National Park Service Geologic Type Section Inventory

*Great Lakes Inventory & Monitoring Network*

Natural Resource Report NPS/GLKN/NRR—2021/2327
ON THE COVER
View looking east at the eroded cross-bedded sandstone at Chapel Rock, type locality of the Chapel Rock Member of the Munising Formation in Pictured Rocks National Lakeshore. Photo provided by Gresham Halstead Photography.
National Park Service Geologic Type Section Inventory

Great Lakes Inventory & Monitoring Network

Natural Resource Report NPS/GLKN/NRR—2021/2327

Tim Henderson,¹ Vincent L. Santucci,¹ Tim Connors², and Justin S. Tweet³

¹National Park Service
Geologic Resources Division
1849 “C” Street, NW
Washington, D.C. 20240

²National Park Service
Geologic Resources Division
Post Office Box 25287
Denver, Colorado 80225

³National Park Service
9149 79th Street S.
Cottage Grove, Minnesota 55016

November 2021

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado
The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Great Lakes Inventory and Monitoring Network and Natural Resource Publications Management websites. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

# Contents

| Figures .................................................................................................................. | v         |
| Tables .................................................................................................................. | ix        |
| Photographs ....................................................................................................... | ix        |
| Executive Summary .............................................................................................. | xi        |
| Acknowledgments ................................................................................................. | xv        |
| Dedication .......................................................................................................... | xvii      |
| Introduction ....................................................................................................... | 1         |
| Geology and Stratigraphy of the GLKN I&M Network Parks .................................. | 3         |
| Precambrian ....................................................................................................... | 4         |
| Paleozoic .......................................................................................................... | 4         |
| Mesozoic ............................................................................................................ | 6         |
| Cenozoic ............................................................................................................. | 6         |
| National Park Service Geologic Resource Inventory ........................................... | 7         |
| GRI Products ...................................................................................................... | 7         |
| Geologic Map Data ............................................................................................. | 7         |
| Geologic Maps .................................................................................................... | 8         |
| Source Maps ........................................................................................................ | 8         |
| GRI GIS Data ..................................................................................................... | 8         |
| GRI Map Posters ................................................................................................. | 9         |
| Use Constraints .................................................................................................. | 9         |
| Methods ............................................................................................................... | 11        |
| Methodology ....................................................................................................... | 11        |
| Definitions ......................................................................................................... | 16        |
| Apostle Island National Lakeshore (APIS) .......................................................... | 17        |
| Grand Portage National Monument (GRPO) .......................................................... | 25        |
| Ice Age National Scenic Trail (IATR) and Ice Age National Scientific Reserve (ICAG) | 29        |
## Contents (continued)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indiana Dunes National Park (INDU)</td>
<td>35</td>
</tr>
<tr>
<td>Isle Royale National Park (ISRO)</td>
<td>39</td>
</tr>
<tr>
<td>Keweenaw National Historical Park (KEWE)</td>
<td>51</td>
</tr>
<tr>
<td>Mississippi National River and Recreation Area (MISS)</td>
<td>57</td>
</tr>
<tr>
<td>Pictured Rocks National Lakeshore (PIRO)</td>
<td>67</td>
</tr>
<tr>
<td>Saint Croix National Scenic River (SACN)</td>
<td>77</td>
</tr>
<tr>
<td>Sleeping Bear Dunes National Lakeshore (SLBE)</td>
<td>83</td>
</tr>
<tr>
<td>Voyageurs National Park (VOYA)</td>
<td>89</td>
</tr>
<tr>
<td>Recommendations</td>
<td>95</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>97</td>
</tr>
<tr>
<td>Appendix A: Source Information for GRI Maps of GLKN Parks</td>
<td>103</td>
</tr>
<tr>
<td>Appendix B: Geologic Time Scale</td>
<td>109</td>
</tr>
</tbody>
</table>
Figures

**Figure 1.** Map of Great Lakes I&M Network parks including: Apostle Island National Lakeshore (APIS), Grand Portage National Monument (GRPO), Indiana Dunes National Park (INDU; a National Lakeshore when the map was created), Isle Royale National Park (ISRO), Mississippi National River and Recreation Area (MISS), Pictured Rocks National Lakeshore (PIRO), Saint Croix National Scenic River (SACN), Sleeping Bear Dunes National Lakeshore (SLBE), and Voyageurs National Park (VOYA) (NPS). Keweenaw National Historical Park (KEWE) is not considered a formal I&M park. .......................... 3

**Figure 2.** Screenshot of digital bedrock geologic map of Pictured Rocks National Lakeshore showing mapped units. ....................................................................................................... 12

**Figure 3.** GEOLEX search result for Hennepin Member unit. .................................................. 13

**Figure 4.** Stratotype inventory spreadsheet of the GLKN displaying attributes appropriate for geolocation assessment. ................................................................................................................. 15

**Figure 5.** Park map of APIS, Wisconsin (NPS). ........................................................... 13

**Figure 6.** Geologic map of APIS, Wisconsin ........................................................................ 19

**Figure 7.** Modified geologic map of APIS showing stratotype locations ................................. 20

**Figure 8.** Sea caves forming along the rocky mainland unit shoreline of APIS, type area of the Bayfield Group (NPS/HAL PRANGER). ...................................................................................... 22

**Figure 9.** A window eroded into the Devils Island Sandstone at the type locality at Devil’s Island, APIS (NPS/TRISTA THORNBERRY-EHRLICH). .............................................................. 23

**Figure 10.** Sea caves eroded into pink and white quartz sandstone of the Devils Island Sandstone at APIS (NPS). .................................................................................................................... 24

**Figure 11.** Park map of GRPO, Minnesota (NPS). ................................................................. 26

**Figure 12.** Geologic map of GRPO, Minnesota ....................................................................... 27

**Figure 13.** Park map of IATR/ICAG, Wisconsin (NPS) .......................................................... 30

**Figure 14.** Modified geologic map of IATR/ICAG (SOUTH) showing stratotype locations. .............................................................................................................................................. 31

**Figure 15.** Modified geologic map of IATR/ICAG (NORTH) showing stratotype locations. .............................................................................................................................................. 32

**Figure 16.** Canyon wall exposures consisting of sandstone and conglomerate of the Parfreys Glen Formation near the type section in Parfrey’s Glen, Wisconsin. ................................. 34
### Figures (continued)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 17</td>
<td>Park map of INDU, Indiana (NPS)</td>
<td>36</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Geologic map of INDU, Indiana.</td>
<td>37</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Park map of ISRO, Michigan (NPS).</td>
<td>40</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Geologic map of ISRO, Michigan.</td>
<td>41</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Modified geologic map of ISRO showing stratotype locations</td>
<td>42</td>
</tr>
<tr>
<td>Figure 22</td>
<td>Schematic columnar section of named lava flows of the Portage Lake Volcanics on ISRO</td>
<td>44</td>
</tr>
<tr>
<td>Figure 23</td>
<td>Slabbed rock sample of the Amygdaloid Island Flow with characteristic agate amygdules collected from the type locality at the northeast end of Amygdaloid Island</td>
<td>45</td>
</tr>
<tr>
<td>Figure 24</td>
<td>Well-developed columnar jointing in the Edwards Island Flow at the type locality on the north side of Edwards Island</td>
<td>47</td>
</tr>
<tr>
<td>Figure 25</td>
<td>Rocky shoreline of Scoville Point, type locality of the Scoville Point Flow of the Portage Lake Volcanics consisting of resistant, porphyritic lava flows (NPS/KAITLYN KNICK).</td>
<td>48</td>
</tr>
<tr>
<td>Figure 26</td>
<td>View looking northwest at the Dassler Cabin and Guest House from Scoville Point, type locality of the Scoville Point Flow (NPS).</td>
<td>49</td>
</tr>
<tr>
<td>Figure 27</td>
<td>Park map of KEWE, Michigan (NPS).</td>
<td>52</td>
</tr>
<tr>
<td>Figure 28</td>
<td>Geologic map of KEWE, Michigan.</td>
<td>53</td>
</tr>
<tr>
<td>Figure 29</td>
<td>Modified geologic map of KEWE showing stratotype locations</td>
<td>54</td>
</tr>
<tr>
<td>Figure 30</td>
<td>Park map of MISS, Minnesota (NPS).</td>
<td>58</td>
</tr>
<tr>
<td>Figure 31</td>
<td>Geologic map of MISS, Minnesota.</td>
<td>59</td>
</tr>
<tr>
<td>Figure 32</td>
<td>Modified geologic map of MISS showing stratotype locations</td>
<td>60</td>
</tr>
<tr>
<td>Figure 33</td>
<td>Type locality exposures of the St. Peter Sandstone below historic Fort Snelling, MISS (NPS/JUSTIN TWEET).</td>
<td>62</td>
</tr>
<tr>
<td>Figure 34</td>
<td>Type section bluff exposures of the Nokomis Sandstone Member of the Glenwood Formation and Hennepin Member of the Glenwood Formation along the Mississippi River at Lock and Dam No. 1, MISS (NPS/JUSTIN TWEET).</td>
<td>63</td>
</tr>
</tbody>
</table>
## Figures (continued)

| Figure 35. | Close-up view of the Lock and Dam No. 1 bluff exposure showing the stratigraphic contacts between the Hennepin, Harmony Hill, and Nokomis Sandstone Members of the Glenwood Formation and the Chana Member of the Pecatonica Formation (NPS/JUSTIN TWEET). | 64 |
| Figure 36. | Type section of the Hidden Falls Member of the Platteville Formation in Hidden Falls Park, MISS (NPS/JUSTIN TWEET) | 65 |
| Figure 37. | Park map of PIRO, Michigan (NPS). | 68 |
| Figure 38. | Geologic map of PIRO, Michigan. | 69 |
| Figure 39. | Modified geologic map of PIRO showing stratotype locations | 70 |
| Figure 40. | Heavily eroded, cross-bedded sandstone at Chapel Rock, type locality of the Chapel Rock Member of the Munising Formation (NPS). | 72 |
| Figure 41. | Close up view of eroded, cross-bedded sandstone at Chapel Rock, type locality of the Chapel Rock Member of the Munising Formation (NPS). | 73 |
| Figure 42. | View looking east at eroded, cross-bedded sandstone at Miner’s Castle, type locality of the Miner’s Castle Member of the Munising Formation (NPS). | 74 |
| Figure 43. | Eroded caves and cracks in the base of Miner’s Castle, consisting of horizontal and cross-bedded sandstone of the Miner’s Castle Member of the Munising Formation (NPS). | 75 |
| Figure 44. | Park map of SACN, Minnesota–Wisconsin (NPS). | 78 |
| Figure 45. | Geologic map of SACN, Minnesota–Wisconsin. See Figure 46 for legend. | 79 |
| Figure 46. | Geologic map legend of SACN, Minnesota–Wisconsin. | 80 |
| Figure 47. | Modified geologic map of SACN showing stratotype locations | 81 |
| Figure 48. | Park map of SLBE, Michigan (NPS). | 84 |
| Figure 49. | Geologic map of the mainland unit of SLBE, Michigan. | 85 |
| Figure 50. | Geologic map of North Manitou Island, SLBE, Michigan. | 86 |
| Figure 51. | Geologic map of South Manitou Island, SLBE, Michigan. | 87 |
| Figure 52. | Park map of VOYA, Minnesota (NPS). | 90 |
| Figure 53. | Geologic map of VOYA, Minnesota. | 91 |
| Figure 54. | Modified geologic map of VOYA showing stratotype locations | 92 |
### Tables

**Table 1.** List of GLKN stratotype units sorted by age with associated reference publications and locations. ................................................................. xii

**Table 2.** List of APIS stratotype units sorted by age with associated reference publications and locations. ................................................................. 21

**Table 3.** List of IATR/ICAG stratotype units sorted by age with associated reference publications and locations. ................................................................. 33

**Table 4.** List of ISRO stratotype units sorted by age with associated reference publications and locations. ................................................................. 43

**Table 5.** List of KEWE stratotype units sorted by age with associated reference publications and locations. ................................................................. 55

**Table 6.** List of MISS stratotype units sorted by age with associated reference publications and locations. ................................................................. 61

**Table 7.** List of PIRO stratotype units sorted by age with associated reference publications and locations. ................................................................. 71

**Table 8.** List of SACN stratotype units sorted by age with associated reference publications and locations. ................................................................. 82

**Table 9.** List of VOYA stratotype units sorted by age with associated reference publications and locations. ................................................................. 93

### Photographs

Justin Tweet pointing out the base of the Platteville Formation during a geologic field trip to Mississippi National River and Recreation Area (MISS). (Photo courtesy of J. Tweet) .......... xvii
Executive Summary

A fundamental responsibility of the National Park Service (NPS) is to ensure that park resources 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 which 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, 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 2005). 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 was 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 and Monitoring Network (GRYN) as the pilot network for initiating this project. 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 Great Lakes Inventory & Monitoring Network (GLKN).
The goal of this project is to consolidate information pertaining to geologic type sections which 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 GLKN shows there are currently no designated stratotypes for Grand Portage National Monument (GRPO), Indiana Dunes National Park (INDU), and Sleeping Bear Dunes National Lakeshore (SLBE); Apostle Island National Lakeshore (APIS) has one type locality and one type area; Ice Age National Scenic Trail (IATR) and affiliated Ice Age National Scientific Reserve (ICAG) have two type sections; Isle Royale National Park has nine type localities (ISRO); Keweenaw National Historical Park (KEWE) has one type locality and one type area; Mississippi National River and Recreation Area (MISS) has five type sections, one type locality, and one type area; Pictured Rocks National Lakeshore (PIRO) has two type localities; Saint Croix National Scenic River (SACN) has one type area; and Voyageurs National Park (VOYA) has one reference locality (Table 1).

This report ends 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 GLKN stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Park</th>
<th>Unit Name</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>IATR / ICAG</td>
<td>Mikana Member, Copper Falls Formation</td>
<td>Attig et al. 1988</td>
<td>Type section: roadcut on west side of a north–south road, in NE/4 SE/4 SW/4 sec. 7, T. 36 N., R. 10 W., Rice Lake North 7.5-minute Quadrangle, Barron Co., WI.</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>MISS</td>
<td>West Campus Formation</td>
<td>Stone 1966</td>
<td>Type section: roadcut on north side of U.S. Highway 12 where it passes through the West Campus, University of Minnesota, NE/4 SW/4 NW/4 sec. 25, T. 29 N., R. 24 W., New Brighton Quadrangle, southeastern MN. Type area: terraces at 253–256 m (830–840 ft) level on both sides of Mississippi River from St. Anthony Falls south to Lake Street Bridge, MN.</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>MISS</td>
<td>Hidden Falls Member, Platteville Formation</td>
<td>Sloan 1956</td>
<td>Type section: in Hidden Falls Park, on the Mississippi River 0.8 km (0.5 mi) south of Ford Motor Company plant, St. Paul, Ramsey Co., MN.</td>
<td>Late Ordovician</td>
</tr>
<tr>
<td>MISS</td>
<td>Hennepin Member, Glenwood Formation</td>
<td>Templeton and Willman 1963</td>
<td>Type section: bluff on west side of Mississippi River at Lock and Dam No. 1, Minneapolis, in NE/4 SW/4 NW/4 sec. 17, T. 28 N., R. 23 W. [approx. Lat. 44 deg. 54 min. 54 sec. N., Long. 93 deg. 12 min. 11 sec. W., St. Paul West 7.5-minute Quadrangle], Hennepin Co., eastern MN.</td>
<td>Late Ordovician</td>
</tr>
<tr>
<td>Park</td>
<td>Unit Name</td>
<td>Reference</td>
<td>Stratotype Location</td>
<td>Age</td>
</tr>
<tr>
<td>------</td>
<td>-----------</td>
<td>-----------</td>
<td>---------------------</td>
<td>-----</td>
</tr>
<tr>
<td>MISS</td>
<td>Nokomis Sandstone Member, Glenwood Formation</td>
<td>Templeton and Willman 1963</td>
<td>Type section: bluff on west side of Mississippi River at Lock and Dam No. 1, Minneapolis, in NE/4 SW/4 NW/4 sec. 17, T. 28 N., R. 23 W., St. Paul Quadrangle, Hennepin Co., MN.</td>
<td>Late Ordovician</td>
</tr>
<tr>
<td>MISS</td>
<td>St. Peter Sandstone</td>
<td>Stauffer 1934</td>
<td>Type section: bluff where Minnesota River (formerly called St. Peter's River) joins Mississippi River, Hennepin Co., southern MN. Type locality: at Fort Snelling, MN.</td>
<td>Middle–Late Ordovician</td>
</tr>
<tr>
<td>IATR / ICAG</td>
<td>Parfreys Glen Formation</td>
<td>Clayton and Attig 1990</td>
<td>Type section: Parfreys Glen, SE/4 NE/4 sec. 22, T. 11 N., R. 7 E., 8 km (5 mi) southeast of Baraboo, Sauk Co., WI.</td>
<td>Cambrian–Ordovician</td>
</tr>
<tr>
<td>PIRO</td>
<td>Miner's Castle Member, Munising Formation</td>
<td>Hamblin 1958</td>
<td>Type locality: Miner's Castle in Pictured Rocks cliffs, on southern shore of Lake Superior [NW ¼, SW ¼ sec. 3, T. 47 N., R. 18 W.], Alger Co., MI.</td>
<td>Late Cambrian</td>
</tr>
<tr>
<td>PIRO</td>
<td>Chapel Rock Member, Munising Formation</td>
<td>Hamblin 1958</td>
<td>Type locality: Chapel Rock near eastern end of Pictured Rocks cliffs along the southern coast of Lake Superior, Alger Co., MI.</td>
<td>Late Cambrian</td>
</tr>
<tr>
<td>SACN</td>
<td>Franconia Formation</td>
<td>Berkey 1897</td>
<td>Type area: exposures in vicinity of Franconia, Chisago Co., MN.</td>
<td>Late Cambrian</td>
</tr>
<tr>
<td>ISRO</td>
<td>Middle Point Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: on the south shore of Grace Harbor about 0.8 km (0.5 mi) northeast of Middle Point, ISRO.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>ISRO</td>
<td>Long Island Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: Long Island, ISRO.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>ISRO</td>
<td>Tobin Harbor Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: well-exposed on the south arm of Porter Island, along the north side of Tobin Harbor, ISRO.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>ISRO</td>
<td>Washington Island Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: on the south side of Washington Island, where it caps the highest ridge, ISRO.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>ISRO</td>
<td>Grace Island Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: on a point south of the campground on Grace Island, ISRO.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>ISRO</td>
<td>Hill Point Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: along the south side of Pickerel Cove eastward to Hill Point, ISRO.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>ISO</td>
<td>Amygdaloid Island Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: on promontory south of Crystal Cove, east end of Amygdaloid Island, north shore of eastern ISRO.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>KEWE</td>
<td>Keweenawan Supergroup</td>
<td>Brooks 1876; Craddock 1972</td>
<td>Type area: the Keweenaw Peninsula in western Michigan and northwestern WI.</td>
<td>Proterozoic</td>
</tr>
</tbody>
</table>
Table 1 (continued). List of GLKN stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Park</th>
<th>Unit Name</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEWE</td>
<td>Greenstone Flow, Portage Lake Volcanics</td>
<td>Huber 1973</td>
<td>Type locality: Keweenaw Peninsula, MI.</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>VOYA</td>
<td>Lac La Croix Granite, Vermillion Granitic Complex</td>
<td>Southwick and Sims 1980</td>
<td>Reference locality (=quartz–feldspar gneiss border facies): near the mouth of Long Slough [meant to be Deep Slough] on Namakan Lake, Hale Bay 7.5-minute Quadrangle, MN.</td>
<td>Archean</td>
</tr>
</tbody>
</table>
Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections for the national parks of the Great Lakes Inventory and Monitoring Network (GLKN). 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 stratotype inventory and other NPS projects. Randy, Nancy and David manage the National Geologic Map Database for the United States (NGMDB, https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl?glx=1) and the U.S. Geologic Names Lexicon (“GEOLEX”, https://ngmdb.usgs.gov/Geolex/search), the national compilation of names and descriptions of geologic units for the United States, two 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. 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 Great Lakes Inventory and Monitoring Network and various network parks, including Mark Hart, Rebecca Key, Alan Kirschbaum, and Thomas Parr (GLKN). Additional thanks to John Yellich (Michigan Geological Survey), Kevin Kincare (USGS), and Anthony Runkel and Harvey Thorliefson (Minnesota Geological Survey) for their interest in NPS geology and assistance with the review of this inventory report.

This project is possible through the support from research associates and staff in the National Park Service Geologic Resources Division and we extend our thanks to Hal Pranger, Julia Brunner, Jason Kenworthy, and Jim Wood.
Dedication

This Great Lakes Inventory and Monitoring Network Geologic Type Section Inventory is dedicated to Justin Tweet, paleontologist with the NPS Paleontology Program. Justin is duty stationed near Minneapolis–St. Paul, Minnesota, and lives in proximity to several NPS areas in the Great Lakes I&M Network. His research and field visits focused on the geology and paleontology along the Mississippi National River and Recreation Area and Saint Croix River National River have contributed valuable information to several NPS reports, including this inventory for geologic type sections with the parks of the Great Lakes I&M Network. In appreciation for Justin’s nearly 15 years of service and contributions, we are proud to dedicate this report to him.

Justin Tweet pointing out the base of the Platteville Formation during a geologic field trip to Mississippi National River and Recreation Area (MISS). (Photo courtesy of J. Tweet)
Introduction

The NPS Geologic Type Section Inventory Project (“Stratotype Inventory Project”) is a continuation of and complements other 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 team are to increase understanding and appreciation of the geologic features and processes in parks and to provide robust geologic information for use in park planning, decision making, public education, and resource stewardship.

Documentation of stratotypes (i.e., type sections/type localities/type areas) 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 2005). The importance of stratotypes lies in the fact that they represent important comparative sites where past investigations can be built upon or reexamined, 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, but only those within 48 km (30 mi) of park boundaries are presented in this report.

This geologic type section inventory for the parks of the Great Lakes Inventory & Monitoring Network (GLKN) follows standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network type section 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 have stepped up to undertake 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 occurred 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 which define important scientific information associated with geologic strata. Geologic formations are commonly 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. 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;

• Understanding and interpreting the geologic record depends upon 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 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 also prevents the protection of these localities from activities which 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, the hope is 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 GLKN I&M Network Parks

The Great Lakes Inventory and Monitoring Network (GLKN) includes nine NPS units in Indiana, Michigan, Minnesota, and Wisconsin (Figure 1). Indiana Dunes National Park (INDU) is located in Indiana. Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), and Sleeping Bear Dunes National Lakeshore (SLBE) are located in Michigan. Grand Portage National Monument (GRPO), Mississippi National River and Recreation Area (MISS), and Voyageurs National Park (VOYA) are located in Minnesota. Minnesota also shares Saint Croix National Scenic Riverway (SACN) with adjoining Wisconsin. Finally, Apostle Islands National Lakeshore (APIS) is located in Wisconsin. Several non-network parks are also discussed or noted in this report, including Keweenaw National Historic Site (KEWE) in Michigan, and Ice Age National Scenic Trail (IATR) and associated NPS-affiliated unit Ice Age National Scientific Reserve (ICAG) in Wisconsin. The GLKN parks are united by the influence of the Great Lakes; six of the nine units have lakeshore extents on either Lake Michigan or Lake Superior (APIS, GRPO, INDU, ISRO, PIRO, and SLBE).

Figure 1. Map of Great Lakes I&M Network parks including: Apostle Island National Lakeshore (APIS), Grand Portage National Monument (GRPO), Indiana Dunes National Park (INDU; a National Lakeshore when the map was created), Isle Royale National Park (ISRO), Mississippi National River and Recreation Area (MISS), Pictured Rocks National Lakeshore (PIRO), Saint Croix National Scenic River (SACN), Sleeping Bear Dunes National Lakeshore (SLBE), and Voyageurs National Park (VOYA) (NPS). Keweenaw National Historical Park (KEWE) is not considered a formal I&M park.
The geology and geography of the GLKN parks is strongly influenced by ancient and very recent geologic events. Bedrock is almost exclusively Precambrian and early Paleozoic in age (see Appendix B for a geologic time scale), and some of the oldest rocks in the NPS are found in GLKN parks, while the surficial features were primarily sculpted by glaciers and then reworked by fluvial and lacustrine processes. Most of the present topography reflects the most recent glacial episode, culminating around 25,000 to 20,000 years ago, and the millennia since then during which vast glacial lakes grew and drained, and the modern drainage was established.

**Precambrian**
The GLKN is within the craton, or stable ancient core, of North America, which coalesced from smaller crustal blocks between about 2.5 and 1.0 billion years ago. Approximately 1.1 billion years ago, the North American craton began to rift but stopped, leaving faults and thick intervals of igneous rock in an “n”-shaped scar perhaps from as far as Texas to Alabama, passing through the GLKN from southwestern Minnesota to the present location of Lake Superior and then south through Michigan. The presence of the rift zone is still felt in the GLKN; Lake Superior is within a structural basin formed by the rift, and the rift’s ancient faults have helped define the St. Croix Valley.

By far the oldest rocks in a GLKN park are found in VOYA, which has outcrops of igneous and metamorphic rocks of late Archean age, between 3.0 and 2.5 billion years old. Paleoproterozoic rocks are exposed at GRPO as the Rove Formation (Thornberry-Ehrlich 2019), and at the non-network NPS-affiliated ICAG, where the Baraboo Quartzite of late Paleoproterozoic age is exposed at the Devil’s Lake State Park unit as part of the exhumed Baraboo Range (Clayton and Attig 1990). Outcrops of Mesoproterozoic rocks can be found at five of the GLKN network parks, as well as at IATR, ICAG, and KEWE. These rocks are either igneous in origin, representing the Midcontinent Rift, or sedimentary, filling the structural basin left by the rift. APIS has in ascending order the basin-filling Orienta Sandstone, Devils Island Sandstone, and Chequamegon Sandstone (Thornberry-Ehrlich 2015). At GRPO, the Pigeon River Diabase intruded the Rove Formation during rifting (Thornberry-Ehrlich 2019). ISRO has outcrops of the Portage Lake Volcanics and the younger basin-filling Copper Harbor Conglomerate (Thornberry-Ehrlich 2008). PIRO has outcrops of the Jacobsville Sandstone (Blewett 2012), a sedimentary unit of uncertain late Mesoproterozoic–Neoproterozoic age. SACN crosses a variety of Precambrian bedrock units, but glacial and other surficial deposits conceal most of them. There are small outcrops of the Clam Falls Volcanics (sometimes lumped in or identified as the Chengwatana Volcanics) and overlying Copper Harbor Conglomerate (Tweet and Santucci 2018). Among the non-network units, KEWE has a similar complement of Mesoproterozoic basalts followed by basin fill (Copper Harbor Conglomerate, Nonesuch Formation, Freda Sandstone, and Jacobsville Sandstone). Most bedrock exposures in IATR and ICAG are buried by glacial and other surficial deposits (Black 1974), which reflects these units’ establishment for Ice Age features. However, rift basalts are exposed in the Interstate State Park unit of ICAG (Black 1974), which is also one of IATR’s trailheads.

**Paleozoic**
By the beginning of the Paleozoic, approximately 540 million years ago, the rift basins had long been filled with sedimentary rocks and significant erosion had occurred in some areas, wearing down
ancient Precambrian bedrock in places such as near Taylors Falls in SACN and the Devil’s Lake State Park unit of ICAG; this Cambrian exhumation can be identified due to the presence of conglomeratic facies between the ancient bedrock and typical Cambrian rocks (Clayton and Attig 1990; Tweet and Santucci 2018). Shallow continental seas began to encroach during the Cambrian. Most of the Cambrian deposition in GLKN parks occurred during the late Cambrian. The Jordan Sandstone is exposed in MISS (Tweet 2014). PIRO has outcrops of the late Cambrian–Early Ordovician Munising Formation (Blewett 2012). SACN is located in a classic study area for the late middle–late Cambrian of North America, and includes outcrops of the Mount Simon Sandstone, Eau Claire Formation, Wonewoc Sandstone, Tunnel City Group (Franconia Formation of older references), St. Lawrence Formation, and Jordan Sandstone (Tweet and Santucci 2018). Non-network IATR and ICAG have some areas of Cambrian bedrock outcrops, primarily at the Devil’s Lake, Interstate, and Mill Bluff State Park units of ICAG and associated segments of IATR (Black 1974). These have, respectively, the Parfreys Glen Formation (Clayton and Attig 1990); the Tunnel City Group and conglomeratic facies (Wirth et al. 1998); and the Mount Simon, Eau Claire, and Wonewoc Formations and Tunnel City Group (Clayton 1989).

After a geologically brief marine retreat at the close of the Cambrian, the seas returned in the Early Ordovician, leading to the widespread deposition of carbonate rocks in the GLKN. Further sea level changes were followed by an even more extensive advance in the Late Ordovician, producing heavily fossiliferous carbonates and shales punctuated by bentonite beds representing massive volcanic eruptions. The same three GLKN parks with Cambrian rocks (MISS, PIRO, and SACN) are also represented in the Ordovician. MISS has outcrops of the Early Ordovician Prairie du Chien Group, and of the St. Peter Sandstone, Glenwood Formation, Platteville Formation, Decorah Shale, and Cummingsville Formation from the Middle–Late Ordovician marine advance (Tweet 2014). PIRO has the period-crossing Munising Formation mentioned above and the Au Train Formation, generally dated to the Early Ordovician (Miller et al. 2006) but reportedly including Late Ordovician fossils at a locality in the park (Oetking 1952). SACN has widely distributed outcrops of the Early Ordovician Prairie du Chien Group and a small area with the St. Peter Sandstone, Glenwood Formation, Platteville Formation, and Decorah Shale preserved by faulting (Tweet and Santucci 2018). Non-network IATR and ICAG have Ordovician rocks at the Cross Plains State Park unit, including the Prairie du Chien Group, St. Peter Sandstone, and Platteville Formation (National Park Service 2012).

Events after the Ordovician are poorly known in the GLKN parks, none of which have any exposed bedrock younger than the early Late Ordovician Cummingsville Limestone found in MISS. Silurian and Devonian bedrock is present at INDU and SLBE but is buried by Quaternary surficial deposits (see discussion in Hunt et al. 2008). Younger Paleozoic rocks are widespread in some areas outside of the parks within the GLKN, such as the well-known Michigan Basin, but these and other post-Ordovician formations are represented in GLKN parks only by eroded material, often transported by glaciers and/or washed up from offshore. Examples of such detrital material include stones with Silurian and Devonian fossils found at INDU and SLBE, and fossiliferous Paleozoic stones found at APIS and ISRO (Hunt et al. 2008).
Mesozoic
There is practically no record of the Mesozoic in GLKN parks, or elsewhere in the GLKN for that matter, except for Western Interior Seaway rocks in northern and western Minnesota. A reworked Late Cretaceous ammonite has been found at a locality in MISS (Cobban and Merewether 1983); the most likely origin is from Western Interior Seaway rocks to the northwest, from which it was either directly transported by glaciers or by fluvial action after some glacial transport. At the Devil’s Lake State Park unit of ICAG there are local gravel deposits on unglaciated East Bluff (some with Ordovician, Silurian, or Devonian fossils) thought to have been deposited by Cretaceous or Cenozoic fluvial activity when the surrounding land surface was much higher (Clayton and Attig 1990; “East Bluff Member of the Windrow Formation” of Andrews 1958).

Cenozoic
The pre-glacial Cenozoic is likewise undocumented in GLKN parks and the GLKN as a whole. The geologic record does not resume until the glaciations of the Pleistocene, and succeeding glaciations usually obliterated the deposits of the previous episode, so most of what we know for a given location pertains to the most recent glaciation and following events. Quaternary deposits are not handled consistently in the literature: in some cases they are put into formations, but in others they are described only in terms of their depositional process (“alluvium”, “lacustrine”, etc.). Formations reported from GLKN units include the latest Pleistocene Copper Falls Formation and primarily early Holocene Miller Creek Formation at APIS (Thornberry-Ehrlich 2015); the West Campus Formation at MISS (Stone 1966); and the Copper Falls, Cromwell, Miller Creek, New Ulm, Pierce, River Falls, Trade River, and West Campus Formations at SACN (National Park Service 2018).
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 three 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, and (3) 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 GLKN parks: VOYA on June 1–2, 2000; ISRO on June 16, 2004; INDU on June 28–29, 2010; SLBE on June 30, 2010; MISS and SACN on July 19, 2010; APIS on July 20–21, 2010; GRPO on July 21, 2010; and PIRO on July 23, 2010. No scoping session has been held for KEWE.

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 2020, GRI reports have been completed for APIS, GRPO, INDU, ISRO, and VOYA. 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 GLKN 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](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). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter 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](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 two types: surficial or bedrock. 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. GRI has produced various maps for the GLKN 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 a master geology document (PDF) for a specific park. The GRI team uses a unique “GMAP ID” value for each geologic source map, and all sources used to produce the GRI GIS datasets for the GLKN 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 SACN and VOYA were compiled using data model version 2.3, which is available at [https://www.nps.gov/articles/gri-geodatabase-model.htm](https://www.nps.gov/articles/gri-geodatabase-model.htm); the APIS, GRPO, INDU, ISRO, KEWE, MISS and PIRO data are based on older data models and need to be upgraded to the most recent version. This 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](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](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 APIS, GRPO, INDU, ISRO, KEWE, MISS, PIRO, SACN, SLBE, or VOYA 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**
Selected geologic data is draped over shaded relief images of the park and surrounding area to create posters 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 upon the information provided in the GRI posters. 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 U.S. National Map Accuracy Standards (https://pubs.usgs.gov/fs/1999/0171/report.pdf), 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

We describe here the methods employed and definitions adopted during this inventory of geologic type sections located within the administrative boundaries of the parks in the GLKN. This report is part of a more extensive inventory of geologic type sections throughout the National Park System. Therefore, the methods, definitions, and challenges identified here pertain not only to the parks of the GLKN, 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. For some park units specific information is not available which limits the final report. No fieldwork was done as part of this inventory, which is therefore dependent on existing information for 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 which transcend state boundaries. Geologic formations and other units which cross state boundaries may be referenced with different names in each of the states the units are mapped. An example would be the Triassic Chugwater Formation in Wyoming, which is equivalent to the Spearfish Formation in the Black Hills of South Dakota and Wyoming.

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 stratotypes of the GLKN 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 bedrock geologic map of Pictured Rocks National Lakeshore showing mapped units.
Each map unit name is then queried in the U.S. 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 Hennepin Member of the Glenwood Formation.

![GEOLEX search result for Hennepin Member unit.](image)

Published GEOLEX stratotype spatial information is provided in three formats: (1) descriptive, using distance from nearby points of interest; (2) latitude and longitude coordinates; or (3) Township/Range/Section (TRS) coordinates. TRS coordinates are based upon subdivisions of a
single 93.2 km² (36 mi²) township into 36 individual 2.59 km² (1 mi²) sections, and were converted into Google Earth (.kmz file) locations using Earth Point (https://www.earthpoint.us/TownshipsSearchByDescription.aspx). They are typically presented in an abbreviated format such as “sec. [#], T. [#] [N. or S.], R. [#] [E. or W.].” The most accurate GEOLEX descriptions using TRS coordinates can help locate features within 0.1618 km² (0.0625 mi²). Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the park 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) is a stratotype officially designated; (2) is the stratotype on NPS land; (3) has it undergone a quality control check in Google Earth using a GRI digital geologic map overlay; (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) was the geologic unit found in GEOLEX; and (10) a generic notes field (Figure 4).
Figure 4. Stratotype inventory spreadsheet of the GLKN 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 adopted for this inventory. This code describes explicit practices for classifying and naming all formally defined geologic units. An important designation for a geologic unit is known as a **stratotype**–the standard (original or subsequently designated) basis for definition or recognition of a geologic unit or boundary (North American Commission on Stratigraphic Nomenclature 2005). There are several variations of stratotype 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 2005). 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 2005).

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 2005). 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 2005).

4. **Lithodeme**: the term “lithodeme” is defined as a mappable unit of plutonic (igneous rock that solidified at great depth), highly metamorphosed, or pervasively deformed rock and is a term equivalent in rank to “formation” among stratified rocks (North American Commission on Stratigraphic Nomenclature 2005). The formal name of a lithodeme consists of a geographic name followed by a descriptive term that denotes the average modal composition or lithology of the rock (example: Cathedral Peak Granodiorite). Lithodommes are commonly assigned type localities, type areas, and reference localities.
Apostle Island National Lakeshore (APIS)

Apostle Islands National Lakeshore (APIS) is an archipelago park unit that includes 21 of the 22 islands in southwestern Lake Superior in Ashland and Bayfield Counties, Wisconsin (Figure 5). The lakeshore also includes 19 km (12 mi) of mainland shoreline along the northwestern edge of the Bayfield Peninsula. Established on September 26, 1970, APIS encompasses about 28,075 hectares (69,377 acres) that includes sea cliffs, sea caves, seascapes, terraces, wave-cut benches, arches, beaches, and old growth forest. Inland features of APIS include glaciated landscapes where glaciers eroded bedrock, forming grooves and striations, and deposited thick mantles of glacial sediments (Thornberry-Ehrlich 2015). The namesake for the park unit is uncertain, but may stem from early French explorers, who referred to them collectively after the 12 biblical apostles, or perhaps the name was inspired by a band of thieves who used the straits, caves, and coves of the islands when hijacking the payloads of fur traders (Stucker 1974; Thornberry-Ehrlich 2015).

The geology of APIS includes units that date back more than one billion years and form the basement rock for all the islands. Exposed strata within APIS consists of the Mesoproterozoic Bayfield Group, including the Orienta Sandstone, Devils Island Sandstone, and Chequamegon Sandstone (Figure 6). These sandstone units were deposited in sand flats and a series of braided streams and shallow lakes within the failed Midcontinent Rift System of the North American craton (an ancient, stable part of continental crust). Volcanic rocks associated with the rift system are buried beneath the sandstones of the Bayfield Group. More than a billion years after the sandstones of the Bayfield Group were deposited, Pleistocene glaciation intermittently advanced and retreated across the Lake Superior region, eroding the bedrock between resistant rock knobs that would become the Apostle Islands (Thornberry-Ehrlich 2015). A series of glacial deposits are found throughout APIS and include the Miller Creek and Copper Falls Formations. Locally, the Bayfield Group is overlain by postglacial shoreline sediments, representing an unconformity (period of nondeposition or erosion) of nearly 1.1 billion years.

APIS contains two identified stratotypes that define the Mesoproterozoic Bayfield Group and Devils Island Sandstone of the Bayfield Group (Figure 7; Table 2). In addition to the designated stratotypes located within APIS, stratotypes located within 48 km (30 mi) of park boundaries include the Mesoproterozoic Chequamegon Sandstone (type locality), Eileen Sandstone (type locality), Quaternary Douglas Creek Member of the Miller Creek Formation (two reference sections), and the Pleistocene Copper Falls Formation (type section and reference section).
Figure 5. Park map of APIS, Wisconsin (NPS).
Figure 6. Geologic map of APIS, Wisconsin.
Figure 7. Modified geologic map of APIS showing stratotype locations. The transparency of the geologic units layer has been increased.
Table 2. List of APIS stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayfield Group</td>
<td>Craddock 1972</td>
<td>Type area: along the Wisconsin shore of Lake Superior, from the Apostle Islands and the Bayfield Peninsula westward to near Superior</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Devils Island Sandstone, Bayfield Group (PCdi)</td>
<td>Nuhfer and Dalles 1987</td>
<td>Type locality: exposures on the northern two-thirds of Devil's Island, Ashland County, northwestern WI</td>
<td>Mesoproterozoic</td>
</tr>
</tbody>
</table>

The Mesoproterozoic Bayfield Group of the Keweenawan Supergroup was originally described by Thwaites (1912) as the Bayfield sandstone group before it was redescribed as the Bayfield Group by Leith et al. (1935). The group is named for its occurrence in Bayfield County, Wisconsin. The type area of the group is designated along the Wisconsin shore of Lake Superior, from the Apostle Islands and the Bayfield Peninsula westward to near Superior (Figures 7 and 8; Table 2; Craddock 1972). In the type area, Thwaites (1912) estimated the thickness of the Bayfield Group at about 1,310 m (4,300 ft). The Bayfield Group has been divided into (ascending order) the Orienta Sandstone, Devils Island Sandstone, and Chequamegon Sandstone. The Bayfield Group overlies the Oronto Group and unconformably underlies upper Cambrian rocks.

The Devils Island Sandstone of the Bayfield Group was named by Thwaites (1912) for exposures on Devils Island in Ashland County, Wisconsin. The type locality of the formation is designated from exposures on the northern two-thirds of Devils Island (Figures 7 and 9; Table 2; Nuhfer and Dalles 1987). Type locality exposures measure about 91 m (300 ft) thick and consist of pink and white, thin-bedded, fine-grained quartz sandstone with abundant ripple marks (Thwaites 1912; Nuhfer and Dalles 1987). On Devils Island, the formation is commonly eroded to form sea cliffs and caves that sometimes have fissures that reach the surface (Figure 10; Nuhfer and Dalles 1987). The Devils Island Formation occurs conformably between the underlying Orienta Sandstone and overlying Chequamegon Sandstone.
Figure 8. Sea caves forming along the rocky mainland unit shoreline of APIS, type area of the Bayfield Group (NPS/HAL PRANGER).
Figure 9. A window eroded into the Devils Island Sandstone at the type locality at Devil’s Island, APIS (NPS/TRISTA THORNBERRY-EHRLICH).
Figure 10. Sea caves eroded into pink and white quartz sandstone of the Devils Island Sandstone at APIS (NPS).
Grand Portage National Monument (GRPO)

Grand Portage National Monument (GRPO) is located in Cook County, northeastern Minnesota near the U.S. border with Ontario, Canada (Figure 11). Originally established as a national historic site on September 15, 1951, the park unit was redesignated as a national monument on September 2, 1958 (Anderson 2017). GRPO encompasses about 287 hectares (710 acres) and preserves the earliest fur trading site in the NPS. The 13.7 km (8.5 mi) portage, known as the Gitchi Onigaming (Great Carrying Place) by the Ojibwe tribe, was a vital link on one of the principal trade routes for American Indians, explorers, missionaries, and fur traders heading for the Northwest. As a long narrow tract of land, the monument boundary extends between 30–90 m (100–300 ft) on each side of the historic portage trace itself, all within both the Grand Portage Indian Reservation and the unincorporated community of Grand Portage (Thornberry-Ehrlich 2019). The Grand Portage post of the North West Company has been reconstructed at the eastern terminus of the portage on Lake Superior.

The bedrock geology of GRPO predominantly consists of ancient sedimentary rocks of the Mesoproterozoic Rove Formation that are approximately 1.7 billion years old (Figure 12). The fine-grained sediments of the Rove Formation were deposited at a time when much of northern Minnesota was underwater in a marine basin known as the Animikie Basin. Approximately 1.1 billion years ago, large-scale extensional forces led to the development of the Midcontinent Rift that stretches through the Lake Superior region. As extension stretched and weakened the crust, molten rock migrated upward through cracks and fractures. Some of the magma intruded the older Rove Formation to form the Pigeon River Diabase (a dark, crystalline igneous rock), while some magma erupted at the surface to form lava flows today found along the rim of Lake Superior (Figure 12; Thornberry-Ehrlich 2019). During the Pleistocene, the advance and retreat of ice sheets across the Great Lakes region scoured the ancient bedrock of GRPO, forming valleys within the Rove Formation that filled with glacial sediments and leaving the resistant diabase intrusive rocks as ridges.

There are no designated stratotypes identified within the boundaries of GRPO. There are three identified stratotypes located within 48 km (30 mi) of GRPO boundaries, for the Paleoproterozoic Rove Formation (type section and type area) and Mesoproterozoic Puckwunge Formation (type section).
Figure 11. Park map of GRPO, Minnesota (NPS).
Figure 12. Geologic map of GRPO, Minnesota.
Ice Age National Scenic Trail (IATR) and Ice Age National Scientific Reserve (ICAG)

The Ice Age National Scenic Trail (IATR) is a recreational footpath that generally follows the edge of the last glacial advance and is located across 30 counties in Wisconsin (Adams, Barron, Burnett, Chippewa, Clark, Columbia, Dane, Door, Fon Du Lac, Green, Jefferson, Juneau, Kewaunee, Langlade, Lincoln, Manitowoc, Marathon, Marquette, Polk, Portage, Rock, Rusk, Sauk, Sheboygan, Taylor, Walworth, Washington, Waukesha, Waupaca, and Waushara Counties). Established on October 3, 1980, the IATR protects significant resources associated with Wisconsin’s glacial past (Anderson 2017). The trail winds along the outermost end moraine of the late Wisconsin Glaciation (~30,000 to 10,000 years ago) through a landscape containing a number of glacial landforms such as moraines, kames, drumlins, erratics, kettle lakes, potholes, eskers, marshes, meltwater channels, gorges, ice-walled lake plains, outwash plains, and glacial lake beds (NPS undated; Mickelson et al. 2011). When completed, the scenic trail will traverse approximately 1,931 km (1,200 mi); currently about 1,062 km (660 mi) of trail are constructed and open for use (Figure 13).

The Ice Age National Scientific Reserve (ICAG) was established on October 13, 1964 with a purpose to protect and preserve nationally significant examples of glacial landforms associated with Wisconsin’s glacial heritage (Anderson 2017). Encompassing approximately 13,152 hectares (32,500 acres), each of the nine individual reserve units is managed as a park recreational area, natural area, or wildlife area. The Ice Age National Scenic Trail connects six of the nine units of ICAG: Interstate Park, Chippewa Moraine, Devil’s Lake State Park, Cross Plains, Kettle Moraine State Forest – Northern Unit, and Two Creeks Buried Forest. Each reserve unit of ICAG protects a unique array of landforms created by different glacial processes. ICAG is administered as an affiliated unit, not a formal NPS unit. IATR and ICAG are not formally part of the GLKN, but they are included here for completeness.

Together, IATR and ICAG contain or are in very close proximity (>1 km or 0.6 mi) to two stratotypes that represent the Cambrian–Ordovician Parfreys Glen Formation and the Pleistocene Mikana Member of the Copper Falls Formation (Figures 14 and 15; Table 3). When fully completed, the IATR has the potential to add an additional stratotype for the Mikana Member (reference section). It is important to note that the Cambrian Devils Lake Formation and Cretaceous(?) East Bluff Member of the Windrow Formation were named for exposures near Devils Lake State Park along the IATR/ICAG, but these units lack formal stratotype designations and have been subsequently abandoned.
Figure 13. Park map of IATR/ICAG, Wisconsin (NPS).
Figure 14. Modified geologic map of IATR/ICAG (SOUTH) showing stratotype locations.
Figure 15. Modified geologic map of IATR/ICAG (NORTH) showing stratotype locations.
Table 3. List of IATR/ICAG stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mikana Member, Copper Falls Formation</td>
<td>Attig et al. 1988</td>
<td>Type section: roadcut on west side of a north–south road, in NE/4 SE/4 SW/4 sec. 7, T. 36 N., R. 10 W., Rice Lake North 7.5-minute Quadrangle, Barron Co., WI</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Parfreys Glen Formation</td>
<td>Clayton and Attig 1990</td>
<td>Type section: Parfreys Glen, SE/4 NE/4 sec. 22, T. 11 N., R. 7 E., 8 km (5 mi) southeast of Baraboo, Sauk Co., WI</td>
<td>Cambrian–Ordovician</td>
</tr>
</tbody>
</table>

The Cambrian–Ordovician Parfreys Glen Formation was named by Clayton and Attig (1990) after its type section located at Parfrey’s Glen, a small valley on the south flank of the Baraboo Hills approximately 8 km (5 mi) southeast of the city of Baraboo, Wisconsin (Figure 14; Table 3). The type section measures about 30 m (98 ft) thick and predominantly consists of sandstone ranging from white through variable shades of brown, gray, and yellow in fresh exposures (Figure 16; Clayton and Attig 1990). In many areas the unit is conspicuously conglomeratic, consisting of pebbles, cobbles, and boulders several meters in diameter (Clayton and Attig 1990). Clayton and Attig (1990) state that exposures of the unit appear to be restricted to a 2 km (1.2 mi) wide band that occurs along both sides of the North and South Ranges of the Baraboo Hills. The Parfreys Glen Formation unconformably overlies lower Proterozoic rocks of the “Rowley Creek slate” and unconformably underlies the Mesozoic Windrow Formation (Clayton and Attig 1990).
The Pleistocene Mikana Member of the Copper Falls Formation was named by Johnson (1984, 1986) and formally defined by Attig et al. (1988) for exposures near the community of Mikana in Barron County, Wisconsin. The type section is designated in a roadcut on the west side of a north–south road (24 ½ Street) (NE/4 SE/4 SW/4 sec. 7, T. 36 N., R. 10 W.), in the Rice Lake North 7.5-minute Quadrangle (Figure 15; Table 3; Attig et al. 1988). The type section consists of several centimeters of loess that overlie 3 m (10 ft) of reddish-brown, slightly gravelly to gravelly sandy loam till (Attig et al. 1988). A reference section of the Mikana Member is designated in a roadcut (SW/4 NW/4 SW/4 sec. 15, T. 33 N., R. 9 W.) in the Chain Lake 7.5-minute Quadrangle (Attig et al. 1988). With future construction of the IATR, this reference section may occur within 1 km (0.6 mi) of the proposed scenic trail route. The Mikana Member overlies the Pokegama Creek Member or undifferentiated sand and gravel of the Copper Falls Formation, and underlies sand and gravel of the Miller Creek Formation.
Indiana Dunes National Park (INDU)

Indiana Dunes National Park is located along the southern shore of Lake Michigan in Lake, La Porte, and Porter Counties, Indiana (Figure 17). It was authorized on November 5, 1966, as a national lakeshore and redesignated a national park on February 15, 2019. INDU encompasses approximately 6,210 hectares (15,347 acres) of beaches, dunes, bogs, oak savannas, marshes, swamps, prairie remnants, rivers, and forests (Anderson 2017). The park was established to preserve the lake front, Indiana Dunes, and other areas of scenic, scientific, and historic interest from encroaching urban development. The park contains 24 km (15 mi) of shoreline with sand dunes that rise from the shores of Lake Michigan. The boundaries of INDU are spread across several units, including one national historic landmark (Joseph Bailly Homestead), four national natural landmarks (Pinhook Bog, Cowles Bog, Dunes Nature Preserve, and Hoosier Prairie), and the Heron Rookery area and trail (Thornberry-Ehrlich 2020).

The geology of INDU has been influenced by multiple advances and retreats of the Laurentide ice sheet and by fluctuating levels and extents of the Great Lakes. Relic shorelines are preserved at INDU and record relative lake-level changes in Lake Michigan through geologic time. Three major coastal geomorphic features are found in the park and correlate to Lake Michigan highstands (interval of time when relative lake-level is elevated for a given area): the Glenwood, Calumet, and Tolleston beaches (Capps et al. 2007; Thornberry-Ehrlich 2020). The Laurentide ice sheet eroded preexisting Paleozoic bedrock. Buried beneath INDU are the Silurian Wabash Formation, Devonian Muscatatuck Group, Late Devonian Antrim Shale, and Devonian–Mississippian New Albany Shale (Thornberry-Ehrlich 2020). As the ice age glaciers intermittently waxed and waned throughout the Pleistocene Epoch, they deposited sediment across the landscape. Mapped units at INDU are geologically recent and consist of Pleistocene and younger deposits associated with beaches, fan deltas, spits, dunes, lagoons, strandplains, channels, and floodplains (Figure 18).

There are no designated stratotypes identified within the boundaries of INDU. There are no identified stratotype located within 48 km (30 mi) of INDU boundaries.
Figure 17. Park map of INDIANA, Indiana (NPS).
Figure 18. Geologic map of INDU, Indiana.
Isle Royale National Park (ISRO)

Isle Royale National Park (ISRO) is located in northwestern Lake Superior near the Canadian border in Keweenaw County, Michigan (Figure 19). Established on March 3, 1931, ISRO encompasses about 231,395 hectares (571,790 acres) spread across one large island surrounded by approximately 400 smaller islands. Portions of ISRO were designated a wilderness area on October 20, 1976, and the park became a Biosphere Reserve in 1980 (Anderson 2017). The main island is located about 16 km (10 mi) east of the Minnesota mainland, and more than 48 km (30 mi) north of the upper peninsula of Michigan. The park is only accessible by seaplane from Houghton, Michigan, or by boat ferry from Houghton or Copper Harbor, Michigan, or Grand Portage, Minnesota. The remote, forested islands of ISRO are ideal natural laboratories that host a unique environment that responds to natural influences with little human interference (Thornberry-Ehrlich 2008).

The bedrock geology of ISRO predominantly consists of ancient thick lava flows of the Mesoproterozoic Portage Lake Volcanics of the Bergland Group and overlying strata of the Copper Harbor Conglomerate of the Oronto Group (Figure 20). Numerous flow units of the Portage Lake Volcanics occur in ISRO, including the Scoville Point, Edwards Island, Middle Point, Long Island, Tobin Harbor, Washington Island, Grace Island, Minong, Huginnin, Hill Point, and Amygdaloid Island flows. The Greenstone Flow of the Portage Lake Volcanics forms Greenstone Ridge which is the backbone of Isle Royale and measures up to 240 m (790 ft) thick (Thornberry-Ehrlich 2008). Many of the geologic units exposed at ISRO form a regional-scale syncline that extends beneath the surface of Lake Superior, reappearing on the Keweenaw Peninsula of Michigan (Huber 1975). The youngest geologic units of ISRO are unconsolidated surficial deposits consisting of glacial deposits and alluvium. During the last significant glacial maximum (~11,000 years ago) glaciers scoured the Great Lakes area leaving grooves, fjord-like inlets, rocky finger-like promontories of land, and drowned valleys with abundant glacial deposits of till and erratics (glacier-transported rock fragment that differs from local bedrock) (Thornberry-Ehrlich 2008).

ISRO contains nine identified stratotypes that represent individual flow units of the Mesoproterozoic Portage Lake Volcanics (Figure 21; Table 4). In addition to the designated stratotypes located within ISRO, stratotypes located within 48 km (30 mi) of the park boundaries include the Proterozoic Animikie Group (type locality) and the Mesoproterozoic Puckwunge Formation (type section).
Figure 19. Park map of ISRO, Michigan (NPS).
Figure 20. Geologic map of ISRO, Michigan.
Figure 21. Modified geologic map of ISRO showing stratotype locations. The transparency of the geologic units layer has been increased.
**Table 4.** List of ISRO stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scoville Point Flow, Portage Lake Volcanics (psp)</td>
<td>Huber 1973</td>
<td>Type locality: well-exposed on the end of Scoville Point, at the east end of Rock Harbor</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Edwards Island Flow, Portage Lake Volcanics (pei)</td>
<td>Huber 1973</td>
<td>Type locality: on the north side of Edwards Island</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Middle Point Flow, Portage Lake Volcanics (pmp)</td>
<td>Huber 1973</td>
<td>Type locality: on the south shore of Grace Harbor about 0.8 km (0.5 mi) northeast of Middle Point</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Long Island Flow, Portage Lake Volcanics (pil)</td>
<td>Huber 1973</td>
<td>Type locality: Long Island</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Tobin Harbor Flow, Portage Lake Volcanics (pth)</td>
<td>Huber 1973</td>
<td>Type locality: well-exposed on the south arm of Porter Island, along the north side of Tobin Harbor</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Washington Island Flow, Portage Lake Volcanics (pwi)</td>
<td>Huber 1973</td>
<td>Type locality: on the south side of Washington Island, where it caps the highest ridge</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Grace Island Flow, Portage Lake Volcanics (pgi)</td>
<td>Huber 1973</td>
<td>Type locality: on a point south of the campground on Grace Island</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Hill Point Flow, Portage Lake Volcanics (php)</td>
<td>Huber 1973</td>
<td>Type locality: along the south side of Pickerel Cove eastward to Hill Point</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Amygdaloid Island Flow, Portage Lake Volcanics (pai)</td>
<td>Huber 1973</td>
<td>Type locality: on promontory south of Crystal Cove, east end of Amygdaloid Island, north shore of eastern Isle Royale</td>
<td>Mesoproterozoic</td>
</tr>
</tbody>
</table>

The Mesoproterozoic Portage Lake Volcanics of the Keweenawan Supergroup were named by White et al. (1953) for exposures at Portage Lake, about 16 km (10 mi) south of the Ahmeek Quadrangle in Houghton County, Michigan. Huber (1973, 1975) provides detailed descriptions of the individual flow units of the Portage Lake Volcanics found at ISRO and in the type area on Keweenaw Peninsula (see KEWE; Figure 22). The Amygdaloid Island Flow is the oldest flow unit of the Portage Lake Volcanics at ISRO described by Huber (1973) and is named after its type locality on the east end of Amygdaloid Island on a promontory south of Crystal Cove (Figure 21; Table 4). The flow consists of resistant andesite that contains an abundance of pink agate amygdules (vesicles or cavities in igneous rocks filled with secondary minerals) (Figure 23; Huber 1973). The Amygdaloid Island Flow forms the highest ridge running the length of Amygdaloid Island (Huber 1973).
Table 22. Schematic columnar section of named lava flows of the Portage Lake Volcanics on ISRO. Figure 17 in Huber (1975).

<table>
<thead>
<tr>
<th>Named lava flows:</th>
<th>Unnamed rock sequences:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Numerous thin ophitic flows with as many as seven interbedded sandstone and conglomerate units</td>
</tr>
<tr>
<td>Scoville Point Flow (porphyrite)</td>
<td>Several thin ophitic flows</td>
</tr>
<tr>
<td>Edwards Island Flow (trap)</td>
<td>Conglomerate—known from drill records</td>
</tr>
<tr>
<td>Middle Point Flow (porphyrite)</td>
<td>Several thin ophitic flows</td>
</tr>
<tr>
<td>Long Island Flow (trap)</td>
<td>Sandstone—known from drill records</td>
</tr>
<tr>
<td>Tobin Harbor Flow (porphyrite)</td>
<td>Tuff-breccia</td>
</tr>
<tr>
<td>Washington Island Flow (ophite)</td>
<td>Conglomerate—known from drill records</td>
</tr>
<tr>
<td>Greenstone Flow (ophite)</td>
<td>Sequence of thin to thick (more than 100 ft) flows chiefly ophitic, with one or more sedimentary units suggested by drill data</td>
</tr>
<tr>
<td>Grace Island Flow (porphyrite)</td>
<td>Tuff-breccia</td>
</tr>
<tr>
<td>Minong Flow (trap)</td>
<td>Sequence of thin to thick flows, chiefly ophitic, with one or more sedimentary units suggested by drill data</td>
</tr>
<tr>
<td>Huginnin Flow (porphyrite)</td>
<td>One or more ophitic flows present locally</td>
</tr>
<tr>
<td>Hill Point Flow (ophite)</td>
<td>Sequence of thin to moderately thick flows, chiefly ophitic. Several sedimentary units and a felsite indicated by drill records</td>
</tr>
<tr>
<td>Amygdaloid Island Flow (trap)</td>
<td>Breccia</td>
</tr>
<tr>
<td></td>
<td>Lava flows, chiefly ophitic</td>
</tr>
</tbody>
</table>
Figure 23. Slabbed rock sample of the Amygdaloid Island Flow with characteristic agate amygdules collected from the type locality at the northeast end of Amygdaloid Island. Figure 15 in Huber (1973) and 75 in Huber (1975).

The Hill Point Flow of the Portage Lake Volcanics was named by Huber (1973) after its type locality along the south side of Pickerel Cove eastward to Hill Point (Figure 21; Table 4). Huber (1973) describes the Hill Point Flow as an ophite (volcanic rock containing exceptionally coarse crystals >2 cm or 0.8 in) that serves as a stratigraphic marker bed for its distinct texture and thickness. Exposures of the flow form steep cliffs along the north shore of the island from Huginnin Cove to McCargoe Cove and at the type locality. Although no thickness is reported from the type locality, a drill log from Lane (1898) taken on the western end of ISRO shows the unit reaches a thickness of 48 m (158 ft).

The Grace Island Flow of the Portage Lake Volcanics was named by Huber (1973) after its type locality on a point south of the campground on Grace Island (Figure 21; Table 4). The thickness of the flow at the type locality is unknown, but the unit reaches a thickness of about 15 m (50 ft) on Washington Island (Huber 1973). The flow is characterized as one of the most distinctive volcanic rocks at ISRO, containing large, euhedral (well-formed) tabular plagioclase crystals distributed
unevenly in a fine-grained groundmass (Huber 1973). From the type locality, the Grace Island Flow can be traced eastward for about 10 km (6 mi) in scattered outcrops (Huber 1973).

The Washington Island Flow of the Portage Lake Volcanics was named by Huber (1973) after its type locality on the south side of Washington Island where the flow is more than 61 m (200 ft) thick and caps the highest ridge (Figure 21; Table 4; Huber 1973). The rock is described by Huber (1973) as an ophite containing distinctly large augite and plagioclase grains. The flow also contains a uniform distribution of dark green chlorite that gives the rock a pervasive greenish speckled appearance (Huber 1973).

The Tobin Harbor Flow of the Portage Lake Volcanics was named by Huber (1973) after its type locality along the north side of Tobin Harbor on the south arm of Porter Island (Figure 21; Table 4). The flow measures about 15 m (50 ft) thick in the type locality and consists of porphyritic (having a groundmass of crystals too small to differentiate by eye and a smaller number of larger visible crystals) rock with millimeter-sized plagioclase crystals that are non-uniform in size and form clusters. The Tobin Harbor Flow is younger and identical in appearance to the Middle Point Flow, but the two units are separated by the Long Island Flow and interbedded sedimentary and igneous rocks (Huber 1973).

The Long Island Flow of the Portage Lake Volcanics was named by Huber (1973) after its type locality on Long Island (Figure 21; Table 4). At the type locality, the flow projects only a few meters or feet above water level, and a stratigraphic thickness of no more than 7.5 m (25 ft) is visible (Huber 1973). The flow is described as consisting of very dark gray or black, fine-grained aphanitic (crystals too small to be visible) rock that displays well-developed polygonal jointing at the type locality and on Third Island (Huber 1973). Although the Long Island and Edwards Island flows appear similar, the Long Island Flow commonly contains small, bluish agate amygdules that help distinguish the two units in outcrop (Huber 1973).

The Middle Point Flow of the Portage Lake Volcanics was named by Huber (1973) after its type locality on the south shore of Grace Harbor about 0.8 km (0.5 mi) northeast of Middle Point (Figure 21; Table 4). The thickness of the flow at the type locality is about 15 m (50 ft) and can be traced northeastward through scattered outcrops for approximately 19 km (12 mi) (Huber 1973). The Middle Point Flow is described as a porphyritic lava flow with millimeter-sized plagioclase crystals that share a texture similar to the Scoville Point Flow except that the plagioclase crystals are less uniform in size and tend to form groups or clusters (glomeroporphyritic texture) (Huber 1973).

The Edwards Island Flow of the Portage Lake Volcanics was described by Huber (1973) and named after its type locality on the north side of Edwards Island (Figures 21 and 24; Table 4). Thickness of the flow is about 15 m (50 ft) and predominantly consists of dark gray or black, fine-grained aphanitic rock with well-developed columnar jointing (Huber 1973). From the type locality, the flow can be traced westward for nearly 48 km (30 mi) to just northwest of Hay Bay, where the flow exposures become concealed by surficial cover (Huber 1973).
Figure 24. Well-developed columnar jointing in the Edwards Island Flow at the type locality on the north side of Edwards Island. Figure 18 in Huber (1975).

The Scoville Point Flow of the Portage Lake Volcanics was named by Huber (1973) after its type locality at Scoville Point on the east end of Rock Harbor (Figures 21, 25, and 26; Table 4). Type locality exposures are about 30 m (100 ft) thick and predominantly consist of resistant, porphyritic lava flows that contain fine, equant millimeter-sized plagioclase crystals distributed uniformly in a fine-grained matrix (Huber 1973).
Figure 25. Rocky shoreline of Scoville Point, type locality of the Scoville Point Flow of the Portage Lake Volcanics consisting of resistant, porphyritic lava flows (NPS/KAITLYN KNICK).
Figure 26. View looking northwest at the Dassler Cabin and Guest House from Scoville Point, type locality of the Scoville Point Flow (NPS).
Keweenaw National Historical Park (KEWE)

Keweenaw National Historical Park (KEWE) is located on the Keweenaw Peninsula in Baraga, Houghton, Keweenaw, and Ontonagon Counties, Michigan (Figure 27). Established on October 27, 1992, KEWE encompasses about 756 hectares (1,869 acres) and includes two primary units, the Calumet Unit and the Quincy Unit (Anderson 2017). The historical park preserves and interprets the story of the rise, domination, and decline of the region’s copper mining industry, beginning with prehistoric activity nearly 7,000 years ago through large-scale industrial mining in the 1800s and 1900s. The Keweenaw Peninsula contains some of the most extensive known deposits of native copper in the world and is one of the only sites in the country where aboriginal mining of copper occurred. Copper artifacts made by American Indians on the peninsula were traded as far south as present-day Alabama. The park’s Keweenaw Heritage Site partners operate most visitor facilities, offering diverse experiences and views of the industry and its participants. KEWE is not formally part of the GLKN, but it is included here for completeness.

The geology of KEWE predominantly consists of ancient billion-year-old lava flows associated with the formation of the Midcontinent Rift System of the North American craton (an old, stable part of the continental crust). As regional extensional forces stretched the crust, a rift system developed from at least as far southwest as Kansas through the Lake Superior region and into and beyond southern Michigan that allowed molten rock to migrate upward through fractures and faults. The entirety of the bedrock at KEWE is igneous rocks of the Portage Lake Volcanics, including the igneous units of the Scales Creek, Kearsarge, and Greenstone lava flows (Figure 28). Volcanic activity associated with the Midcontinent Rift produced large-scale economically recoverable native copper that is 97% pure. Evidence of Pleistocene glaciation that advanced and retreated across the Great Lakes region can be found in many locations throughout the Keweenaw Peninsula in the form of kettle lakes, gravel and sand deposits, and glacial grooves in exposed basalt.

KEWE contains two identified stratotypes that define the Proterozoic Keweenawan Supergroup and Mesoproterozoic Greenstone Flow of the Portage Lake Volcanics (Figure 29; Table 5). In addition to the designated stratotypes located within KEWE, stratotypes located within 48 km (30 mi) of the park boundaries include the Mesoproterozoic Jacobsville Formation (type locality) and Copper Harbor Formation (type area).
Figure 27. Park map of KEWE, Michigan (NPS).
Figure 28. Geologic map of KEWE, Michigan.
Figure 29. Modified geologic map of KEWE showing stratotype locations. The transparency of the geologic units layer has been increased.
<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keweenawan Supergroup</td>
<td>Brooks 1876;</td>
<td>Type area: Keweenaw Peninsula in western Michigan and northwestern Wisconsin</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td></td>
<td>Craddock 1972</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenstone Flow, Portage Lake</td>
<td>Huber 1973</td>
<td>Type locality: Keweenaw Peninsula, MI</td>
<td>Mesoproterozoic</td>
</tr>
<tr>
<td>Volcanics (Yplg)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The rocks of the Proterozoic Keweenawan Supergroup were originally described by Brooks (1876). The group consists of a thick sequence of subaerially deposited volcanic rocks (mostly flood basalts) and sedimentary rocks that were deposited in and near the Midcontinent Rift during the Mesoproterozoic (Cannon and Nicholson 1992). The type area for the group is located on the Keweenaw Peninsula in western Michigan and northwestern Wisconsin (Figure 29; Table 5; Craddock 1972). In the type area, the exposed Middle Keweenawan volcanic rocks are at least 4,600 m (15,000 ft) thick with an average flow thickness of 13 m (43 ft) (White 1960; Cannon and Nicholson 1992). The Upper Keweenawan rocks of the Bayfield and Oronto Groups have a combined thickness of about 7,300 m (24,000 ft) in the type area (Thwaites 1912; White 1971; Cannon and Nicholson 1992). The rocks of the Keweenawan Supergroup unconformably overlie the Sibley Group and unconformably underlie upper Cambrian strata (Cannon and Nicholson 1992).

The Mesoproterozoic Greenstone Flow of the Portage Lake Volcanics was originally described as the Greenstone group by Irving (1883) who named the unit after prominent exposures along Greenstone Ridge in ISRO. The type locality of the flow is on Keweenaw Peninsula where exposures reach a thickness of more than 500 m (1,640 ft) (Figure 29; Table 5; Cannon and Nicholson 2001). At ISRO, Huber (1973, 1975) described the flow as an ophite (volcanic rock containing exceptionally coarse crystals >2 cm or 0.8 in) with a greenish hue that could be subdivided into four divisions: (1) a lower ophitic zone 30 m (100 ft); (2) a central pegmatitic (texture featuring large crystals at least 2.5 cm or 1 in long, frequently much larger) zone 23 m (75 ft); (3) an upper ophitic zone 53 m (175 ft); and (4) an uppermost columnar-jointed interval 15 m (50 ft). The central pegmatitic zone is missing in exposures in the type locality. The Greenstone flow occurs between the overlying Washington Island Flow and underlying Minong Flow.
Mississippi National River and Recreation Area (MISS)

Mississippi National River and Recreation Area (MISS) encompasses a 115 km (72 mi) tract of the Mississippi River corridor through the Twin Cities metropolitan area in Anoka, Dakota, Hennepin, Ramsey, and Washington Counties, Minnesota (Figure 30). Established on November 18, 1988, MISS includes approximately 21,762 hectares (53,775 acres) of river, tallgrass prairie, oak savanna, floodplain forest, and wetlands. MISS features a wealth of significant natural, cultural, historic, scenic, economic, and scientific resources, complemented by a variety of recreational opportunities (Anderson 2017). The character of the Mississippi River changes dramatically in MISS, starting as a modest-sized river under protection as a state wild and scenic river. The river plunges over its only true waterfall (St. Anthony Falls) in Minneapolis, and enters a deep, wooded gorge before opening up into a forested floodplain (Mississippi National River and Recreation Area 2021). Prominent attractions within the park include the St. Anthony Falls Historic District, Historic Fort Snelling and the adjacent Fort Snelling State Park, Minnehaha Falls, and the rustic Winchell Trail.

The bedrock geology of MISS is predominantly composed of Paleozoic sedimentary rocks ranging from Cambrian through Ordovician in age (Figure 31). The oldest bedrock in MISS pertains to the late Cambrian Ironton Sandstone, Galesville Sandstone, St. Lawrence Formation, Franconia Formation, and the Jordan Sandstone, although only the Jordan Sandstone is exposed. Younger Ordovician rocks of MISS include the Prairie du Chien Group, St. Peter Sandstone, Platteville Formation, Glenwood Formation, Decorah Shale, and the Cummingsville Formation. Many bedrock units of MISS have historical character associated with American Indian tribes and early colonial traders. During the Pleistocene, the Illinoian and Wisconsinan glaciation events influenced the development of the landscape in MISS. The park unit sits near the terminus of the Wisconsinan event, exhibiting a glaciated landscape to the north that contains terminal moraines, till, glacial lake deposits, glacial drift, and outwash deposits.

MISS contains seven identified stratotypes that can be subdivided into five type sections, one type locality, and one type area (Figure 32; Table 6). In addition to the designated stratotypes located within MISS, stratotypes located within 48 km (30 mi) of the park boundaries include the Mesoproterozoic Solor Church Formation (type section and two reference sections); Cambrian Birkmose Member of the Lone Rock Formation (type section), St. Lawrence Formation (type section), and Jordan Sandstone (type section); Ordovician Shakopee Formation (type locality), New Richmond Member of the Shakopee Formation (type locality), Willow River Member of the Shakopee Formation (type area and reference section), and Hager City Dolomite Member of the Oneota Formation (type locality and reference section); Pliocene–Pleistocene Pierce Formation (type section and three reference sections), Hershey Member of the Pierce Formation (type section and reference section), and Kinnickinnic Member of the Pierce Formation (type section and reference section); Quaternary Arsenal Sand (type section and type area), Hillside Sand (type section), Falcon Heights Sand (type section), and Turtle Lake Sand (type area); and Pleistocene Fridley Formation (type area and two lithofacies type sections), New Brighton Formation (type area and three lithofacies type sections), Twin Cities Member of the New Ulm Formation (type section), and River Falls Formation (type section and reference section).

57
Figure 30. Park map of MISS, Minnesota (NPS).
Figure 31. Geologic map of MISS, Minnesota.
Figure 32. Modified geologic map of MISS showing stratotype locations. The transparency of the geologic units layer has been increased. The type sections of the Hennepin and Nokomis Members are at the same location.
The Middle to Late Ordovician St. Peter Sandstone was originally described by Owen (1847) and named after exposures along St. Peter’s River (now the Minnesota River). Stauffer (1934) designated the type section and type locality at Fort Snelling, where the unit forms the bluff where the Minnesota River joins the Mississippi River in Hennepin County, Minnesota (Figures 32 and 33; Table 6). The type section measures approximately 50 m (163 ft) thick and consists of thick-bedded, very-fine- to coarse-grained, white to yellowish-brown sandstone with an interval of siliceous blue shale (Stauffer 1934; Templeton and Willman 1963). The type section of the St. Peter Sandstone overlies the Shakopee Dolomite and underlies the Glenwood Formation. At Fort Snelling the bluff is currently partly covered by masonry (Figure 33). (The St. Peter Sandstone and other succeeding units at MISS were long described as Middle Ordovician only, but are now known to extend into the Late Ordovician.)

### Table 6. List of MISS stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Campus Formation</td>
<td>Stone 1966</td>
<td>Type section: roadcut on north side of U.S. Highway 12 where it passes through the West Campus, University of Minnesota, NE/4 SW/4 NW/4 sec. 25, T. 29 N., R. 24 W., New Brighton Quadrangle, southeastern MN Type area: terraces at 253–256 m (830–840 ft) level on both sides of Mississippi River from St. Anthony Falls south to Lake Street Bridge, MN</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Hidden Falls Member,</td>
<td>Sloan 1956</td>
<td>Type section: in Hidden Falls Park, on the Mississippi River 0.8 km (0.5 mi) south of Ford Motor Company plant, St. Paul, Ramsey Co., MN</td>
<td>Late Ordovician</td>
</tr>
<tr>
<td>Platteville Formation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hennepin Member,</td>
<td>Templeton and</td>
<td>Type section: bluff on west side of Mississippi River at Lock and Dam No. 1, Minneapolis, in NE/4 SW/4 NW/4 sec. 17, T. 28 N., R. 23 W. [approx. Lat. 44 deg. 54 min. 54 sec. N., Long. 93 deg. 12 min. 11 sec. W., St. Paul West 7.5-minute Quadrangle], Hennepin Co., eastern MN</td>
<td>Late Ordovician</td>
</tr>
<tr>
<td>Glenwood Formation</td>
<td>Willman 1963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nokomis Sandstone</td>
<td>Templeton and</td>
<td>Type section: bluff on west side of Mississippi River at Lock and Dam No. 1, Minneapolis, in NE/4 SW/4 NW/4 sec. 17, T. 28 N., R. 23 W., St. Paul Quadrangle, Hennepin Co., MN</td>
<td>Middle Ordovician</td>
</tr>
<tr>
<td>Member, Glenwood</td>
<td>Willman 1963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Peter Sandstone</td>
<td>Stauffer 1934</td>
<td>Type section: bluff where Minnesota River (formerly called St. Peter’s River) joins Mississippi River, Hennepin Co., southern MN Type locality: at Fort Snelling, MN</td>
<td>Middle–Late Ordovician</td>
</tr>
<tr>
<td>(Osp)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Middle to Late Ordovician St. Peter Sandstone was originally described by Owen (1847) and named after exposures along St. Peter’s River (now the Minnesota River). Stauffer (1934) designated the type section and type locality at Fort Snelling, where the unit forms the bluff where the Minnesota River joins the Mississippi River in Hennepin County, Minnesota (Figures 32 and 33; Table 6). The type section measures approximately 50 m (163 ft) thick and consists of thick-bedded, very-fine- to coarse-grained, white to yellowish-brown sandstone with an interval of siliceous blue shale (Stauffer 1934; Templeton and Willman 1963). The type section of the St. Peter Sandstone overlies the Shakopee Dolomite and underlies the Glenwood Formation. At Fort Snelling the bluff is currently partly covered by masonry (Figure 33). (The St. Peter Sandstone and other succeeding units at MISS were long described as Middle Ordovician only, but are now known to extend into the Late Ordovician.)
The Late Ordovician Nokomis Sandstone Member of the Glenwood Formation was originally named by Templeton and Willman (1963). The member is named after its type section exposure located 2.4 km (1.5 mi) east of Lake Nokomis (formerly Amelia Lake), Minnesota (Templeton and Willman 1963). The type section is designated as the exposure in west bluff of Mississippi River at Lock and Dam No.1 in Minneapolis (Figures 32, 34, and 35; Table 6; Templeton and Willman 1963). Thickness of the type section is about 3.30 m (10.83 ft) and consists of thin-bedded to massive, coarse-grained, greenish-gray, white, or tan sandstone (Templeton and Willman 1963). The Nokomis Sandstone Member unconformably overlies the St. Peter Sandstone and conformably underlies the Harmony Hill Shale of the Glenwood Formation. In practical applications it is usually lumped with the lithologically similar underlying St. Peter Sandstone, although it is still considered part of the Glenwood Formation (Mossler 2008). The section is still visible, but access is restricted because it is within part of Lock and Dam No. 1 that is closed to the public. Figures 34 and 35 come from approximately 110 m (360 ft) due north on the same bluff.
Figure 34. Type section bluff exposures of the Nokomis Sandstone Member of the Glenwood Formation and Hennepin Member of the Glenwood Formation along the Mississippi River at Lock and Dam No. 1, MISS (NPS/JUSTIN TWEET).
The Late Ordovician Hennepin Member of the Glenwood Formation was named by Templeton and Willman (1963) for exposures in Hennepin County in eastern Minnesota. Templeton and Willman (1963) designated the type section in a bluff on the west side of the Mississippi River at Lock and Dam No. 1 in Minneapolis (the same locality as the Nokomis Sandstone Member) (Figures 32, 34, and 35; Table 6). The member is 0.686 m (2.25 ft) thick at the type section and consists of nodular to thin-bedded, greenish-gray limestone (Templeton and Willman 1963). In the Templeton and Willman (1963) system, the Hennepin Member was included in the Pecatonica Formation with the overlying Chana Member, overlying the Harmony Hill Member of the Glenwood Formation. Generally in Minnesota the Chana Member name is not used, the Pecatonica is used as the basal member of the Platteville Formation (equivalent to the Chana Member), and the Hennepin Member is assigned to the Glenwood Formation (Mossler 2008).

The Late Ordovician Hidden Falls Member (or Hidden Falls Bed) of the Platteville Formation was formally proposed by Sloan (1956) and named after its type section in Hidden Falls Park on the Mississippi River, about 0.8 km (0.5 mi) south of Ford Motor Company plant in St. Paul, Minnesota (Figures 32 and 36; Table 6). The unit consists of blocky to massive, olive-gray limestone and dolostone that contains an uppermost thin yellowish-orange bentonitic shale (Sloan 1956; Mossler
Thickness of the type section is 1.75 m (5.75 ft), and the member varies slightly from about 1.6 to 2.0 m (5.5–6.5 ft) thick in the Twin Cities area (Sloan 1956). The member occurs between the underlying Mifflin Member and overlying Magnolia Member of the Platteville Formation.

Figure 36. Type section of the Hidden Falls Member of the Platteville Formation in Hidden Falls Park, MISS (NPS/JUSTIN TWEET). Yellow dashed lines mark the approximate upper and lower contacts of the member.

The Pleistocene West Campus Formation (or West Campus Sand) was named by Stone (1966) after exposures on the West Campus of the University of Minnesota in Minneapolis. The type section of the formation was located in a roadcut on the north side of U.S. Highway 12 where it passed through the university campus, in NE/4, SW/4, NW/4 sec. 25, T. 29 N. R. 24 W. (Figure 32; Table 6; Stone 1966). Stone (1966) also designated the type area as terraces at the 253–256 m (830–840 ft) level on both sides of the Mississippi River from St. Anthony Falls south to Lake St. Bridge, Minneapolis (Figure 32; Table 6). The unit is characterized as consisting of varicolored generally cross-bedded gravelly fine to coarse sand that contains lenses of silt, gravel, and moderately well-sorted sand that overlie the Platteville Formation (Stone 1966). At the time Stone described the formation, Highway 12 crossed the campus concurrently with Washington Avenue, but the Highway 12 designation was
later transferred to be concurrent with Interstate 94 in this area, so it no longer crosses the campus. Stone described the area just after the bridge and the roads serving it had been replaced on the West Campus; in the decades since then, vegetation and further infrastructure development has left no trace of a roadcut on the north side of the former Highway 12 route through campus.
Pictured Rocks National Lakeshore (PIRO)

Pictured Rocks National Lakeshore (PIRO) is located along the southeastern shores of Lake Superior in Alger County, Michigan (Figure 37). Established on October 5, 1972, PIRO encompasses approximately 29,637 hectares (73,236 acres) of multicolored sandstone cliffs, long beach strands, sand dunes, waterfalls, inland lakes, wetlands, hardwood and coniferous forests, and a diverse biological community (Anderson 2017). The geologic formations that are the namesake for PIRO form 15–61 m (50–200 ft) tall sandstone cliffs that extend over 24 km (15 mi) of shoreline and have been eroded to form sea caves, arches, blowholes, turrets, and stone spires. The nickname “Pictured Rocks” is from the streaks of mineral stain found on the cliff exposures that form when groundwater percolates through the rock and runs down the rock face. Among the most common color-producing mineral components include iron (red and orange), copper (blue and green), manganese (brown and black), and limonite (white).

The bedrock geology of PIRO predominantly consists of sedimentary rocks and deposits from two different intervals of geologic time: (1) the Mesoproterozoic, Cambrian, and Ordovician; and (2) the late Quaternary (Figure 38). The oldest rocks in PIRO pertain to the Mesoproterozoic Jacobsville Sandstone located in the northern area of the park unit. A significant portion of PIRO consists of the late Cambrian Munising Formation, which forms the “Pictured Rocks” along the lakeshore. The Early Ordovician Au Train Formation is found in the inland southern area of the park unit. During the Pleistocene, glaciers intermittently advanced and retreated across the Great Lakes region, leaving behind surficial deposits of till and outwash. Melting of glacial ice eroded several channels into the Cambrian bedrock of PIRO, including those now occupied by Chapel Creek and Mosquito River.

PIRO contains two identified stratotypes that define the Chapel Rock and Miner’s Castle Members of the late Cambrian Munising Formation (Figure 39; Table 7). In addition to the designated stratotypes located within PIRO, stratotypes located within 48 km (30 mi) of the park boundaries include the Early Ordovician Au Train Formation (type locality).
Figure 37. Park map of PIRO, Michigan (NPS).
Figure 38. Geologic map of PIRO, Michigan.
Figure 39. Modified geologic map of PIRO showing stratotype locations. The transparency of the geologic units layer has been increased.
Table 7. List of PIRO stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miner’s Castle Member, Munising Formation (Cm)</td>
<td>Hamblin 1958</td>
<td>Type locality: Miner’s Castle in Pictured Rocks cliffs, on southern shore of Lake Superior [NW ¼, SW ¼ sec. 3, T. 47 N., R. 18 W.], Alger Co., MI</td>
<td>late Cambrian</td>
</tr>
<tr>
<td>Chapel Rock Member, Munising Formation (Cm)</td>
<td>Hamblin 1958</td>
<td>Type locality: Chapel Rock near eastern end of Pictured Rocks cliffs along the southern coast of Lake Superior, Alger Co., MI</td>
<td>late Cambrian</td>
</tr>
</tbody>
</table>

The late Cambrian Chapel Rock Member of the Munising Formation was named by Hamblin (1958) and named after its type locality at Chapel Rock near the eastern end of Pictured Rocks cliffs along the southern coast of Lake Superior in Ager County, Michigan (Figures 39 and 40; Table 7). At the type locality and along the Pictured Rock cliffs the member ranges in thickness from 12–18 m (40–60 ft) (Hamblin 1958). The Chapel Rock Member consists of well-sorted, medium-grained sandstone that is white, tan, or pinkish-red in fresh exposures, but is colored in brilliant shades of red, yellow, green, black, brown, and white due to groundwater seepage down the face of the cliffs (Hamblin 1958). The member contains conspicuous large-scale trough cross-bedding, as well as mud cracks, ripple marks, sand concretions measuring 3–5 cm (1–2 in) in diameter, clastic sandstone dikes, and clay pellets (Figure 41; Hamblin 1958). The Chapel Rock Member overlies the informal basal conglomerate member of the Munising Formation and underlies the Miner’s Castle Member.
Figure 40. Heavily eroded, cross-bedded sandstone at Chapel Rock, type locality of the Chapel Rock Member of the Munising Formation (NPS).
The late Cambrian Miner’s Castle Member (also known as the Miners Castle Member) of the Munising Formation was proposed by Hamblin (1958) and named after its type locality at Miner’s Castle in Pictured Rocks cliffs along the southern shore of Lake Superior, Michigan (Figures 39 and 42; Table 7). Type locality exposures are 43 m (140 ft) thick and predominantly consists of poorly sorted, light-gray to white sandstone with thin lenses of blue shale that have surficial stains of red, brown, yellow, and black in the Pictured Rocks cliffs (Hamblin 1958). Unlike the large-scale trough cross-bedding of the Chapel Rock Member, the Miner’s Castle Member contains small-scale cross-bedding. Additional sedimentary structures of the unit include extensive horizontal bedding, mud cracks, ripple marks, and large elliptical concretions about 8–46 cm (3–18 in) in the longest dimension (Figure 43; Hamblin 1958). The Miner’s Castle Member overlies the Chapel Rock Member and underlies the Au Train Formation.
Figure 42. View looking east at eroded, cross-bedded sandstone at Miner’s Castle, type locality of the Miner’s Castle Member of the Munising Formation (NPS).
Figure 43. Eroded caves and cracks in the base of Miner’s Castle, consisting of horizontal and cross-bedded sandstone of the Miner’s Castle Member of the Munising Formation (NPS).
Saint Croix National Scenic River (SACN)

Saint Croix National Scenic Riverway (SACN) encompasses 406 km (252 mi) of river, including the Saint Croix River and the Namekagon River in midwestern Minnesota (Chisago, Pine, and Washington Counties) and Wisconsin (Bayfield, Burnett, Douglas, Pierce, Polk, Saint Croix, Sawyer, and Washburn Counties) (Figure 44). When SACN was originally established on October 2, 1968, only the upper 160 km (100 mi) of the Saint Croix River and entire 160 km (100 mi) course of the Namekagon River were included. The lower 84 km (52 mi) of the Saint Croix River were added to SACN under a 1972 amendment. The riverway contains approximately 27,304 hectares (67,470 acres) of river and forested landscape, and is recognized for its scenic, geologic, recreational, cultural, and ecological resources. Prominent features at SACN include: the Saint Croix and Namekagon Rivers and their tributaries; cascading rapids and waterfalls; riparian, wetland, and broad floodplain areas flanking the waterways; and steep bedrock cliffs.

The bedrock geology of SACN predominantly consists of Paleozoic sedimentary strata including Cambrian sandstones and Ordovician carbonate rocks (Figures 45 and 46). The geologic history of the SACN area includes regional-scale extension associated with the Mesoproterozoic Midcontinent Rift event, the deposition of younger Paleozoic strata, and recent Pleistocene glaciation. Some of the oldest bedrock occurs in the northern area of SACN along the Saint Croix River and consists of lithic sandstones, mudstones, and conglomerates of the Mesoproterozoic Oronto and Bayfield Groups. Some of the youngest units in the park unit are Pleistocene or younger surficial deposits that include the Miller Creek, New Ulm, West Campus, Trade River, Cromwell, and Copper Falls Formations, floodplain alluvium, and colluvium (Figure 45).

SACN contains one identified stratotype that defines the late Cambrian Franconia Formation (Figure 47; Table 8). In addition to the designated stratotypes located within SACN, stratotypes located within 48 km (30 mi) of the park boundaries include the Mesoproterozoic Chengwatana Volcanic Group (type section and type locality), Eileen Sandstone (type locality), Solor Church Formation (reference section), and Hinckley Sandstone (type section); Cambrian Birkmose Member of the Lone Rock Formation (type section; adjacent to the section of the scenic river managed by Wisconsin in Hudson); Ordovician Willow River Member of the Shakopee Formation (type area) and New Richmond Member of the Shakopee Formation (type locality); Pliocene–Pleistocene Pierce Formation (type section and three reference sections), Hershey Member of the Pierce Formation (type section and reference section), and Kinnickinnic Member of the Pierce Formation (type section and reference section); Quaternary Arsenal Sand (type section and type area), Turtle Lake Sand (type area), Falcon Heights Sand (type section), Hillside Sand (type section), Miller Creek Formation (type section), Hanson Creek Member of the Miller Creek Formation (type section), and Douglas Member of the Miller Creek Formation (type section); and the Pleistocene New Brighton Formation (type area and three facies type sections), Falun Member of the New Ulm Formation (type section and two reference sections), Twin Cities Member of the New Ulm Formation (type section), River Falls Formation (type section and reference section), Fridley Formation (type area and two facies type sections), Copper Falls Formation (type section and reference section), Poskin Member of the Copper Falls Formation (type section and reference section), Mikana Member of the Copper Falls Formation
(type section), and the Pokegama Creek Member of the Copper Falls Formation (type section and reference section).

Figure 44. Park map of SACN, Minnesota–Wisconsin (NPS).
Figure 45. Geologic map of SACN, Minnesota–Wisconsin. See Figure 46 for legend.
Figure 46. Geologic map legend of SACN, Minnesota–Wisconsin.
Figure 47. Modified geologic map of SACN showing stratotype locations. The transparency of the geologic units layer has been increased.
The late Cambrian Franconia Formation was named by Berkey (1897) after exposures in the type area in the vicinity of Franconia, Chisago County, Minnesota (Figure 47; Table 8). In the type area the formation forms bluff exposures measuring about 30 m (100 ft) thick that predominantly consist of thick-bedded, fine-grained white quartz sandstone with thin seams of green shale (Berkey 1897). The formation includes conspicuous glauconite, which imparts a greenish color to the rock (Twenhofel et al. 1935; Agnew et al. 1956). The Franconia Formation overlies the Ironton Sandstone and underlies the St. Lawrence Formation (Mossler 1987). The Franconia Formation is superseded by the Tunnel City Group for usage in Minnesota and Wisconsin (e.g., Mossler 2008).

Table 8. List of SACN stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Franconia Formation</td>
<td>Berkey 1897; see Twenhofel et al. 1935</td>
<td>Type area: exposures in vicinity of Franconia, Chisago Co., MN</td>
<td>late Cambrian</td>
</tr>
</tbody>
</table>
Sleeping Bear Dunes National Lakeshore (SLBE)

Sleeping Bear Dunes National Lakeshore (SLBE) is located along the northeastern shores of Lake Michigan in Benzie and Leelanau Counties, Michigan (Figure 48). Established on October 21, 1970, SLBE encompasses nearly 28,817 hectares (71,210 acres) that are distributed among four mainland units and the North and South Manitou Islands. The administrative boundaries of the park unit include about 105 km (65 mi) of Lake Michigan shoreline and numerous inland lakes and streams. The designation of SLBE is in recognition of its outstanding natural features, which include rivers, sandy beaches, beech–maple forests, clear lakes, lakeshore bluffs, and the namesake sand dunes that rise 140 m (460 ft) above Lake Michigan (Anderson 2017). The park unit contains a number of features that include an island lighthouse, lifesaving service stations, coastal villages, and agricultural landscapes.

The geology of SLBE consists of young Quaternary deposits in a region that has been heavily influenced by Pleistocene glaciation events (Figures 49–51). Geologic features in SLBE such as Pyramid Point, Sleeping Bear Plateau, and Empire Bluffs are glacial moraines (ridges of unconsolidated glacial deposits left behind when glaciers retreat) that steered more recent glacial ice into Good Harbor and various lakes in the region. Thousands of years of wave action have truncated the moraines so that they now appear as headland bluffs, including the steep sand and gravel faces so prominent at Empire bluffs, Sleeping Bear bluffs, and Pyramid Point. The popular sand dunes of SLBE are perched atop the topographically elevated glacial moraines and were formed as the moraine deposits were reworked by wind and water. As the moraines eroded, lighter sand-sized material was carried higher upward on top of the moraines while heavier stones fell downward into the beach. Over long periods of time this natural sifting process would help form the famous dunes of SLBE.

There are no designated stratotypes identified within the boundaries of SLBE. There is one identified stratotype located within 48 km (30 mi) of SLBE boundaries, for the Late Devonian Antrim Shale (type locality).
Figure 48. Park map of SLBE, Michigan (NPS).
Figure 49. Geologic map of the mainland unit of SLBE, Michigan.
Figure 50. Geologic map of North Manitou Island, SLBE, Michigan.
Figure 51. Geologic map of South Manitou Island, SLBE, Michigan.
Voyageurs National Park (VOYA)

Voyageurs National Park (VOYA) is located in the southern part of the Canadian Shield approximately 195 km (120 mi) north of Duluth along the U.S.–Canada border in St. Louis and Koochiching Counties, Minnesota (Figure 52). Established on April 8, 1975, VOYA encompasses approximately 88,302 hectares (218,200 acres) of interconnected waterways of four large lakes and more than 1,000 islands. At VOYA, the narrow passages that connect the Kabetogama, Namakan, Rainy, and Sand Point Lakes were once the route of French-Canadian voyageurs (Anderson 2017). The lakes collectively surround the Kabetogama Peninsula, which is the main land area of the park and contains numerous inland lakes and boreal forest. The park preserves and protects a hydrologically complex and sensitive environment where impermeable bedrock inhibits groundwater flow and thin soils allow relatively rapid surface runoff (Graham 2007). The region of VOYA experienced a short-lived gold boom in the late 19th century, and several abandoned mines are located in the northwestern part of the park.

The bedrock geology of VOYA contains some of the oldest rocks on the North American continent and provide evidence of ancient orogenic episodes that occurred approximately 2.5 billion years ago. Metamorphic rocks at VOYA are exposed in the west and central portions of VOYA and include Archean-age schists, gneisses, quartzites, metaconglomerates, and greenstones that formed due to high pressures and elevated temperatures. Exposed in the east and southeast areas of VOYA are ancient igneous units that include Archean-age intrusive rocks, the Lac La Croix Granite, and Paleoproterozoic diabase (a dark, crystalline igneous rock) (Figure 53). The intermittent advance and retreat of Pleistocene glaciers have eroded the ancient bedrock to create striations and grooves as well as the regions numerous lake basins. As the glaciers retreated, they deposited glacial erratics, ground moraine debris, and unconsolidated till that now forms the distinctive undulating topography at VOYA (Graham 2007).

VOYA contains one identified stratotype that defines the quartz–feldspar gneiss border facies of the late Archean Lac La Croix Granite (Figure 54; Table 9). In addition to the designated stratotypes located within VOYA, stratotypes located within 48 km (30 mi) of the park boundaries include the late Archean Lac La Croix Granite (type area and reference locality).
Figure 52. Park map of VOYA, Minnesota (NPS).
Figure 53. Geologic map of VOYA, Minnesota.
Figure 54. Modified geologic map of VOYA showing stratotype locations. The transparency of the geologic units layer has been increased.
Table 9. List of VOYA stratotype units sorted by age with associated reference publications and locations.

<table>
<thead>
<tr>
<th>Unit Name (map symbol)</th>
<th>Reference</th>
<th>Stratotype Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lac La Croix Granite,</td>
<td>Southwick and Sims 1980</td>
<td>Reference locality (=quartz–feldspar gneiss border facies): near the mouth of Long Slough [meant to be Deep Slough] on Namakan Lake, Hale Bay 7.5-minute Quadrangle, MN</td>
<td>late Archean</td>
</tr>
<tr>
<td>Vermillion Granitic Complex</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The late Archean Lac La Croix Granite of the Vermillion Granitic Complex was formally proposed by Southwick and Sims (1980) and named after its type area exposures south of Lac La Croix in northern St. Louis County, Minnesota. Although the type area is located outside VOYA, Southwick and Sims (1980) designated a reference locality for the quartz–feldspar gneiss border facies near the mouth of Long Slough (mistaken for Deep Slough) on Namakan Lake in the Hale Bay 7.5-minute Quadrangle (Figure 52; Table 9). The quartz–feldspar gneiss border facies consists of light-gray to grayish-pink granite gneiss that is well-exposed along the south shore of Namakan Lake, and has been interpreted as metasomatically (chemical alteration of rock by hydrothermal fluids) replaced wall rock near the contact of the Lac La Croix Granite (Southwick 1972; Southwick and Sims 1980). The Lac La Croix Granite has broadly gradational contacts with associated migmatitic rocks (rocks with metamorphic and igneous components due to partial melting of a wholly metamorphic precursor) (Southwick and Sims 1980).
Recommendations

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. Upon publication of the GLKN Geologic Type Section Inventory report, the NPS Geologic Resources Division should schedule a briefing for the staff of the GLKN and respective network parks.

3. The Minong Flow, Huginnin Flow, and Island Mine Conglomerate Bed of the Mesoproterozoic Portage Lake Volcanics were originally named by Lane (1898) for their respective occurrences at Minong Mine, Huginnin Cove, and Island Mine, ISRO. However, no formal stratotype designations for these units have been assigned. It is recommended that stratotypes for these units 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 these 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 infrastructure 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.

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.

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.

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/petrologic samples collected from type sections within respective 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.

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).
Literature Cited


Appendix A: Source Information for GRI Maps of GLKN Parks

APIS


GRPO


INDU
ISRO


KEWE


MISS


PIRO


SACN


SLBE

VOYA

Appendix B: Geologic Time Scale

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

NPS 920/177818, November 2021