

Geologic Resources Inventory Scoping Summary

Apostle Islands National Lakeshore

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The Geologic Resources Inventory (GRI) provides each of 270 identified natural area National Park System units with a geologic scoping meeting and summary (this document), a digital geologic map, and a geologic resources inventory report. The purpose of scoping is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and monitoring and research needs. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity to discuss park-specific geologic management issues, and if possible include a site visit with local experts.

The National Park Service held a GRI scoping meeting for Apostle Islands National Lakeshore on July 20-21, 2010 both out in the field on a boating site visit from Bayfield, Wisconsin, and at the headquarters building for the Great Lakes Network in Ashland, Wisconsin. Jim Chappell (Colorado State University [CSU]) facilitated the discussion of map coverage and Bruce Heise (NPS-GRD) led the discussion regarding geologic processes and features at the park. Dick Ojakangas from the University of Minnesota at Duluth and Laurel Woodruff from the U.S. Geological Survey presented brief geologic overviews of the park and surrounding area. Participants at the meeting included NPS staff from the park and Geologic Resources Division; geologists from the University of Minnesota at Duluth, Wisconsin Geological and Natural History Survey, and U.S. Geological Survey; and cooperators from Colorado State University (see table 2). This scoping summary highlights the GRI scoping meeting for Apostle Islands National Lakeshore including the geologic setting, the plan for providing a digital geologic map, a prioritized list of geologic resource management issues, a description of significant geologic features and processes, lists of recommendations and action items, and a record of meeting participants.

Park and Geologic Setting

Established on September 26, 1970, Apostle Islands National Lakeshore encompasses 28,074 ha (69,372 ac) of which 11,057 ha (27,323 ac) are submerged lands and 13,557 ha (33,500 ac) are designated wilderness among 21 islands (of 22 total), and 19 km (12 mi) of mainland shoreline along the southern shore of Lake Superior in northeast Wisconsin. The park boundary extends 0.40 km (0.25 mi) offshore on the lake surface. The state of Wisconsin owns submerged land below the high watermark. Islands included within the park are Basswood, Bear, Cat, Devils, Eagle, Gull, Hermit, Ironwood, Long (actually now a sand spit), Manitou, Michigan, North Twin, Oak, Otter, Outer, Raspberry, Rocky, Sand, South Twin, Stockton, and York islands. Madeline Island, the largest island of the Apostles, is not part of the park. Geologic features within the park include high bluffs, sea cliffs, sea caves, sandscapes (i.e., sand spits, cusped forelands, beaches, tombolos, dunes), terraces, wave-cut benches, and arches. Lake Superior's surface is at 183 m (602 ft) above sea level. Oak Island, the highest island, is approximately 335 m (1,100 ft) above sea level. This 152 m (500 ft) of relief is significant given the relatively small size of most of the islands.

The bedrock at Apostle Islands consists of fluvial clastic rocks that were deposited in a post-rift subsidence basin of the 1.1 billion year old Midcontinent rift. The Midcontinent rift, which stretches from Kansas through the Lake Superior region and into southern Michigan, is filled with more than

20 km of basalts overlain by more than 10 km of clastic and lacustrine sediments, which comprise the Keweenaw Supergroup. Bedrock exposed in cliffs and benches at the water's edge at the Apostle Islands consist of three nearly flat-lying conformable units listed in order from oldest to youngest: the Orienta, Devils Island, and Chequamegon formations of the Bayfield Group. The Lake Superior basin was created by Pleistocene glacial erosion of sedimentary rocks along the rift axis. At the last glacial maximum 18,000 years ago, this area of Wisconsin was buried beneath ice of the Superior Lobe. Ice melted out of the region approximately 10,000 years ago, creating a series of proglacial lakes that formed at the retreating front of the glacier. Bedrock in many areas is covered by glacial deposits, including outwash, till, and lacustrine sediments.

Each island has its own unique character expressed through history, geology, biology, and modern uses. Some islands have steep, 0.6 to 46 m (2 to 150 ft) bluffs of sandy glacial till mantling all sides. Other islands have protected areas of sand accumulation, whereas others have dramatically sculpted rocky shores.

Geologic Mapping for Apostle Island National Lakeshore

During the scoping meeting, Jim Chappell (CSU) showed some of the main features of the GRI's digital geologic maps, which reproduce all aspects of paper maps, including notes, legends, and cross sections, with the added benefit of being GIS compatible. The NPS GRI Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation for the GRI Program and allows for rigorous quality control. Staff members digitize maps or convert digital data to the GRI digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase and shapefile format, layer files complete with feature symbology, FGDC-compliant metadata, an Adobe Acrobat PDF help document that captures ancillary map data, and a map document that displays the map, and provides a tool to access the PDF help document directly from the map document. Final data products are posted at <http://science.nature.nps.gov/nrdata/>. The data model is available at <http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm>.

When possible, the GRI Program provides large scale (1:24,000) digital geologic map coverage for each park's area of interest, which is often composed of the 7.5-minute quadrangles that contain park lands (fig. 1). Maps of this scale (and larger) are useful to resource managers because they capture most geologic features of interest and are spatially accurate within 12 m (40 ft). The process of selecting maps for management begins with the identification of existing geologic maps (table 1) and mapping needs in the vicinity of the park unit boundary. Scoping session participants then select appropriate source maps for the digital geologic data or develop a plan to obtain new mapping, if necessary.

Table 1. GRI Mapping Plan for Apostle Islands National Lakeshore

Covered Quadrangles	Relationship to the park	Citation	Format	Assessment	GRI Action
All QOI listed below	Covers all of park	Nicholson, S. et al, 20xx, Bedrock Geologic Map of the Superior Region (unpublished), USGS, 1:100,000 scale.	Digital	Yes - bedrock	Convert to GRI data model – use also for bedrock coverage of GRPO
All QOI listed below	Covers all of park	Clayton, Lee, 1985, Pleistocene Geology of the Superior Region, Wisconsin, Wisconsin Geological and Natural History Survey, Regional Map Series 3, 1:250000 scale	Paper	Yes - surficial	Digitize QOI

During the meeting, the following quadrangles of interest were determined to be necessary for park resource management needs: Outer Island, Cat Island, Rocky Island, Bear Island, Sand Island OE N, Michigan Island, Michigan Island OE S, Stockton Island, Oak Island, York Island, Sand Island, Squaw Bay, Amnicon Point, Madeline Island, Bayfield, Mount Ashwabay, Cornucopia, Bark Bay, Bark Bay OE N, Chequamegon Point, Long Island, Washburn, Ashland East, Ashland West, Odanah and Cedar 7.5 minute quadrangles.

While there is sufficient coverage of bedrock and surficial mapping for the Apostle Islands National Lakeshore area of interest (fig. 1), both mapping types are fairly small scale; 1:100,000 and 1:250,000 scale, respectively. Meeting participants, including park personnel, agreed that the USGS bedrock mapping, shown in Table 1, which is currently being produced by the USGS (hopefully available 2011), will be sufficient for the park's bedrock mapping needs.

The park's surficial mapping needs can be met initially by using the Pleistocene Geologic map of the Superior Region (Clayton, 1985), produced by the Wisconsin Geological and Natural History Survey (Table 1). Because Apostle Islands National Lakeshore is a very dynamic lakeshore, meeting participants and park personnel agreed that more detailed surficial mapping is needed – specifically with regards to coastal processes and shoreline change. Bruce Heise (GRD) and Jamie Robertson (WSGS) agreed to have follow-up conversations addressing new surficial and coastal processes mapping. In the meantime, the GRI will digitize and convert data listed in Table 1 and will clip data to the area of interest for Apostle Islands National Lakeshore.

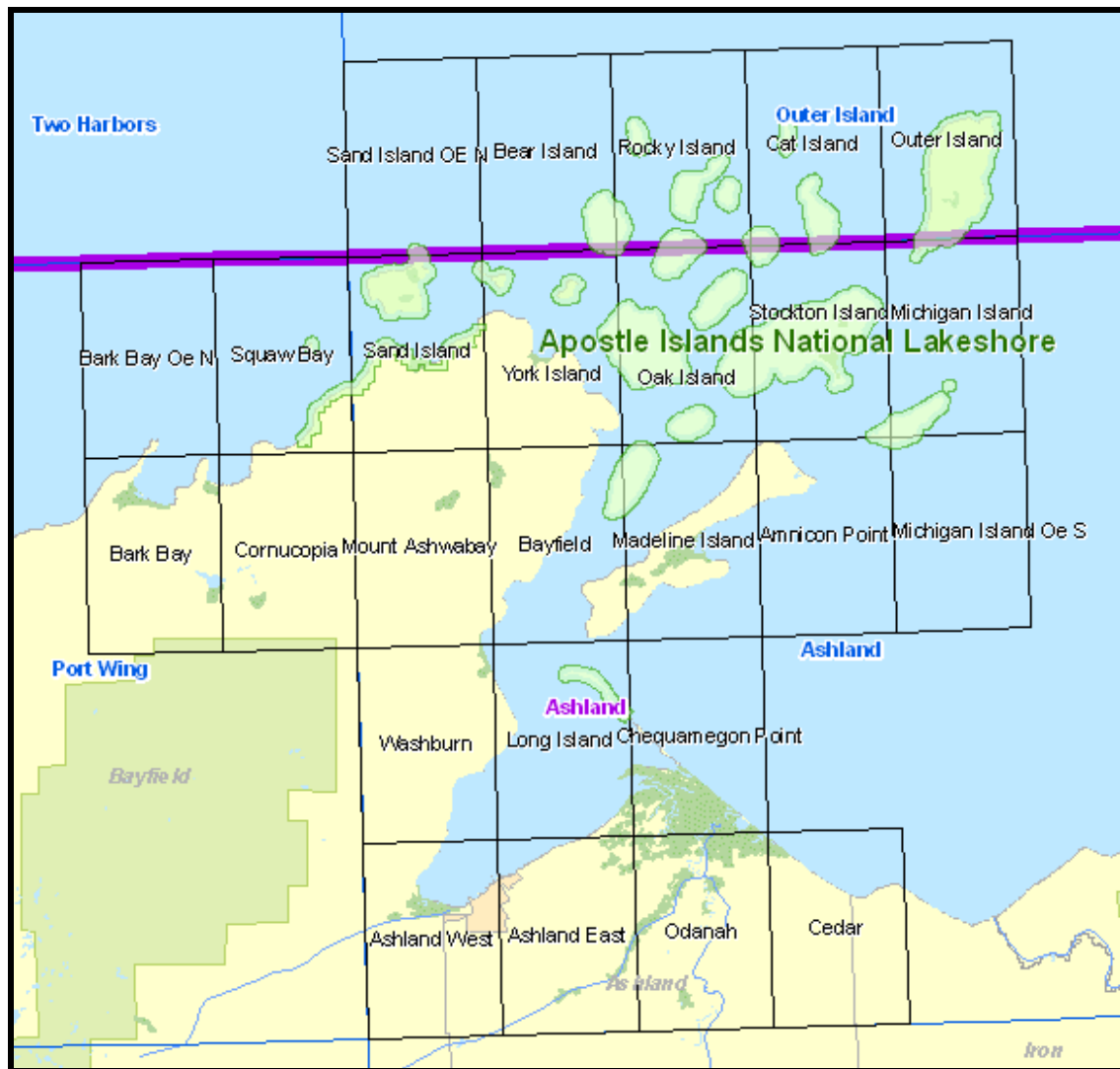


Figure 1. Area of interest for Apostle Islands National Lakeshore. 7.5-minute quadrangles are labeled in black; names and lines in blue indicate 30x60-minute quadrangles; 1x2 degree quadrangles shown with purple text and purple boundaries. Green outlines indicate park boundary.

The Wisconsin Geological and Natural History Survey's website has a 1:500,000-scale landforms map available for the entire state. Resource managers are interested in pursuing repeat aerial photography of the shorelines and sandscapes within the park. This would help with shoreline evolution studies and predicting future landform patterns and changes in response to changing climate. The park also has new soil and vegetation maps that may provide a basis for surficial geologic mapping at large scales.

[September, 2013 Mapping Update – the above mentioned USGS bedrock map of the Superior region remains delayed due to issues relating to mapping on the Canadian side of the border. At the 2011 Geological Society of America (GSA) annual meeting in Minneapolis, MN, USGS geologists recommended using these maps instead for source material:

Nicholson, S.W., Cannon, W.F., Woodruff, L.G., and Dicken, C.L., 2004, Bedrock Geologic Map of the Port Wing, Solon Springs, and Parts of the Duluth and Sandstone 30' X 60' Quadrangles, Wisconsin, U.S. Geological Survey, Open-File Report OF-2004-1303, 1:100000 scale. (GRI Source Map ID 70276)

Nicholson, S.W., Dicken, C.L., Foose, M.P., and Mueller, Julie, 2004, Integrated Geologic Map Databases for the United States, the Upper Midwest States: Minnesota, Wisconsin, Michigan, Illinois, and Indiana, U.S. Geological Survey, Open-File Report OF-2004-1355, 1:500000 scale. (GRI Source Map ID 70281)

Cannon, W.F., Woodruff, L.G., Nicholson, S.W., Hedgman, C.A., and Barber-Delach, R.D., 1999, Digital Bedrock Geologic Map of the Ashland and Northern Part of the Ironwood 30' X 60' Quadrangles, Wisconsin, and Michigan, U.S. Geological Survey, Open-File Report OF-99-546, 1:100000 scale. (GRI Source Map ID 2227)

Clayton, Lee, 1985, Pleistocene Geology of the Superior Region, Wisconsin, Wisconsin Geological and Natural History Survey, Regional Map Series 3, 1:250000 scale. (GRI Source Map ID 3795)

The GRI team delivered a final digital geologic map and GIS product to the park in September, 2012]

Geologic Resource Management Issues

The scoping session for Apostle Islands National Lakeshore provided the opportunity to develop a list of geologic features and processes that will be expanded upon in the final GRI report. During the meeting, participants discussed geologic resource management concerns including slope and shoreline processes, disturbed lands, potential energy development, and seismicity.

Slope and shoreline processes

Hillslope issues at Apostle Islands National Lakeshore include pervasive erosion, blockfall, and slumping. Steep bluffs of thick, reddish, loosely cemented glacial till on many islands are very prone to slumping (fig. 2). Steep ravines continue to form in the clay layers (also referred to as clay banks although the composition is more of a sandy loam). These features resemble hoodoos. At Raspberry and Outer islands, the shoreline displays steep, erodible banks of glacial till that required shoreline stabilization to protect historic light stations. At Raspberry Island, stabilization included installation of riprap (gabbro boulders), reducing the slope of the bluff to approximately 2:1, vegetative plantings, and a variety of bioengineering techniques, including brush layering, facines, and log cribs (fig. 3). In addition, a drainage system was installed to capture seepage and overland flow. This solution has worked to stabilize the slope, but required bringing in a large amount of soil and with it, a high number of exotic species. On Outer Island, in addition to riprap and a drainage trench, bioengineering techniques were used on the slope that worked with the existing topography. This technique worked well, maintaining a more natural looking slope and did not require the import of a large amount of soil.

At Oak Island, a sea arch recently collapsed attesting to the active shoreline erosion and wave action. Faults and joints within the bedrock tend to concentrate weathering and rocks often spall

along these surfaces. There is some risk to visitor safety in kayaks along the base of the steeper cliffs and in sea caves in the event of mass wasting.

Disturbed lands

Because of its long history of human occupation and relative youth as a NPS unit, portions of the landscape within the park could be considered disturbed lands, such as reclaimed homesteads and other anthropogenic features, such as quarries, farms, fishing camps, landings, and structures. However, few of these features are targets for remediation. Most are left to naturally reach a state of equilibrium with the environment and many of them are important cultural resources. Four late 19th century sandstone quarries are present on three islands (Basswood, Hermit, and Stockton). The dark brown sandstone of the Precambrian Chequamegon Formation graces many buildings throughout the region. The color of this stone stems from oxidized iron (hematite) presenting evidence of subaerial exposure to the atmosphere during original deposition as redbeds. Groundwater seeping through the sandstones can leave bleached fringes around fractures and joints. Quarrying was a short-lived industry in the islands, only lasting from the late 1860s to the late 1890s. The quarries closed around 1900 when developers began to prefer the lighter colors of the Indiana limestone for building stone. Quarries and even cut blocks were abandoned. Visitors can see these blocks on the shore of Hermit Island (also called Wilson Island) (fig. 4). The park has a quarry management plan. To maintain the cultural resource and for interpretive purposes, some quarries are cleared.

Potential energy development and regional land use

In the early 1990s, oil prospectors explored for oil in the Ashland area. The drill bottomed out at less than 1,524 m (5,000 ft) and found no hydrocarbons. Other potential energy development includes proposed wind farms on Madeline Island and the mainland, potentially impacting the park's viewshed.

There is some discussion about the potential to use some bedrock units within the Great Lakes Network for carbon sequestration. This process involves injecting condensed carbon dioxide into deep sediments for long term storage. Requirements for this type of operation include some pore space at depth and a suitable impermeable cap layer. The Midcontinent rift contains thousands of feet of sediment at a suitable depth, but the lack of porosity suggests these rocks would be poor reservoirs. There is saline groundwater at great depth, which could be a complicating factor. The carbon dioxide is generated from coal-fired power plants within the region, and condensing it would require significant amounts of energy and money.

Seismicity

The cratonic core of the North American continent is not a hotspot for seismicity. Nevertheless, seismic events can occur regionally as buried ancient structures accommodate stresses within Earth's crust. In the Great Lakes area, these stresses are not generally tectonic in nature, but instead are the result of isostatic rebound as the crust adjusts to the lack of weight of the glacial ice since the end of the last ice age in the Pleistocene. There are myriad old faults and fractures that cross the Wisconsin in the subsurface. The University of Minnesota at Duluth has a seismograph. Earthscope, a multidisciplinary research program, will eventually serve seismic data in its mission to utilize freely available data from instruments that measure motions of Earth's surface and record seismic waves (www.earthscope.org).



Figure 2. Steep bluffs of glacial till at Raspberry Island. View is to the northwest. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).



Figure 3. Shoreline stabilization at the lighthouse on Raspberry Island. View is to the north. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).



Figure 4. Sandstone quarried blocks on the shore of Hermit Island. View is to the west. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Features and Processes

Shoreline features and processes

The evolution of the Apostle Islands is intimately tied to the glacial history of the area. As mentioned below in the glacial features section, the islands are remnants of rift sedimentary rocks left behind as high points upon glacial retreat from the area. While the glaciers were retreating, a series of ever-lowering glacial lakes formed at the base of the glacial ice. Shoreline processes have been sculpting the lakeshores of the Apostle Islands ever since. Myriad coastal features appear throughout the 21 islands that make up the park.

Wind and wave energy continually sculpt bedrock shorelines into cliffs, embayments, rocky headlands, sea caves, sea stacks (spires or pinnacles), windows, and arches. In particular, the properties of the Devils Island Formation, including thinly laminated, flat bedding, and flaggy sandstone composition, lend themselves to the formation of sea caves and arches (fig. 5). Spectacular examples of sea caves (and in winter, ice caves) occur on Devils Island and the mainland where the Devils Island Formation crops out. The presence of faults and joints tends to focus embayment and cave formation.

On Stockton Island (the second largest of the Apostle Islands) there are steep bluffs of red clay till, yellow sand beaches, rocky shores of Precambrian sandstone, and a double tombolo connecting Stockton Island with the former island of Presque Isle, forming one large island. The tombolo formed where wind and wave action accumulated reddish sand between the two islands from both sides creating a natural sand trap. The tombolo captured a freshwater lagoon during its accretion and

hosts a pine savannah forest. The tombolo has beaches, dunes, and washover fans (figs. 6 and 7). There is also a small (0.6 ha [1.5 ac]) cusped foreland on the northwest side of Stockton Island.

The park contains sand-based features such as dunes, beaches, beach ridges, swales, barriers, tombolos, spits, and cusped forelands (triangular masses of sand) that are collectively referred to as “sandscapes”. In general, sand accumulates on the sheltered, southern sides of the islands. Outer Island has a large sand spit (6.7 ha [16.5 ac]) and trapped lagoon on its southeastern end. Cat Island has a small (0.6 ha [1.5 ac]), relatively fragile sand on its south side (fig. 8). Bear, Ironwood, Oak, Otter, and Raspberry Island have small (0.2 to 0.4 ha [0.5 to 1 ac]) cusped forelands. Rocky and Michigan islands have fairly large cusped forelands (2 and 3 ha [5 and 7.5 ac] respectively) and trapped lagoons. Rocky Island’s landscape includes a foredune, upland area, beach berm, cusped foreland, and ridge and swale complex exist on the eastern shore where accretion occurs as opposed to the eroding western shore. On the western shore are wave-cut benches, no spit point, and more of a gradual, erosional curving shoreline. The shoreline system throughout the park is dynamic with shifting sands evolving into ephemeral landforms that can change in a single storm. The system at the park is wholly natural with the exception of some shoreline stabilization near lighthouses in danger of degradation such as on Raspberry and Outer islands. No beach nourishment occurs within the park. There is some bottom dredging at the Little Sand Bay marina on the mainland and occasionally at Stockton Presque Isle harbor. The local township uses the dredged material for road work.

Geology and history connections

The Apostle Islands have a long record of human inhabitation and land use. The earliest records include American Indian sites. These early people may have been the first in the area to extract native copper. Early uses of the island include logging, homesteads, and fishing outposts. Rocky Island became a National Register area for the Norwegian fish cultural heritage there. On Manitou Island, a fish camp is an interpretive opportunity. The location of the islands off the Bayfield Peninsula made them strategic locations to place lighthouses intended to guide ships safely to mainland harbors and away from treacherous rocky shoals and islands. The park includes 8 lighthouses and 6 light stations, the largest collection of light stations in the NPS. There are light stations on Devils, Long, Michigan, Outer, Raspberry, and Sand islands, all of which are listed on the National Register of Historic Place.

Paleontological resources

According to the paleontological resource inventory and monitoring report prepared by the Geologic Resources Division for Apostle Islands National Lakeshore, the park contains fossiliferous clasts in the glacial drift from elsewhere. These include corals in chert and limestone cobbles. The bedrock units in the park are Precambrian and do not contain fossils. There are some debatable trace fossils allegedly found in the Bayfield Group. There is potential for Pleistocene megafauna. There is also an approximately 10,000-year pollen record contained in local bogs.

Glacial features

During the Pleistocene, episodic cooler climates led to global glaciation events. Of these, the Illinoian and later Wisconsinan events strongly influenced the development of the landscape in the Apostle Islands National Lakeshore area. The Superior Lobe excavated the Superior Basin and deposited vast amounts of glacial outwash and till (though few moraine deposits) on the Apostle

Islands. Glacial lobes descending into the Great Lakes area became progressively thinner with distance from their source. In Iowa for instance, the Des Moines lobe was only a few hundred feet thick. The lobe was locally some 400 m (1,300 ft.) thick, with a maximum thickness of approximately 0.8 km (0.5 mi) further north. The glaciers advanced through preexisting stream valleys through the area. Particularly resistant landforms, such as the topographically higher Bayfield Peninsula, split the lobe into two sublobes—the Chippewa Lobe to the east and the Superior Lobe to the south. Resistant remnants of sandstone at the flanks of the ancient rift valley were left after glacial retreat as islands sheltered by the Bayfield peninsula in Lake Superior. A splay of sand formed between the two lobes created the deep sands on the interior of the peninsula, and trends south-southwest towards the Saint Croix River Valley.

Some islands contain thick reddish, sandy till deposits at the shoreline. These are sometimes referred to as the Miller Creek Formation. These deposits tend to weather into steep, high bluffs reaching some 46 m (150 ft.) above the lakeshore. At Raspberry Island, the outer shoreline displays steep, erodible banks of glacial till. Glacial erratic's are present on many of the islands. A notable example is the greenstone boulder on the edge of the tombolo at Stockton Island. The islands also contain ice contact or ice margin features.

A series of proglacial lakes formed landward of the large continental glacier during its Pleistocene retreat from northeastern Wisconsin. Locally, the Superior Lobe descended south through the Lake Superior basin, covering the area beneath a thick sheet of ice. Glacial Lake Duluth formed as this glacier retreated northward. Vast amounts of clay-rich, lacustrine deposits deposited within Glacial Lake Duluth persist in scant areas on the highlands of some islands within the park such as Raspberry Island. The series of glacial lakes also created coastal, wave-cut terraces along shorelines of the islands.

Aeolian features

Aeolian features at Apostle Islands National Lakeshore include dunes and barrier sand spits. Long Island (now connected to the mainland via a narrow sand spit) was an island as recently as the 1970s. Park resource managers expect the narrow spit to continue to migrate into the lake and ultimately breach in a storm event forming Long Island, the island, again. Long Island's barrier system is very dynamic and has 2.4 km (1.5 mi) of extensive, active dunes. The tombolo between Stockton Island and Presque-Isle has the second largest dune area in the park. There may be some windblown silt (loess) deposits covering isolated areas on glacial outwash. These types of deposits formed prior to extensive revegetation following glacial retreat. They are easily eroded and/or incorporated into the soil profile.

Lacustrine features

Lacustrine features exist on the tops of most islands as upland bogs and marshes. Many are ephemeral with no defined drainage. The park also has lagoon areas trapped by accreting sands and backwater sloughs left stranded as recessional features.

The Midcontinent rift and regional geology

During the Precambrian, upwelling caused by a mantle plume resulted in the development of the Midcontinent rift, a major tectonic feature stretching from Kansas through the Lake Superior region, and into southern Michigan. All the rock units related to the rift are called the Keweenaw

Supergroup. The rift developed in three stages over some 50 million years from around 1100 million years ago to 1050 million years ago. The first stage was the initial rifting of the continental rocks and accompanying volcanism that spanned close to 14 million years. The rift developed as a central graben (sag basin) bounded on either side by normal faults. Following the end of significant volcanism, the second stage was continued sagging within the rift because of thermal subsidence, with accompanying sedimentation and no volcanism. In the deepest part of the rift under Lake Superior, rift rocks have been imaged nearly to the Moho at 30 km (19 mi), with about 20 km of basalt flows overlain by about 10 km of sediment. The third stage in rift history occurred when the extensional regime shifted to compression at the onset of the Grenville Orogeny (mountain building event) to the east of the rift. This late-stage compressional event, that may have begun about 1080 million years and culminated about 1060 million years, changed the sense of motion along the rift-bounding normal fault, and uplifted the central rift graben relative to its flanks.

Volcanism within the central rift basin began with voluminous eruptions of molten rock (basaltic magma) at about 1109 million years with waning activity lasting until about 1086 million years ago. Large volumes of magma erupted as lava flows from vents along the center of the rift, spreading laterally towards the rift margins. The earliest lavas are the basalts of the Powder Mill Group (1108 to 1099 Ma), overlain by basalts of the Bergland Group (1099 to 1086 Ma), which includes the Portage Lake Volcanics in Michigan and the Chengwatana Volcanics in Wisconsin. One flow, the Greenstone flow dated at 1094 million years, is more than 305 m (1,000 ft) thick and can be traced for approximately 80 km (50 mi) across the Lake Superior basin. Around 1102 Ma, magma bodies that cooled at depth were intruded into rocks on either side of the rift basin, forming the Duluth Complex of Minnesota and the Mellen Complex of Wisconsin. The basal units of the Duluth Complex host numerous nickel-copper deposits. The Portage Lake Volcanics contain world-class native copper mineralization that was actively mined from the 1850s until the 1950s.

Numerous conglomerate units between lava flows contain rocks eroded from the rift flanks, denoting short breaks in volcanic activity. Thick sedimentary units, including sandstone, conglomerate, and shale, overlie the volcanics within and outside of the rift basin. These sedimentary units are the interbasinal Oronto Group (Copper Harbor Conglomerate, Nonesuch Formation, and Freda Sandstone), exposed at many areas along the southern shore of Lake Superior, and the extrabasinal redbeds of the Bayfield Group (Orienta, Devils Island, and Chequamegon formations), exposed at Apostle Islands National Lakeshore. This sedimentary section in general fines upwards as the slopes and sediment supply from surrounding areas decreased. The White Pine mine extracted copper sulfides from the Nonesuch Formation. With the exception of the Nonesuch Formation, which is typically a dark gray to black argillite/shale unit, sediments related to the rift tend to be brown to red. There is some debate as to whether the sediments that formed the Nonesuch Formation collected in a closed, lacustrine basin, or an open marine setting, but geologists have found no conclusive evidence of tidal action, which would support a marine origin, so but this remains a topic for research (contact Dick Ojakangas).

The bedrock at Apostle Islands National Lakeshore comprises sedimentary rocks of the Bayfield Group. The oldest unit, the Orienta Formation, is 1,000 m (3,280 ft) thick, the Devils Island Formation is 100 m (328 ft) thick, and the youngest unit, the Chequamegon Formation, is 150 m (492 ft) thick. Most of these rocks appear reddish due to the presence of oxidized iron. The mineralogy is dominated by quartz and feldspar and changes in their relative percentages from the oldest to the youngest units suggest a shift in provenance from volcanic rocks to plutonic rocks.

Mudcracks, cross beds, and ripplemarks are common. Due to post-glacial uplift, streams have cut deep valleys to the shorelines. Shoreline processes of waves, wind, freeze-and-thaw, and mass wasting continue to sculpt and wear away the bedrock of the islands. The Devils Island Formation is notable for the large number of sea caves that have developed where the rocks form cliffs along the Lake Superior shore.

Fluvial features and processes

There are ephemeral streams on the islands, but Sand River, on the mainland shoreline is the primary fluvial feature in the park. There is a delta at the mouth of Sand River. The estuary-like area includes a sandscape spit, bogs, and some small terraces flanking the river. Sand River frequently floods, but not in areas of concern for park resource managers. The mainland portion of the park, including the mouth of Sand River is in an area of complex land management between the NPS and the Red Cliff Indian Reservation.

Unique features

Among the various sand features at the park, the double tombolo between Stockton Island and Presque-Isle is of particular interest. The Holocene sand washed up against Precambrian sandstone, representing a gap in geologic time of over one billion years. Geologists consider this feature to be an unconformity.

Devils Island is the type locality for the Precambrian Devils Island Formation. The conformable (as opposed to erosional) contact between the Devils Island Formation and the overlying Chequamegon Formation sits at the very southern tip of Devils Island.

The park protects certain unique ecosystems and flora and fauna communities. The park provides habitat for over 150 species of breeding birds, includes important migratory bird concentration areas, provides important colonial bird nesting areas, and includes critical habitat for the endangered piping plover community that nests on Long Island. Bat habitat exists on the steep rocky cliffs fronting some islands as well as some of the park's historic lighthouses. The park includes a diverse collection of sandscapes, including the double tombolo on Stockton Island which includes a large wetland area, trapped by the accreting sand which supports rich bog flora with a number of rare plants. This marsh is a nascent peat bog with abundant sphagnum moss. The tombolo also supports a dune (beach grass) environment, a pine savannah forest, and denser northern mixed hardwood forests. The park also includes a number of old-growth forest remnants, including one of the best examples of hemlock hardwood forest left in the upper Great Lakes. A very important issue currently facing resource managers is controlling the deer population on islands where populations did not occur historically and which still maintain a lush understory of Canada yew, a plant that has been nearly extirpated on the mainland. Deer can between the islands or cross on ice in the winter months. Important disturbance factors include blowdown and fire. Blowdown is a larger disturbance factor in the park than fire and results from exposure of the Apostle Islands to storms and high winds of Lake Superior. The majority of logging occurred between the mid-1800s and 1940, with sporadic logging taking place as recently as 1974. The amount of logging varied considerably from island to island. Forest within the park are recovering, although hemlock and white pine that were targeted mid- to late-1800s remain in much lower abundance than they were historically. Park resource managers are uncertain as to the extent that logging contributed to erosion of the upland areas of the islands.



Figure 5. Sculpted coastline along Devils Island. View is to the northwest. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

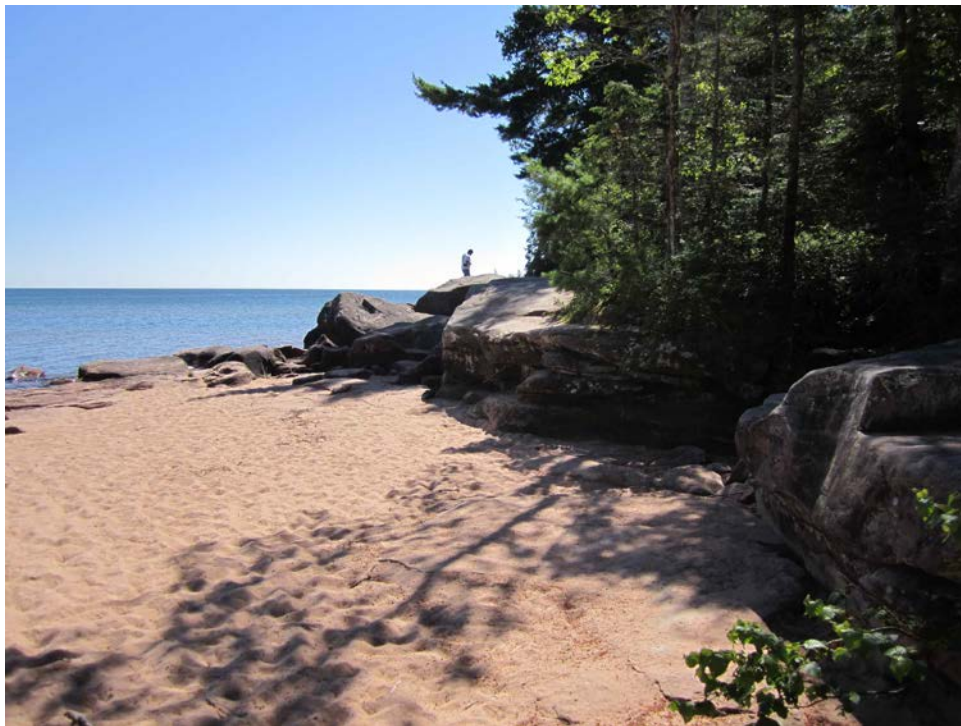


Figure 6. Double tombolo connecting Stockton Island and Presque-Isle. Note the contact between the Holocene sand and Precambrian sandstone. View is to the southeast. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).



Figure 7. View from a dune of the trapped wetland in the double tombolo. View is to the west. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).



Figure 8. Cuspate foreland of sand projecting from Cat Island. View is to the northwest. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Recommendations for Resource Managers

1. Access the “onegeology” global portal interface.
2. Consult the Wisconsin Geological Survey’s website for geologic information (<http://www.uwex.edu/wgnhs/>).
3. Visit the National Fossil Day (October 13) website prepared in partnership between the NPS and American Geological Institute.
4. Contact the Minnesota Geological Survey and/or the Wisconsin Geological and Natural History Survey for information about potential carbon sequestration operations.
5. Try to coordinate with the upcoming Ashland 2011 Institute on Lake Superior Geology’s Bayfield field trip.

Action Items

1. GRI report author will consult the Wisconsin Geological and Natural History Survey’s website for pertinent publications (<http://www.uwex.edu/wgnhs/>).
2. GRI report author will obtain copy of Dick Ojakangas’ 2009 cross section.
3. GRI team will obtain a copy of the USGS upcoming 2011 publication on the rift geology.
4. GRI report author will obtain a copy of the park’s book on geology that contains detailed sedimentary structures, but not much regional geologic framework.
5. GRI report author will obtain a copy of LeBarge’s Lake Superior book.

References

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring—Great Lakes Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/120. National Park Service, Fort Collins, Colorado.

National Park Service. 2010. Apostle Islands National Lakeshore. www.nps.gov/apis (accessed August 10, 2010).

Table 2. Scoping Meeting Participants

Name	Affiliation	Position
Peggy Burkman	NPS, APIS	biologist
Eric Carson	Wisconsin Geological Survey	geologist
Jim Chappell	Colorado State University	geologist
Ulf Gafvert	NPS, GLKN	GIS Specialist
Bruce Heise	NPS, Geologic Resources Division	geologist
Jason Kenworthy	NPS, GRD	report coordinator
Richard Ojakangas	University of Minnesota (Duluth)	geologist
Jamie Robertson	Wisconsin Geological Survey	geologist
Brandon Seitz	NPS, GRPO	biological science technician
Trista Thornberry-Ehrlich	Colorado State University	geologist
Julie Van Stappen	NPS, APIS	Chief, Planning and Resource Management
Laurel Woodruff	USGS	geologist

