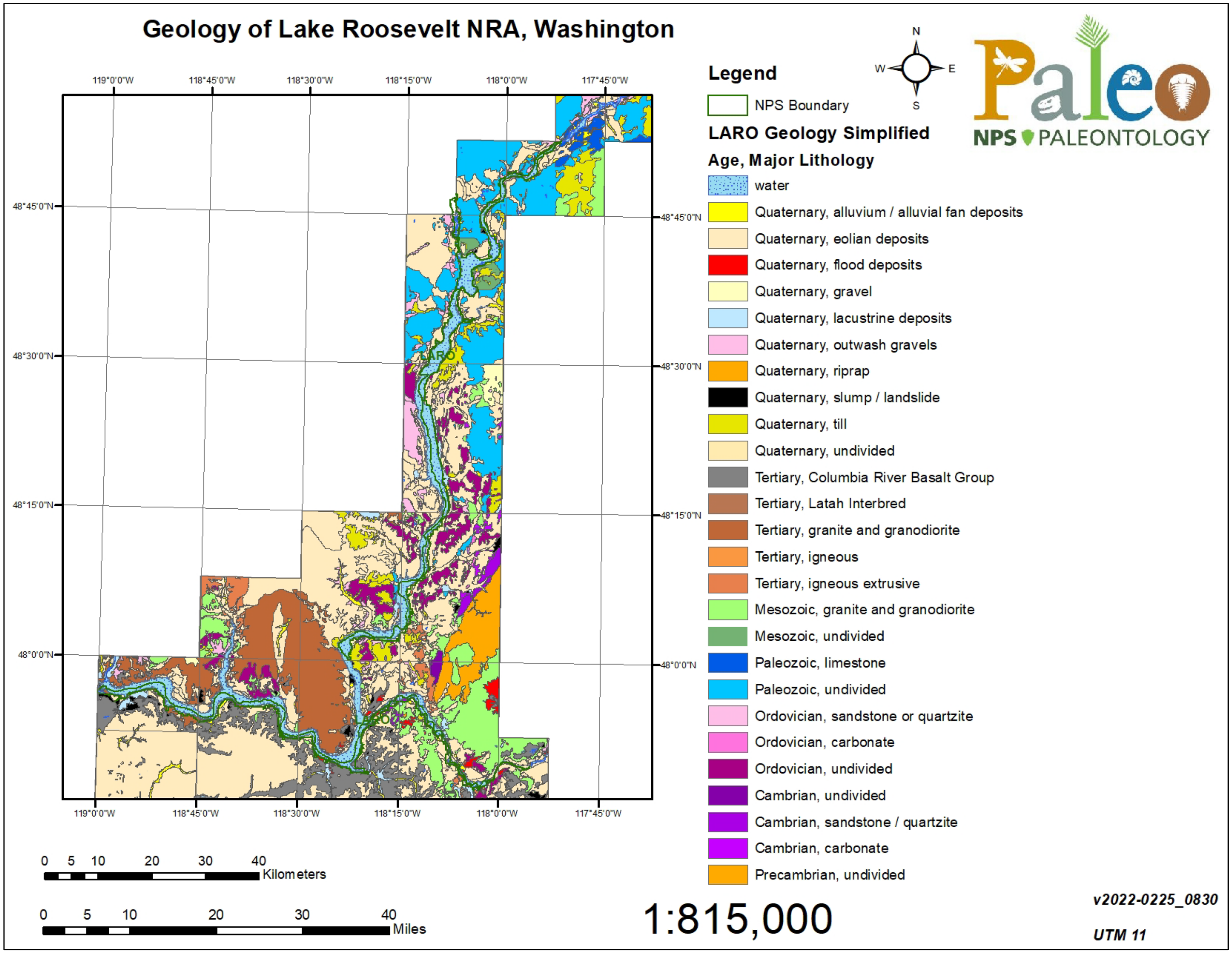


Figure 30. Geologic map of LARO, Washington. Data modified and simplified from LARO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047546.

Minidoka National Historic Site (MIIN)

Minidoka National Historic Site (MIIN) consists of the Minidoka War Relocation Center in Jerome County, Idaho, and the Bainbridge Island Memorial located along the Puget Sound in Kitsap County, Washington (Figure 31). Proclaimed on January 17, 2001, and redesignated as a national historic site on May 8, 2007, MIIN encompasses approximately 160 hectares (396 acres) (National Park Service 2016a). The national historic site protects historical and cultural resources associated with the unlawful relocation and internment of Nikkei (Japanese American citizens and legal residents of Japanese ancestry) during World War II. The attack on Pearl Harbor in December 1941 intensified hostility towards Japanese Americans, and as wartime hysteria grew President Roosevelt signed Executive Order 9066 that forced more than 120,000 Nikkei into prison camps across the nation. In south-central Idaho, MIIN preserves a small portion of the original 13,355-hectare (33,000-acre) Minidoka War Relocation Center, one of 10 camps constructed to hold the excluded Nikkei communities (National Park Service 2016b). Located about 1,125 km (700 mi) northwest, the Bainbridge Island Memorial in Washington recognizes and honors the first Nikkei to be forcibly removed from Bainbridge Island under Executive Order 9066. The Bainbridge Island Memorial protects the original site where 227 men, women, and children were incarcerated and relocated to the Manzanar War Relocation Center in California (National Park Service 2016b).

The geology of MIIN consists of young, Quaternary-age deposits that can be subdivided into two groups of rocks: 1) Pleistocene volcanic rocks including the basalt of Wilson Butte and basalt of Rocky Butte in south-central Idaho; and 2) Quaternary glacial deposits of the Vashon Drift and pre-Vashon deposits in Washington (Figures 32 and 33; Haugerud 2005; Othberg et al. 2012). Volcanic rocks that underlie the Minidoka War Relocation Center in Idaho are widespread units consisting of dark gray to black, fine-grained and glassy basalt (Othberg et al. 2012). Units mapped at the Bainbridge Island Memorial in Washington consist of pre-Vashon deposits largely composed of sedimentary rocks of fluvial, lacustrine, glacial, and possible marine origin, as well as sandstone and gravel of the Pleistocene Esperance Sand Member of the Vashon Drift (Haugerud 2005).

There are no designated stratotypes identified within the boundaries of MIIN. There are five identified stratotypes located within 48 km (30 mi) of MIIN boundaries in south-central Idaho, including the Miocene Banbury Basalt (type locality) and Pleistocene Melon Gravel (type locality), Yahoo Clay (reference section), Sand Springs Basalt (type locality), and Thousand Springs Basalt (type locality). In Washington there are six identified stratotypes located within 48 km (30 mi) of MIIN boundaries, for the Pleistocene Lawton Clay Member of the Vashon Drift (type section), Possession Drift (type locality), Whidbey Formation (type section and type locality), and Double Bluff Drift (type section and type locality).

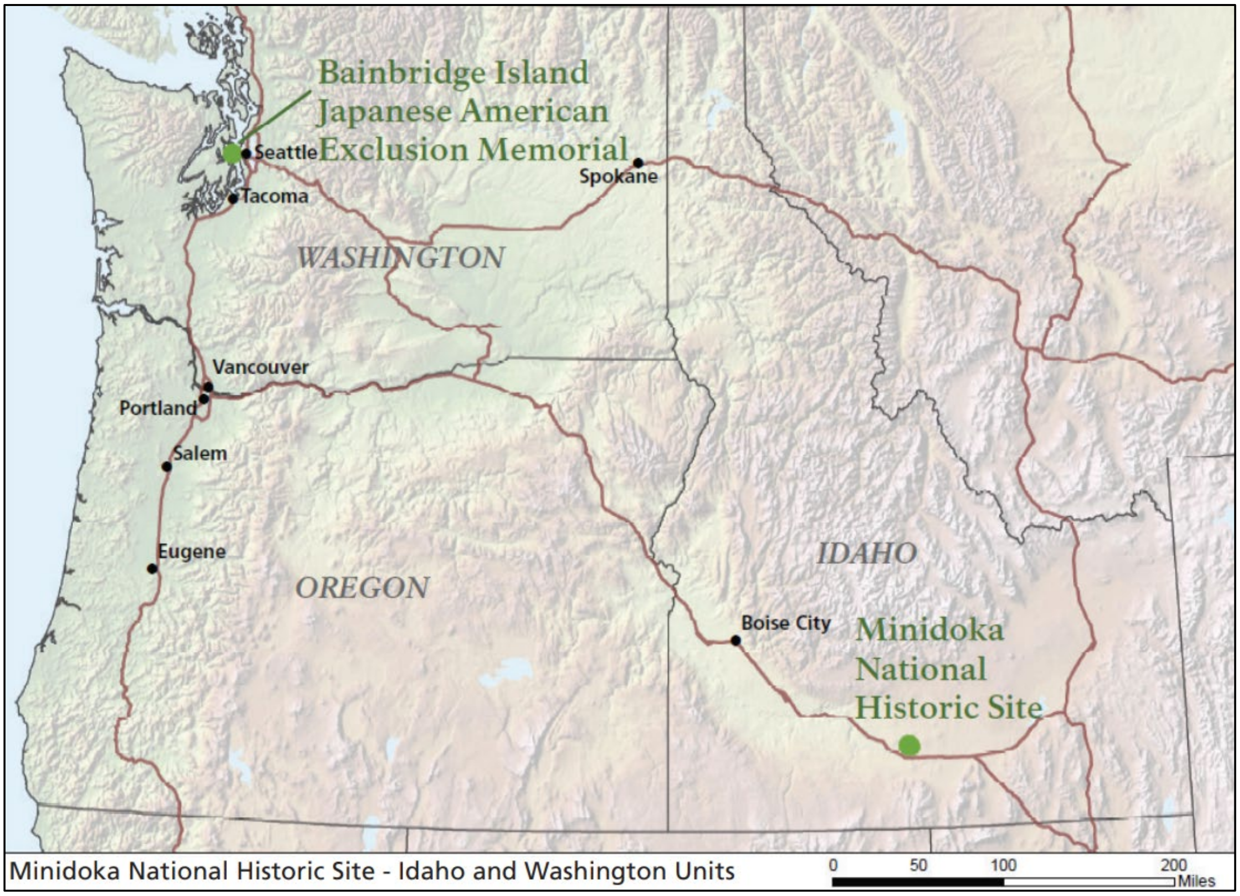


Figure 31. Regional map of MIIN, Idaho–Washington (NPS).

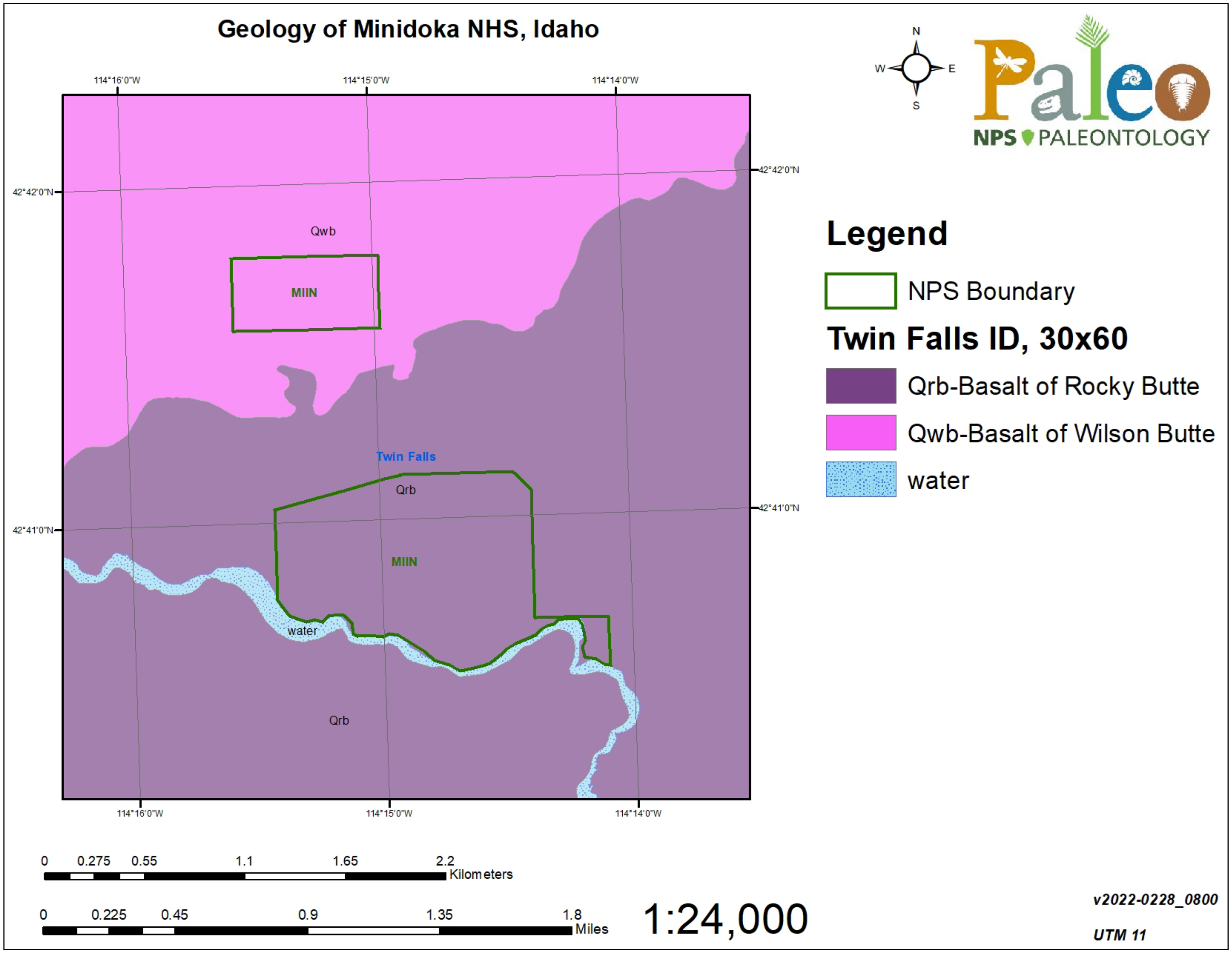


Figure 32. Geologic map of MIIN, Idaho. Data modified from Idaho GS data at https://www.idahogeology.org/Product/GM-49.

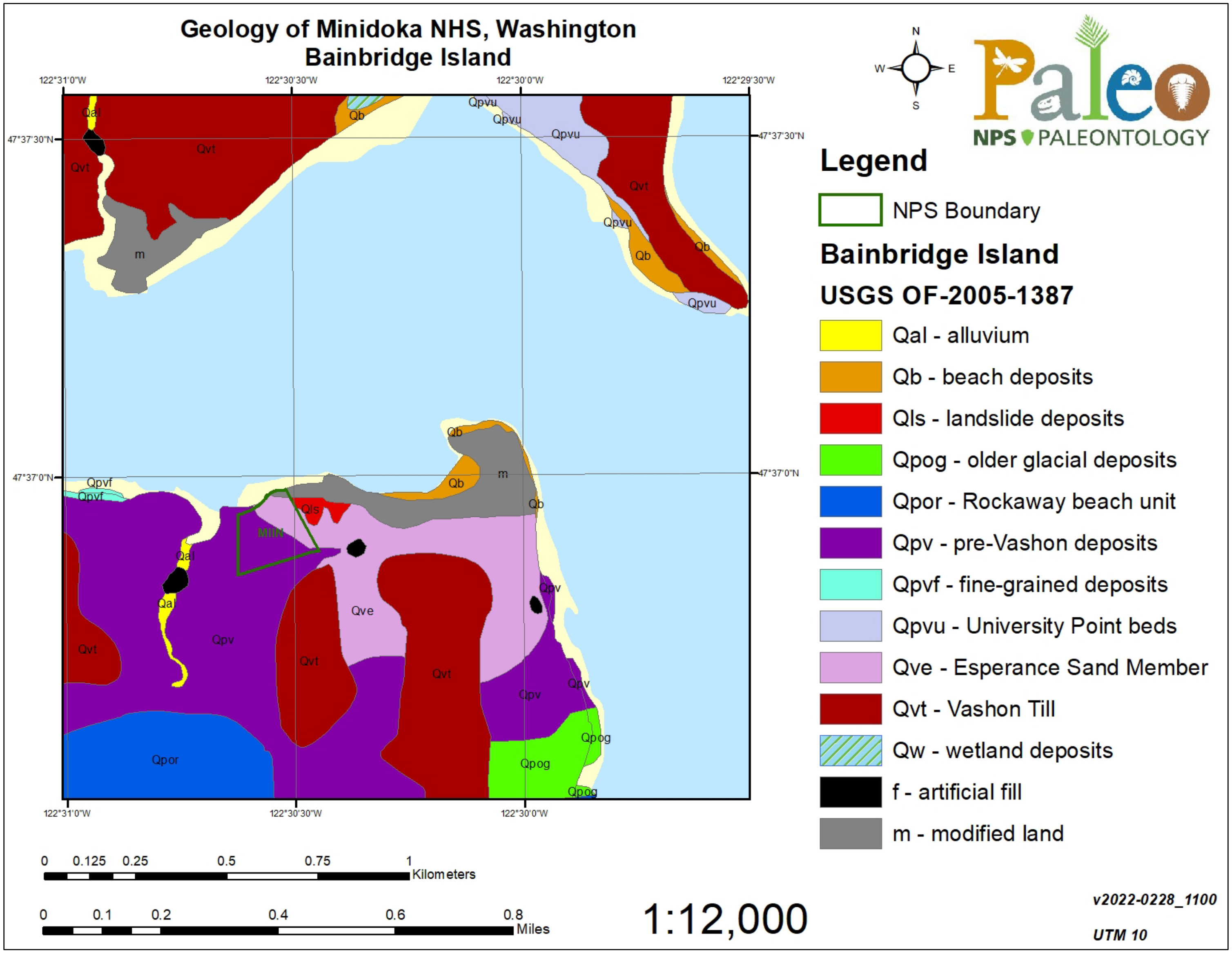


Figure 33. Geologic map of MIIN, Washington. Data modified from USGS data at https://pubs.usgs.gov/of/2005/1387/.

Nez Perce National Historical Park (NEPE)

Nez Perce National Historical Park (NEPE) includes 38 sites distributed across Idaho, Washington, Oregon, and Montana (Clark, Clearwater, Idaho, Lewis, and Nez Perce Counties, Idaho; Okanogan County, Washington; Wallowa County, Oregon; and Beaverhead, Blain, and Yellowstone Counties, Montana; Figure 34). Eight sites are owned and managed by the National Park Service: Spalding (park unit headquarters), Bear Paw, Buffalo Eddy, Canoe Camp, Heart of the Monster, Old Chief Joseph Grave, White Bird Battlefield, and Big Hole National Battlefield (see BIHO for more information). Established on May 15, 1965, NEPE encompasses approximately 1,847 hectares (4,565 acres) and commemorates the history, culture, and contributions of the Nez Perce. The park includes sites associated with the Nez Perce War of 1877 and the flight of Chief Joseph and his band. Several of the park sites are connected by the Nez Perce National Historic Trail which preserves the route taken by Chief Joseph and his band of Nez Perce when they attempted to reach Canada in 1877.

The bedrock geology of NEPE consists of sedimentary and igneous rocks that span in age from the Triassic to more recent surficial deposits (Figures 35–41). Some of the oldest rocks in the park are located along the Snake River in the Bear Paw Unit and are represented by the Triassic Wild Creek Sheep Formation of the Seven Devils Group and Cretaceous-age sedimentary rocks of the Telegraph Creek and Carlile Formations. Volcanic rocks of the Miocene-age Grande Ronde Basalt of the Columbia River Basalt Group are mapped in the Buffalo Eddy, Spalding, and White Bird Battlefield units. Younger Quaternary deposits are found in the Camp Canoe, Heart of the Monster, Old Chief Joseph Grave, Spalding, and White Bird Battlefield units and represent alluvium (unconsolidated deposits of sand, silt, clay, and gravel), mass-wasting deposits, active landslide deposits, alluvial fans, and terrace gravels.

There are no designated stratotypes identified within the boundaries of NEPE. There are 39 identified stratotypes located within 48 km (30 mi) of NEPE boundaries, for the Permian Hunsaker Creek Formation (type section) and Windy Ridge Formation (type locality); Triassic Martin Bridge Formation (type section, principal reference section, reference section), BC Creek Member of the Martin Bridge Formation (type section), Eagle Creek Member of the Martin Bridge Formation (type section), Scotch Creek Member of the Martin Bridge Formation (type section and three reference sections), Summit Point Member of the Martin Bridge Formation (type section and reference section), Doyle Creek Formation (two reference sections), and Wild Sheep Creek Formation (type section and reference section); and Miocene Imnaha Basalt (type section, type locality, three reference sections), Saddle Mountains Basalt (reference section), Asotin Member of the Saddle Mountains Basalt (type locality), Buford Member of the Saddle Mountains Basalt (type locality and reference section), Craigmont Member of the Saddle Mountains Basalt (type locality), Grangeville Member of the Saddle Mountains Basalt (type locality), Icicle Flat Member of the Saddle Mountains Basalt (type locality), Pomona Member of the Saddle Mountains Basalt (reference section), Swamp Creek Member of the Saddle Mountains Basalt (type locality), Weissenfels Ridge Member of the Saddle Mountains Basalt (type locality), Wilbur Creek Member of the Saddle Mountains Basalt (type locality and reference section), Priest Rapids Member of the Wanapum Basalt (two reference sections), Roza Member of the Wanapum Basalt (two reference sections), and Grande Ronde Basalt (type locality).

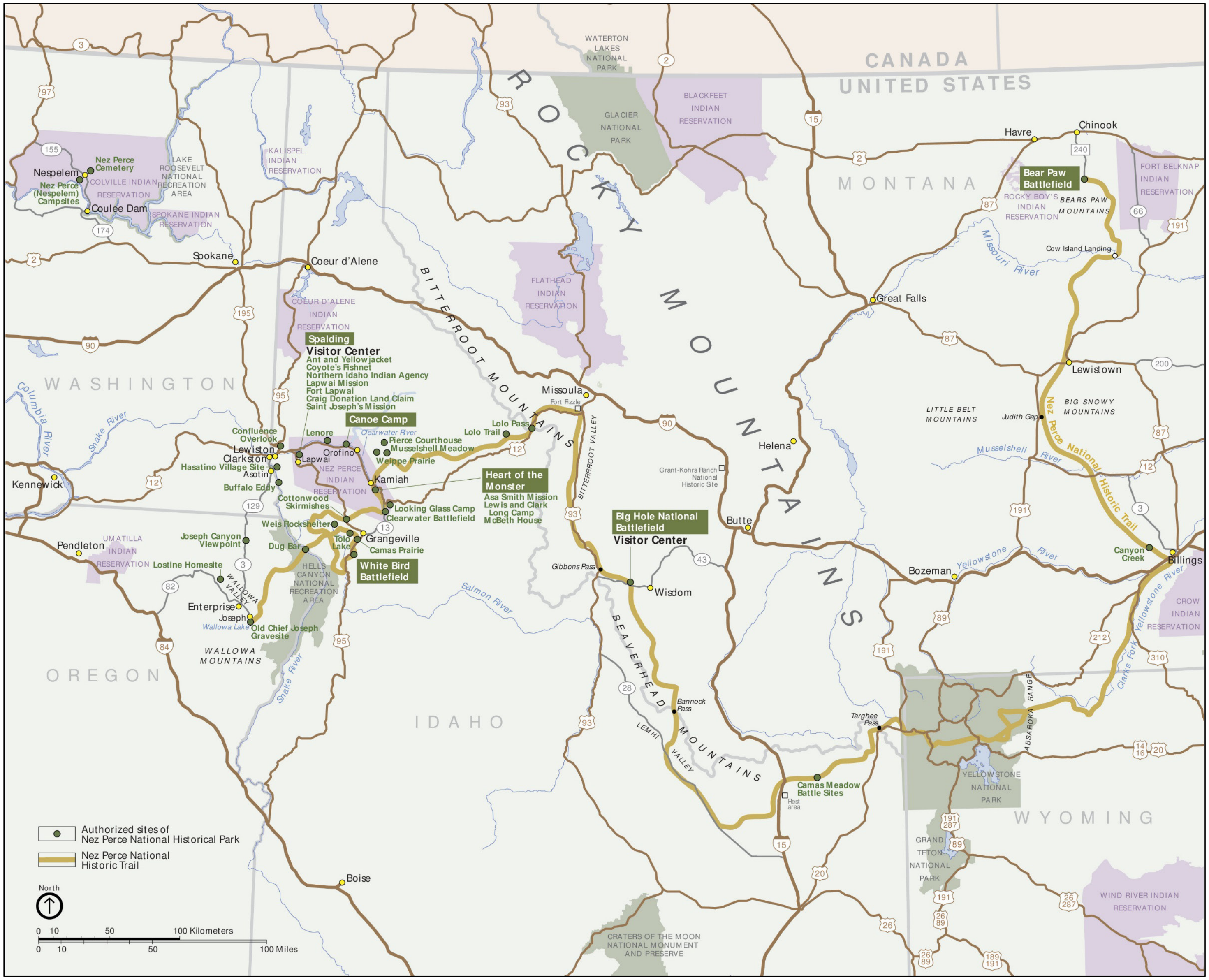


Figure 34. Regional map of NEPE, Idaho–Montana–Oregon–Washington (NPS).

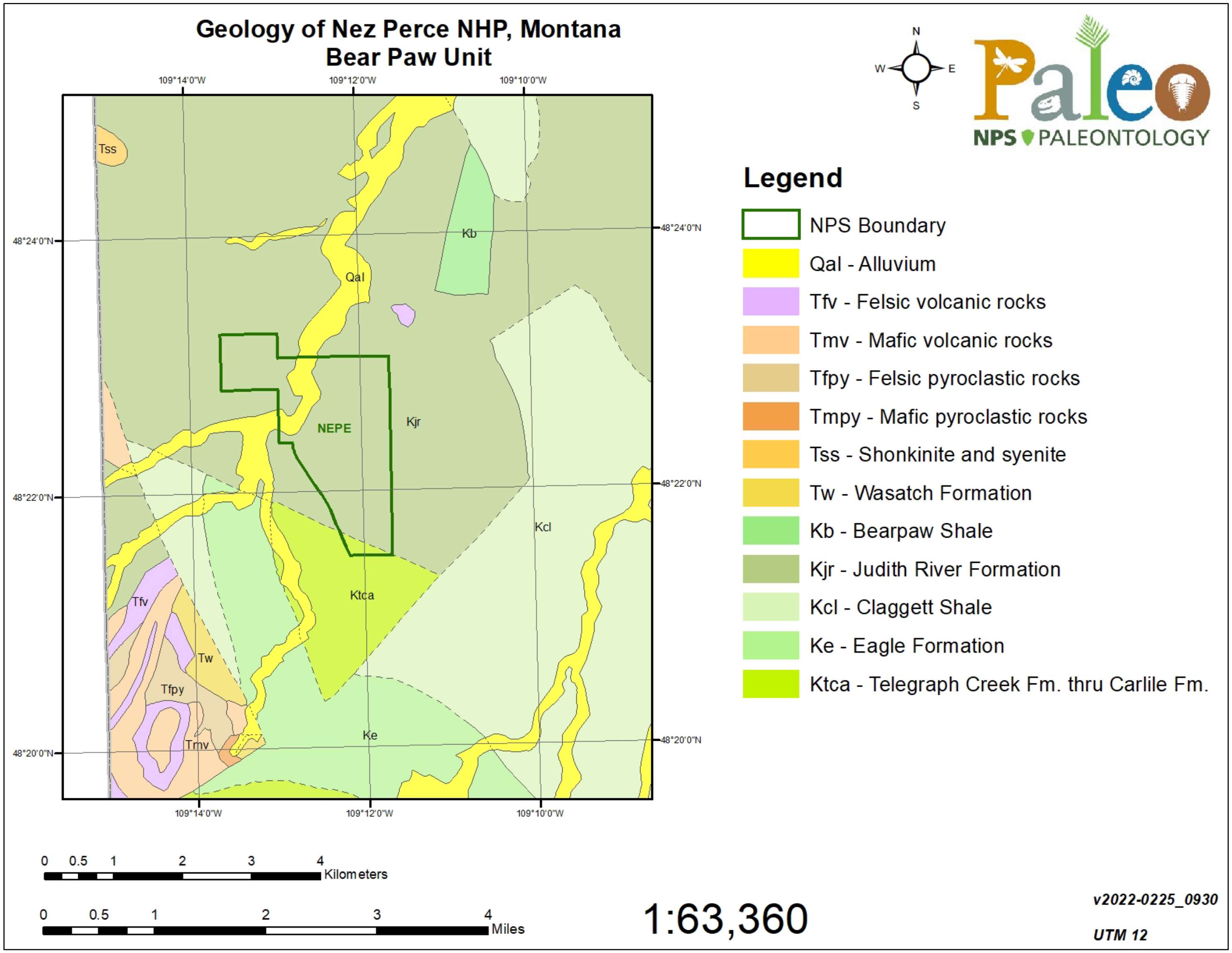


Figure 35. Geologic map of NEPE (Bear Paw Unit), Montana. Data modified from NEPE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047474.

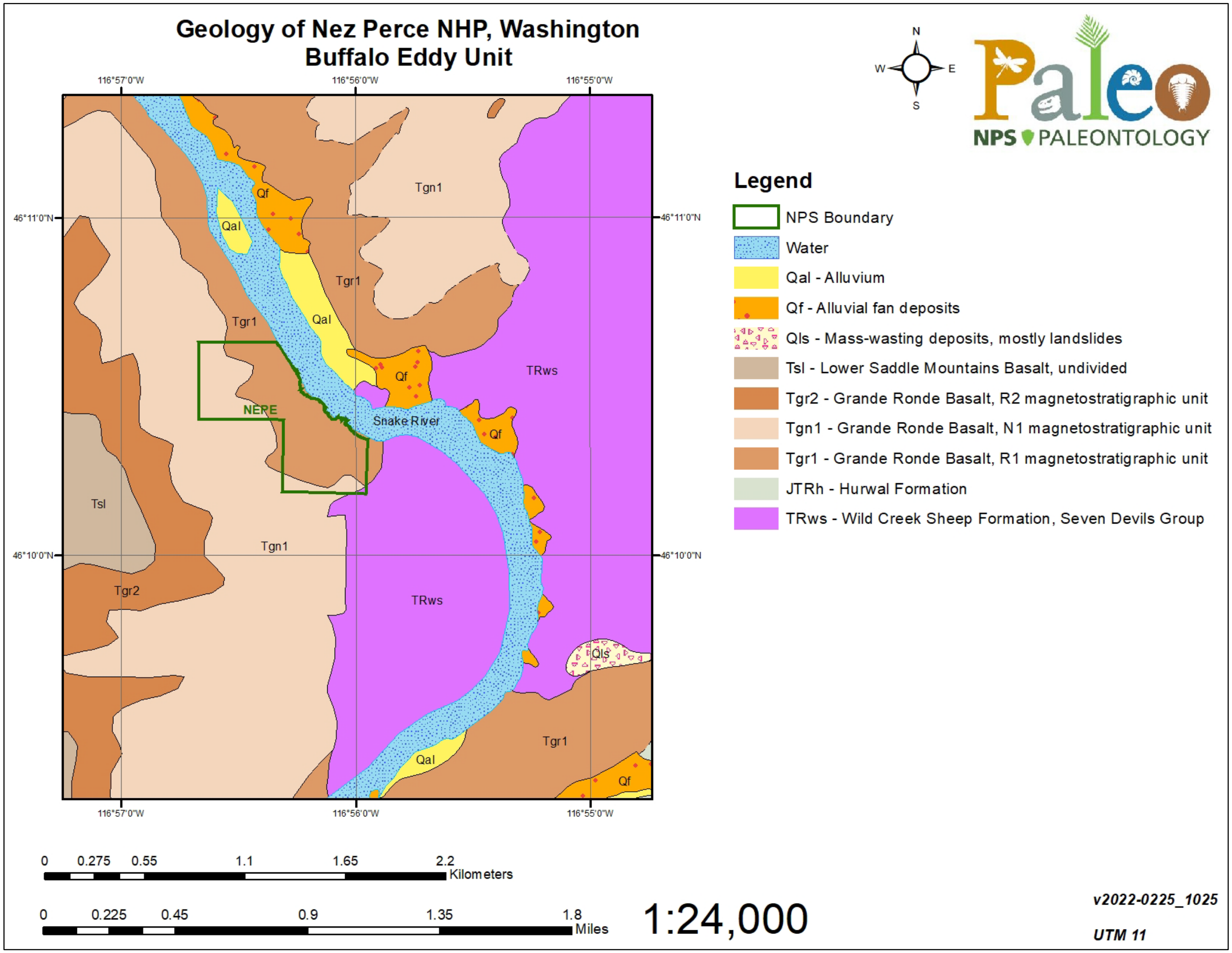


Figure 36. Geologic map of NEPE (Buffalo Eddy Unit), Washington. Data modified from NEPE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047476.

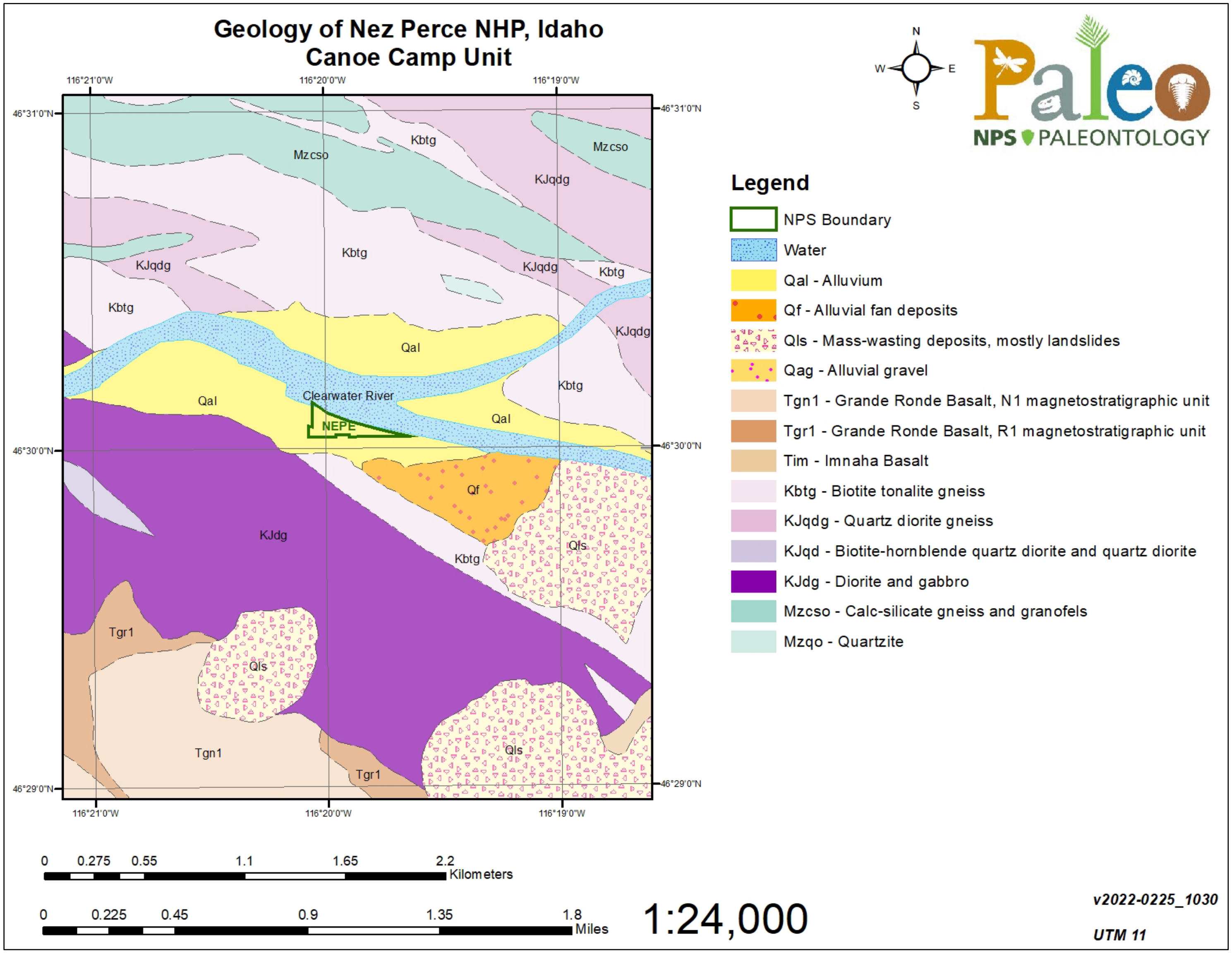


Figure 37. Geologic map of NEPE (Canoe Camp Unit), Idaho. Data modified from NEPE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047477.

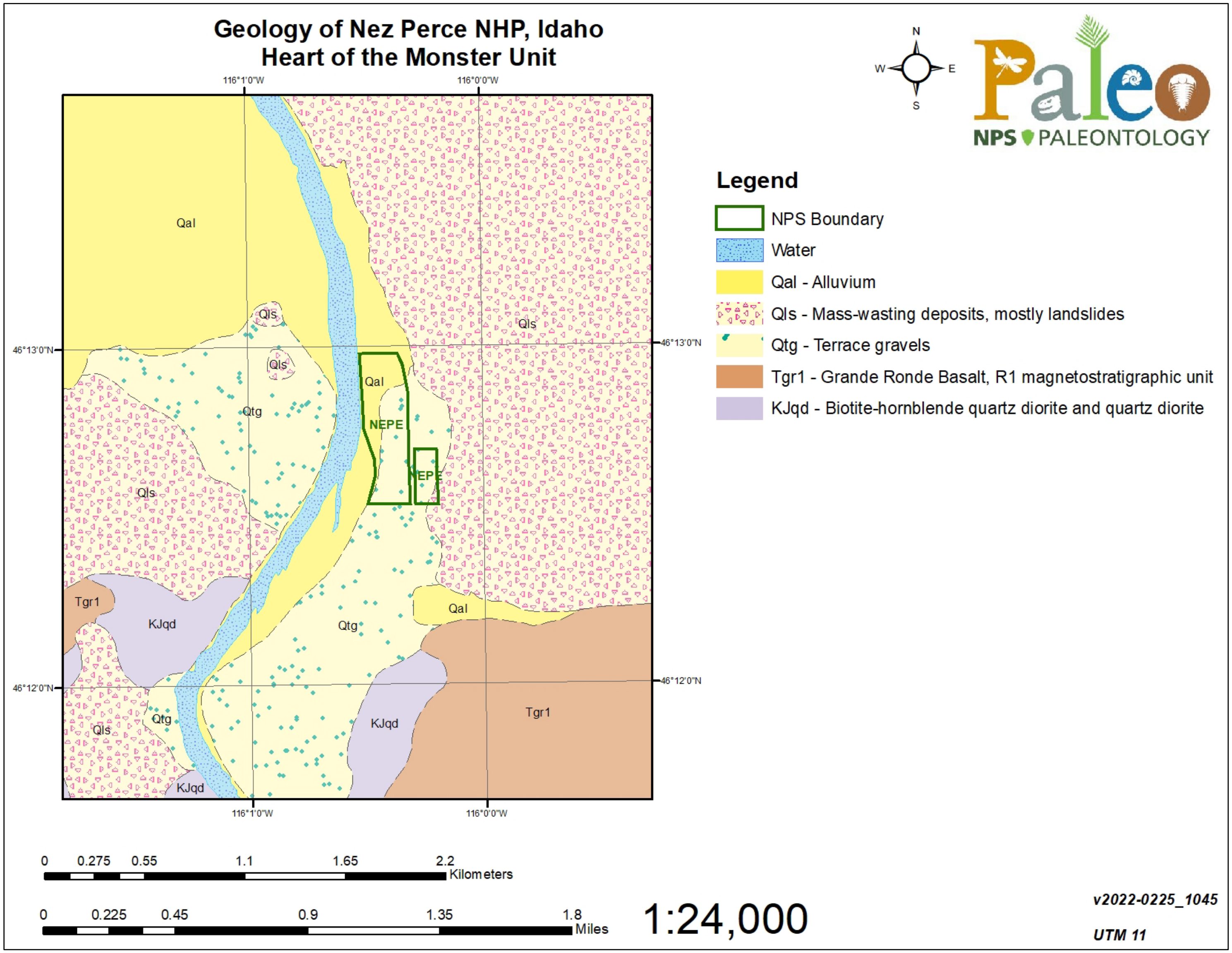


Figure 38. Geologic map of NEPE (Heart of the Monster Unit), Idaho. Data modified from NEPE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047480.

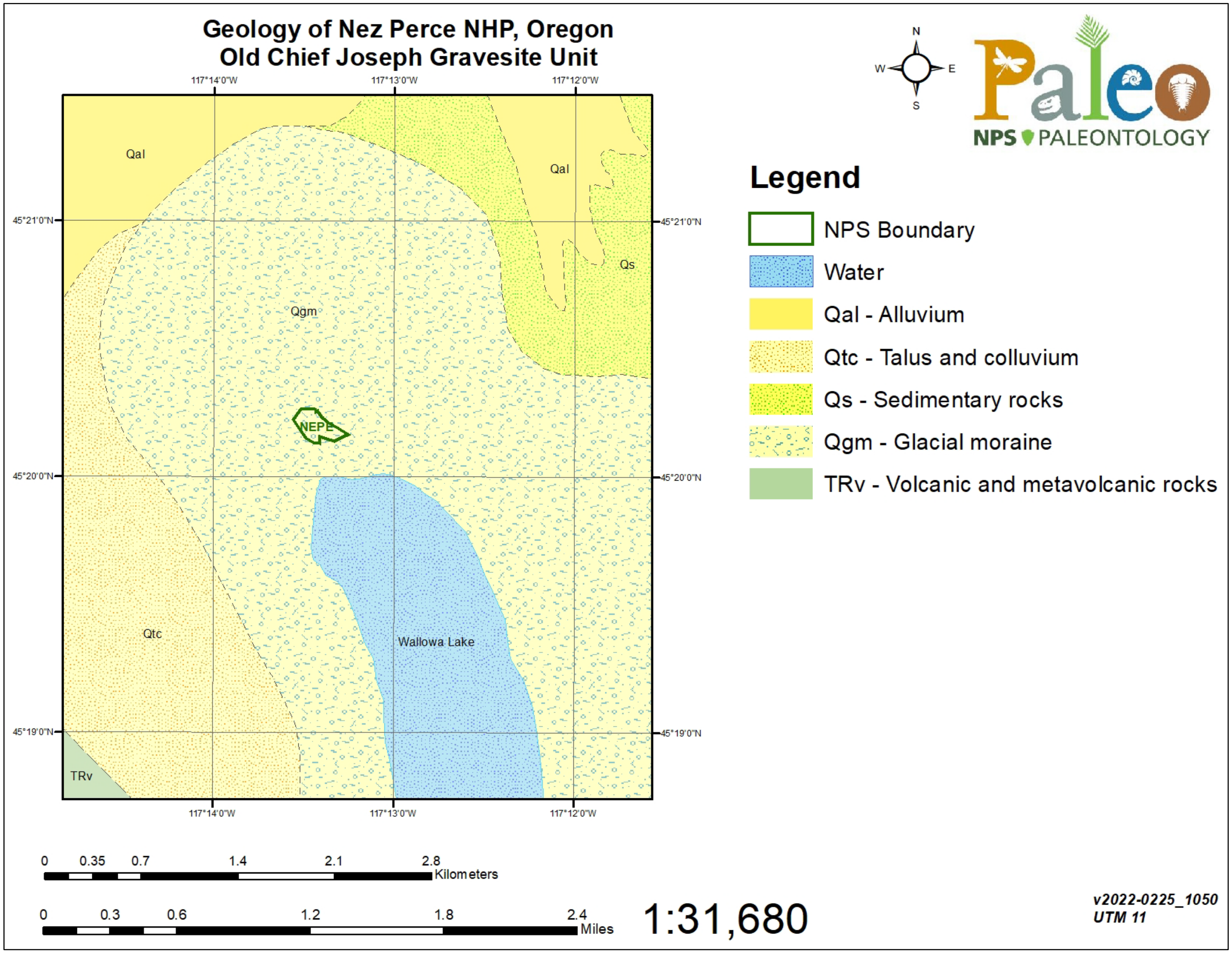


Figure 39. Geologic map of NEPE (Old Chief Joseph Gravesite Unit), Oregon. Data modified from NEPE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047481.

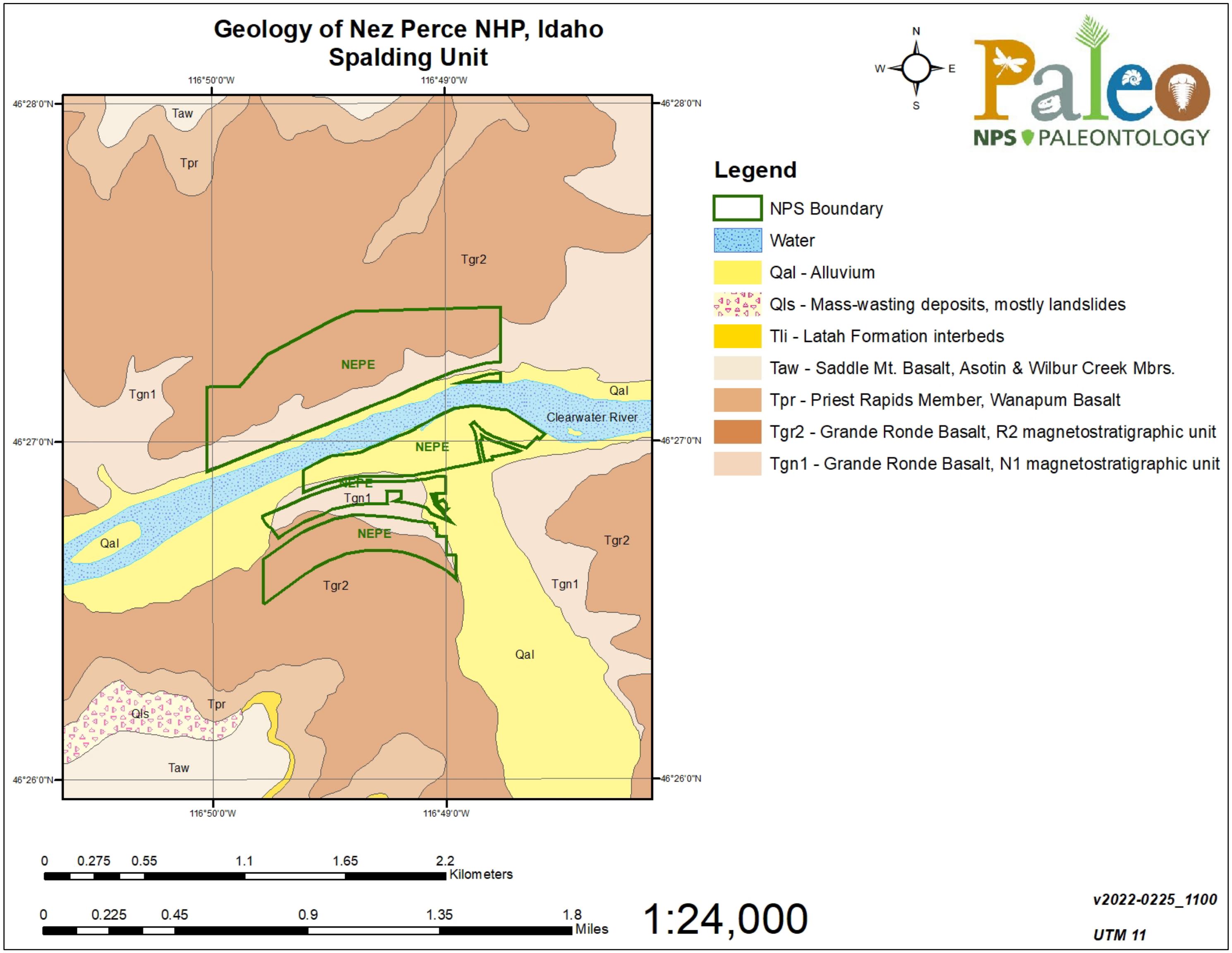


Figure 40. Geologic map of NEPE (Spalding Unit), Idaho. Data modified from NEPE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047482.

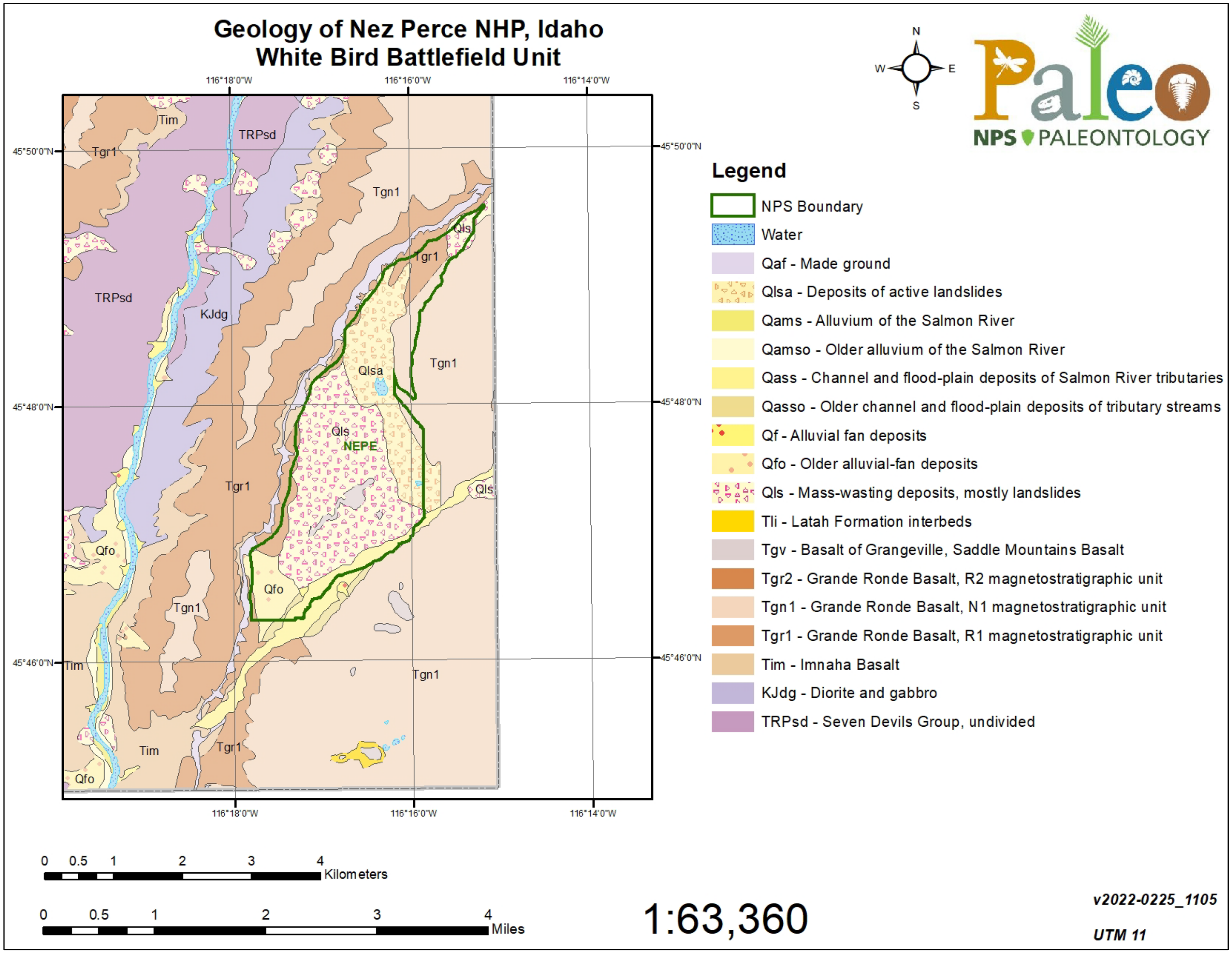


Figure 41. Geologic map of NEPE (White Bird Battlefield Unit), Idaho. Data modified from NEPE GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1047484.

Whitman Mission National Historic Site (WHMI)

Whitman Mission National Historic Site is located west of the Blue Mountains near the confluence of the Walla Walla River and Mill Creek in Walla Walla County, Washington (Figure 42). Originally established as Whitman National Monument on June 29, 1936, the park unit was redesignated as a national historic site on January 1, 1963 (National Park Service 2016a). The 56-hectare (139 acre) site is the location of the 1836 American Board of Commissioners for Foreign Missions (ABCFM) Christian mission established by Marcus and Narcissa Whitman. Ignorance, racism, and ethnocentrism associated with the ABCFM towards the Weyíiletpuu (Cayuse) and Walúulapam (Walla Walla) tribes resulted in many deaths and served as a catalyst for the expansion of the United States into the Pacific Northwest (National Park Service 2016a). WHMI preserves a sacred piece of Cayuse homeland, interpreting the tragic events surrounding the 19th-century Christian mission, memorializing those who died there and promoting a deeper understanding of its lasting impact on history (National Park Service 2017). Located on a steep hill surrounded by the floodplain of the Walla Walla River and Mill Creek, WHMI contains a restored mill pond and creek, an apple orchard, and historic buildings such as the Mission House site, blacksmith shop, and grist mill.

Situated in the Columbia Basin physiographic province, WHMI and its immediate surroundings overlie the buried remnants of one of the largest continental flood basalt eruptions to occur in the Western Hemisphere. Approximately 17–6 million years ago, lava flows of the Columbia River Basalt Group erupted across the region of Idaho, Oregon, and Washington and flooded about 160,000 km^2 (63,000 mi^2) of the Columbia Plateau (Graham 2014b). During the Pleistocene, cataclysmic flooding associated with failures of glacially dammed lakes transformed the WHMI region as floodwaters accumulated behind Wallula Gap. When floodwaters abruptly slowed at Wallula Gap, sediments settled out of suspension in the quiet waters beginning with coarser, heavier gravel and sand grains followed by finer-grained silt and clay. At least 40 times the repeated formation and failure of glacially dammed lakes produced a cycle of sedimentation that are recorded in Pleistocene rhythmites (Touchet Beds) located in WHMI (Figure 43; Graham 2014b).

There are no designated stratotypes identified within the boundaries of WHMI. There are six identified stratotypes located within 48 km (30 mi) of WHMI boundaries, for the Miocene Saddle Mountains Basalt (two reference sections), Ice Harbor Member of the Saddle Mountains Basalt (type locality), Pomona Member of the Saddle Mountains Basalt (reference section), and Frenchman Springs Member of the Wanapum Basalt (reference section), and the Miocene–Pliocene McKay Formation (reference section).

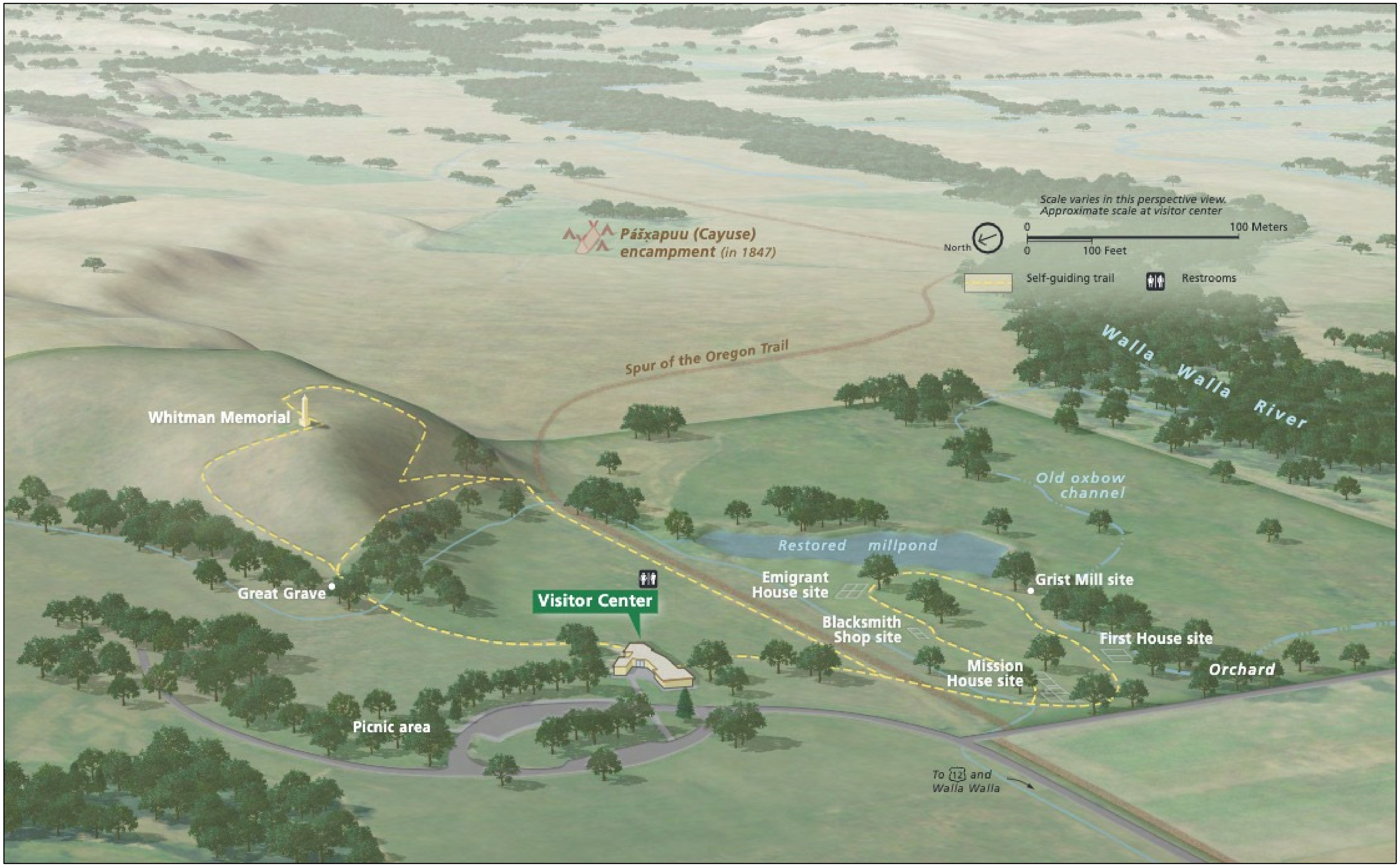


Figure 42. Park map of WHMI, Washington (NPS).

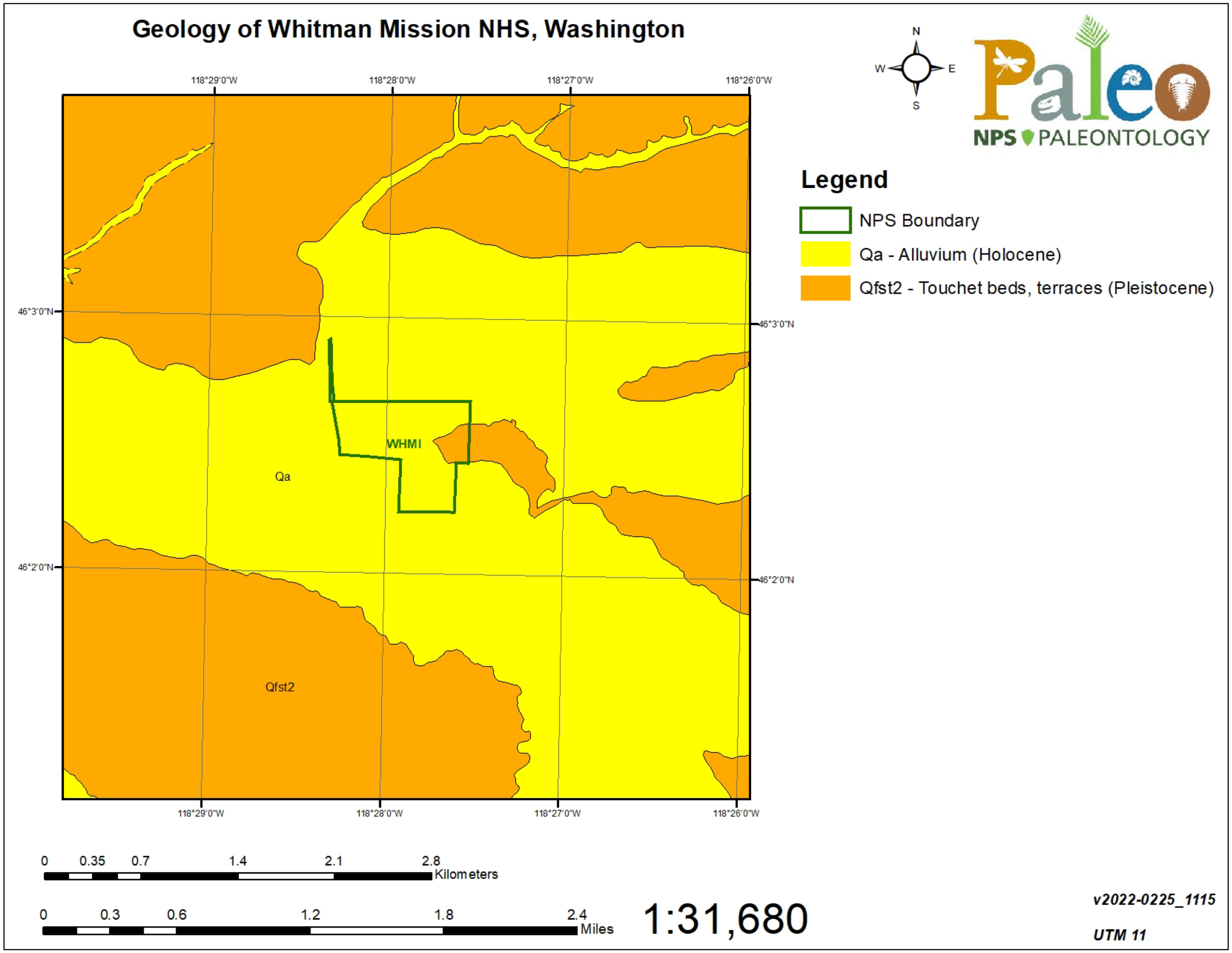


Figure 43. Geologic map of WHMI, Washington. Data modified from WHMI GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/1046987.

Recommendations

See also protocols in Brocx et al. (2019), from which several of these recommendations were adapted:

1) The NPS Geologic Resources Division should work with park and network staff to increase their awareness and understanding about the scientific, historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes). *Stratotypes represent unique geologic exposures and should be considered extremely important to protect for the advancement of the scientific community for future generations.*

2) Once the UCBN Geologic Type Section Inventory report is finalized, the NPS Geologic Resources Division should schedule a briefing for the staff of the UCBN and respective network parks.

3) The Fossil Gulch Ash and Peters Gulch Ash are two principal marker beds of the Pliocene Glenns Ferry Formation that are named after geographic locations in HAFO (Powers and Malde 1961; Malde 1972). However, no formal stratotype designations have been identified for these units. Therefore, we recommend that formal stratotypes be designated in order to A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard the exposures.

4) The NPS Geologic Resources Division should work with park and network staff to ensure they are aware of the location of stratotypes in park areas. This information would be important to ensure that proposed park activities or development would not adversely impact the stability and condition of these geologic exposures. Preservation of stratotypes should not limit availability for future scientific research but help safeguard these exposures from infrastructural development.

5) The NPS Geologic Resources Division should work with park 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), NPS staff 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 and network staff to compile and update a central inventory of all designated stratotypes and potential future nominations (after Brocx et al. 2019).

8) The NPS Geologic Resources Division should ensure the park-specific Geologic Type Section Inventory Reports are widely distributed and available online.

9) The NPS Geologic Resources Division should work with park and network staff to regularly monitor geologic type sections to identify any threats or impacts to these geologic heritage features in parks.

10) The NPS Geologic Resources Division should work with park and network staff to obtain good photographs of each geologic type section within the parks. 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 geologic type sections. GPS locations should also be recorded and kept in a database when the photographs are taken.

11) The NPS Geologic Resources Division should work with park and network staff to consider the collection and curation of geologic samples from type sections within NPS areas. Samples collected from type section exposures can be useful as reference specimens to support future studies, especially where stratotypes may be lost through natural processes or human activities.

12) The NPS Geologic Resources Division should work with park and network staff to utilize selected robust internationally and nationally significant type sections as formal teaching/education sites and for geotourism so that the importance of the national- and international-level assets are more widely (and publicly) known, using information boards and walkways (after Brocx et al. 2019).

13) The NPS Geologic Resources Division should work with park and network staff in developing conservation protocols of significant type sections, either by appropriate fencing, walkways, and information boards or other means (e.g., phone apps) (after Brocx et al. 2019).

Literature Cited

Albright, L. B., M. O. Woodburne, T. J. Fremd, C. C. Swisher, B. J. MacFadden, and G. R. Scott. 2008. Revised chronostratigraphy and biostratigraphy of the John Day Formation (Turtle Cove and Kimberly Members), Oregon, with implications for updated calibration of the Arikareean North American Land Mammal Age. Journal of Geology 116(3):211–237.

Bailey, M. M. 1989. Revisions to the stratigraphic nomenclature of the Picture Gorge Basalt Subgroup, Columbia River Basalt Group. Pages 67–84 *in* S. P. Reidel and P. R. Hooper, editors, Volcanism and tectonism in the Columbia River Flood-Basalt Province. Geological Society of America, Boulder, Colorado. Special Paper 239.

Bailey, R. G. 1976. Ecoregions of the United States (map). US Department of Agriculture, US Forest Service, Intermountain Region, Ogden, Utah.

Bernknopf, R. L., D. S. Brookshire, D. R. Soller, M. J. McKee, J. F. Sutter, J. C. Matti, and R. H. Campbell. 1993. Societal value of geologic maps. U.S. Geological Survey, Reston, Virginia. Circular 1111. Available at: https://pubs.er.usgs.gov/publication/cir1111 (accessed March 2, 2022).

Bestland, E. A., G. J. Retallack, C. C. Swisher, III, and T. Fremd. 1993. Timing of cut-and-fill sequences in the John Day Formation (Eocene-Oligocene), Painted Hills area, central Oregon. Geological Society of America Abstracts and Programs 25(5):9.

Bestland, E. A., G. J. Retallack, T. Fremd, D. A. Swanson, and R. A. Haugerud. 1994. Sequence stratigraphy of the Eocene-Oligocene transition: examples from the non-marine volcanically influenced John Day Basin. Pages A1–A19 *in* D. A. Swanson and R. A. Haugerud, editors. Geologic field trips in the Pacific Northwest. University of Washington, Department of Geological Sciences, Seattle, Washington.

Bestland, E. A., G. J. Retallack, and C. C. Swisher, III. 1997. Stepwise climate change recorded in Eocene-Oligocene paleosol sequences from central Oregon. The Journal of Geology 105(2):153–172.

Bestland, E. A., P. E. Hammond, D. L. S. Blackwell, M. A. Kays, G. J. Retallack, and J. Stimac. 1999. Geologic framework of the Clarno Unit, John Day Fossil Beds National Monument, central Oregon. Oregon Geology 61(1):3–19.

Brocx, M., C. Brown, and V. Semeniuk. 2019. Geoheritage importance of stratigraphic type sections, type localities and reference sites—review, discussion and protocols for geoconservation. Australian Journal of Earth Sciences 66(6):823–836.

Cope, E. D. 1888. Report of the Sub-Committee on the Cenozoic (Interior). The American Geologist 2:285–299. Available at: https://www.biodiversitylibrary.org/page/54972021 (accessed March 2, 2022).

Enlows, H. E. 1973. Rattlesnake Formation. Pages in J. D. Beaulieu, editor. Geologic field trips in northern Oregon and southern Washington. Oregon Department of Geology and Mineral Industries, Portland, Oregon. Bulletin 77.

Enlows, H. E. 1976. Petrography of the Rattlesnake Formation at the type area, central Oregon. Department of Geology and Mineral Industries, Portland, Oregon. Oil and Gas Investigations 25:1–34.

Evans, T. J. 2016. General standards for geologic maps. Section 3.1 *in* M. B. Carpenter and C. M. Keane, compilers. The geoscience handbook 2016. AGI Data Sheets, 5th edition. American Geosciences Institute, Alexandria, Virginia.

Fenneman, N. M. 1946. Physical divisions of the United States (map). U.S. Geological Survey, Washington, D.C. Unnumbered. Scale 1:7,000,000. Available at: https://pubs.er.usgs.gov/publication/70207506 (accessed February 24, 2022).

Fisher, R. V. 1967. Early Tertiary deformation in north-central Oregon. AAPG Bulletin 51(1):111–123.

Fisher, R. V., and J. M. Rensberger. 1972. Physical stratigraphy of the John Day Formation, central Oregon. University of California Publications in Geological Sciences 101:1–45.

Fremd, T. J. 2010. Guidebook: SVP Field Symposium 2010, John Day Basin Field Conference. Society of Vertebrate Paleontology.

Gradstein, F. M., J. G. Ogg, M. D. Schmitz, and G. M. Ogg, editors. 2020. Geologic time scale 2020. Elsevier, Amsterdam, Netherlands.

Graham, J. P. 2009. Hagerman Fossil Beds National Monument Geologic Resources Inventory Report. Natural Resource Report NPS/NRPC/GRD/NRR—2009/162. National Park Service, Denver, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/663764 (accessed March 2, 2022).

Graham, J. P. 2014a. John Day Fossil Beds National Monument: Geologic Resources Inventory Report. Natural Resource Report NPS/NRSS/GRD/NRR—2014/846. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2215343 (accessed March 2, 2022).

Graham, J. P. 2014b. Whitman Mission National Historic Site: Geologic Resources Inventory Report. Natural Resource Report NPS/NRSS/GRD/NRR—2014/839. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2214806 (accessed March 2, 2022).

Haugerud, R. 2005. Preliminary geologic map of Bainbridge Island, Washington, U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1387. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1387/ (accessed March 2, 2022).

Henderson, T., V. L. Santucci, T. Connors, and J. S. Tweet. 2020. National Park Service geologic type section inventory: Greater Yellowstone Inventory & Monitoring Network. Natural Resource Report NPS/GRYN/NRR—2020/2198. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2280034 (accessed March 2, 2022).

Hunt, R. M., Jr., and E. Stepleton. 2004. Geology and paleontology of the upper John Day beds, John Day River Valley, Oregon: lithostratigraphic and biochronologic revision in the Haystack Valley and Kimberly areas (Kimberly and Mount Misery Quadrangles). Bulletin of the American Museum of Natural History 282. Available at: http://hdl.handle.net/2246/450 (accessed March 2, 2022).

KellerLynn, K. 2018. Craters of the Moon National Monument and Preserve: Geologic Resources Inventory Report. Natural Resource Report NPS/NRSS/GRD/NRR—2018/1783. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2256965 (accessed March 2, 2022).

Keroher, G. C., and others. 1966. Lexicon of geologic names of the United States for 1936–1960. U.S. Geological Survey, Washington, D.C. Bulletin 1200. Available at: https://pubs.er.usgs.gov/publication/b1200 (accessed March 2, 2022).

Limbert, R. W. 1924. Among the craters of the moon: an account of the first expeditions through the remarkable volcanic lava beds of southern Idaho. The National Geographic Magazine 45:303–328.

Malde, H. E. 1972. Stratigraphy of the Glenns Ferry Formation from Hammett to Hagerman, Idaho. U.S. Geological Survey, Washington, D.C. Bulletin 1331-D. Available at: https://pubs.er.usgs.gov/publication/b1331D (accessed March 2, 2022).

Malde, H. E. 1982. The Yahoo Clay, a lacustrine unit impounded by the McKinney Basalt in the Snake River Canyon near Bliss, Idaho. Pages 617–628 *in* B. Bonnachsen and R. M. Breckenridge, editors. Cenozoic geology of Idaho. Idaho Bureau of Mines and Geology, Boise, Idaho. Bulletin 26.

Malde, H. E., and H. A. Powers. 1972. Geologic map of the Glenns Ferry-Hagerman area, west-central Snake River Plain, Idaho. U. S. Geological Survey, Washington, D.C. Miscellaneous Geologic Investigations Map 696. Scale 1:48,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_9466.htm (accessed March 2, 2022).

Marsh, O. C. 1875. Ancient lake basins of the Rocky Mountain region. American Journal of Science, 3rd series, 9(49):49–52. Available at: https://www.biodiversitylibrary.org/page/36868432 (accessed March 2, 2022).

Merriam, J. C. 1901. A contribution to the geology of the John Day basin. University of California Publications in Geological Sciences 2(9):269–314.

Merriam, J. C., C. Stock, and C. L. Moody. 1925. The Pliocene Rattlesnake Formation and fauna of eastern Oregon, with notes on the geology of the Rattlesnake and Mascall deposits. Carnegie Institution of Washington Publication 347:43–92.

National Park Service. 2014. Craters of the Moon National Monument and Preserve, Idaho. National Park Service Foundation Document. Available at: http://npshistory.com/publications/foundation-documents/crmo-fd-2014.pdf (accessed March 2, 2022).

National Park Service. 2015a. Hagerman Fossil Beds National Monument, Idaho. National Park Service Foundation Document. Available at: http://npshistory.com/publications/foundation-documents/hafo-fd-2015.pdf (accessed March 2, 2022).

National Park Service. 2015b. Lake Roosevelt National Recreation Area, Washington. National Park Service Foundation Document. Available at: http://npshistory.com/publications/foundation-documents/laro-fd-2015.pdf (accessed March 2, 2022).

National Park Service. 2016a. National Parks Index: 2012–2016. Official Index of the National Park Service. Available at: https://www.nps.gov/aboutus/upload/npindex2012-2016.pdf (accessed March 2, 2022).

National Park Service. 2016b. Minidoka National Historic Park, Idaho and Washington. National Park Service Foundation Document. Available at: http://npshistory.com/publications/foundation-documents/miin-fd-2016.pdf (accessed March 2, 2022).

National Park Service. 2017. Whitman Mission National Historic Site, Washington. National Park Service Foundation Document. Available at: http://npshistory.com/publications/foundation-documents/whmi-fd-2017.pdf (accessed March 2, 2022).

National Park Service. 2018. City of Rocks National Reserve, Idaho. National Park Service Foundation Document. Available at: http://npshistory.com/publications/foundation-documents/ciro-fd-2018.pdf (accessed March 2, 2022).

North American Commission on Stratigraphic Nomenclature. 2021. North American stratigraphic code. Stratigraphy 18(3):153–204.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77(1):118–125.

Othberg, K.L., J. D. Kaufmann, V. S. Gillerman, and D. L. Garwood. 2012. Geologic map of the Twin Falls 30 x 60 Minute Quadrangle, Idaho. Idaho Geological Survey, Moscow, Idaho. Geologic Map 49. Scale 1:100,000. Available at: https://www.idahogeology.org/product/GM-49 (accessed March 2, 2022).

Powers, H. A., and H. E. Malde. 1961. Volcanic ash beds as stratigraphic markers in basin deposits near Hagerman and Glenns Ferry, Idaho. Pages B167–B170 *in* Short papers in the geologic and hydrologic sciences, articles 1-146. U.S. Geological Survey, Washington, D.C. Professional Paper 424-B. Available at: https://pubs.er.usgs.gov/publication/pp424B (accessed March 2, 2022).

Prothero, D. R., J. M. Hoffman, and S. E. Foss. 2006. Magnetic stratigraphy of the upper Miocene (Hemphillian) Rattlesnake Formation, central Oregon. PaleoBios 26:37–42.

Swanson, D. A., T. L. Wright, P. R. Hooper, and R. D. Bentley. 1979. Revisions in stratigraphic nomenclature of the Columbia River Basalt Group. Pages G1–G59 *in* Contributions to stratigraphy, 1979. U.S. Geological Survey, Washington, D.C. Bulletin 1457-G. Available at: https://pubs.er.usgs.gov/publication/b1457G (accessed March 2, 2022).

Thornberry-Ehrlich, T. 2010. City of Rocks National Reserve: Geologic Resources Inventory Report. Natural Resource Report NPS/NRPC/GRD/NRR—2010/191. National Park Service, Ft. Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/664634 (accessed March 2, 2022).

Walker, G. W. 1979. Revisions to the Cenozoic stratigraphy of Harney Basin, southeastern Oregon. U.S. Geological Survey, Washington, D.C. Bulletin 1475. Available at: https://pubs.er.usgs.gov/publication/b1475 (accessed March 2, 2022).

Waters, A. C. 1961. Stratigraphic and lithologic variations in the Columbia River basalt. American Journal of Science 259(8):583–611.

Wilmarth, M. G. 1938. Lexicon of geologic names of the United States (including Alaska). U.S. Geological Survey, Washington, D.C. Bulletin 896. Available at: https://pubs.er.usgs.gov/publication/b896 (accessed March 2, 2022).

Appendix A: Source Information for GRI Maps of UCBN Parks

BIHO

- GMAP 2423: Ruppel, E. T., J. M. O'Neill, and D. A. Lopez. 1993. Geologic map of the Dillon 1° x 2° Quadrangle, Idaho and Montana. U.S. Geological Survey, Reston, Virginia. Geologic Investigations Series 1803-H. Scale 1:250,000. Available at: https://pubs.usgs.gov/imap/i-1803-h/ (accessed March 2, 2022).
- GMAP 53078: Bergantino, R. N., K. W. Porter, and B. C. Hearn, Jr. 2002. Geologic map of the Rocky Boy 30′ x 60′ Quadrangle, north-central Montana. Montana Bureau of Mines and Geology, Butte, Montana. Open File Report 451. Scale 1:100,000.

CIRO

- GMAP 4154: Miller, D. M., R. L. Armstrong, D. R. Bedford, and M. Davis. 2008. Preliminary geologic map and digital database of the Almo Quadrangle and City of Rocks National Reserve, Cassia County, Idaho. U.S. Geological Survey, Reston, Virginia. Open-File Report 2008-1103. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2008/1103/ (accessed March 2, 2022).

CRMO

- GMAP 922: Kuntz, M. A., D. E. Champion, and R. H. Lefebvre. 1990. Geologic map of the Fissure Butte Quadrangle, Blaine and Butte Counties, Idaho. U.S. Geological Survey, Reston, Virginia. Geologic Quadrangle Map 1635. Scale 1:24,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_1158.htm (accessed March 2, 2022).
- GMAP 923: Kuntz, M. A., R. H. Lefebvre, and D. E. Champion. 1989. Geologic map of the Inferno Cone Quadrangle, Butte County, Idaho. U.S. Geological Survey, Reston, Virginia. Geologic Quadrangle Map 1632. Scale 1:24,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_1155.htm (accessed March 2, 2022).
- GMAP 925: Champion, D. E., M. A. Kuntz, and R. H. Lefebvre. 1989. Geologic map of the North Laidlaw Butte Quadrangle, Blaine and Butte Counties, Idaho. U.S. Geological Survey, Reston, Virginia. Geologic Quadrangle Map 1634. Scale 1:24,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_1157.htm (accessed March 2, 2022).
- GMAP 926: Kuntz, M. A., R. H. Lefebvre, and D. E. Champion. 1989. Geologic map of The Watchman Quadrangle, Butte County, Idaho. U.S. Geological Survey, Reston, Virginia. Geologic Quadrangle Map 1633. Scale 1:24,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_1156.htm (accessed March 2, 2022).
- GMAP 74483: Kuntz, M. A., B. Skipp, D. E. Champion, P. B. Gans, D. P. Van Sistine, and S. R. Sanders. 2007. Geologic map of the Craters of the Moon 30′ x 60′ Quadrangle, Idaho. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 2969. Scale 1:100,000. Available at: https://pubs.er.usgs.gov/publication/sim2969 (accessed March 2, 2022).

- GMAP 76005: Kuntz, M. A., D. E. Champion, B. R. Turrin, P. B. Gans, H. R. Covington, and D. P. VanSistine. 2018. Geologic map of the north half of the Lake Walcott 30′×60′ Quadrangle, Idaho. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 3405. Scale 1:100,000. Available at: https://pubs.er.usgs.gov/publication/sim3405 (accessed March 2, 2022).
- GMAP 75655: Skipp, B., and M. A. Kuntz. 2009. Geologic map of the Arco 30′ x 60′ Quadrangle, south-central Idaho. Idaho Geological Survey, Moscow, Idaho. Geologic Map 47. Scale 1:100,000. Available at: https://www.idahogeology.org/product/GM-47 (accessed March 2, 2022).

HAFO

- GMAP 1242: Malde, H. E., and H. A. Powers. 1972. Geologic map of the Glenns Ferry-Hagerman area, west-central Snake River Plain, Idaho. U.S. Geological Survey, Washington, D.C. Miscellaneous Geologic Investigations Map 696 (Sheets 1 and 2). Scale 1:48,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_9466.htm (accessed March 2, 2022).
- GMAP 75638: Othberg, K. L., J. D. Kauffman, V. S. Gillerman, and D. L. Garwood. 2012. Geologic map of the Twin Falls 30 x 60 Quadrangle, Idaho. Idaho Geological Survey, Moscow, Idaho. Geologic Map 49. Scale 1:100,000 (digital data scale 1:24,000). Available at: https://www.idahogeology.org/product/GM-49 (accessed March 2, 2022).

JODA

- GMAP 4956: Bestland, E. A. and G. J. Retallack. 1994. Plate I: Geologic map of the Clarno area. *In* Geology and paleoenvironments of the Clarno Unit, John Day Fossil Beds National Monument, Oregon. NPS Contract CX-9000-1-10009. Scale 1:7,400.
- GMAP 4957: Bestland, E. A. and G. J. Retallack. 1994. Plate II: Geologic map of the Clarno unit area. *In* Geology and paleoenvironments of the Clarno Unit, John Day Fossil Beds National Monument, Oregon. NPS Contract CX-9000-1-10009. Scale 1: 4,500.
- GMAP 4958: Bestland, E. A. and G. J. Retallack. 1994. Plate III: Sample location map for the Clarno area. *In* Geology and paleoenvironments of the Clarno Unit, John Day Fossil Beds National Monument, Oregon. NPS Contract CX-9000-1-10009. Scale 1: 34,000.
- GMAP 4959: Bestland, E. A. and G. J. Retallack. 1994. Plate I: Geologic map of the Painted Hills area. *In* Geology and Paleoenvironments of the Painted Hills Unit, John Day Fossil Beds National Monument, Oregon. NPS Contract CX-9000-1-10009. Scale 1:7,300.
- GMAP 4960: Bestland, E. A. and G. J. Retallack. 1994. Plate II: Geologic map of the Painted Hills. *In* Geology and Paleoenvironments of the Painted Hills Unit, John Day Fossil Beds National Monument, Oregon. NPS Contract CX-9000-1-10009. Scale 1:4,500.
- GMAP 4961: Bestland, E. A. and G. J. Retallack. 1994. Plate III: Sample location map for the Painted Hills area. *In* Geology and Paleoenvironments of the Painted Hills Unit, John Day Fossil Beds National Monument, Oregon. NPS Contract CX-9000-1-10009. Scale 1:34,000.

- GMAP 74821: Niewendorp, C. A., M. D. Jenks, M. L. Ferns, I. P. Madin, P. E. Staub, and L. Ma, L. 2006. Oregon geologic data compilation—Release 3, State of Oregon, Oregon Department of Geology and Mineral Industries, Portland, Oregon. Oregon geologic data compilation 3.

LARO

- GMAP 74514: Kiver, E. P., and D. F. Stradling. 1995. Boundary 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74515: Kiver, E. P., and D. F. Stradling. 1995. Northport 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74516: Kiver, E. P., and D. F. Stradling. 1995. Onion Creek 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74517: Kiver, E. P., and D. F. Stradling. 1995. China Bend 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74518: Kiver, E. P., and D. F. Stradling. 1995. Bossburg 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74519: Kiver, E. P., and D. F. Stradling. 1995. Marcus 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74520: Kiver, E. P., and D. F. Stradling. 1995. Boyds 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74521: Kiver, E. P., and D. F. Stradling. 1995. Kettle Falls 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74522: Kiver, E. P., and D. F. Stradling. 1995. Bangs Mountain 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74523: Kiver, E. P., and D. F. Stradling. 1995. Little Falls 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74524: Kiver, E. P., and D. F. Stradling. 1995. Mica Mountain 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.

- GMAP 74525: Kiver, E. P., and D. F. Stradling. 1995. Grand Coulee Dam 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 74526: Kiver, E. P., and D. F. Stradling. 1995. Inchelium 15 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:62,500.
- GMAP 74527: Kiver, E. P., and D. F. Stradling. 1995. Hunters 15 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:62,500.
- GMAP 74528: Kiver, E. P., and D. F. Stradling. 1995. Wilmont Creek 15 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:62,500.
- GMAP 74529: Kiver, E. P., and D. F. Stradling. 1995. Keller (southern half) 15 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:62,500.
- GMAP 74530: Kiver, E. P., and D. F. Stradling. 1995. Turtle Lake 15 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:62,500.
- GMAP 74531: Kiver, E. P., and D. F. Stradling. 1995. Lincoln 15 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:62,500.
- GMAP 74532: Kiver, E. P., and D. F. Stradling. 1995. Wilbur 15 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:62,500.
- GMAP 75151: Kiver, E. P., and D. F. Stradling. 1995. Jack Woods Butte 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.
- GMAP 75152: Kiver, E. P., and D. F. Stradling. 1995. Broadax Draw 7.5 Minute Quadrangle map. Geology of the Franklin D. Roosevelt Reservoir shoreline: glacial geology, terraces, landslides, and lineaments. Report to Bureau of Reclamation. Scale 1:24,000.

MIIN

- GMAP 74282: Haugerud, R. 2005. Preliminary geologic map of Bainbridge Island, Washington. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1387. Scale 1:24,000. Available at: https://pubs.usgs.gov/of/2005/1387/ (accessed March 2, 2022).
- GMAP 75638: Othberg, K. L., J. D. Kaufmann, V. S. Gillerman, and D. L. Garwood. 2012. Geologic map of the Twin Falls 30 x 60 Minute Quadrangle, Idaho. Idaho Geological Survey, Moscow, Idaho. Geologic Map 49. Scale 1:100,000. Available at: https://www.idahogeology.org/product/GM-49 (accessed March 2, 2022).

NEPE

- GMAP 14587: Walker, G. W. 1979. Reconnaissance geologic map of the Oregon part of the Grangeville Quadrangle, Baker, Union, Umatilla, and Wallowa Counties, Oregon. U.S. Geological Survey, Washington, D.C. Miscellaneous Investigations 1116. Scale 1:250,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_8976.htm (accessed March 2, 2022).
- GMAP 63323: Fleck, R. J. and R. E. Criss. 2004. Location, age, and tectonic significance of the western Idaho Suture Zone (WISZ). U.S. Geological Survey, Reston, Virginia. Open-File Report 2004-1039. Scale 1:2,247,000. Available at: https://pubs.usgs.gov/of/2004/1039/ (accessed March 2, 2022).
- GMAP 68029: Othberg, K. L., R. M. Breckenridge, and D. W. Weisz. 2003. Surficial geologic map of the Lapwai Quadrangle, Nez Perce County, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 12. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-12 (accessed March 2, 2022).
- GMAP 68033: Weisz, D. W., K. L. Othberg, and R. M. Breckenridge. 2003. Surficial geologic map of the Kooskia Quadrangle, Idaho County, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 16. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-16 (accessed March 2, 2022).
- GMAP 68034: Weisz, D. W., K. L. Othberg, and R. M. Breckenridge. 2003. Surficial geologic map of the Kamiah Quadrangle, Idaho and Lewis Counties, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 17. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-17 (accessed March 2, 2022).
- GMAP 68040: Othberg, K. L., D. W. Weisz, and R. M. Breckenridge. 2002. Surficial geologic map of the Orofino West Quadrangle, Clearwater, Lewis, and Nez Perce Counties, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 5. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-5 (accessed March 2, 2022).
- GMAP 68042: Othberg, K. L., D. W. Weisz, and R. M. Breckenridge. 2002. Surficial geologic map of the Ahsahka Quadrangle, Clearwater County, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 7. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-7 (accessed March 2, 2022).
- GMAP 72142: Kauffman, J. D., G. F. Davidson, R. S. Lewis, and R. F. Burmester. 2005. Geologic map of the Orofino West Quadrangle, Clearwater, Lewis, and Nez Perce Counties, Idaho. Idaho Geological Survey, Moscow, Idaho. Geologic Map 40. Scale 1:24,000. Available at: https://www.idahogeology.org/product/GM-40 (accessed March 2, 2022).
- GMAP 74832: Washington Division of Geology and Earth Resources. 2005. Digital 1:100,000-scale geology of Washington State, version 1.0. Washington Geological Survey, Olympia, Washington. Open File Report 2005-3. Scale 1:100,000.

- GMAP 74848: Kauffman, J. D., D. L. Garwood, K. L. Schmidt, R. S. Lewis, K. L. Othberg, and W. M. Phillips. 2006. Geologic map of the Idaho Parts of the Orofino and Clarkston 30x60 Minute Quadrangles. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 69. Scale 1:100,000. Available at: https://www.idahogeology.org/product/DWM-69 (accessed March 2, 2022).
- GMAP 74849: Kauffman, J. D., R. S. Lewis, And P. E. Myers. 2006. Geologic map of the Kooskia Quadrangle, Idaho County, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 61. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-61 (accessed March 2, 2022).
- GMAP 74850: Lewis, R. S., R. F. Burmester, J. D. Kauffman, R. M. Breckenridge, K. L. Schmidt, M. D. McFaddan, and P. E. Myers. 2007. Geologic map of the Kooskia 30x60 Minute Quadrangle, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 93. Scale 1:100,000. Available at: https://www.idahogeology.org/product/DWM-93 (accessed March 2, 2022).
- GMAP 74861: Garwood, D. L., K. L. Schmidt, J. D. Kauffmann, D. E. Stewart, R. S. Lewis, K. L. Othberg, and P. J. Wampler. 2008. Geologic map of the White Bird Quadrangle, Idaho County, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 101. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-101 (accessed March 2, 2022).
- GMAP 74869: Bush, J. H., D. L. Garwood, and J. D. Kauffman. 2005. Geologic map of the Lapwai Quadrangle, Nez Perce County, Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Web Map 41. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-41 (accessed March 2, 2022).
- GMAP 74871: Kauffman, J. D., R. S. Lewis, and P. E. Myers. 2006. Geologic map of the Kamiah Quadrangle, Lewis and Idaho Counties, Idaho. Idaho Geological Survey, Moscow, Idaho. Geologic Map 42. Scale 1:24,000. Available at: https://www.idahogeology.org/product/DWM-42 (accessed March 2, 2022).
- GMAP 74895: Lewis, R. S., J. H. Bush, R. F. Burmester, J. D. Kauffman, D. L. Garwood, P. E. Myers, and K. L. Othberg. 2005. Geologic map of the Potlatch 30x60 Minute Quadrangle, Idaho. Idaho Geological Survey, Moscow, Idaho. Geologic Map 41. Scale 1:100,000. Available at: https://www.idahogeology.org/product/GM-41 (accessed March 2, 2022).
- GMAP 75002: Lewis, R. S., and T. P. Frost. 2005. Major oxide and trace element analyses for igneous and metamorphic rock samples from northern and central Idaho. Idaho Geological Survey, Moscow, Idaho. Digital Analytical Data 2. Available at: https://www.idahogeology.org/product/DAD-2 (accessed March 2, 2022).
- GMAP 75003: Kauffman, J. D. 2007. Major oxide and trace element analyses for volcanic rock samples from Idaho, 1996 through 2006. Idaho Geological Survey, Moscow, Idaho. Digital Analytical Data 4. Available at: https://www.idahogeology.org/product/DAD-4 (accessed March 2, 2022).

- GMAP 75004: Kauffman, J. D. 2008. Major oxide and trace element analyses for volcanic rock samples from Idaho, 1978 through 2005. Idaho Geological Survey, Moscow, Idaho. Digital Analytical Data 1. Available at: https://www.idahogeology.org/product/DAD-1 (accessed March 2, 2022).
- GMAP 75007: Criss, R. E., and R. J. Fleck. 1987. Petrogenesis, geochronology, and hydrothermal systems of the northern Idaho batholith and adjacent areas based on $^{18}O/^{16}O$, D/H, $^{87}Sr/^{86}Sr$, K-Ar, and $^{40}Ar/^{39}Ar$ studies. Pages 95–137 *in* T. L. Vallier, editor. Geology of the Blue Mountains region of Oregon, Idaho, and Washington: the Idaho Batholith and its border zone. U.S. Geologic Survey, Reston, Virginia. Professional Paper 1436. Available at: https://pubs.er.usgs.gov/publication/pp1436 (accessed March 2, 2022).

WHMI

- GMAP 74831: Derkey, R. E., D. F. Stradling, K. A. Lindsey, and T. L. Tolan. 2006. Geologic map of the College Place and Walla Walla 7.5-Minute Quadrangles, Walla Walla County, Washington, and Umatilla County, Oregon. Washington Geological Survey, Olympia, Washington. Geologic Map 62. Scale 1:24,000.

Appendix B: Geologic Time Scale

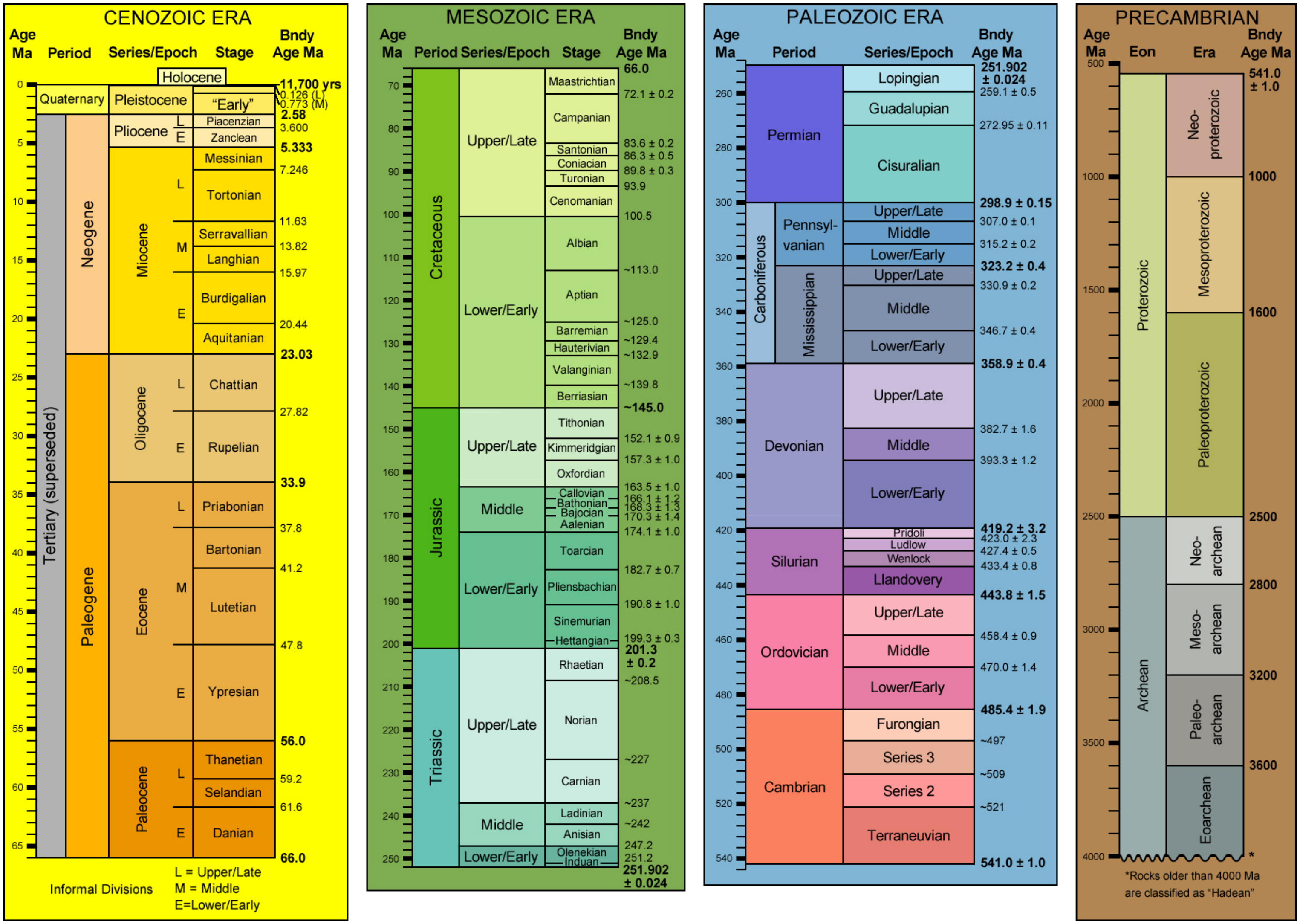


Figure B1. Geologic Time Scale. **Ma**=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

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