National Park Service
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Natural Resource Program Center

Voyageurs National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2007/007

THIS PAGE:
A geologist highlights a geologic contact during a Geologic Resource Evaluation scoping field trip at Voyageurs NP, MN

ON THE COVER:
Aerial view of Voyageurs NP, MN

NPS Photos

Voyageurs National Park

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Geologic Resources Division
Natural Resource Program Center
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Executive Summary

This report has been developed to accompany the digital geologic map produced by Geologic Resource Evaluation staff for Voyageurs National Park in Minnesota. It contains information relevant to resource management and scientific research.

Located in the southern part of the Canadian Shield and sharing a common boundary with Canada, Voyageurs National Park contains some of the oldest rocks on the North American continent. The bedrock records evidence of mountain- building episodes that occurred approximately 2,500 million years ago as well as continental glaciation that affected the area as recently as 10,000 years ago. Congress recognized Voyageurs geologic significance in the park's 1971 enabling statute.

A Geologic Resources Inventory (now Geologic Resources Evaluation) scoping meeting was held at Voyageurs National Park on June 1- 2, 2000, to discuss the status of geologic mapping in the park, to assess resource management issues and needs, and to evaluate the geologic resources (features and processes) of the park.

The geologic issues identified at Voyageurs National Park fall into the following categories:

- Submerged boating hazards
- Surface water
- Historic mining and abandoned mines
- Geologic interpretation
- Earthquake potential

Islands of various shapes and sizes dot the lakes in Voyageurs National Park. Submerged rocks along their rocky shorelines pose hazards to boats and canoes. Shallow areas and narrow waterways connecting the lakes may conceal rocks just below the surface. Navigation charts identifying these hazards could help visitors avoid serious accidents and possible injuries.

Voyageurs NP preserves and protects a hydrologically complex and sensitive environment. Impermeable bedrock impedes groundwater flow and thin soils allow relatively rapid surface runoff. The lakes comprising much of the park are controlled reservoirs and are a primary water source for both domestic and industrial use in the Voyageurs area. Surface runoff into the lakes may impact water quality by introducing heavy sediment loads, higher turbidity, and contamination from historical mining and milling activities.

Northern Minnesota has experienced gold mining booms in the past. Several abandoned mines from the short lived gold boom of the late nineteenth century still can be found in the northwestern part of the park. Open adits and shafts associated with some of these mines may pose safety hazards, and liquid mercury from the milling process may have contaminated lake sediments. Interpretation of the complex metamorphic geology of Voyageurs is of great interest to the park natural resources staff. The metamorphic rocks at Voyageurs are the result of high pressures and elevated temperatures found at great depths in the crust. Siltstones and shales transformed into schists and gneisses; sandstones and conglomerates metamorphosed into quartzites and metaconglomerates; and oceanic sediments and basaltic lavas formed greenstone belts containing such distinct features as pillow lavas and metal deposits.

The Pleistocene Ice Age left its mark on Voyageurs National Park. Glacial erratics, or ice- rafted rocks, are abundant in the park. These displaced blocks range in size from pebbles to blocks the size of automobiles. Ground moraine debris, interspersed with lakebed sediments, forms a distinctive undulating topography.

Glacial striations and groove marks that were scratched and gouged into the bedrock by moving glaciers show the direction of ice movement. Striations in Voyageurs point south, south by southwest, and southwest.

Thirty- two distinct rock units have been mapped in the vicinity of Voyageurs. The igneous and metamorphic units have a relatively high resistance to erosion and present few geologic hazards. Some rock units have provided sites for pictographs and petroglyphs. Most of the geologic units in Voyageurs have global significance because Archean rocks are relatively rare.

The rocks exposed at Voyageurs National Park preserve windows into both the very distant past and the very recent past. The degree of metamorphism and deformation of Archean bedrock at Voyageurs records at least one mountain- building episode followed by millions of years of erosion. Few such exposures exist elsewhere on earth. The relatively recent Pleistocene ice age, also evident in Voyageurs, left a history recorded in the grooves and striations on bedrock, glacial erratics, and unconsolidated sediment.

Although Minnesota has one of the lowest occurrence levels of earthquakes in the United States, participants at the 2000 scoping meeting recognized earthquakes as a potential hazard for Voyageurs. In the unlikely event of a severe earthquake, movement would likely occur along ancient fault planes that cut through the park.

Introduction

The following section briefly describes the regional geologic setting and the National Park Service Geologic Resource Evaluation Program.

Purpose of the Geologic Resources Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS- 75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non- geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes. Scoping meetings are usually held for individual parks and on occasion for an entire Vital Signs Monitoring Network. The GRE mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. As a companion to the digital geologic maps, the GRE team prepares a park- specific geologic report that aids in use of the maps and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation web site (http://www2.nature.nps.gov/geology/inventory/).

Park Setting and History

Voyageurs National Park protects 218,200.17 acres in the lake country of northern Minnesota. Of these, 134,246 acres are land and 83,808 acres are water. Roads end a short distance beyond the entry points into the park. Watercraft are necessary for access to the Kabetogama Peninsula, the islands, and most of the shoreline of the park. In the winter, access may be gained by cross-country skis, snowshoes, or snowmobiles. The park includes 655 miles (1,054 km) of undeveloped shoreline and over 1,000 islands. Located about 15 miles (24 km) east of International Falls, Minnesota, Voyageurs National Park follows the international boundary between the US and Ontario, Canada for 55 miles (89 km). The Boundary Waters Canoe Area Wilderness in Superior National Forest lies immediately east of the park (figure 1).

The roadless Kabetogama Peninsula, south of Rainy Lake and north of Kabetogama Lake, is the main land area in Voyageurs. Water from the lakes drains to the northwest to Lake of the Woods and then to Lake Winnipeg in Canada, eventually flowing into Hudson Bay, the only U.S. park to do so(Kiver and Harris 1999).

For over 8,000 years, Native Americans have lived in the Voyageurs area. The "Red Paint People" left clues of their Stone Age culture in the pictographs painted on rock cliffs with red ocher and in artifacts, such as slate knives and arrowheads.

The Ojibwa (Chippewa in the U.S.) tribe was the largest and most powerful Native American tribe in an area extending as far west as Manitoba and Saskatchewan east to Quebec. In the United States their range extended northeast to Iroquois territory and west to the Great Plains and the Sioux.

From the 1600s to the early 1800s, French- Canadian fur traders and canoe- men known as Voyageurs traveled in birch- bark canoes guided by the Ojibwa people who showed them the best water routes to follow from Grand Portage, east of the park on the northwest shores of Lake Superior, to the shores of Lake Athabasca in northwestern Saskatchewan. The Voyageurs canoed and portaged the 2,000- mile (3,220- km) journey from Grand Portage to Lake Athabasca trading furs and other goods. Their well established waterway between Lake Superior and Lake of the Woods was made the international boundary by the 1783 treaty ending the American Revolution.

Within 50 years following the decline of the fur trade, practically all of the virgin north woods forest was logged. A short and unprofitable gold mining boom swept the Kabetogama Peninsula between 1893 and 1898. Rainy Lake City in the northwest corner of the park filled up with prospectors and miners but declined from a settlement of 500 people to a ghost town in five years.

As early as 1891, the Minnesota legislature officially noted local interest in establishing a national park on the Kabetogama Peninsula. Public Law 91- 661 authorized Voyageurs National Park in 1971, and Voyageurs National Park was established in 1975 to preserve the scenery, geological conditions, and waterway system.

Geologic Setting

The park is at the southern end of the Canadian Shield, a large area of exposed basement rock containing some of the oldest Precambrian rocks in North America and forming the ancient core of the continent (Hemstad et al. 2002).

The Precambrian is divided into two eons: Archean (3,800+ to 2,500 million years) and the Proterozoic (2,500 to 540 million years) Most of the rocks in Voyageurs NP are igneous and metamorphic rocks of Archean age. The metamorphic rocks, mostly schists and gneisses, are exposed in the west and central portions of Voyageurs and igneous granitic rocks are exposed in the east and southeast areas of the park. These units belong to the Quetico subprovince of the Superior Physiographic Province (Day 1990; Harris et al. 1995; Kiver and Harris 1999; Davis et al. 1994). Voyageurs National Park straddles the transition from volcanogenic greywacke and granite of the Quetico subprovince to the metamorphosed sedimentary and volcanic rocks of the Wabigoon subprovince (figure 3) (Day 1990; Weeks and Andrascik 1998).

Metamorphic rocks of the more northern Wabigoon subprovince form the islands in the extreme northwestern segment of the park and are part of a northeast trending greenstone belt. The Rainy Lake – Seine River fault zone, a major northeast- southwest trending right- lateral strike- slip fault zone, marks the contact between the two subprovinces. The rocks at Voyageurs have been deformed by at least three episodes of Precambrian folding and faulting. Each episode has resulted in a specific pattern of deformation. The metamorphic and igneous rocks reveal a history of moving lithospheric plates, ancient subduction zones, mountain building episodes, and extensive volcanic activity (Kiver and Harris 1999).

During the Ice Age in the Pleistocene Epoch, which began about 190,000 years ago, the region experienced at least four periods of glaciation that shaped and carved the bedrock into the landscape seen by visitors today (Davis et al. 1994; Weeks and Andrascik 1998; Kiver and Harris 1999). The Precambrian was exposed during the most recent period of glaciation, the Wisconsin period, which lasted from 50,000 to 11,000 B.C.

Glaciers scoured the region scooping- out dozens of lake basins while scratching and polishing rock surfaces by dragging loose rocks over the surface leaving lakes, outwash (mostly sand and gravel), and till deposits. Today the rugged and varied topography includes rolling hills interspersed with irregular slopes and outcrops of bedrock between bogs, beaver ponds, swamps, islands, small lakes, and the four large lakes.

Lake elevations are about 1,100 feet (335 m) above mean sea level and land elevations in the west and north sections of the park rarely exceed the lake elevations by more than 100 feet (30 m) (Weeks and Andrascik, 1998). In the east section of the Kabetogama Peninsula and along the south shores of Kabetogama, Namakan, and Sand Point lakes, land elevations are commonly 100 to 200 feet (30- 60 m) higher (Weeks and Andrascik 1998; NPS 1994).

Biotite schist is the most widespread rock type in the park and forms the bedrock for most of the Kabetogama Peninsula (Day 1990; Hemstad et al. 2002). Outcrops of schist are relatively low and flat because the glaciers more easily eroded the schist than the surrounding granitic rocks.

A broad belt of mixed gneiss trends through the middle of Kabetogama and Namakan Lakes. The gneiss lies between biotite schist to the north and massive granite to the south and consists of layers and irregular masses of biotite schist separated by sheets of granite. Most outcrops contain highly contorted folds.

Granitic rocks compose the terrane south of Kabetogama Lake and Sullivan Bay. The mineral composition and texture vary greatly over short distances so that the rocks range from true granites to hornblende quartz diorite. Glaciers rounded and smoothed the granitic outcrops and marked them with glacial striations, chattermarks, and glacial polish.

Mafic dikes, common in the area, are the youngest rocks at Voyageurs. The dikes are primarily composed of gabbro and diorite and cut through older granitic rocks.

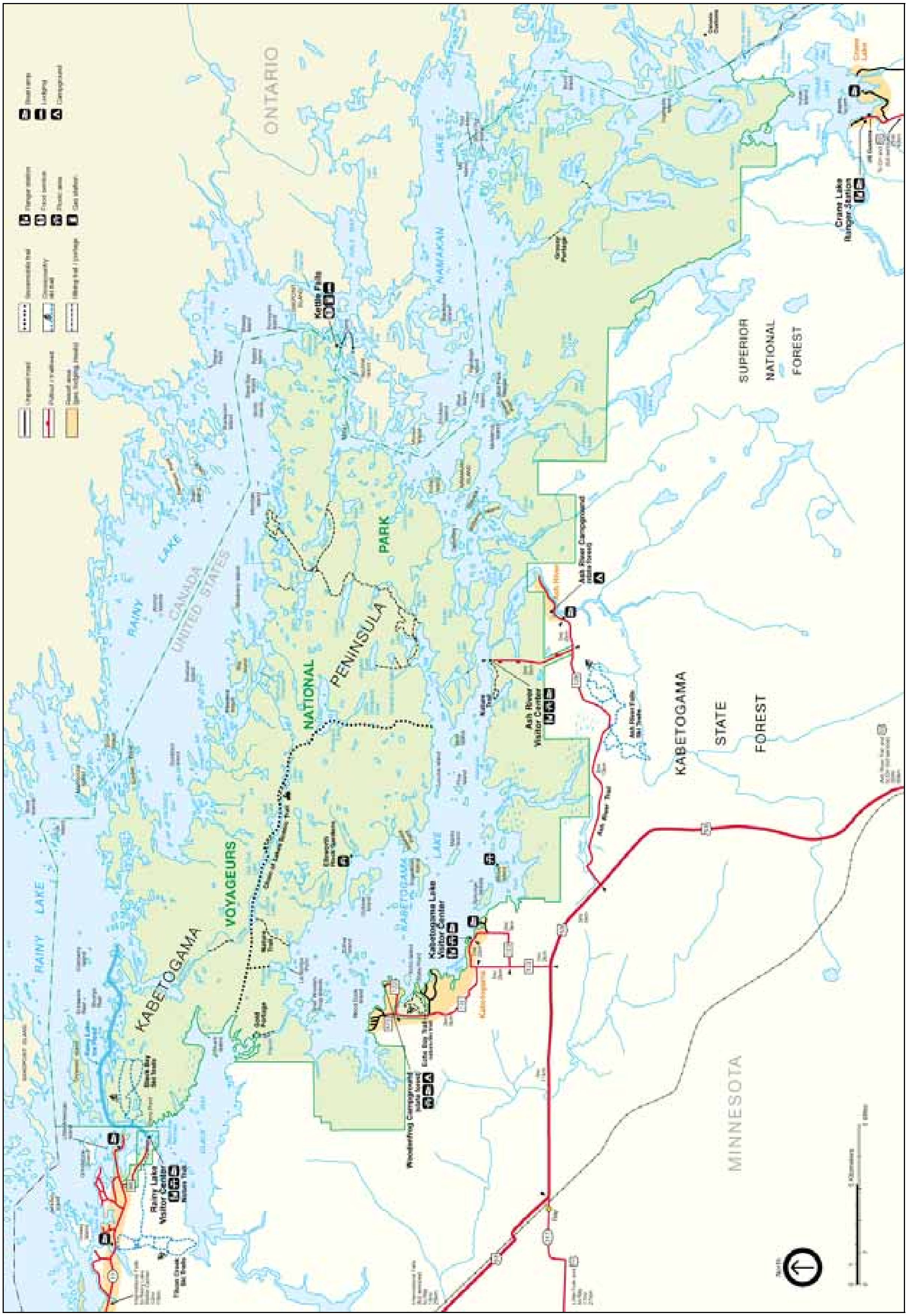

Figure 1. Map of Voyageurs National Park.

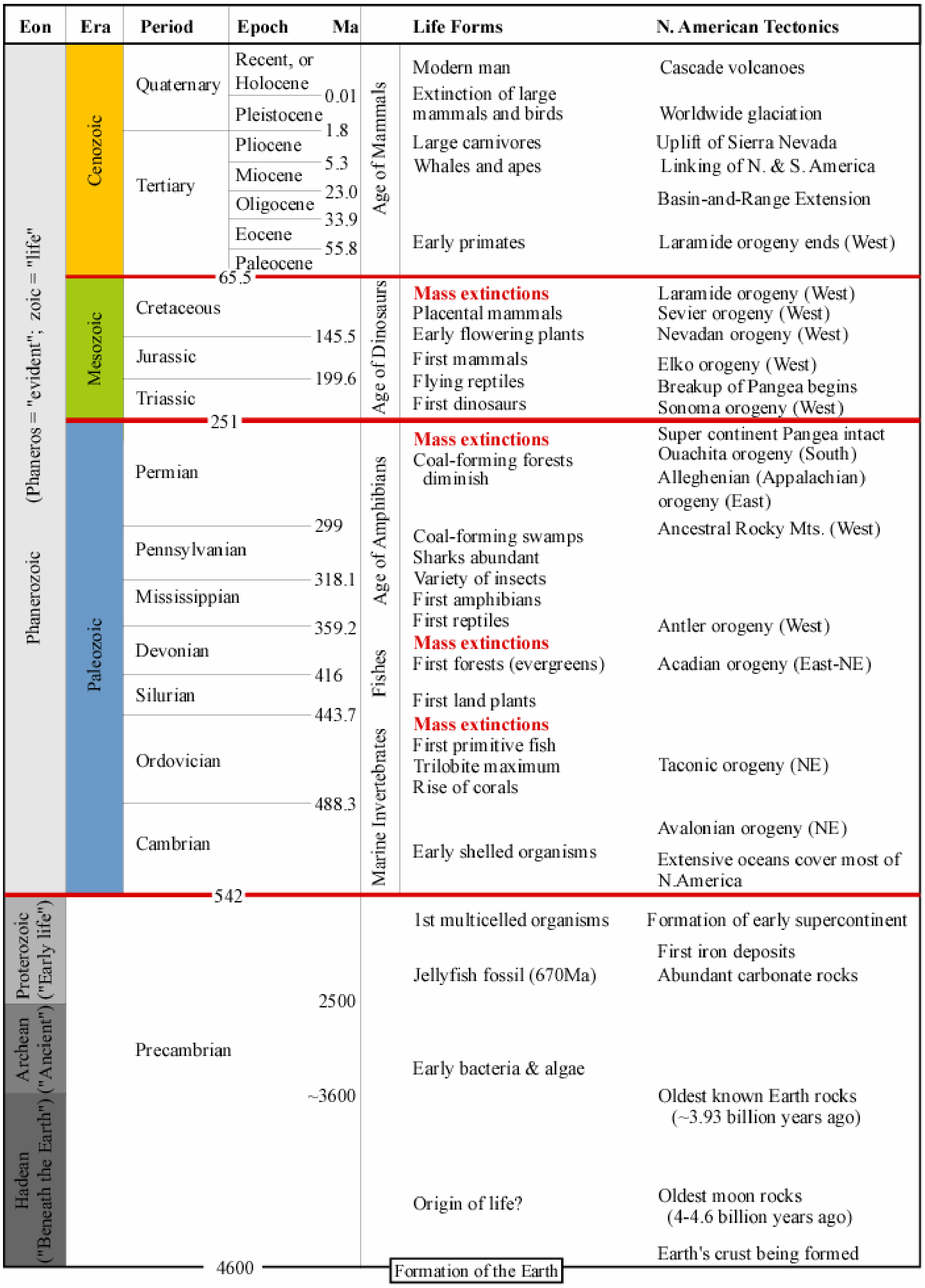

Figure 2. Geologic time scale; adapted from the U.S. Geological Survey and International Commission on Stratigraphy. Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years.

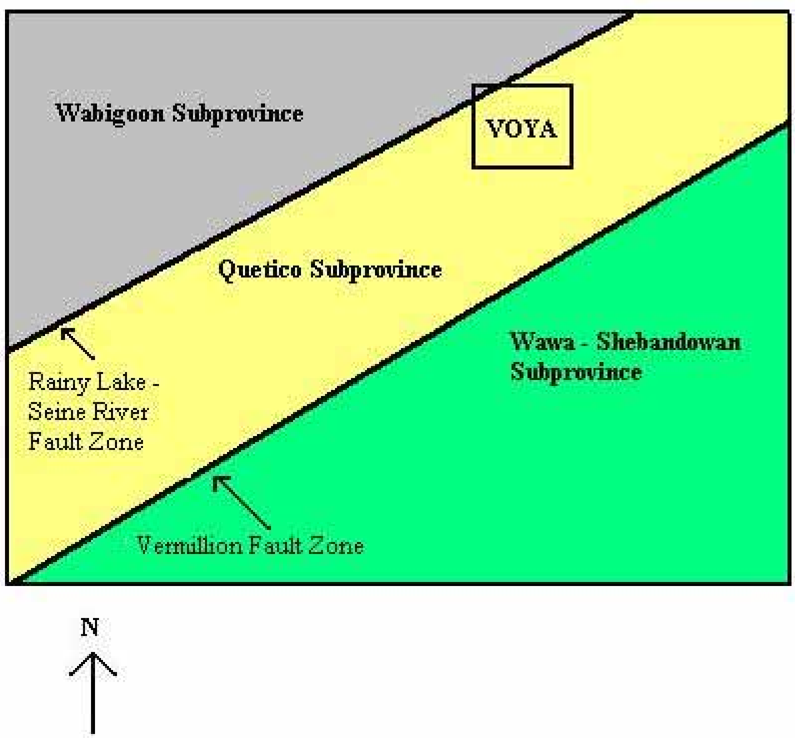

Figure 3. A schematic drawing of subprovinces of the Superior Province. Contacts between subprovinces are fault zones.

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Voyageurs National Park on June 1- 2, 2000, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. The following section synthesizes the scoping results, in particular, those issues that may require attention from resource managers.

This section addresses geologic issues as they affect the ecosystem and park management.

Sharing a common boundary with Canada, Voyageurs National Park is part of a hydrologically complex and sensitive environment. Over the past several decades, numerous natural resource issues have arisen and almost all of these issues relate directly or indirectly to water (Weeks and Andrascik 1998). These issues are covered by Weeks and Andrascik (1998) in Technical Report NPS/NRWRS /NRTR- 98/201. In addition the following geologic issues have been identified by the park:

- Submerged boating hazards
- Hydrogeology
- Mineral resources
- Abandoned mine hazards
- Surficial deposits
- Earthquake potential

Snowmobile use regulations and the preservation of petroglyphs are management issues beyond the scope of this report. While written for resource managers, this report may also provide information useful to the interpretive staff of Voyageurs, specifically the section on Geologic History.

Submerged Boating Hazards

As in any lake with rocky shorelines, the lakes in Voyageurs contain rocks that lie just below the surface. Motor boats and canoes may scrape their hulls or propellers on these rocks. Both large and small rocky islands lie within Rainy Lake, Kabetogama Lake, Namakan Lake, Sandy Point Lake, the bays within the lakes, and the narrows that connect the lakes and bays. Rocky reefs such as Ericksons Reef and Shortys Reef in Rainy Lake present hazards to boats. In addition to property damage, submerged boating hazards are a visitor and park safety concern. Much of the park can only be reached by boat and damaged boats may strand people creating difficult rescue situations. A map identifying near- surface, submerged rocks and reefs should help visitors avoid these hazards although bathymetric maps may serve the same purpose.

Hydrogeology

The bedrock at Voyageurs is relatively impermeable to groundwater flow and these units are not aquifers (Davis et al. 1994). Wells in this area typically yield less than five gallons per minute (Weeks and Andrascik 1998). Numerous fractures and faults, may provide some structural control for the limited groundwater resources.

The bedrock is relatively impermeable and the soil is thin, resulting in rapid runoff of surface water. Voyageurs is part of the Rainy Lake basin, the headwaters of the Hudson Bay watershed. The Namakan River is the largest single source of inflow to the park, and water quality research has shown that the Namakan River is of higher quality and purity than Namakan Lake, Sand Point Lake, and Rainy Lake (Davis et al. 1994). Annual maximum flows usually occur in April or early May as a result of snowmelt. Due to minimal groundwater resources in the area, surface water is the primary water source for domestic and industrial use. Consequently, external upstream activities may impact Voyageurs with increased sediment loads, higher turbidity levels, and increased nutrient levels leading to increase algal growth. There is some potential of contamination from historical mining and milling activities (Davis et al. 1994; Weeks and Andrascik 1998).

Mineral Resources

The enabling statute for Voyageurs National Park contains a broad prohibition against all mining and mineral development activities within the unit. This prohibition encompasses mining on both federal and nonfederal lands within the park (see 16 U.S.C. § 160f(c)). In addition, Minnesota Statutes specifically exclude mining within Voyageurs National Park (Stat. 6132.2000, Subpart 2 B and Stat. 84B.03, Subdivision 1). The State also prohibits any mineral exploration or mining- related surface disturbances within 0.25 mile (0.4 km) of Voyageurs National Park (Stat. 6132.2000, Subpart 3 B).

Historic Mining Activity

During the gold- mining boom from 1893 to 1898, numerous prospects and small mines opened in northern Minnesota, mostly in greenstone belts. Greenstone belts are linear regions of rocks comprised of fine- grained metasedimentary rocks including silt- to sand- sized tuffaceous (volcanic ash derived) material and submarine basalt flows and pillow lavas. Minor amounts of gold associated with shear zones and fracture systems bearing quartz veins, gossans (deposits of hydrated oxides of iron), and iron formations were discovered in the northeast- tending Rainy Lake greenstone belt that passes through the northwestern corner of Voyageurs (Davis et al. 1994).

The Minnesota Geological Survey (MGS) evaluated the mineral potential of Voyageurs prior to its establishment as a national park (MGS 1969). Seven samples were collected from the Rainy Lake greenstone belt. Three of these samples contained "significant amounts of gold, silver, and copper" (MGS, 1969, p. 14) and one contained detectable amounts of platinum group metals. Because of these results and the productive gold mining operations on the Canadian side of the greenstone belt, the MGS recommended that this portion of the proposed park remain accessible for prospecting and possible mining. Congress did not agree with this recommendation, hence the inclusion of broad language prohibiting all mining in the park.

For the first time since the 1930s, high gold prices in the late 1970s and early 1980s, as well as several major discoveries in Canada, led to further mineral exploration in the Voyageurs area outside the park. Exploration was primarily in the greenstone belt, 2 to 9 miles (3- 14 km) west of the park boundary, and to a lesser extent on the geophysical anomalies south and southwest of Voyageurs. Four exploration projects were completed in the area between 1984 and 1991. The only metal encountered in near economic concentrations was gold, and anomalous concentrations were largely in the range of 100 parts per billion (ppb) to 3.5 parts per million (ppm). The highest values encountered were about 10 ppm (0.292 ounce/ton) and were from very thin (about 1 foot) and very rare zones of mineralization. To justify any serious efforts at mineral reserve definition or mine development, grades on the order of 6 to 10 ppm would be necessary over intervals of several feet. These deposits would also have to show evidence of internal continuity (Davis et al. 1994). No such deposits were located during exploration.

In 1993, the U.S. Bureau of Mines revisited the mineral potential of Voyageurs National Park (Davis et al. 1994). Their area of interest included not only Voyageurs but also a 30- mile (48 km) radius around the park. Their investigation included a literature search (including management response plans), fieldwork, petrologic and mineralogical studies, mine inspections, modeling studies of the mineral deposits, mines, and economic impacts, and GIS database processing and modeling. In addition, they addressed the probable effects of proposed changes to the existing mining rules by the State of Minnesota in order to "encourage mineral exploration and development" (Davis et al. 1994, p. 1).

This comprehensive evaluation by the Bureau of Mines determined that gold mineralized areas were "simply mineral occurrences and do not constitute even subeconomic resources" (Davis et al., 1994, p. 1). Mine modeling studies conducted as part of this project indicated that any mine development that might occur within a 30- mile (48 km) radius of Voyageurs National Park would not pose a serious threat to the park management or diminish visitor enjoyment of the park (Davis et al. 1994). Additionally, the study showed that the Metallic Minerals Leasing Rules of the State of Minnesota and the proposed revisions to those rules would have minimal, if any, impact on foreseeable levels of mineral- related activities in the state as a whole, and particularly in the area of influence of Voyageurs National Park (Davis et al. 1994).

The Tilson Creek banded iron formation is known to be an extensive area of carbonate- rich iron formation west of Voyageurs, and locally high gold concentrations have been documented within very restricted horizons of these same iron formations. However, commercial exploration has not encountered significant occurrences of economic gold concentrations in anywhere near the dimensions necessary to justify mining (Davis et al. 1994). Although magmatic nickel and copper mineralization occurs in nearby mafic gabbros in Canada, none have proven to be major resources, and no similar mafic host-rocks have been mapped in Voyageurs. Within the 30-mile (48 km) radius of the park, a limited number of small mafic bodies have been recognized, but these contain a very low potential for magmatic nickel- copper deposits (Davis et al. 1994)

In summary, the potential for establishing mining operations in the Voyageurs area, adjacent to the park, is very low. No evidence exists to indicate that the area might host massive, or disseminated, sulfides of base metals. Gold mineralization in the area does not approach the definition of an ore body, or even a subeconomic mineral resource. The better concentrations of gold appear very thin and highly discontinuous. (Davis et al. 1994).

Abandoned Mine Hazards

The gold rush of the Rainy Lake District in 1893 was sparked by the discovery gold in the extreme northwestern corner of the park on Little American Island. The Little American Mine, located in the park, is the only mine to have achieved even modest production in the United States portion of the Rainy Lake- Seine River mining district (Davis et al. 1994).

Thirteen abandoned mines with 22 openings are present in Voyageurs National Park. All are located in the northwestern corner of the park along structures within the Rainy Lake greenstone belt. Some abandoned prospect pits, shafts, and open cuts are concealed by vegetation. These sites, including two of the "unnamed prospects" described below, have been examined by qualified park staff and do not pose major hazards (Chris Holbeck, Voyageurs NP Chief of Resource Management, personal communication, 2006).

Although no obvious environmental hazards were observed during the field examinations for the 1994 Bureau of Mines report, liquid mercury was used to recover gold in the amalgamation process for at least three sites now inside the park (Davis et al. 1994). The three historical sites were near Rainy Lake City, at the Lyle Mine site, and at the Little American Mine site. The mill at Rainy Lake City processed a significant tonnage of ore from 1894 through 1897. The other two sites were never very productive.

When the mills at these three sites were disassembled for removal, liquid mercury may have contaminated the local surface and the adjacent waters of Rainy Lake. With a specific gravity of 13.5, mercury is essentially insoluble in water and sinks to the lowest sites in any body of water where it is incorporated into the sediment. Mercury tends to stay in bottom sediments unless remobilized by severe storm events, high winds, or disturbance by boat propellers. Mercury levels in Voyageur lake sediment have not been evaluated. Although core sampling and lab testing could determine the amount of mercury, it would also disturb and remobilize whatever mercury is present.

Fish and wildlife in Voyageurs National Park show elevated levels of mercury even in comparison to those in the Superior National Forest (NPS 2001). The source of the mercury, however, is considered to be atmospheric, originating some distance away from the park.

Little American Mine

The Rainy Lake mining district is in the extreme northwestern part of the park. It encompasses Little American and Big American islands, Dryweed Island, Bushyhead Island and smaller islands between Dryweed Island and the Kabetogama Peninsula (figure 1). The only mine in the Rainy Lake district (USA) with recorded gold production, the Little American Mine was developed by two vertical shafts and an open cut along the vein structure. Most of the ore was taken from an open cut, which is west of the main shaft. The open cut strikes N 80° E and is about 200 feet (61 m) long and 5 to 15 feet (1.5- 5 m) wide. All that remains of the 210- foot (64 m) main shaft is a collapse depression. In 1994, this mine opening posed a safety hazard, but since then, measures have been taken to make the mine safe (Chris Holbeck, Voyageurs NP Chief of Resource Management, personal communication, 2005).

Lyle Mine

The Lyle Mine, the second largest mine developed in the Rainy Lake district, began operations in 1894. The mine is located on a small island directly north of Dryweed Island (figure 1). By 1994, two 40- foot (12 m) deep shafts had been filled in and were unidentifiable, but the main Lyle shaft was flooded to within 10 feet (3 m) of the surface and had been fenced off and partially filled with miscellaneous debris (Davis et al. 1994).

The mine was cared for by cabin residents for about 50 years. When the park acquired the property the residents moved out leaving a water and trash filled open shaft accessible to visitors. The park has an unfunded PMIS proposal to close the shaft with polyurethane foam but as of April, 2007 it remains open and unsafe (NR Staff Voyageurs NP, personal communication, 2007).

Big American Mine

Located near the southwestern end of Big American Island (just west of Dryweed Island, figure 1) and about 60 feet (18 m) above the level of Rainy Lake, the Big American Mine began operations in late 1894 or early 1895. It saw only limited development until May of 1897 when the Lyle Mining Company bought the property. Although extensive plans were designed for the mine, the main shaft was only sunk to a depth of 50 feet (15 m) before it was terminated. In 1994, the shaft was flooded to within 10 feet (3 m) of the surface and secured with a chain link and cable cover by the National Park Service (Davis et al. 1994). It is currently considered safe (Chris Holbeck, Voyageurs NP Chief of Resource Management, personal communication, 2005).

Old Soldier Mine

Another mine that began operations in 1894, the Old Soldier Mine, is located on a small peninsula off the north shore of Dryweed Island (figure 1). The vertical shaft was sunk to approximately 20 feet (6 m) below lake level (about 30 ft, 9 m, total depth). The shaft, located on private land inside the park, has been capped by a 10 x 10 ft. (3 x 3 m) concrete slab.

Bushyhead Mine

The Bushyhead Mine is located near the center of Bushyhead Island, due south of Dryweed Island (figure 1). It also began operations in 1894. Two vertical shafts, one 30 feet (9 m) deep and another 100 feet (30 m) deep, are now flooded and filled with sand and debris. Although the drifts have been filled, an adit remains open. It is partially flooded but remains accessible near the shore of Rainy Lake. The portal is stable and is now a habitat for bats (Chris Holbeck, Voyageurs NP Chief of Resource Management, personal communication, 2005).

Hope-Still Mine and Little Chicago Mine

Two other prospects with mine workings are the Hope-Still Mine and the Little Chicago Mine, both located on small islands south of Dryweed Island (figure 1) in the park. The Hope- Still Mine is a relatively minor prospect probably dating to 1894. The shaft, less than 30 feet (9 m) is on private land and is flooded to within 7 feet (2 m) of the surface and covered by a small storage shed with a trap door for access.

The Little Chicago Mine is a very modest prospect located on the southwest side of a small unnamed island lying directly south of Dryweed Island and east of Big American Island. The only identifiable workings are a shallow, 5 x 8 ft (1.5 x 2.4 m) prospect pit that is now debris filled and less than 3 feet (1 m) deep.

Unnamed Prospects

Many small prospect pits are located along the greenstone trend and southern Rainy Lake. Almost all of these prospects are in quartz veins and most are very limited. Two sites may pose a safety hazard. The first is located on the north side of a modest- sized, unnamed island directly northeast of Dove Bay and consists of a shallow 8 x 12 ft (2.4 x 3.7 m) vertical shaft. The shaft is flooded to within 6 feet (1.8 m) of the surface but is easy to overlook.

The second potentially hazardous unnamed prospect is located on a small unnamed island directly north of Dove Bay. The 8 x 10 ft (2.4 x 3 m) shaft is flooded to within 12 feet (4 m) of the surface and somewhat debris filled.

Surficial Deposits

Surficial deposits in Voyageurs National Park are composed mostly of sandy tills, lake deposits, and localized glacial outwash deposits of sand and gravel produced from glacial scouring and prolonged erosion.

Most of these surficial deposits and soils are shallow and relatively recent (<10,000 years) with low nutrient levels and high acidity, and are susceptible to erosion. At Voyageurs, the available water capacity of most soils in ranges from very low to moderate (Weeks and Andrascik 1998). The underlying bedrock is nearly impermeable, presenting challenges to the development of septic systems and water wells.

On level upland forested areas in the park sandy and silty tills derived from metamorphic rocks, such as schists and greenstones, are higher in nutrients, moderately acidic, and better able to hold water. Till deposits on the southwest end of the park have more limestone than those in the rest of the park (NPS 2001). Rivers that drain into Kabetogama Lake from these areas give the lake distinct water chemistry from the other large lakes in the park.

Soils and surficial deposits have been impacted by a variety of activities in the park, such as; removal to build structures and facilities, and logging practices such as building logging roads and removal of tree roots. Recreational users have affected the soil by camping, boating, picnicking, and other activities at developed and undeveloped sites. Specific impacts include: compaction, trampling and destruction of vegetation, increased erosion, disturbance to wetlands, and reduction in porosity and infiltration rates. For information about soils please contact Pete Biggam, Soil Inventory Program Manager for the NPS Geologic Resources Division (303)- 987- 6948.

It is estimated that there have been between 750 and 1,000 temporary occupation sites in Voyageurs since the native Ojibwa and later the Voyageurs made camp on the islands. There were about 400 recreational cabins, mostly restored, and numerous camping sites, now limited to 250 (Chris Holbeck, Voyageurs NP Chief of Resource Management, personal communication, 2006).

Earthquake Potential

Participants at the scoping session in 2000 recognized the potential for earthquakes as a geologic hazard for Voyageurs National Park (Appendix B). However, Minnesota has one of the lowest occurrence levels of earthquakes in the United States (Chandler 1994). Since 1860, a total of 19 small to moderate earthquakes have been documented in Minnesota and are attributed to minor reactivation of ancient faults in response to modern stresses. The largest well- documented earthquakes recorded magnitudes of 4.6 to 4.8, although a magnitude 5.0 earthquake shook nearly all of northern Minnesota in 1917. Epicenters of four of the five earthquakes with magnitudes greater than 4.0 were located in the west- central part of the state. The epicenter of the fifth earthquake with a magnitude larger than 4.0 was located in the southern part of the state near New Prague, MN. No epicenters have been recorded in the Voyageurs area in historical time. While weak to moderate earthquakes occasionally occur in Minnesota, a severe earthquake is very unlikely (Chandler 1994).

Geologic Features and Processes

This section provides descriptions of the most prominent and distinctive geologic features and processes in Voyageurs National Park.

Geologic features and processes in Voyageurs reflect the two widely separated time periods that formed the present landscape: the older, 2.5 billion year old Precambrian (Archean) and the Pleistocene Epoch ice age. The ancient rocks form part of a large area of basement rocks called the Canadian Shield, which is part of the North American craton (see Glossary).

The Archean rocks at Voyageurs are associated with a mountain- building episode called the Kenoran (Algoman) orogeny. The Kenoran orogeny is the earliest datable orogeny in North America (Harris et al. 1995). Both igneous and metamorphic rocks are exposed in Voyageurs. Schists and gneisses, the products of metamorphism, are exposed in the west and central portions of the park (Rainy Lake and Kabetogama Lake) while granite, an igneous rock, is exposed on the east end at Namakan Lake and Sand Point Lake. Immediately south of the park and extending to the Vermillion Fault is a broad transition zone that contains bands of migmatite, a rock type that has characteristics of both igneous and metamorphic processes.

The advance and retreat of Pleistocene glaciers as recently as 10,000 years ago left an indelible imprint on the rock in Voyageurs. Characteristic features of continental glaciation observed in Voyageurs range from scratches and grooves on bedrock to the chain- like pattern of lakes that formed from glacial scouring.

Precambrian Features and Processes

Voyageurs National Park is in the Superior physiographic province. The Superior physiographic in the Voyageurs area is divided into two subprovinces: the Quetico subprovince and the Wabigoon subprovince separated by the Rainy Lake- Seine River fault zone (figure 3). The park is mostly in the Quetico subprovince which is composed primarily of biotite schists and granitic rocks with only rare evidence of regional volcanic activity. The Wabigoon subprovince, however, is extremely variable. It contains numerous intrusive bodies and volcanically- derived greenstone belts. The Wawa subprovince also contains greenstone belts, but they are more localized and do not extend into Voyageurs. These rocks represent the juxtaposition of a sedimentary basin (Quetico subprovince) with a volcanic island arc (Wabigoon subprovince) (Davis et al. 1994).

In Precambrian time deep crustal processes transformed sedimentary deposits into dense, recrystallized, and often foliated, metamorphic rocks. High pressures and temperatures at depth preferentially align mineral crystals, especially mica, in metamorphic rocks. Depending on the degree of pressure and temperature and the original composition of the sediments, this crystal alignment imparts a foliated or schistose character to the rocks. Submarine mudstones are converted to various schists. Siltstones, sandstones, and conglomerates are metamorphosed into metasiltstones, metasandstones (quartzites), and metaconglomerates. At Voyageurs a result of these metamorphic processes is the biotite schist that dominates the landscape.

The Rainy Lake- Seine River fault zone, which separates the Quetico subprovince from the more northern Wabigoon subprovince, is a major, northeast- southwest trending strike- slip fault zone, trending N 80° E, that cuts through the northwestern part of Voyageurs and extends westward to International Falls. The fault has transported the rocks in the greenstone belt a considerable distance from their place of origin. The greenstone belt is 1.25- 2 miles (2- 3.2 km) wide and includes Big American Island, Dryweed Island, and the smaller islands between Dryweed Island and the Kabetogama Peninsula. At the Seven Sisters Islands further to the west, greenstone interfingers with pods of anorthositic gabbro (see Glossary).

Greenstone belts are not as highly metamorphosed as the other Archean rocks in Voyageurs National Park. They are of special interest to economic geologists because greenstone belts are often host rocks for metallic mineral deposits. All of the known metallic mineral occurrences in Voyageurs National Park and the surrounding area have been found in the metasedimentary and metavolcanic rock units in the Rainy Lake greenstone belt. Greenstone belts form unique elongated downwarps of mixed metasedimentary and metavolcanic rocks. The green color comes from minerals such as chlorite, epidote, and actinolite that formed during metamorphism.

Pillow lavas in the greenstone belts indicate that they were extruded in a marine seafloor environment. Most of the pillow structures in the Voyageurs area have been destroyed by metamorphism, but a few “pillows” up to three feet long (1 m) have been found on a small islet off Steamboat Island (north of Cranberry Bay).

Some of the poorly sorted mixtures of clay, mica, and quartz (graywackes) are derived from the decomposition of pyroclastic debris (tuff and ash) suggesting that some explosive volcanic activity occurred in the area during Precambrian time. Lapilli tuff (see Glossary) can be found near Dog Island. Other clastic material has characteristics of rapid deposition by marine currents, possibly in an ocean trench (Harris et al. 1995). The fine-grained sediments lithified into mudstones or siltstones that later metamorphosed to chlorite- schist, a green, foliated rock. The coarse silt to sand- sized sedimentary part of the greenstone belt formed a feldspar- rich sandstone, or arkose, that metamorphosed to meta-arkose.

Interspersed with these rocks and the pillow basalts are seafloor hot- spring- derived chemical sedimentary layers high in silica and iron carbonate that may locally contain metallic sulfides and precious metals. These layers became banded iron formations, a principal source of iron in the Mesabi Range of northeastern Minnesota. Amorphous metallic sulfides and minor gold and silver are often found along with silica and iron in these banded iron formations. These minerals probably formed in the Precambrian by much the same geologic processes that are active on modern day seafloors. Hot spring vents on today's seafloors often have chimney-like mineral walls built up around them. These vents are referred to as black smokers. Minerals associated with sediments deposited around black smokers include copper, zinc, lead, nickel, manganese, gold, and silver.

The granitic rocks in Voyageurs are part of the Vermillion Granitic Complex and vary widely in composition. Rock types include granite, biotite granite, granodiorite, and quartz diorite (see the Map Unit Properties Table in the next section) (Davis et al. 1994). The Lac La Croix biotite granite batholith is the largest and youngest igneous intrusion in the area. It also comprises the principal rock type in the majority of the Boundary Waters Canoe Area Wilderness. Age dates on these granitic rocks show them to be almost as old as the schists, ranging in age from 2,690 million years before present (B.P.) to 2,640 million years B.P.

During a period of very slow cooling in the late stage of granitic emplacement, numerous thin, tabular- to irregular- shaped bodies of very coarse- grained crystalline rocks solidified. These coarse- grained igneous rocks are pegmatites. Pegmatites are recognized by their coarse- grained texture, pink coloration (potassium feldspar), and a composition similar to granite but often with rare minerals, some of gem quality.

Precambrian Fault Systems

Three regional fault systems are present in Voyageurs: 1) a northwesterly- trending fault system that hosts the Kabetogama- Kenora Dike Swarm, 2) a set of regional structures that are almost perpendicular to the Kabetogama- Kenora Dike Swarm, and 3) a set of regional structures that lie wholly within the Lac La Croix biotite granite batholith in eastern Voyageurs National Park.

The Kabetogama- Kenora Dike Swarm formed about 2,200 to 2,100 million years B.P., in the Proterozoic Eon, when crustal bulging opened a northwest- trending fracture system in the area. Dark, intrusive rocks including gabbro, quartz diorite, and quartz diabase filled the fractures. The Kabetogama- Kenora Dike Swarm in Voyageurs is typical of the tabular dikes that formed in the long, linear fractures. They can be traced for several miles in length, while seldom exceeding 300 feet (91 m) in width. A mafic dike cuts the bedrock at the Kabetogama Visitor Center. Magnetite (magnetic iron oxide) is present in some of the dikes, allowing them to be mapped by means of surface or aerial magnetic surveys, even in areas of deep soil cover (Davis et al. 1994).

The regional faults that cross almost perpendicular to the Kabetogama- Kenoran Dike Swarm are a secondary set of faults subparallel to the subprovince boundary structures. These faults cannot be traced for as great a distance and do not appear to have significantly displaced major rock units as those in the Kabetogama-Kenora Dike Swarm. The most notable segments of this fault system are the two faults within Voyageurs that are responsible for the two Chains of Lakes. The westernmost of these two faults controls the alignment of Locator, War Club, Quill, and Loiten Lakes while the second major structure is expressed by topographic lows containing Oslo, Brown, and Beast Lakes, and the western extension of Mica Bay (Davis et al. 1994).

The third set of regional structures form a grid- like fracture network in the granite. There is a very strong north- south fracture set and a similar, linear, but somewhat less well- defined east- west fracture set. The fractures are probably related to the cooling of the batholith.

Three phases of Precambrian deformation are recorded in the rocks at Voyageurs. The deformation folded the bedrock and can be recognized by the following (Day 1990):

- Phase 1: southwest- plunging en echelon (stacked) folds
- Phase 2: small- scale folds, a strong schistosity in the rocks, mineral lineations, and a progressive transition in ductile deformation from the first phase
- Phase 3: high- angle faults and shear zones

Quaternary Features and Processes

Glaciation

Over the last 2 million years, glaciers have advanced and retreated in North America many times. As recently as 10,000 years ago, the glaciers of late Wisconsin age covered Voyageurs National Park (Mikelson et al. 1983). Terminal moraines of Wisconsin age are primarily located south of the park in the southern Great Lakes area. In the more northern areas, where the ice was thicker and more erosive, glaciers scoured thousands of lake basins into the underlying bedrock. These lake basins were linked from west to east in southern Canada and the northern United States forming a remarkable waterway used for passage by Native Americans, voyageurs, explorers, and missionaries.

Because the Voyageurs area is well within the major advance of the continental glaciers, very few morainal deposits exist. The prominent landforms are glacially scoured surfaces and extremely thin residual soils. Four types of glacial deposits are found in Voyageurs: lakebed sediments, outwash gravels, peat, and till. Glacial outwash and till (glacial debris) deposits are usually less than 100 feet (30 m) thick (Davis et al. 1994; Harris et al. 1995).

Glacial debris and outwash deposits left by retreating glaciers thicken westward to the extensive lake bed deposits of postglacial Lake Agassiz. Lake Agassiz was a vast, inland body of water that covered hundreds of square miles north and south of the international boundary for several thousand years (Teller and Clayton 1983; Harris et al. 1995). Four of the five major phases of Lake Agassiz are recorded in the Voyageurs region (Teller and Clayton 1983; Davis et al. 1994).

Holocene peat deposits formed in hollows or depressions such as old lake basins, bogs, and swamps.

Deposits of unsorted glacial debris, or till, formed ground moraines and end moraines. Ground moraine debris was deposited under the ice sheet and interspersed with lakebed sediments forming an undulating surface known as “swell- and- swale” topography. End moraine till left hummocky ridges along the front of the ice sheet. One of these till deposits, left by the last, glacial retreat can be seen along the southwest shore of Rainy Lake.

Glacial erratics are abundant in the Voyageurs area. These rocks of various compositions were transported from the north by glaciers and deposited randomly over the landscape when the glaciers melted. They range in size from pebbles to large boulders. For example, a large, light- colored granitic rock approximately 10 feet (3 m) in diameter is visible in Cranberry Bay where it rests on dark colored schist bedrock. Also, migmatite erratic sits on chlorite schist of the greenstone belt along the shoreline of Skipperrock Island in Rainy Lake.

Glacial striations and glacial grooves appear as parallel, linear scratches or furrows on bedrock and erratics. Striations form from the scraping and scratching of quartz grains and hard, sharp rock fragments frozen into the bottom of the ice scratching across rock surfaces as glaciers move. Striations are generally oriented in the direction of glacial movement. In Voyageurs National Park, striations point south, south by southwest, and southwest (Harris et al. 1995). Cross- striations on some outcrops indicate more than one direction of ice movement.

Repeated abrasion by glacial movement has smoothed and polished many of the bedrock exposures in the park. On highly resistant outcrops in Voyageurs, glacial polish still appears glossy and fresh or only slightly weathered.

Ellsworth Rock Garden

Although man- made, the Ellsworth Rock Garden is a unique feature in Voyageurs National Park constructed with local material. Built between 1944 and 1965, the rock garden was created by one man, retired Chicago building contractor Jack Ellsworth. The garden is located behind Cutover Island, near Clyde Creek on the northeast shore of Lake Kabetogama. Access to the garden is only by boat, or in the winter, by snowmobile, skis or snowshoes.

Ellsworth was also a sculptor and, with his wife, collected thousands of rocks of all sizes from all over the area, often transporting them across the lake. The Ellsworths used the rocks to terrace the hillside near their home and within the terraces, they erected stone sculptures of a variety of forms. For example, a stone duck is perched on the side of a hill overlooking the lake, a deer stands behind a tree, a flat slab of rock supported by three triangular rocks forms a table, and stone monoliths stand in the woods.

At its peak, the Ellsworth Rock Garden contained over 200 sculptures. About 80 of these have been restored and in 2001, Lamp, Rynearson and Associates, Inc. worked with historical architects to retrace and locate as many features as possible using GIS.

Figure 4. Massive Precambrian rocks, like those pictured above, are exposed throughout Voyageurs National Park.

Map Unit Properties

This section provides a description for and identifies many characteristics of the map units that appear on the digital geologic map of Voyageurs National Park. The table is highly generalized and is provided for informational purposes only. Ground disturbing activities should not be permitted or denied on the basis of information contained in this table. More detailed unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the NPS Geologic Resources Division.

This section identifies the specific properties of the different geologic formations that may influence park management decisions. Geologic features and processes often occur in or can be restricted to a particular stratigraphic unit (group, formation, or member). This section ties together the geologic features with the formation properties, and also with the accompanying digital geologic map.

The rocks exposed at Voyageurs National Park are primarily igneous and metamorphic. Igneous rocks record both intrusive and extrusive events. Metamorphic rocks include metamorphosed igneous and sedimentary units.

The following table presents a view of the stratigraphic column and an itemized list of features for each rock unit. This table includes properties specific to each unit in the stratigraphic column including: map symbol, name, description, resistance to erosion, geologic hazards, suitability for development (e.g. trails, campgrounds, and/or buildings), mineral resources, and global significance.

In general, the igneous and metamorphic units are resistant to weathering and erosion. Schistose rocks will erode more easily than granitic rocks or quartzite because the grains are bound more loosely and schist is composed of oriented micas that give the rock its characteristic schistosity. Water can enter between the mica sheets as well as decompose the mica thus loosening the grain structure. Schistose rocks will also fracture and split along these planes of weakness developed during metamorphism. Granite and quartzite are rich in quartz which is very resistant and the grains interlock more tightly preventing water to enter.

Few geologic hazards are significant with regard to the specific units perhaps because of the low topographic relief and emphasis on water- related activities. Soil disturbance may be an issue for certain units that are exposed along the shoreline. If the Rainy Lake- Seine River fault was reactivated due to an extremely rare earthquake, some units might fracture and deform along previous fault planes. Many of the units comprise islands or parts of islands and shorelines. Near- shore submerged blocks of these units may pose a boating hazard.

Some of the units, especially in the greenstone belt in the northwest part of Voyageurs, have limited exposures, and some comprise islands whose aerial extent may limit development. Those bedrock units that are more extensively distributed throughout the park and which have shoreline access are more suitable for development.

This column primarily includes minerals that might be easily recognized in the unit as a whole and does not address economic mineral resources. Gold in the Schistose Tectonite (Ast) and Schistose Feldspathic Quartzite (Asq) is disseminated gold found in the greenstone belt. No economic deposits of gold have been found within Voyageurs National Park and it is not open to mineral entry (Davis et al. 1994).

Rock units identified in the 'other' column occupy shorelines and thus, might be favorable units in which to find pictographs or petroglyphs.

Most of the units have global significance because Precambrian rocks of this age have limited exposures on Earth. Voyageurs' Archean rocks provide windows into the very distant past.

Map Unit Properties Table

Precambrian Age	Map Unit (symbol)	Unit Description	Erosion Resistance	Hazards	Suitability for Development	Global Significance	Other
Proterozoic (0.57- 2.5 BA)	Diabase (Pd)	Fine- to coarse- grained, dark- brown to black; forms NW- trending dikes of Kenora- Kabetogama dike swarm; sharply discordant to structural grain of the enclosing Archean rocks; hornblende diorite in center of large dikes & hornblende gabbro toward margins. One dike had an U- Pb age of 2,067 +/- 5 Ma.	High	Not significant	Limited impact on development	Precambrian igneous activity	Gold occurrence
Proterozoic & Late Archean	Schistose tectonite (Ast)	Phyllitic & schistose, scaly to platy; composed principally of phyllosilicates, quartz, & carbonate minerals; tan to dark- greenish gray; variants include sericite- carbonate phyllite, biotite- rich phyllonite, & chlorite- rich phyllonite; found in & adjacent to major fault zones	Limited to islands in Rainy Lake fault zone	Active fault; Boat hazards	Island size should limit development	Precambrian crustal compression	Gold occurrence
LATE ARCHEAN (2.5-3.0)	QUETICO SUBPROVINCE OF THE SUPERIOR PROVINCE						
	Pegmatite (Ap)	Coarse- to very coarse- grained, light- pinkish gray; mostly potassium- feldspar, quartz, muscovite, & plagioclase. Mafic minerals are rare to absent; potassium feldspar crystals are euhedral & as long as 25 cm.; intrudes biotite schist south of the Rainy Lake- Seine River fault zone.	High	Boat hazards	Limited exposures	Evidence of Late Archean intrusive event	
	Leucogranite (Alg)	Muscovite- & biotite- bearing, medium- to coarse- grained, strongly to moderately foliated granite; weathers very light- gray to almost white; forms predominantly lenticular intrusions, most of which are quasi- conformable to bedding & foliation in the wall rock, & numerous thin sills, dikes, & veinlets too small to show at map scale; related to the pegmatite (Ap) & is generally intruded by it.	Not significant	Boat hazards	Limited exposures: shoreline campgrounds?	Evidence of Late Archean intrusive event	
	Biotite Schist (Aqs)	Fine- to medium grained, light- to dark- gray; derived from rhythmically bedded, texturally graded greywacke & shale. Composed mostly of plagioclase, quartz, biotite, & muscovite; minor garnet, sillimanite, kyanite, & hornblende; individual beds are typically 5- to 20- cm- thick; some sandy beds are as thick as 2 meters; characteristic & dominant rock type in the northern part of the Quetico subprovince, south of the Rainy Lake- Seine River fault zone.	High: dominant rock type in northern part of the park	Possible soil disturbance; Boat hazards	Suitable – extensive shoreline	Evidence for tectonic compression & Late Archean metamorphism	Pictographs possible
	Lineated, mylonitized Granite (Avm)	Part of *Vermillion Granitic Complex*. Mylonitic, equigranular, strongly lineated granite. Thought to have been granite of unit Avl or granite- rich migmatite of unit Avg prior to intense deformation.	Probably lower than surrounding rocks due to deformation	Probably not significant	Limited to SE the park: shoreline campgrounds?	None	
	Lac LaCroix Granite (Avl)	Part of *Vermillion Granitic Complex*. Biotite granite, massive to weakly foliated, medium- grained, somewhat porphyritic, light- gray to light- pink. Contains scattered inclusions of variably digested biotite schist, amphibolite, tonalite, trondhjemite, & leucogranite migmatite, typically less than about 5 percent; grades into granite- rich migmatite (Avg) as the proportion of inclusions increases.	High: a major rock type in southern Voyageurs	Possible soil disturbance; Boat hazards	Suitable – inland exposure; shoreline in SE	Evidence of major Archean intrusive event	Pictographs possible
	Granite –rich migmatite (Avg)	Part of *Vermillion Granitic Complex*. Granite of the Lac LaCroix type that contains abundant inclusions (between 5 and 25 %); inclusions may be several meters in size & consist of biotite schist, amphibolite, tonalite, trondhjemite, & leucogranite migmatite, as well as pale gray, ovoid to wispy inclusions of granitoid rock.	High: a major rock type in southern Voyageurs	Possible soil disturbance	Suitable – extensive shoreline	Evidence of major Archean intrusive event	Pictographs possible
	Biotite-hornblende quartz diorite (Avq)	Part of *Vermillion Granitic Complex*. Massive, medium- grained, medium- to dark- gray. Extensively brecciated & invaded by pink granite of Lac LaCroix type (unit Avl); exposed south of Voyageurs, not in park.	NA	NA	NA	NA	NA
	Leucogranite-rich migmatite (Avt)	Part of *Vermillion Granitic Complex*. Layered migmatite within mostly biotite schist; comparable to unit Aqs; the injected rock is leucogranite comparable to unit Alg, together with leucotrondhjemite; granitic layers 1 m to 10s of meters thick, typically constituting about 50%- 90% of the bulk rock; contacts with units Alg & Avs are gradational.	Schist layers less resistant than granitic layers	Possible soil disturbance; Boat hazards	Suitable – extensive shoreline	Evidence for 2 episodes of Precambrian compression	
	Migmatite (Ava)	Part of *Vermillion Granitic Complex*. Country rock mostly amphibolite, hornblende gneiss, & biotite- hornblende gneiss; includes granite- rich & amphibolite- rich variants.	Exposed west of Voyageurs	NA	NA	NA	NA
	Schist- rich leucogranite migmatite (Avs)	Part of the *Vermillion Granitic Complex*. Layered migmatite of mostly biotite schist comparable to unit Aqs; country rock is leucogranite comparable to unit Alg, together with leucotrondhjemite; granitic layers range from 1 cm to several m. thick; typically constituting about 10%- 15% of bulk rock; contacts with units Aqs, Alg, & Avt are highly gradational.	Schist layers less resistant than granitic layers	Possible soil disturbance; Boat hazards	Suitable – exposed in central park; shoreline	Evidence for 2 episodes of Precambrian compression	Pictographs?

Precambrian Age	Map Unit (symbol)	Unit Description	Erosion Resistance	Hazards	Suitability for Development	Global Significance	Other
		WABIGOON SUBPROVINCE OF THE SUPERIOR PROVINCE					
LATE ARCHEAN (2.5-3.0)	Granodiorite (Ag)	Medium- to coarse- grained, light- gray to white with biotite & hornblende; exposed in the north part of map area & on Fransen and Susans Islands; moderately foliated w/ elongate mafic xenoliths oriented parallel to E- NE regional trend; may be correlative with granodiorite of the Ottertail Lake stock of NW Ontario, dated at 2,686.1 +1.5/- 1.4 Ma.	Exposed NW of Voyageurs on small islands	NA	NA	Evidence of early Earth: 2.6 Ba rocks	
	Lamprophyre (Al)	Medium- to coarse- grained, dark- green schistose; composed mainly of chlorite, biotite, & pyroxene; west of Dryweed Island, lamprophyre dikes trend NW & E- NE; NW- trending dikes are biotite- hornblende- plagioclase & cutting regional foliation; 10 cm to greater than 50 meters thick; E- NE dikes are hornblende- pyroxene- biotite (Review Islands) with large phenocrysts (1 cm) of pyroxene, subparallel to regional foliation & as thick as 10 m.; an E- oriented dike cuts bedding on the south side of Dryweed Island & contains rounded fragments of quartz diorite 5 mm to 25 cm. in diameter.	Dikes limited to small islands NW of Dryweed Is.	Fracturing in fault zone; Boat hazards	Island size should limit development	None	
	Schistose rhyolite (Ar)	Part of *Seline Group*. Reddish- gray, well- foliated; contains abundant rounded to angular rock fragments, interpreted as a clast- rich felsic flow; rock fragments decrease in abundance up- section from the contact with map units Ac1 and Ac2, sedimentary conglomerates; suite of rock types represented in the rock fragments identical to that in sedimentary clasts of underlying conglomerate; specular hematite locally occurs along joints.	Exposed outside Voyageurs in Tilson Bay/Rainy Lake fault zone	NA	NA	Evidence of Archean volcanic events	Specular Hematite
	Schistose conglomerate 2 (Ac2)	Part of *Seline Group*. Polymictic, clast- supported, green to gray; differs from unit Ac1 in both stratigraphic position & clast composition; contains rounded pebbles, cobbles, & boulders of felsic plutonic rocks, mafic to felsic volcanic rocks, chert, biotite schist, & taconite; plutonic clasts are subspherical to elliptical; volcanic clasts tend to be moderately elongated in the regional lineation; schistose matrix composed of fine- to medium- grained biotite- or chlorite- rich lithic arenite with angular to subrounded granules of volcanic rock fragments, intrusive rock fragments, plagioclase, quartz, & chert; bedding crude to massive; subtle, fining- to coarsening- upward sequences common; dated at 2,686-2,695 Ma.	Exposed outside Voyageurs in Tilson Bay/Rainy Lake fault zone	NA	NA	Sedimentary rocks 2.69- 2.70 Ba	Iron occurrence
	Schistose feldspathic quartzite (Asq)	Part of *Seline Group*. Medium- grained, light- gray to tan; quartz & feldspar grains, angular to subrounded, slightly flattened; matrix mostly fine- grained sericite, quartz, & chlorite; local biotite- & chlorite- rich beds; beds range 5 cm to 1 m thick; subtle planar lamination & trough cross- stratification typical; cross- stratification indicates south & westerly transport directions; unit locally includes discontinuous lenses (10 cm to 1 m thick) of schistose conglomerate containing pebble- to cobble- sized clasts; green rip- up clasts composed of sericite- chlorite schist locally present.	High. Dominant unit on Dryweed Island	Fracturing in fault zone; Boat hazards	Extensive shoreline around Dryweed Is. but within fault zone	Precambrian sedimentary structures preserved in metamorphic rock	Gold Occurrence Pictographs?
	Schistose conglomerate 1 (Ac1)	Part of *Seline Group*. Green to gray, rounded to angular pebbles, cobbles, & boulders of mafic to felsic volcanic rocks, pebbles of chert, & rare clasts of felsic plutonic rocks & iron- formation; numerous angular to rounded quartz pebbles common near top on the SW end of Dryweed Island; plutonic clasts subrounded to elliptical; volcanic clasts tend to be moderately to strongly elongated in the regional foliation; pebbles, cobbles, & boulders of rhyolite (unit Asr) with eyes of blue quartz are the dominant clast type; schistose matrix composed of fine- to medium- grained biotite- or chlorite- rich lithic arenite containing angular to subrounded grains of volcanic rock fragments, rare intrusive rock fragments, plagioclase, quartz, & chert; bedding is crude to massive with a subtle, overall fining upward; lenses of conglomerate interfinger with tuff beds of unit Aat.	Very limited exposures on Dryweed Island	Possible deformation in fault zone; Boat hazards	Limited exposures; within fault zone	Sedimentary rocks of Archean age	
	Schistose quartz- eye rhyolite (Aqr)	Part of *Seline Group*. Medium- gray to light- green, well- foliated with euhedral phenocrysts of plagioclase & distinctive, double terminated crystals of blue quartz.	Very limited exposures on Dryweed Island	In fault zone; Boat hazards	Too limited to sustain development	Evidence of Archean volcanic event	
	Schistose mafic volcanic wacke and tuff (Ams)	Meta- igneous Extrusive: Part of *Seline Group*. Dark green, strongly foliated chlorite schist; schistose, fine- to medium- grained, containing angular to subrounded sand grains of dominantly mafic volcanic rocks, plagioclase, quartz & chert.	Exposed outside Voyageurs in Rainy Lake fault zone	NA	NA	Archean mafic volcanism	
	Schistose accretionary tuff and tuff breccia (Aat)	Part of *Seline Group*. Gray to pink, consisting of abundant accretionary clasts in a schistose to phyllitic chlorite- dominated matrix; clasts are flattened & rotated & range from one to 10 cm in the longest dimension; internally, they are fine- grained & consist of a sugary pink rind that grades inward to a light- green inner rind & pink core; individual beds 10 cm to 2 m. thick, well graded, & with sequences predominately fining southward; scour- valleys are locally present implying younger rocks to the south.	Limited to E. tip of Dryweed Is; tuff usually resistant to erosion	In fault zone; Boat hazards	Too limited to sustain development	Evidence of Archean volcanic event	
	Tonalite (At)	Part of *Seline Group*. Fine- to medium- grained, light- gray to white, moderately to well foliated, biotite- rich; unit crosscuts diorite (unit Ad) & probably represents the latest phase of a shallow intrusion; similar rocks to the NE have been dated at about 2,729 to 2,736 Ma.	Exposed outside the park in Jackfish Bay fault zone	NA	NA	NA	Source of mica
	Diorite (Ad)	Part of *Seline Group*. Fine- to medium- grained, medium- to dark- gray, moderately to well foliated, biotite- & hornblende- bearing; cut by tonalite (unit At); locally forms angular brecciated fragments surrounded by the tonalite; unit occurs north of tonalite on Grassy Island & as thin sills within felsic & mafic metavolcanic rocks.	Exposed outside the park in Jackfish Bay fault zone	NA	NA	NA	

Precambrian Age	Map Unit (symbol)	Unit Description	Erosion Resistance	Hazards	Suitability for Development	Global Significance	Other
LATE ARCHEAN (2.5-3.0)	Leucogabbro (Alb)	Part of *Seline Group*. Medium- grained, light- gray to white, moderately foliated plagioclase- rich, amphibole- bearing; exposed in the northern portion of the area on the Fox Islands.	Compose Fox Islands	Boat hazards?	Limited aerial extent	None	
	Schistose gabbro (Asg)	Part of *Seline Group*. Medium- to coarse- grained, dark- green, texturally layered, strongly foliated metagabbro to diorite; forms small, glacially polished Whaleback Island just north of Steamboat Island in the northern part of the area; dominant mineral assemblage consists of plagioclase, pyroxene, amphibole, chlorite, & quartz; disseminated "brassy" sulfide blebs throughout; minor pyrite & chalcopyrite.	High. Forms Whaleback Island	Boat hazards?	Very limited aerial extent	None	
	Schistose felsic rocks (Asf)	Part of *Seline Group*. Very strongly foliated, light- green to gray; interpreted as metamorphosed dacite tuff interfingering with flows of map rhyolite and tuff (unit Asr) below.	Outside the park	NA	NA	NA	
	Schistose rhyolite & dacite (Asr)	Part of *Seline Group*. Light- to medium- gray, well- foliated; flows contain euhedral phenocrysts of plagioclase and distinctive, doubly terminated blue quartz.	Small islands in Rainy Lake fault zone	Boat hazards?	Small islands; limited aerial extent	Archean volcanic flows	Pictographs?
	Volcanic conglomerate (Avc)	Part of *Seline Group*.Bimodal, matrix- supported, gray to dark- green- gray; contains moderately to highly stretched felsic to mafic volcanic clasts that appear to have been originally rounded to subrounded; discontinuous beds as thick as one to 10 meters interstratified with felsic and mafic metavolcanic rocks; matrix is biotite- or chlorite- rich, fine- grained tuffaceous meta- arenite; stretched rhyolite clasts that contain doubly terminated blue quartz phenocrysts probably derived from the schistose rhyolite and dacite unit (Asr) above; may represent subaerial debris flows.	Exposed outside the park	NA	NA	May represent Precambrian subaerial debris flows	Blue quartz
	Amphibolite schist (As)	Part of *Seline Group*. Very strongly foliated; dark- green; composed of hornblende, biotite, and chlorite with thin, discontinuous lenses of brown iron- carbonate alteration, thin beds of magnetite- rich schist, and dark- gray cherty layers; occurs along the north side of the Rainy Lake- Seine River fault zone.	Exposed outside the park	NA	NA	NA	
	Mafic schist (Am)	Part of *Seline Group*. Mostly chlorite schist, scaly to massive, dark green- gray, derived from mafic volcanic flows and interstratified tuff; less common sericite schist derived from felsic tuff; rock grades tectonically into the sheared rock of the schistose tectonite unit (Ast) with local thin interbeds of sulfide- rich iron formation and highly altered fragmental rocks along the fault (on the small island NE of Dryweed Island); metabasalt and interbedded tuffaceous sequences generally thin; metabasalts are fine- grained composed of chlorite, green hornblende and plagioclase with minor biotite, magnetite, and ilmenite, & relict vestiges of vesicular pillow basalts.	Limited exposures on E. tip of Dryweed Island; in Rainy Lake fault zone.	Boat hazards?	Very limited aerial extent in a fault zone	Volcanic pillows lavas represent submarine flows in Precambrian	Gold, iron occurrence

Unit descriptions are from Hemstad et al. 2002.

Geologic History

This section highlights the map units (i.e., rocks and unconsolidated deposits) that occur in Voyageurs National Park and puts them in a geologic context in terms of the environment in which they were deposited and the timing of geologic events that created the present landscape.

Some of the oldest rocks in the world are exposed in Voyageurs National Park. About 2.5- 4.5 billion years ago (Ba), plate- tectonic processes generated a number of isolated areas of continental crust. In North America, rocks formed by these early tectonic events are found in Minnesota, Wyoming, parts of Canada, and Greenland.

These bedrock units were shaped and carved by at least four periods of glaciation. The most recent continental glaciation in North America ended about 10,000 years ago. All evidence of the geologic history that has occurred between these two widely separated periods is missing from Voyageurs and most of the Canadian Shield.

Precambrian

Archean Eon (2.5-3.0 Ba)

Relatively little is known about the early Precambrian since there were few fossils preserved and hard- bodied organisms are not found prior to about 550 million years ago at the beginning of the Cambrian Period (figure 2). However, excellent exposures of Archean rocks in northern Minnesota, including the Voyageurs area, reveal a protracted and complex structural evolution (Davis et al. 1994). The Archean basement complex of intensely metamorphosed rocks of sedimentary, volcanic, and intrusive igneous origin, dated at 2.6 Ba and older, is commonly referred to as pre- Kenoran. The earliest gneisses and schists, rich in mica, may have originally been sandstones (Harris et al. 1995). Following the emergence of the continental rocks of the Superior Province about 2.7- 3.0 Ba, structural deformation occurred over more than 100 million years.

In late Archean time (2.8- 2.5 Ba), repeated episodes of continental collision and north- south directed compression and subduction generated a mountain-building episode known in North America as the Algoman Orogeny. This orogeny formed the gneisses, schists, and granites exposed today in Voyageurs National Park (Miller et al. 1987; Kiver and Harris 1999). Subduction of oceanic crust beneath the cratonic crust generated volcanic islands in the Precambrian sea. Zones of thick, basaltic lava accumulated in linear basins (back-arc basins) formed between the less- dense continental crust and the volcanic islands. These lava- filled basins created today's greenstone belts (Kiver and Harris 1999). The oldest known rock in Minnesota, the Ely greenstone, formed at this time.

During the Algoman Orogeny, a great number of tectonic faulting and folding events deformed the rocks in the north- central Minnesota part of the Superior Province. Today, these event are seen in the three geologically distinct subprovinces, Wabigoon ,Quetico, and Wawa (figure 3).

Major fault zones form the boundaries between the three subprovinces. The northeast- southwest trending Rainy Lake- Seine River fault zone separates the Quetico subprovince from the Wabigoon subprovince to the north. South of Voyageurs, the Vermillion fault zone marks the boundary between the Quetico subprovince and the Wawa subprovince (figure 3). The Quetico subprovince has been interpreted as a classical sedimentary basin (fore- arc or back- arc basin) developed between two active volcanic island chains (volcanic arcs) represented by the Wabigoon and Wawa subprovinces (figure 4) (Davis et al. 1994).

These ancestral fault zones developed oblique, northwesterly components of movement that caused extensive strike- slip motion. Locally, segments on these faults were displaced by more than 20 miles (32 km), with the north side of faults displaced to the east (Davis et al. 1994).

At least three phases of deformation folded the bedrock of Voyageurs (Day 1990). The first episode produced southwest - plunging en echelon folds. The second phase of deformation was the most intense in the area and is recognized by small- scale folds, a strong schistosity in the rocks, mineral lineations, and a progressive transition in ductile deformation from the first phase to the second phase. The third phase produced high- angle faults and shear zones. Regional folding appears to have occurred prior to, concurrent with, and after regional metamorphism.

Sedimentary units were complexly folded along east-west axes and commonly have very steep to vertical dips. North- south directed compression generated regional, arch- like convex folds, or flexures, in sedimentary strata (antiformal syncline or anticlinoria) along east-northeasterly trends. Regional metamorphism accompanied compressive north- south oriented thrusting and folding.

Later in the orogeny, the granitic plutons found in Voyageurs intruded into the area. Mineral- rich fluids from these plutons produced dikes, pegmatites, and quartz veins that concentrated metallic minerals in parts of the greenstone belts.

Proterozoic Eon (2.5-0.5 Ba)

The Proterozoic Eon represents about 40 percent of all geologic time. By 1.8 Ba, isolated regions had joined into a single large craton that included what we see today as Greenland, central Canada, and the north- central United States. The Midcontinent Rift that forms the axis of Lake Superior formed during this time and is likely the surface expression of a rising plume of hot mantle material (Hauser 1996). Faults and igneous dikes mark the northwest arm of this rift. Lava flows poured from long fissures to fill the axes of synclinal basins. Magma that did not breach the surface crystallized into granitic plutons that are now exposed in the park.
Deformation in the Voyageurs area seems to have terminated by the time the northwest- trending diabase dike swarm was emplaced around 2.12 Ba (Day 1990). The Proterozoic diabase dikes of the Kabetogama- Kenora Dike Swarm in Voyageurs formed in long, linear fractures between 2.2 and 2.1 Ba. Proterozoic schistose tectonite (fault rock) intrude the older Archean rocks.

Prolonged Erosion (570 Ma – 0.19 Ma)

By the end of the Precambrian, the long series of tectonic events that created the basement complex of the Canadian Shield was over. Millions of years of erosion left only the roots of ancient mountains exposed (Harris et al. 1995). Extensive seaways covered much of the craton during the Early Paleozoic, but during the Late Paleozoic, Mesozoic, and Cenozoic, the province stood above sea level and was extensively eroded. The topography was reduced to a flat rolling plain even before the advance of the Pleistocene glaciers. The glaciers removed most of the Cenozoic deposits and all of the Paleozoic and Mesozoic record. When the first continental glaciers advanced into the Voyageurs area, the landscape was probably of low relief with a fairly uniform soil cover supporting extensive forests (Harris et al. 1995).

Quaternary

Pleistocene Epoch (1.6-0.01 Ma)

Throughout the Ice Age, beginning perhaps 190,000 years ago and extending intermittently in the Voyageurs region to approximately 11,400 years B.P., continental sheet glaciers covered north- central Minnesota, the Great Lakes Region, and most of Eastern Canada (Davis et al. 1994). The Illinoian stage (190,000 to 135,000 years B.P.) was the first glacial event and was followed by a warming period known as the Sangamonian Interglacial (135,000 to 119,000 years B.P.) The Wisconsin stage followed the Sangamonian Interglacial and advanced and retreated across the region from 135,000 years B.P. to 10,000 years B.P. when the Holocene Epoch, or "Recent" geological time period began (figure 2).

During the Pleistocene, glaciers scooped out Lake Superior's basin along the trend of the Midcontinent Rift. At the east end of Lake Superior, the bottom of the lake is 1,302 feet (397 m) below the surface at an elevation of 700 feet (213 m) below sea level (Kiver and Harris 1999).

To the west of Voyageurs, Lake Agassiz formed during glacial retreat. Meltwater from the last continental glacier, backed- up because the north- flowing rivers that drained into Hudson Bay were blocked by ice. Water began to collect in the Red River valley in western Minnesota about 12,000 years ago and then spread over eastern North Dakota and adjacent Canadian Provinces. Lake Agassiz covered the Voyageurs area during glacial retreat from about 11,400 to 9,500 years B.P. (Davis et al. 1994).

Holocene Epoch

Today unconsolidated sediments and thin soils have been superimposed on some of the oldest bedrock in North America. Streams have been reworking and sorting the glacial debris rather slowly due to the low relief in the area. Large basins are now occupied by lakes, ponds, bogs, wetlands, and interconnecting waterways.

The tremendous weight of the ice sheet depressed the crust. When the ice melted, the crust rebounded and it is still rising today. Glacial rebound has caused some lakes to drain away and some lakes to become bogs and swamps. In the Boundary Waters region, the lakes occupy deeper parts of the basins once filled by Lake Agassiz. The land is rising at a rate of about 1 foot (0.3 m) per century (Kiver and Harris 1999).

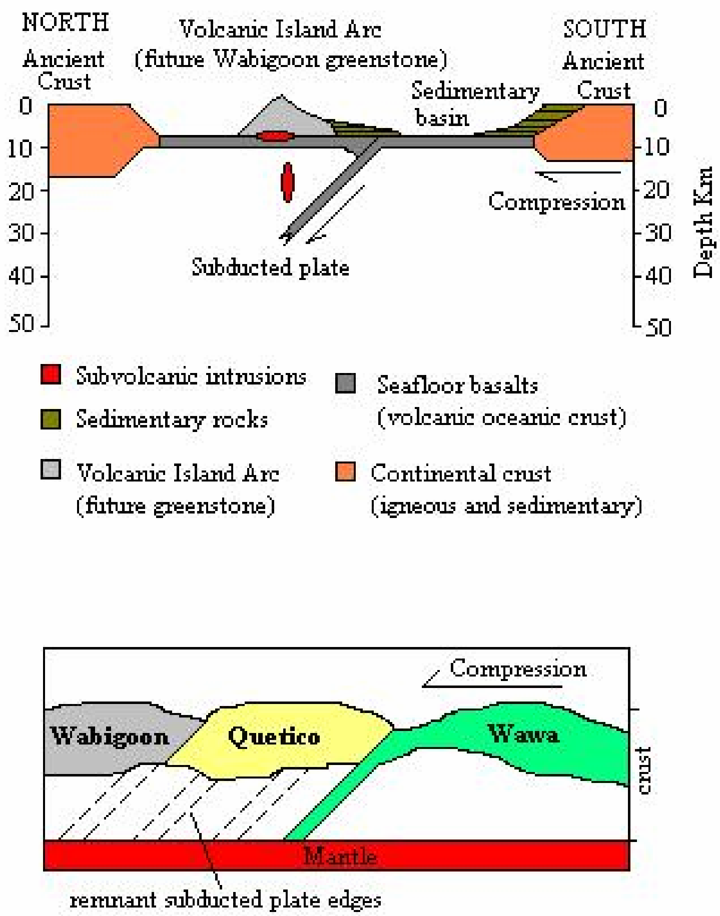

Figure 5. Precambrian subduction and development of subprovinces. Modified from Davis et al. 1994.

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.

anorthosite. An intrusive igneous rock composed almost entirely of calcium- rich plagioclase feldspar.
aquifer. Rock or sediment that is sufficiently porous, permeable, and saturated to be useful as a source of water.
basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks of interest.
basin (structural). A doubly- plunging syncline in which rocks dip inward from all sides (also see dome).
basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.
batholith. A massive, discordant pluton, greater than 100 km^2, (39.6 mi^2) often formed from multiple intrusions.
bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above.
bedrock. The underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.
conglomerate. A coarse- grained sedimentary rock with clasts larger than 2 mm in a fine- grained matrix.
continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25- 60 km (16- 37 mi) and a density of approximately 2.7 grams per cubic centimeter.
craton. The relatively old and geologically stable interior of a continent (also see continental shield).
crust. The outermost compositional shell of Earth, 10- 40 km (6- 25 mi) thick, consisting predominantly of relatively low- density silicate minerals (also see oceanic crust and continental crust).
crystalline. Describes the structure of a regular, orderly, repeating geometric arrangement of atoms; generally refers to igneous and metamorphic rocks.
deformation. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.
dike. A tabular, igneous intrusion that cuts across bedding.
dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.
extrusive. Of or pertaining to the eruption of igneous material onto the surface of Earth.
fault. A break or fracture in rock along which relative movement occurs between the two sides.
formation. Fundamental rock- stratigraphic unit that is mappable and lithologically distinct from adjoining strata and has definable upper and lower contacts.
fracture. Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, fault)
graywacke. A dark gray rock composed of poorly sorted grains of quartz, feldspar, clay and mineral fragments usually indicating rapid deposition.
igneous. Refers to a rock or mineral that originated from molten material; one of the three main classes or rocks: igneous, metamorphic, and sedimentary.
intrusion. A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.
island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.
lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.
lapilli. Airborne volcanic (pyroclastic) fragments that range in size from 2- 64 mm.
lapilli tuff. A pyroclastic rock composed mainly of lapilli.
lava. Magma that has been extruded out onto Earth's surface, both molten and solidified.
left-lateral fault. A strike- slip fault on which the side opposite the observer has been displaced to the left. Also called a sinistral fault.
lithosphere. The relatively rigid outmost shell of Earth's structure, 50 to 100 km (31 to 62 mi) thick, that encompasses the crust and uppermost mantle.
mafic. A rock, magma, or mineral rich in magnesium and iron.
magma. Molten rock generated within Earth that is the parent of igneous rocks.
mantle. The zone of Earth's interior between crust and core.
matrix. The fine- grained interstitial material between coarse grains in porphyritic igneous rocks and poorly sorted clastic sediments or rocks.
member. A stratigraphic unit with definable contacts that subdivides a formation.
metamorphism. Literally, "change in form". Metamorphism occurs in rocks with mineral alteration, genesis, and/or recrystallization from increased heat and pressure.
migmatite. Literally, "mixed rock" with both igneous and metamorphic characteristics due to partial melting during metamorphism.
normal fault. A dip- slip fault in which the hanging wall moves down relative to the footwall.
orogeny. A mountain- building event, particularly a well-recognized event in the geological past (e.g. the Laramide orogeny).
outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.
outwash. Glacial sediment transported and deposited by meltwater streams.
pebble. Generally, small, rounded, rock particles from 4 to 64 mm in diameter.

phyllite. A metamorphic rock intermediate in grade between slate and mica schist.

phyllonite. A rock formed by mechanical degradation (mylonization) of coarser rocks (e.g. granite or gneiss)

pillow lavas. Lavas that extruded in a subaqueous environment characterized by discontinuous, often overlapping bun- shaped masses; usually composed of basalt or andesite.

pluton. A body of intrusive igneous rock.

porosity. The proportion of void space (cracks, interstices) in a volume of a rock or sediment.

right-lateral fault. A strike- slip fault on which the side opposite the observer has been displaced to the right. Also called a dextral fault.

sediment. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of detrital and/or chemical sediment(s).

silt. Clastic sedimentary material intermediate in size between fine- grained sand and coarse clay (1/256- 1/16 mm).

strata. Tabular or sheet- like masses or distinct layers (e.g., of rock).

strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

tectonic. Relating to large- scale movement and deformation of Earth's crust.

terrane. A region or group of rocks with similar geology, age, or structural style.

till. An unsorted, unstratified, and generally unconsolidated heterogeneous mixture of clay, silt, sand, gravel, and boulders deposited directly by and underneath a glacier.

topography. The general morphology of Earth's surface including relief and location of natural and anthropogenic features.

tuff. Generally fine- grained, igneous rock formed of consolidated volcanic ash.

volcanic ash. Fine pyroclastic material ejected from a volcano (also see tuff).

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

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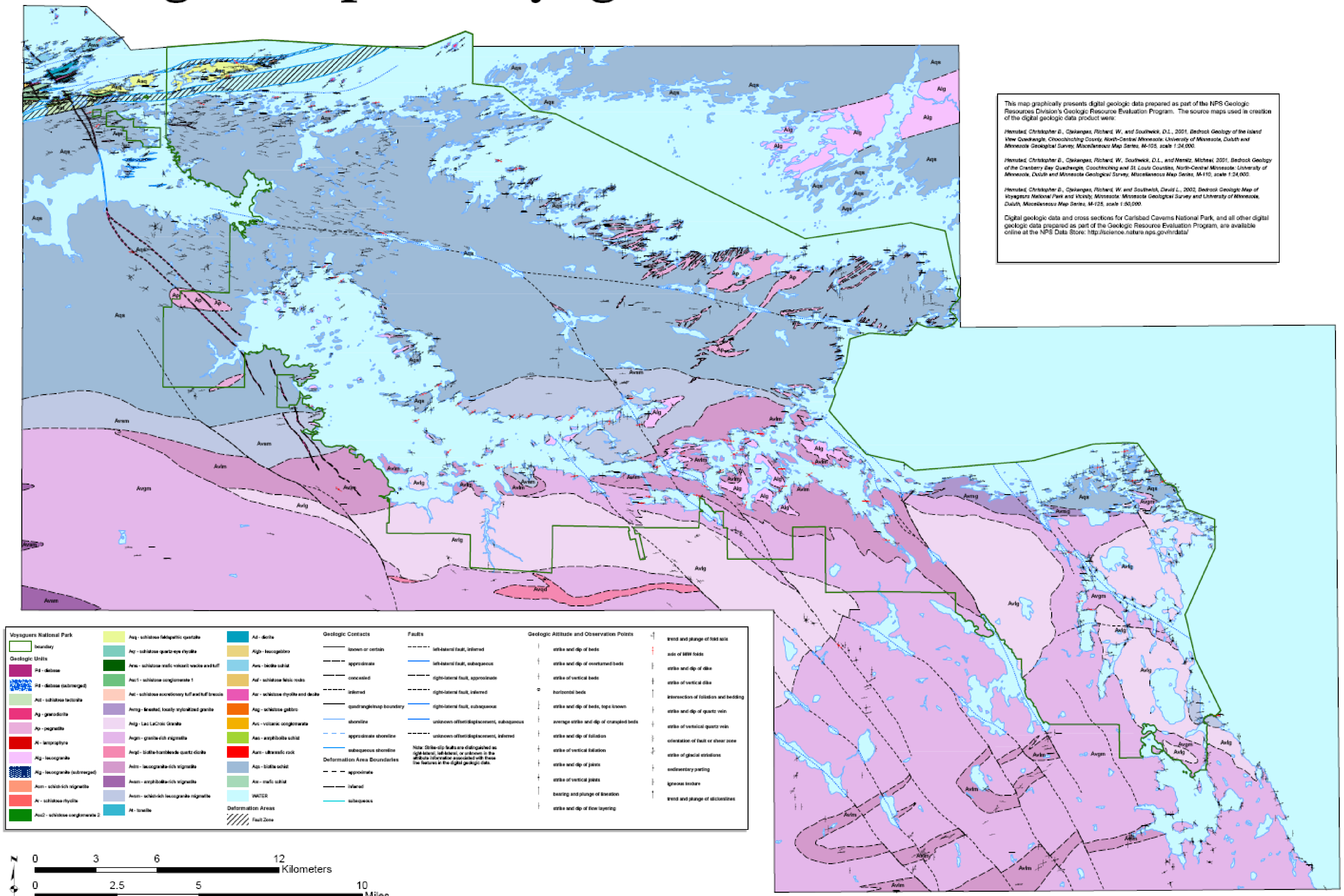
Appendix A: Geologic Map Graphic

The following page provides a preview or "snapshot" of the geologic map for Voyageurs National Park. For a poster size PDF of this map or for digital geologic map data, please see the included CD or visit the GRE publications webpage: http://www2.nature.nps.gov/geology/inventory/gre_publications.cfm.

Geologic Map of Voyageurs National Park



This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resource Evaluation Program. The source maps used in creation of the digital geologic data product were:

Hemstad, Christopher B., Ojakangas, Richard, W., and Southwick, D.L., 2001, Bedrock Geology of the Island View Quadrangle, Koochiching County, North-Central Minnesota: University of Minnesota, Duluth and Minnesota Geological Survey, Miscellaneous Map Series, M-105, scale 1:24,000.

Hemstad, Christopher B., Ojakangas, Richard, W., Southwick, D.L., and Nemitz, Michael, 2001, Bedrock Geology of the Cranberry Bay Quadrangle, Koochiching and St. Louis Counties, North-Central Minnesota: University of Minnesota, Duluth and Minnesota Geological Survey, Miscellaneous Map Series, M-110, scale 1:24,000.

Hemstad, Christopher B., Ojakangas, Richard, W. and Southwick, David L., 2002, Bedrock Geologic Map of Voyageurs National Park and Vicinity, Minnesota: Minnesota Geological Survey and University of Minnesota, Duluth, Miscellaneous Map Series, M-125, scale 1:50,000.

Digital geologic data and cross sections for Carlsbad Caverns National Park, and all other digital geologic data prepared as part of the Geologic Resource Evaluation Program, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/

Produced by Geologic Resources Division

March 2007

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Voyageurs National Park. The scoping meeting occurred June 1- 2, 2000; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact the Geologic Resources Division for current information.

Summary

A geologic resources inventory workshop was held for Voyageurs National Park on June 1- 2, 2000 to view and discuss the park's geologic resources, to address the status of geologic mapping for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), NPS Voyageurs National Park, University of Minnesota and Minnesota Geological Survey staff were present for the workshop.

This involved a very cold and wet one- day field trip to view the geology of the Voyageurs National Park area led by Chris Hemstad (University of Minnesota) and another one- day scoping session to present overviews of the NPS Inventory and Monitoring (I&M) program, the Geologic Resources Division, and the on- going Geologic Resouces Inventory (GRI). Round table discussions involving geologic issues for Voyageurs National Park included interpretation, the status of geologic mapping efforts, sources of available data, geologic hazards, and action items generated from this meeting.

Items of discussion included the following:

Geologic Mapping

Chris Hemstad (University of Minnesota, Ph.D. candidate) is currently involved in a project to produce a compilation geologic map of Voyageurs National Park at 1:50,000 scale. He will be using the existing USGS "I:50,000 scale metric topographic map of Voyageurs National Park, Minnesota (1979)" as the base map.

He is using some of the existing unpublished "detailed reconnaissance" work of David Southwick (Minnesota GS) and Richard Ojakangas (University of Minnesota) and filling in where necessary. Southwick and Okakangas focused their efforts on shoreline mapping as part of mineral appraisal studies. Chris is mapping at 1:24,000 scale using transects across various land areas of Voyageurs National Park. Chris is being funded through the EDMAP program and has received some funding from the NPS- GRI for his mapping activities. USGS funds cover 50 percent and the University of Minnesota covers the other 50 percent. He is in the second year of his EDMAP project.

At the time of this meeting, Chris had completed 1:24,000 scale detailed mapping of the Island View quadrangle (published by the MN GS) and is close to completion of the Cranberry Bay quadrangle.

Previous work of Southwick and Ojakangas is also at 1:24,000 scale (??). both will be compiling their existing work on mylars to be put in a final compilation by Chris. It is assumed that both edge- and unit- matching will be undertaken by all three authors prior to compilation.

Chris sees the ultimate product of the compiled map as a 1:50,000 scale map that could be sold in the Voyageurs visitor center. Funding for this cannot come from GRI, as we are not allowed to fund publication costs and will need to be sought elsewhere.

As part of this mapping, it was suggested to work up the Kettle Falls and Ash River quadrangles (because of its high use) as detailed as possible as part of this project.

Digital Geologic Map coverage

At the time of this meeting, there was still confusion as to how to complete digital geologic coverage. By meetings end, it was suggested that the maps be digitized at the MN GS, so that the maps creator could oversee the digitization and answer any questions that may come up with regards to interpreting the maps.

As of Fall 2000, GRI staff have allocated $5000 to cover digitization costs and will transfer the money to Voyageurs National Park to distribute to the MN GS or whoever will be digitizing the Voyageurs maps in Fall 2000.

If this were done at the MN GS, GRI staff would like to see the NPS Digital Geologic map model utilized (as demonstrated by GRI staff during the scoping session). A copy of the model can be supplied to the digitizing party. Contact Tim Connors for further information.

Disturbed Lands and Abandoned Mineral Lands

Voyageurs staff expressed interest in compiling data about disturbed land sites (gravel sites and old campgrounds and the Kettle Falls area), and other abandoned mineral lands (AML). It was suggested they contact GRD Disturbed Lands/ AML coordinator Dave Steensen (303- 969- 2014) with specific concerns on these matters.

Additionally, the Bureau of Mines has published Mineral Occurrences and Development Potential near Voyageurs National Park, Minnesota (Mineral Land Assessment Open File Report 5- 94).

Interpretation

Currently Kendall Dickinson (retired USGS) is working on Geology of Voyageurs National Park as an interpretive product for the general public. He is also seeking funding for this publication. It is not yet known if this publication would be suitable for the GRI needs of our geologic report and is currently under review by GRD staff.

Southwich and Ojakangas would like the opportunity to critically review this report.

Also mentioned were other geologic publications specific to Minnesota geology including a geology underfoot book and the Roadside Geology of Minnesota, both of which were likely to have sections on VOYA and other NPS areas in Minnesota.

Geologic Report

A comprehensive technical geologic report was discussed as a necessary component of the GRI. Again, at present, it is not known if Dickinson's publication will fulfill this requirement.

It was suggested that perhaps Chris Hemstad, Richard Ojakangas or David Southwick could be "coerced" into writing such a report in their copious free time for compensation. It they are interested, please let GRI staff know.

Miscellaneous

Geologic hazards include boats hitting rocks in the lake, the dangers of falling in the Little American Mine, and potential for earthquakes in the region.

David Southwick mentioned he had done a cooperative report on Pipestone NM; GRI staff would be interested in obtaining this report from the Minnesota Geological Survey

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Voyageurs National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2007/007
NPS D-158, June 2007

National Park Service

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Natural Resource Program Center

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