National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Isle Royale National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/037

THIS PAGE:
Geologic Scoping field trip, Isle Royale NP

ON THE COVER:
Weathered and striated bedrock, Isle Royale NP

NPS Photos

Isle Royale National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/037

Geologic Resources Division
Natural Resource Program Center
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Executive Summary

This report accompanies the digital geologic map for Isle Royale National Park in Michigan, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research.

Isle Royale National Park preserves a remarkable wilderness area in northwest Lake Superior near the Canadian border. Its isolation and severe climate keeps the island relatively free from human influences, creating an ideal natural laboratory to study the complexity of a relatively pristine ecosystem.

Understanding the geology of the northern Lake Superior region enhances understanding of the unique relationship between geology and the environment and the ecosystem of Isle Royale. The landscape of Isle Royale is reflected in the structure and type of underlying rocks and the geologic processes acting on them. The rock units present in Isle Royale consist of ancient thick lava flows interlayered with sedimentary rocks and overlain by conglomerates. The youngest geologic units on the island are surficial unconsolidated deposits, many of which are glacial in origin. Glaciation scoured the area leaving glacial grooves, fjord- like inlets, rocky fingers of land, and drowned valleys with abundant glacial deposits of till and erratics. The age gap between the consolidated bedrock and the unconsolidated surficial deposits is more than 570 million years.

The following issues identified at the Geologic Resource Evaluation (GRE) scoping meeting have geological significance and are important for resource management in the park. These are discussed in detail in the Geologic Issues section with recommendations for inventory, monitoring, and research.

- Submerged geomorphology.
  Approximately two- thirds of the 890- square mile park is below the water level of Lake Superior. Many subaqueous habitats exist at Isle Royale National Park. Environments can change in just a few meters of water. Traditional surficial mapping does not include submerged geology and U.S. Geological Survey (USGS) maps extend to a depth of only 5 m (15 ft) offshore. Data requirements for better characterizing the submerged geomorphology of the park include lidar surveys, satellite imagery, multi- beam mapping, bathymetry, water quality and circulation, shoreline change data, and storm data.
- Ancient Shorelines.
  When the last glaciers retreated from the area less than 10,000 years ago, the fluctuation of the level of Lake Superior formed a series of paleoshorelines. Paleoshoreline features include beach deposits, wave-cut cliffs, terraces and benches. Identifying and mapping ancient shorelines will provide important information for understanding the formation of these shorelines as well as indicating the locations of ancient human settlements and artifacts.
- Abandoned Mine Sites.
  Historic mining, mainly for copper, occurred mostly in the 1800s. There is also evidence that there was some prehistoric mining by Native Americans. Unlike the Keweenaw Peninsula and other areas of the Great Lakes, Isle Royale does not have abundant deposits of copper. Native copper is widely distributed but there are no large lode deposits (Huber, 1983). About 80% of the park is unsurveyed for abandoned mine sites and there is also a need for bat surveys in the park. Two mines of note are the Island Mine and the Minong Mine, both of which were financial failures (Huber, 1983).
- Water Quality and Supply.
  Currently, all drinking water comes from Lake Superior. Although the park is interested in utilizing the groundwater supply for economic reasons, the characteristics of the groundwater aquifer system are not well known. Knowledge of how water travels through the subsurface is essential to predicting hydrologic response to inputs such as contaminants, and other wastes. The water table is high and there may be some contamination from human wastes as well as from petroleum spills and other toxic substances, especially at Rock Harbor, Mott Island, Amygdaloidal Island, and Windigo.
- Other Issues. Other geologic issues discussed during scoping include: species isolation; chlorastrolite, the state gem; wetlands; and recreational demands. These issues are briefly summarized in this report.

Introduction

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

Purpose of the Geologic Resource 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.

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/).

Geologic Setting

Isle Royale National Park protects 571,790 acres (2,300 km^2; 890 mi^2) of a group of islands in Lake Superior. Of this only 132,018 acres is land- based wilderness. Lake Superior is the largest freshwater lake in the world and is the coldest, deepest, and highest in elevation of any of the Great Lakes. At its widest point, Isle Royale National Park is 70 km (45 mi) long and 14 km (9 mi) wide. The park consists of one large island surrounded by approximately 400 smaller islands. This national park was authorized on March 3, 1931, established on April 3, 1940, portions were designated a wilderness area on October 20, 1976, and became a national biosphere reserve in 1980.

The main island is located more than 16 km (10 miles) from the Minnesota mainland, and more than 48 km (30 miles) from the upper peninsula of Michigan. The park is only accessible by seaplane from Houghton, Michigan, or by boat ferry from Houghton or Copper Harbor, Michigan, or Grand Portage, Minnesota. This remote and isolated area harbors a unique environment that responds to natural influences with little human interference. Because it has been relatively protected from human development, heavy forests extend down to the shorelines, reflecting the conditions that must have existed throughout the Lake Superior region prior to settlement.

The highest point on the main island at Isle Royale National Park is Mount Desor at 425 m (1,394 ft) in elevation. The lowest point is the water level elevation of Lake Superior at 183 m (600 ft). Mount Desor sits along Greenstone Ridge which forms the backbone of Isle Royale. The ridge is composed of ancient metamorphosed basaltic lava flows. These flows, named for their characteristic green hue, are part of one of the largest and thickest lava flows on earth. The Greenstone Flow at Isle Royale is up to 240 m (790 ft) thick and extends beneath the surface of Lake Superior, reappearing on the Keweenaw Peninsula of Michigan.

During the last significant glacial maximum, approximately 11,000 years ago, thick ice sheets covered the Great Lakes area. Erosion by these glaciers and to a much lesser degree, their weight, formed huge basins and sculpted the landscape. Glacial scouring helped form parallel ridges and linear valleys, lakes, and harbors.

A washboard- like pattern of linear ridges and parallel valleys, created by the tilted rock layers and the scouring erosive action of the last major glaciation, characterize this topography. These features align parallel in a northeast to southwest trend, affecting many facets of the environment at Isle Royale including animal and plant distribution and migration patterns, microclimates, wetland distribution, and human use. The most prominent ridges on the island are the Greenstone Ridge along Isle Royale's center, Feldtmann Ridge, Minong Ridge, Red Oak Ridge, and Stanley Ridge (figure 1).The alignment of these linear, parallel features, as well as the islands' shape and orientation indicate that the most recent glaciers covering the area flowed from northeast to southwest.

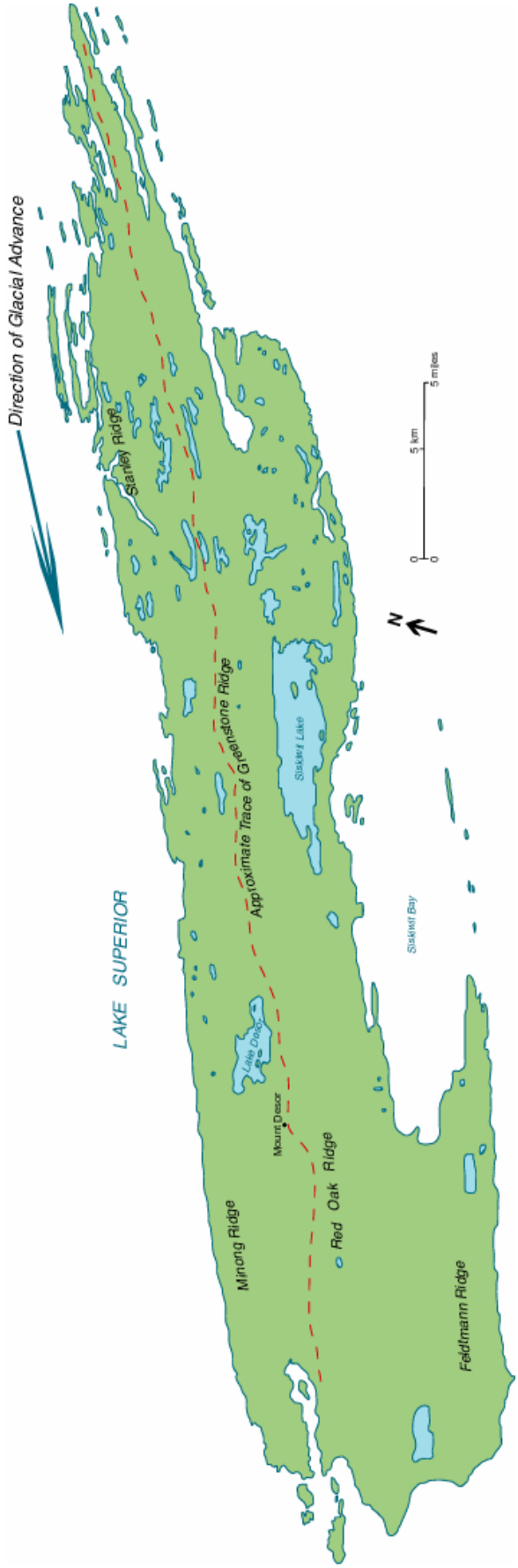

Figure 1. Map of Isle Royale and some surrounding islands with major ridges noted. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Isle Royale National Park on June 16, 2004, 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 managers.

Submerged Geomorphology

Since approximately two- thirds of the 2,300 km^2 (890 mi^2) park is below lake level, understanding the bathymetry and geology of the submerged areas is an important resource management issue. Many subaqueous habitat types exist at Isle Royale National Park and these different environments are strongly related to small changes in depth. Environments can change within meters of topographic relief. U.S. Geological Survey (USGS) maps extend to a depth of only 5 m (16 ft) offshore. Given the coverage of mapping at the park, traditional surficial maps are not sufficient for complex management decisions at Isle Royale.

An interdisciplinary approach to mapping is necessary to produce a useful product for resource management. In addition to understanding the bathymetry and geology of the submerged areas, mapping these areas will provide information regarding fish habitats including shoals, gravel bars, and deeper areas. The isolation and pristine waters surrounding Isle Royale create an ideal setting to study fish populations and to understand geological and geomorphological relationships with fish spawning, distribution, and migration patterns.

Useful data to collect for this effort include lidar surveys, satellite imagery, multi- beam mapping, bathymetry, water quality and circulation, shoreline change, pre- and post- storm comparisons, and lake water circulation data (waves, tides, currents, turbidity, temperature, sediment transport patterns, and species distributions). This ecosystem approach integrates biological, physical, cultural, and oceanographic variables.

Inventory, monitoring, and research suggestions for submerged geomorphology include:

- Promote sub- aqueous mapping projects.
- Relate bathymetry to populations and distributions of fish and other aquatic species.
- Map benthic habitats including sediment types and distribution patterns.

Ancient Shorelines

There are many shoreline types at Isle Royale including beaches, rocky shores, narrow fjord- like inlets, large bays, cliffs, paludal shores, inland lake shores, and wetlands. With historic fluctuating water levels, these environments are submerged or exposed. When the last glaciers retreated from the area, starting 10,000 years ago, a series of intermittent lakes formed, leaving paleoshoreline features on the landscape at Isle Royale. Developed lake levels include Lakes Washburn and Beaver Bay (~9,800- 9700 years ago), Lake Minong (~9,500 years ago), Lake Houghton (~8,000 years ago), and Lake Nipissing (~5,500- 4,700 years ago) (McRae et al. 1998; John Anderton, written comm. 2007).

Isostatic rebound has now lifted these once horizontal lake planes with uplift increasing from southwest to northeast (McRae et al. 1998). Many paleoshoreline features are obscure and difficult to see. Identifying and mapping ancient shorelines will provide important information regarding the history of the relative rise and fall of the lake level in response to glaciation and post-glacial changes. Preliminary studies using GIS and modeled shorelines have provided estimates of the elevation of various post- glacial shorelines around the island (McRae et al. 1998).

This information may also be used to locate ancient human settlements and artifacts often concentrated along shorelines. The oldest known archeological sites are about 4,000 to 5,000 years old. There could be older sites (8,000 to 9,000 years old) along some Minong shorelines. Some have also been found at Thunder Bay, Ontario (Scoping participants, oral comm. 2004). Many of these and other unknown sites could be submerged. Submerged stumps have been found at Grand Island at over 60 m (200 ft) depth, these are believed to be 8,000 years old (Scoping participants, oral comm. 2004). Native copper fragments could have been accessible in paleoshoreline deposits, due to winnowing by wave action along areas void of vegetation (McRae et al. 1998).

USGS mapping by Huber in 1973 included some ancient shoreline mapping. Additionally, the NPS Geologic Resources Division, in cooperation with the Natural Resource Conservation Service (NRCS), initiated a Soil Resource Inventory project in 2005 which will include detailed soil mapping for the park and may provide some ancient shoreline information. This project has an estimated completion date of 2009. However, for resource management at Isle Royale, much remains to be completed and mapped in detail. Huber mapped the paleo- shorelines of post- glacial Lake Minong and Nipissing, published in USGS Professional Paper 754- A, finding more paleoshorelines in the southwest portion of the park than the northeast end. These areas have a high potential for preserving archeological resources.

Following Huber's mapping in 1973, a previously unrecognized event known as the Marquette advance changed geologists' understanding of paleoshorelines in

the area. During the Marquette advance about 11,450 years ago an ice sheet closed the eastern inlets of ancient glacial Lake Agassiz. This ice sheet generated significant glaciofluvial outwash that flowed across the Upper Peninsula of Michigan. Remapping paleoshorelines with this in mind could identify previously unrecognized geomorphologic features.

Inventory, monitoring, and research suggestions for ancient shorelines include:

- Study submerged inlets and paleoshorelines to determine patterns and dates of formation.
- Study paleodrainage for Isle Royale.
- Integrate information from the Soil Resources Inventory with other mapping products.

Abandoned Mine Sites

Native copper on Isle Royale may have attracted Native Americans to the area before European exploration. Although Isle Royale was never a significant source of copper, 14 abandoned mine sites (including prospects) have been inventoried. Historic mining occurred during three different periods: from 1840- 1850s, 1870s, and 1890s. Though widespread, the deposits on Isle Royale were too sparse to prove economically viable for mining.

High temperature fluids, percolating through fissures and conglomerates resulted in the precipitation of native copper in several of the geologic units at Isle Royale; however, such copper has not been found in major concentrations in the park. Copper ore is often composed of copper bearing minerals such as chalcocite (Cu_2S), chalcopyrite ($CuFeS_2$), and cuprite (Cu_2O), but native copper is rarely present in major concentrations. However, native copper deposits on the Keweenaw Peninsula of Michigan are among the most extensive in the world. These are present in two broad categories – lode vein and fissure filling deposits (Huber 1975). Lode deposits contributed about 98 percent of the total copper mined in the Native Copper district of Keweenaw (approximately 5,400,000 tons total).

The Island mine, near the west end of Siskiwit Bay, was located on a conglomerate lode deposit. Most of the historic short- lived mines focused on fissure- filled deposits such as the Minong, Siskiwit, and other various smaller operations. Within these fissures, native copper occurs in nodules and irregular masses in highly altered parent rock. This alteration was concentrated in fracture zones a few inches to many feet wide. Several significant large masses were found at the Minong mine (the largest on the island on the southeastern flank of Pine Mountain near the Minong Ridge Trail) among the approximately 250 tons of copper extracted there (Cannon and Woodruff 1999; Huber 1975). A few of these individual nodules weighed more than a ton (Huber 1975).

In other locations at Isle Royale, veins of quartz, prehnite [$Ca_2Al(AlSi_3O_{10})(OH)$], a layered silicate typically found as a secondary mineral in cavities, and calcite contain scattered grains of native copper. Native copper also occurs in amygdules in metamorphosed lava flows, especially in prehnite- bearing amygdules (Huber 1975).

During the late 1980s, a survey of these historic mining sites in the park focused primarily on areas along trails and near campgrounds and identified 14 sites. However, approximately 80% of the park's backcountry wilderness areas remain unsurveyed for abandoned mine location.

Abandoned mine features may pose several concerns for resource management. Visitor safety is a constant concern wherever open shafts, pits, trenches, and associated waste rock occur. GRD records of Isle Royale National Park surveys in 1984 and 1989 indicate that most mine features accessible to the public have become overgrown and partially filled in or flooded. However, a formal hazard assessment recorded with the Abandoned Mine Lands inventory, maintained by GRD, is recommended as timing and funding permit.

Inventory, monitoring, and research suggestions for abandoned mine sites include:

- Map and create GIS layers of park mining sites
- Perform studies relating historic mine features to biologic diversity (bats) at Isle Royale.
- Complete a comprehensive survey of mine features at Isle Royale, determine if any historic mines pose visitor safety risks that may need remediation.
- Study effects of historic mining features on the hydrogeologic system of the island.
- Develop and promote more interpretive programs on historical exploration and extraction of mineral resources from Isle Royale.
- Reclaim abandoned mine land sites.

Water Quality and Supply

Currently, drinking water is pumped from Lake Superior. In the past it has been expensive to pump, clean, and purify lake water. There are mineral seeps and springs that are critical to moose health; however, most are high in mineral content and would require treatment for human use. Water wells drilled into the underlying aquifer would be economically desirable, but the hydrogeologic characteristics for the park and groundwater aquifer system are not well understood.

Understanding the hydrogeologic system at the park includes knowing how water is traveling through the subsurface for future well siting, and predicting the hydrologic response to inputs such as contaminants and wastes. The movement of nutrients and contaminants through the hydrogeologic system can be modeled by monitoring the composition of system inputs, such as rainfall, and outputs, such as streamflow. Other input sources include wind, surface runoff, groundwater transport, sewage outfalls, landfills, and fill dirt. Streams in effect integrate the surface runoff and groundwater flow of their watersheds. Thus, they provide a cumulative measure of the status of the watershed's hydrologic system. Consistent measurement of these

parameters is crucial to establishing baselines for comparison.

The water table in the park is generally high. Disposal of human waste in shallow privies can contaminate both surface and groundwater. There have been oil spills from boats and facilities as well contamination from lead and other toxic substances on Passage Island, Rock Harbor, Mott Island, Amygdaloidal Island and Windigo. The presence of human wastes, residual PCBs, mercury, and other toxins are a major resource management concern for the park (Scoping participants, oral comm. 2004).

A recent study of annual rainfall at Isle Royale discovered trace amounts of triazine herbicides such as atrazine, deethylatrazine, deisopropylatrazine, cyanazine, and associated metabolites precipitating into soils and water. The predominant westward wind direction carried these airborne contaminants from the upper Midwestern United States. Deep lakes at Isle Royale may have residence times for atrazine that exceed 10 years as opposed to the shallower lakes that promoted faster degradation of the contaminant (Thurman and Cromwell 2000). These contaminants are not yet a threat to the ecosystem, and frequent monitoring of the inland lake waters at Isle Royale would alert resource management to any changes. The pristine nature of the Isle Royale hydrogeologic system makes it ideal to study the nature and quantity of contaminants.

In the mid- 1990's, elevated mercury levels were found in game fish from six of the inland lakes at Isle Royale. This prompted a study to determine the sources of mercury contamination. Originally, bedrock geology was suspected of controlling the mercury concentration in the soil and surface water. However, further investigation revealed mercury concentrations were largely due to airborne deposition. The volcanic rocks had no detectable mercury, but some native copper mineralization had trace amounts (Cannon and Woodruff 1999; Woodruff et al. 2003). Distribution of high mercury concentrations appears to correlate strongly with the presence of organic carbon in the soils, possibly also related to forest fire history. Mercury attaches to organic carbon to form methyl mercury, which is very mobile. Soils burned in 1936 at Isle Royale have low carbon and mercury content compared to unburned areas. Further study may help improve understanding of the distribution of mercury in soils and surficial deposits and contamination of the aquatic system at Isle Royale (Cannon and Woodruff 2000).

Inventory, monitoring, and research suggestions for related issues include:

- Define the influences of bedrock and topography on local watersheds within Isle Royale National Park.
- Map and quantify water in subterranean recharge zones.
- Identify and map the near surface fracture system to help understand surface and groundwater flow regimes.
- Create hydrogeologic models for the park to better manage the groundwater resource and predict the system's response to contamination using wells for hydrogeologic characterization and monitoring.

Other Geologic Issues

Species Isolation

There are many questions regarding species isolation on Isle Royale requiring geologic research. For example, when and how often has the island been isolated from the mainland? During extremely cold seasons, Lake Superior freezes over providing the opportunity for some animals to migrate over ice to the island. In the past Caribou and lynx were on the island, but today it is moose and wolf populations that have been the subject of predator- prey study for many years. This long record of data is invaluable to biologists. Isle Royale has approximately 20 species of mammals compared to 40 present on the mainland. Biological studies have been ongoing at the island because of its isolation and relative lack of human influence.

There are at least 72 species of state- listed plant species (excluding trees) on Isle Royale. These species thrive in the variety of environments including rock openings, rocky shorelines, clearings and beaches, dry bluffs, trails, boreal forest, rocky areas, mixed forests, aquatic areas, bogs, swamps, and burns among others (NPS 2005). Many of these species are rare or uncommon. There are plants native to the Pacific Northwest present on the island. Thus far, it has not been determined why these species are not present on the mainland. One possibility is the unique microclimate and the minimal human influence that exists on the island.

The isolation at Isle Royale can lead to some biological problems for the species present there. Though large in area, the genetic diversity of the animal populations there is limited resulting in inbreeding and perpetuation of weaker genetic traits. The balance between predator and prey and their dependence on specific plant species on the islands can lead to periodic species population collapse.

Inventory, monitoring, and research suggestions for species isolation include:

- Study ancient lake levels and paleoshorelines to determine timing of highstands and lowstands.
- Study paleoclimatic patterns to determine if species isolation correlates with glacial maximums.
- Using genetic data and bathymetry data from Lake Superior, attempt to determine the approximate place of origin and direction of migration for the animal species present at Isle Royale.

Chlorastrolite and Other Mineral Specimens

In addition to the native copper deposits, the geologic units of Isle Royale contain many minerals of interest, including the state gem of Michigan, chlorastrolite, meaning "green star stone" (fig. 2). This mineral is

present as amygdules or vesicular fillings in certain altered lava flows. When weathered out, it appears on some local beaches as pea- sized pebbles. This green gem has a characteristic weathered mosaic or mottled pattern referred to as turtleback (Huber 1975). This gem is actually a variety of the mineral pumpellyite [$Ca_2MgAl_2(SiO_4)(Si_2O_7)(OH)_2 \cdot H_2O$] and is also known as "Isle Royale greenstone." This is somewhat confusing since petrologically, greenstone refers to a rock type composed of the metamorphosed remnants of igneous basalt flows, and is common on Isle Royale.

C.T. Jackson and J.D. Whitney discovered chlorastrolite on Isle Royale in 1847. Raphael Pumpelly later identified it as pumpellyite from a similar mineral first described on the Keweenaw Peninsula in 1825 (Huber 1975). The chlorastrolite variety of pumpellyite might be unique to Isle Royale.

Other significant and interesting minerals on Isle Royale include barite, calcite, chlorite, datolite, epidote, laumontite, natrolite, prehnite, quartz (including several colors of agate), and rare thomsonite (a zeolite). Prehnite, appearing as small pink pebbles, occurs as amygdule fillings, crosscutting veins, fracture filling and as a replacement of other minerals (Huber 1983).

Theft of chlorastrolite and other minerals by collectors is a resource management issue at Isle Royale. In 1997, at a remote site, park rangers found ten large Ziploc bags filled with over 300 pieces of datolite [a semi- precious gemstone - $CaBSiO_4(OH)$] that collectors had found in the shoreline sediments and submerged beaches of Lake Superior. According to the U.S. Attorney's office and Department of the Interior lawyers, mineral collection laws afford protection under National Park Service regulations to submerged Lake Superior mineral resources. Thus, collection of any minerals in Isle Royale National Park is illegal, but no doubt, it continues. Visitors need to be informed of the prohibition against removing any rocks or minerals from the park. Also, increasing patrols, developing interpretive exhibits that discuss the unique minerals of the island and their formation, and investigating local private collections (if possible) may help to eliminate mineral theft.

Wetlands

In nearly every linear parallel valley, low- lying areas are host to wetlands (bogs, swamps, and small ponds). In general, at Isle Royale bogs are unforested and swamps support forests (John Anderton, written comm. 2007). Coring wetlands could provide a wealth of information on the sediment types and distribution, climate changes and patterns, cultural and land use history, and fire history of the island. There is some question as to how potential water well pumping for drinking water and water quality monitoring will affect the springs and wetland areas of the island. Mapping and monitoring water quality and soil characteristics at wetlands can create a baseline record of ecosystem health, useful in understanding future changes.

Recreational Demands

Two goals of the National Park Service are to preserve and protect the natural and cultural resources of each unit and to provide opportunities for visitors to enjoy those resources. Thousands of visitors come to Isle Royale National Park every year to enjoy the bounty of recreational wilderness opportunities. In 2007 there were 15,973 visitors to the park. Visitor activities include hiking, motor boating, kayaking, sailing, canoeing, wildlife viewing, fishing, photography, camping, and picnicking (NPS 2005). Visitors are placing increasing demands on the natural resources of the park. Careful management is necessary to alleviate some of the problems associated with recreational demands and restore damaged areas such as old fire towers, overused trails, and picnic areas. Periodic site investigations by park staff will help identify areas of increased erosion and slope instability.

Many trails, including the Greenstone Ridge Trail, wind through unique biologic and geologic environments in the park. Many of these are fragile and off- trail hiking accelerates their degradation. Associated with hiking, are backcountry camping and picnicking. The park attempts to concentrate the impacts of these forms of recreation in designated areas. Camping in non- designated areas increases the area of impact and places delicate ecosystems at risk. National Park Service wilderness regulations (in accord with the Wilderness Act) place strict restrictions on recreation at Isle Royale.

Figure 2. Chlorastrolite specimens. The largest of these pebbles is approximately one centimeter in diameter. Photo by Roger Weller, Cochise College from http://www.cst.cmich.edu/users/dietr1rv/chlorastrolite.htm (accessed April 22, 2008)

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Isle Royale National Park.

Geology and History Connections

The geology and geologic setting of Isle Royale has heavily influenced its history. Interest in the mineral resources of Isle Royale began as early as 4,000 years ago. Three small pits near Scoville Point indicate that Native Americans found malleable native copper there, useful for making tools and implements to trade as far away as New York, Illinois, and Indiana. For more than 1,000 years (mostly between 800 to 1600), the islands provided Native Americans with materials for tools, animals for food and clothing, and a variety of nuts, berries, and other plants (Edstrom 1994). They came to the island in the summer season, avoiding the area in the winter. It was likely a haven in the midst of Lake Superior's stormy waters as well. By the 1840s, the only Native American presences at Isle Royale were a maple sugaring camp on Sugar Mountain and a seasonal fishing camp on Grace Island.

One of the goals of the park is to preserve historical and archaeological artifacts and features in the area. Maintaining these features often means resisting natural geologic changes, which presents challenges to resource management. Geologic processes such as wave and wind action, chemical weathering, and slope creep are constantly changing the landscape of the park. Wind picks up fine- grained clay, silt, and sand, depositing them in small- scale dune- like features. Also, wind can expose artifacts by winnowing away smaller, obscuring particles. Coastal processes such as longshore drift, wave action, and beach formation constantly alter modern shoreline areas. Surface runoff removes mostly unconsolidated sediments and deposits them in streams and gullies, altering the historical context of the landscape.

The Lake Superior Syncline and Isle Royale Fault

The Lake Superior basin is the result of a combination of a failed continental rift, a geological syncline, and glacial erosion, which preferentially excavated the softer rocks from the middle of the syncline (Mineralogical Society of America (MSA) 2007). The failed continental rift in the middle of the North American craton (The Midcontinent Rift) was active approximately 1.1 billion years ago (Sexton and Henson 1991). The craton is composed of ancient continental crust that has remained more or less stable since the Proterozoic Eon. The approximate trace of the rift extends from northeastern Kansas through Iowa, Minnesota and under Lake Superior. Geophysical evidence suggest there are other segments of the rift that turn south through lower Michigan and perhaps an extension of the rift in Oklahoma.

Normal fault- bounded half grabens characterize the rift system. As rifting proceeded locally, there were two graben- bounding normal faults on either side of the rift: the Keweenaw fault on the eastern side and the Isle Royale fault on the western edge (MSA 2007). The faults bounding the rift area may curve at depth, grading into gently dipping, large crustal detachments that extend into the lower crust of the basin, which thinned significantly during rifting (Cannon et al. 1987; Sexton and Henson 1991).

The sliver of craton between the two bounding normal faults subsided forming a basin. As the craton extended and the basin down- warped, volcanic eruptions emitted thick basalt flows across the basin. Most of these eruptions were subaerial; however, a few pillow lava structures exposed on Isle Royale indicate some underwater eruption (MSA 2007). During quiescent periods between eruptions, erosion of the margins of the basin washed sediments into the basin atop the volcanic rocks. When volcanism proceeded again, basalt flows covered these sediments forming cyclic volcanic-sedimentary layers in the basin. The rift basin accumulated an approximately 20 km (12 miles) thick sequence of volcanics and inter- flow sediments representing one of the deepest such assemblages on earth (Cannon et al. 1987).

The weight of these sediments caused the basin to bow downwards into a synclinal structure. As the syncline subsided and more sediment and volcanic layers were deposited, their weight caused further subsidence (Edstrom 1994). This structure is referred to as the Lake Superior syncline or the Keweenawan basin (fig. 3). At Isle Royale, the entire rock sequence tilted southeast towards the axis of the basin and subsequent erosion has exposed the upturned units on end as individual layers (fig. 4). The dip of these units varies from less than 10° up to 50° (Huber 1973a).

The Lake Superior syncline curves with the surface trace concave to the south following the shape of Lake Superior (Huber 1973a). Deformation along the Isle Royale and Keweenaw faults is responsible for steepening rock strata along the edges of the Lake Superior syncline, thus accentuating the synclinal structure of the basin (fig. 5) (Huber 1973a). This structure is ancient, with stratigraphic thickness of Precambrian age units increasing towards the synclinal axis. This indicates that this structure has been a defined a basin of deposition for a long time (Wolff and Huber 1973; Dickas 1996).

About 30 million years after the continental rift formed, the region experienced compression by the northwest movement of the North American plate accompanying the Grenville orogenic event located several hundred kilometers southeast of Isle Royale. This event involved much of the continental crust in existence at that time. A northern landmass, Laurentia (present- day North America), collided with one or more southern landmasses and island arcs. This compression effectively stopped the rift. The Isle Royale fault, which runs beneath the surface of Lake Superior along the western edge of the island, was reactivated as a thrust fault during this compression. Its upthrown block is to the east of the fault's map trace (Huber 1973a). The Keweenaw fault, which bisects the Keweenaw Peninsula, was also reactivated as a reverse fault.

Glacial Features

In contrast to the alpine glaciers that carved valleys and ridges in areas such as Glacier National Park, the glaciers at Isle Royale were massive, thick, ice sheets that covered millions of acres descending from northern Canada to a terminus south of Lake Superior (fig. 6). Pleistocene glaciation events are commonly divided into four major stages in North America named for the states where deposits of a particular period were first studied or where they are particularly well exposed. These are the Nebraskan, Kansas, Illinoian, and Wisconsinan. These major stages actually represent several advances and retreats – as many as 20 to 30 major glaciations during the Quaternary (John Anderton, written comm. 2007). Glacial ice covered Isle Royale during each major glaciation of the Pleistocene Epoch. Each event overprinted the earlier, leaving little trace. The last major event, part of the Wisconsin glaciation, occurred during the Marquette readvance, approximately 10,025 years ago (Huber 1973b; Woodruff et al. 2003).

Glacial advance and retreat associated with major glaciations are not linear processes, but are rather incremental with smaller pulses of readvance and retreat. During the last major glacial advance at Isle Royale, the overriding glacial ice removed most of the pre- existing surficial debris. This last major glacial advance and retreat event left both depositional and erosional features on the landscape at Isle Royale (Huber 1973b). The glacial retreat event was relatively rapid, leaving a minor amount of glacial debris on the central and eastern portions of the island. Glacial till filled some valleys and smaller depressions, and glacial erratics (large rocks transported on floating ice) are scattered across the island. Till is abundant on the southwest end of the island and mantles most of the bedrock there. Deposits of glacial debris along the ice- margins of the glacier occur on Isle Royale (fig. 7) (Huber 1973b).

Glaciers are powerful agents of erosion, capable of profoundly altering the landscape as they advance and retreat. Glaciers erode primarily by two distinct processes, plucking and abrasion (Dyson 1966). In plucking, the glacier actually quarries out distinct blocks of rock, incorporates these blocks within the ice and transports them as the glacier moves forward. On Isle Royale, the glaciers moved in a trend coincident with the prevailing geologic structure, accentuating the pre-existing valley and ridge topography. This process carved deep ravines through fractured and altered bedrock, especially in the northwest end of the island. Glacial abrasion on Isle Royale is responsible for the rounding, striating, and polishing of the many exposed rock outcrops. Striations reveal that ice movement in the northern part of the island was northeast to southwest; and, across the southern part of the island ice movement was more east to west and oblique to the bedrock unit trends (Woodruff et al. 2003). As with any weathering process, weaker units typically erode away preferentially relative to stronger units. On Isle Royale, exposures of resistant units dominate and only a few weathered and heavily fractured outcrops persist (Huber 1973b).

The ice sheet finally retreated from the Superior Basin between 10,700 to 8,900 years ago creating a thick sequence of glacial lake deposits that records, almost annually, differences in water levels of ancient Lake Agassiz and sedimentation rates (Breckenridge 2004). Lake Agassiz drained eastward into the Lake Superior basin through outlets in the Nipigon basin and Thunder Bay areas, bringing with it distinctive gray lacustrine clays that regionally mark the event (Woodruff et al. 2003). A series of lakes including Lake Minong and Lake Nipissing formed in the Lake Superior basin after the retreat of the ice terminus as described in the ancient shorelines part of the geologic issues section above. The constantly changing water levels of these lakes are recorded as wave- cut benches, cliffs, and beach deposits at Isle Royale. Surficial deposits associated with these lakes arose from reworked glacial debris including granitic rocks from the Canadian Shield and fossiliferous limestone and chert from the Hudson Bay basin (Huber 1973b). Well- developed shoreline deposits indicate periods of relative stability.

Isle Royale as a Natural Laboratory

Preserved by its isolation and generally harsh climate, the environment at Isle Royale National Park allows researchers to all but remove human influence in their studies of the islands (Woodruff et al. 2003). Isle Royale is the single most studied area in the state of Michigan (Edstrom 1994). During the 1950s, an ecosystem model was developed allowing major parameters to be measured directly in the field.

This model linked hydrology, topography, and geology with other ecosystem processes, thereby permitting quantification of biogeochemical cycles and other ecosystem processes sensitive to change. A network of sites for this research includes among other protected areas, Isle Royale National Park. The long- term goal of this research is to obtain increased understanding of ecosystem structure and function and the interrelationships among different facets of the environment.

The primary focus of modern research is on the effects of global change, especially of atmospheric inputs and of climate. In order for this research to be quantifiable, the ecosystem must be studied as an integrated unit. This requires understanding both surficial and subsurface processes, linking these processes to geology and to hydrology. For instance, complex subsurface processes regulate the quality and quantity of nutrients and energy available to the entire ecosystem (Stottlemeyer 2002).

Greenstones

A greenstone is a common name for an assemblage of minerals in a metamorphic rock (typically metamorphosed basalt) that impart a green color to the rock unit. These minerals may include chlorite, actinolite, and/or epidote. Greenstones are prevalent on Isle Royale, forming the backbone of the entire island and many rock outcrops. They are the altered remnants of the Portage Lake Volcanics lava flows.

These lava flows display a relatively limited number of textures based on the distribution, size, and percentage of minerals in the phenocrysts and in the groundmass (or matrix). Some features persisted throughout the change from lava to greenstone including the framework of plagioclase crystals in the groundmass that comprise 60-70% of the total volume. They are randomly oriented, and interlocked creating a mesh- like effect (Rose 1995).

Greenstone Ridge is the highest and longest ridge at Isle Royale. It is named for the distinct metabasalt flow that is up to 240 m (800 ft) thick and is one of several flows that underlie the island and reappear on the Keweenaw Peninsula. Over one billion years old, it is among the largest and thickest known lava flows on the earth.

However, as discussed in the Chlorastrolite and other mineral specimens subsection above, the term greenstone has a double meaning unique to Isle Royale. The other greenstone is the Michigan state gemstone, chlorastrolite, found almost exclusively on the island as pebbles in beach and other shoreline deposits.

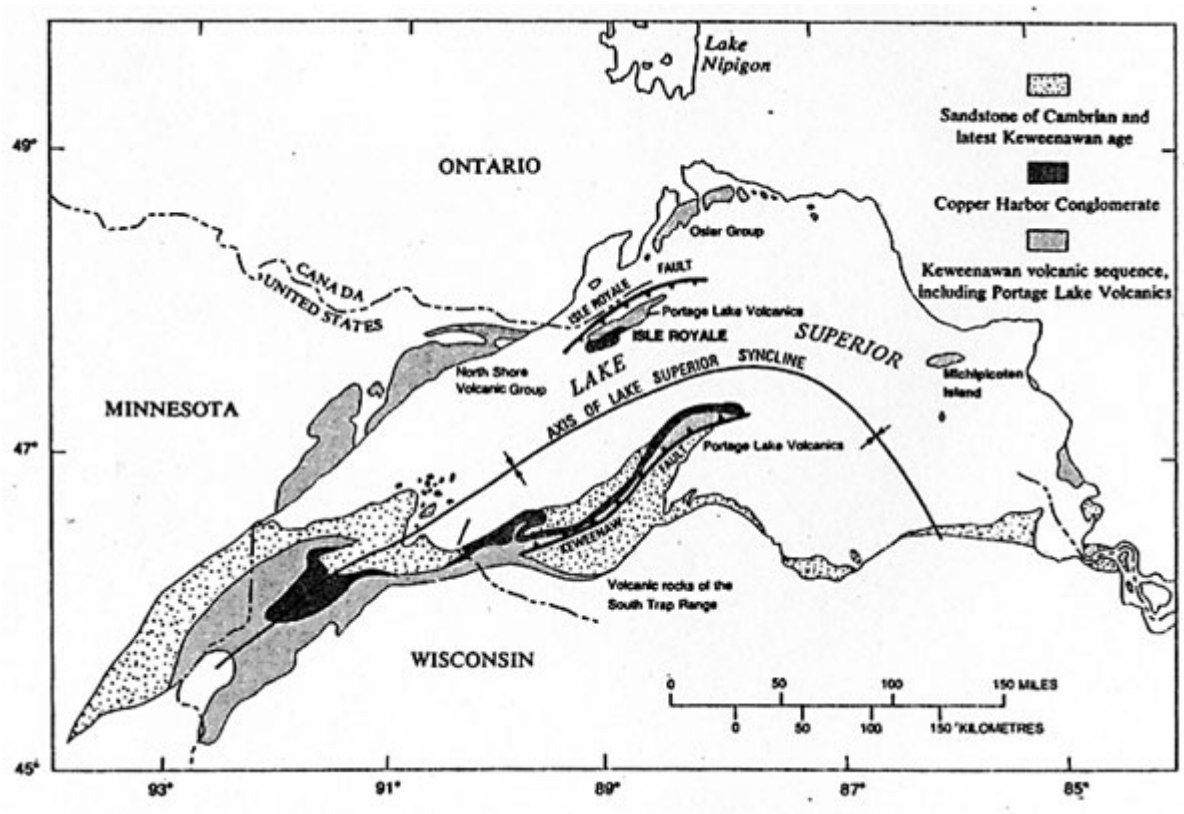

Figure 3. Regional distribution of rock types and geologic structures of the Lake Superior basin. Graphic is from Huber (1975).

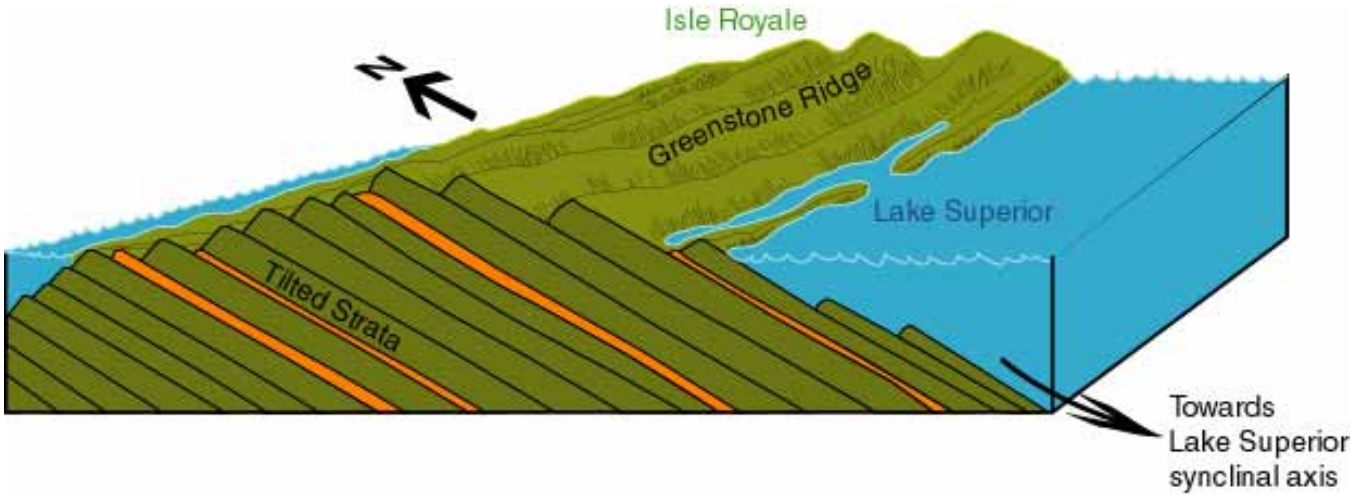

Figure 4. Cross- sectional diagrammatic view of Isle Royale showing strata tilted towards a synclinal axis with ridges of the island defined by the tilted rock unit edges. Graphic adapted from Huber (1973a) by Trista L. Thornberry-Ehrlich (Colorado State University).

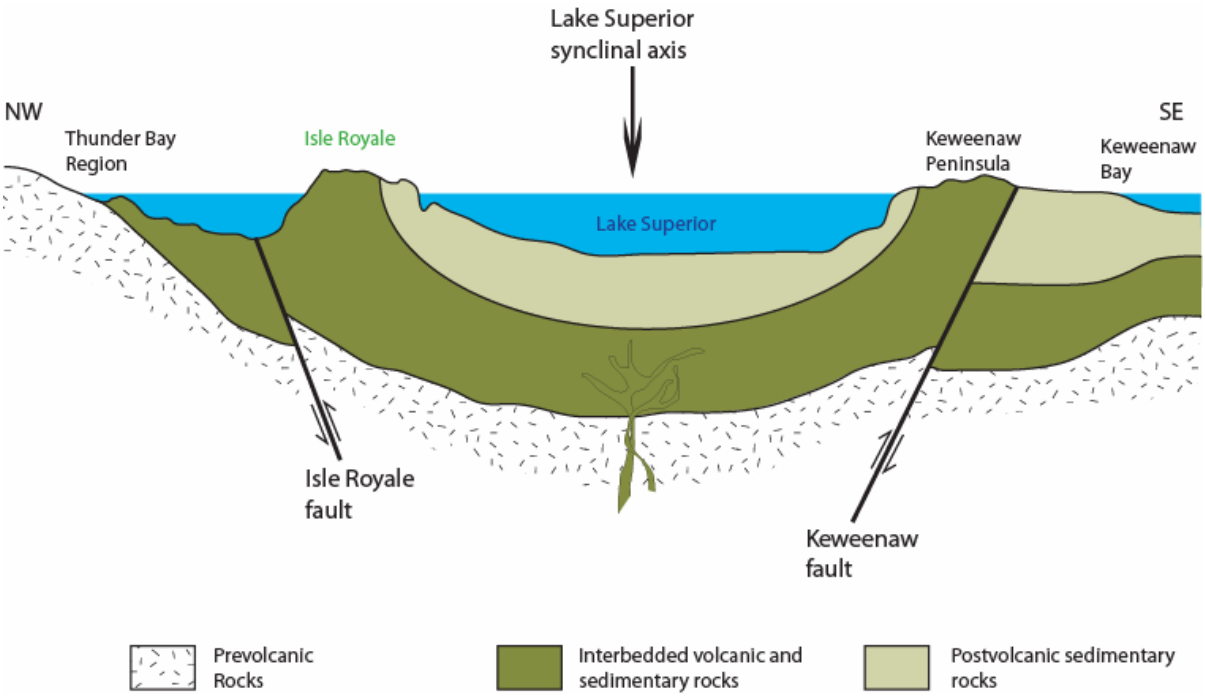

Figure 5: Cross- sectional view of the Lake Superior basin showing basin bounding faults and strata tilted towards the Lake Superior synclinal axis. Diagram is not to scale. Graphic adapted from Huber (1973a) by Trista L. Thornberry-Ehrlich (Colorado State University).

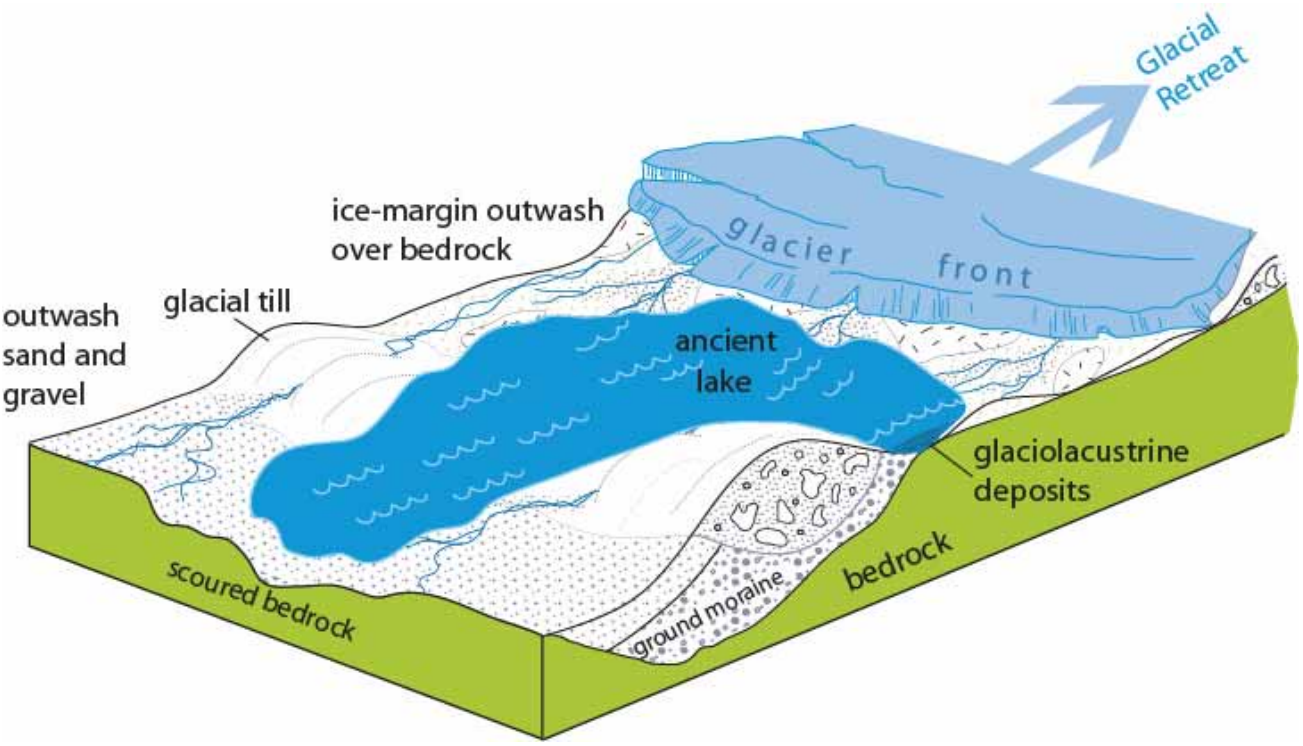

Figure 6. Diagrammatic view of a retreating glacier with scoured bedrock controlling in part the formation of a paleolake. Glacial deposits such as moraines, ice-margin deposits, and glacial till cover the landscape in front of the retreating glacier. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 7. Map showing maximum extent of glacial ice (dark purple line) during Wisconsin event and three later stages (lighter purple-pink lines) during the overall glacial retreat in the Isle Royale area. Note dates on each line and purple arrows indicating direction of glacial movement. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University) from information by Huber (1973b) and John Anderton (written comm. 2007).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of Isle Royale National Park. The accompanying table is highly generalized and is provided for background purposes only. Ground- disturbing activities should not be permitted or denied on the basis of information in this table. More detailed map unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the National Park Service Geologic Resources Division.

The geologic bedrock units exposed at Isle Royale National Park fall into two groups: the Portage Lake Volcanics and the overlying Copper Harbor Conglomerate. Both of these groups are Precambrian in age in a period of time referred to in northern Michigan as the middle Keweenawan (Huber 1973a). The regional Keweenawan group of rocks includes the Precambrian and/or Cambrian Jacobsville Sandstone and Bayfield Group, the Precambrian Freda Sandstone and Nonesuch Shale, the Copper Harbor Conglomerate, Middle Keweenawan major intrusive rocks, a volcanic sequence (locally, the Portage Lake Volcanics), and a Lower Keweenawan sedimentary sequence.

The Portage Lake Volcanic series is mostly comprised of numerous basaltic and andesitic lava flows. There are likely hundreds of individual flows containing porphyritic lavas, meaning large crystals in a fine-grained matrix. Other flows contain ophitic textures characterized by crystals of pyroxene enclosing unoriented plagioclase laths, producing a mottled effect. During major intervolcanic episodes, interbeds of sandstone, conglomerate, and pyroclastic sediments were deposited (Huber 1973a).

The Copper Harbor Conglomerate is a thick wedge of consolidated gravel and sand deposits that overly the Portage Lake Volcanics. These were originally deposited in alluvial fans and flood plains. The clastic materials in these conglomerates were largely derived from older Keweenawan volcanic rocks (pre- Portage Lake), though sandstone and siltstone fragments become more abundant on the eastern edge of the island near Siskiwit Bay (Huber 1973a).

The transition between the two major formations at Isle Royale reflects a gradual cessation of volcanic activity (Wolff and Huber 1973). A major erosional unconformity separates the Copper Harbor Conglomerate from the overlying sediments.

Paleozoic and all but the most recent Cenozoic rock units are missing from Isle Royale National Park. They eroded from the ancient tectonically stable craton (the Canadian Shield) in the vicinity of Isle Royale. The jumbled assortment of rock types, grain sizes, and lack of distinct bedding features characterizes the glacial till deposited on the landscape during the retreat of the last major ice sheets thousands of years ago. Some of these deposits were reworked as talus and beach deposits (Huber 1973a). Deposits of Quaternary alluvium line local river and stream valleys, bogs, wetlands, beaches, and lakes. These consist of unconsolidated clay, silt, sand, pebbles, organic material, and gravel.

Geologic features and processes often occur in or can be restricted to a particular stratigraphic unit (group, formation, or member). This table ties together the geologic features and processes with the properties of the geologic units presented on the accompanying digital geologic map.

Source data for the GRE digital geologic map are from:

Huber, K. 1973a. *Geologic map of Isle Royale National Park, Keweenaw County, Michigan*. Scale 1:62,500.U.S. Geological Survey. Miscellaneous Geologic Investigations Report Map: I- 796.

Huber, K. 1973b. *Glacial and Postglacial Geologic History of Isle Royale National Park, Michigan*. Scale 1:100,000. U.S. Department of the Interior and U.S. Geological Survey. Professional Paper 754- A.

Huber, K. 1983. *The Geologic History of Isle Royale National Park*. U.S. Department of the Interior and U.S. Geological Survey. Formerly U.S Geological Survey Bulletin 1309.

Wolff, R. and Huber K. 1973. *The Copper Harbor Conglomerate (Middle Keweenawan) on Isle Royale, Michigan, and its Regional Implications*. , Scale 1:62,500. U.S. Department of the Interior and U.S. Geological Survey. Professional Paper 754- B.

The following pages present a tabular view of the stratigraphic column and an itemized list of features for each map unit. This sheet includes several properties specific to each unit present in the stratigraphic column including: age, map unit and symbol, description, resistance to erosion, suitability for development, hazards, cultural resources, mineral occurrence, habitat, recreational use potential, and geologic significance.

Map Unit Properties Table

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Development	Hazards	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Global Significance
HOLOCENE	Alluvium (Qal)	Mainly present as lake and stream deposits including modern and elevated beach layers; unit is often mapped as swamps, bogs, and beaver ponds	Low	Suitable for most development unless wetland is present, or unit is exposed on a slope, too porous for waste facilities	Slumps, slides, and slope creep	Native American campsites	Sand, gravel, clay, silt	Unit supports forest, riparian habitat, and wetland areas	Good for most recreation unless near vulnerable wetlands or exposed on slopes	None documented
PLEISTOCENE - HOLOCENE	Talus, slopewash and glacial drift (Qts)	Variety of surficial deposits including glacially transported debris, some elevated beach deposits, mainly present on western third of Isle Royale.	Low	Suitable for most development unless wetland is present, or unit is exposed on a slope, too porous for waste facilities	Slumps, slides, and slope creep	Native American campsites	Beach deposits, loess	Unit supports forests	Good for most recreational uses, unless exposed on slopes	Contains record of last major glacial episode and retreat
PLEISTOCENE	Glacial till (Qg)	Glacial till composed of clays and assorted grain size fragments in ice- margin deposits formed during last ice age retreat.	Low to medium low	Avoid development on this unit if exposed on slope or if clay content is high	Slumps, slides, and slope creep	Native American campsites	Sand, gravel, clay, silt	Unit supports forests	Good for most recreational uses, unless exposed on slopes	Contains record of last major glacial episode
PROTEROZOIC	Copper Harbor Conglomerate: undivided (cu); chiefly conglomerate (cc); boulder and pebble conglomerate (cb); pebble conglomerate (cp); chiefly sandstone (cs)	Interlayered conglomerate and sandstone composed primarily of fragments from felsic (high silica- aluminum) and mafic (low silica, high iron- magnesium) volcanic rocks. cb contains discontinuous beds of reddish pebble conglomerate and sandstone; cp contains arkosic conglomerate in thin to massive beds with interbedded sandstone; cs contains more sandstone interbeds than cp	Medium	Avoid layers with high fracture density and heterogeneity for facilities development	Loose packed, calcite cement between large fragments may render the unit unstable. Highly jointed units may pose rockfall hazard.	None documented	Agates; volcanic rocks including basalt, andesite, trachyte, latite, quartz latite, and rhyolite	Supports northern hardwood forests	Good for most recreational uses unless carbonate cement is degraded rendering outcrops friable	Records vast sedimentary basin during Precambrian transition with underlying volcanics recrods cessation of rifting
PROTEROZOIC	Portage Lake Volcanics: lava flows, undivided (pu); sandstone and conglomerate (psc); pyroclastic rocks (ppP)	Sequences of basalt (mafic) and andesite (more felsic) lava flows interbedded with intervolcanic sedimentary deposits such as sandstone and coarse conglomerates and pyroclastic flows.	Medium to high	Avoid layers with high slopes and high fracture density	If unit is highly fractured and exposed on a slope, rockfall hazards exist	Native American copper mine sites and camps with assorted artifacts	barite, calcite, chlorite, native copper, datolite, epidote, laumontite, natrolite, prehnite, chlorastrolite (pumpellyite), quartz (including agate), and thomsonite	Vesicles and vugs in lava flows may provide nesting – burrow habitat, in NE exposures, units support coniferous boreal forests	Good for most recreational uses unless highly fractured and undercut	Records midcontinental rift environment during the Precambrian age, contains rare minerals such as Michigan state mineral: chlorastrolite
PROTEROZOIC	Flows within Portage Lake Volcanics: Scoville Point Flow (psp); Edwards Island Flow (pei); Middle Point Flow (pmp); Long Island Flow (pli); Tobin Harbor Flow (pth); Washington Island Flow (Pwi)	psp contains blocky plagioclase phenocrysts in a fine-grained matrix; pei & pli have polygonal joints & well-developed columnar structure; pmp is porphyritic with phenocrysts scattered randomly; pth is porphyritic similar to pmp and psp; pwi is an ophite (rocks with crystals of pyroxene enclosing unoriented plagioclase laths) with abundant clots of dark green chlorite and sparse plagioclase phenocrysts (up to 1 cm).	Medium to high	Avoid layers with high slopes and high fracture density	If unit is highly fractured and exposed on a slope, rockfall hazards exist	Native American copper mine sites and camps with assorted artifacts	The Long Island Flow (pli) contains blue agates; native copper in lode deposits and fissure deposits	Vesicles and vugs in lava flows may provide nesting – burrow habitat, in NE exposures, units support coniferous boreal forests	Good for most recreational uses unless highly fractured and undercut	Records midcontinental rift environment during the Precambrian age
PROTEROZOIC	Flows within Portage Lake Volcanics (cont.): Greenstone Flow (pg); Grace Island Flow (pgi); Minong Flow (pm); Huginnin Flow (ph); Hill Point Flow (php); Amygdaloid Island Flow (pai)	pg is a differentiated flow with a coarsely ophitic basal layer, pegmatitic (typically with mat of prominent plagioclase laths) coarse- grained central layer and a medium to finely ophitic upper layer with columnar jointing; pgi is a porphyritic lava flow with clumped lath-shaped plagioclase phenocrysts (2 cm) in a fine- grained matrix; pm contains scattered agates with typical whitish to light bluish tint; ph is a porphyritic lava flow similar to pgi; php is a coarse grained ophite; pai contains abundant reddish agates and coarsely crystalline quartz cores.	Medium to high	Avoid layers with high slopes and high fracture density	If unit is highly fractured and exposed on a slope, rockfall hazards exist	Native American copper mine sites and camps with assorted artifacts	Agate (chalcedony); Amygdaloid Island Flow (pai) contains pinkish agates Native copper in lode deposits and fissure deposits	Vesicles and vugs in lava flows may provide nesting burrow habitat, in NE exposures, units support coniferous boreal forests	Good for most recreational uses unless highly fractured and undercut	Records midcontinent rift environment during the Precambrian

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Isle Royale National Park, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

Archean through Proterozoic

The rock units at Isle Royale record two major sequences of events separated by over 850 million years of the earth's history. The oldest rocks date back to the Proterozoic Era (fig. 8). These are the Keweenawan age sedimentary rocks interbedded with major tholeiitic basaltic lava flows with minor andesite and rhyolite flows within the Portage Lake Volcanics. These flows include the Scoville Point, Edwards Island, Middle Point, Long Island, Washington Island, Greenstone, Grace Island, Minong, Huginnin, Hill Point, and Amygdaloid Island flows (Huber 1975; Woodruff et al. 2003). Absolute ages are between 1,600 Ma and 900 Ma for the Middle Proterozoic lava flows. The youngest units at Isle Royale record the glacial activity during the Pleistocene Epoch. Glacial activity is largely responsible for the significant gap in the rock record, having removed much of the overlying units before depositing an unconsolidated mantle of material over portions of Isle Royale.

Prior to the deposition of the Proterozoic rocks in the Lake Superior region, erosion had beveled the area into a peneplain. The underlying, basement rocks are among the oldest found on earth. These rocks do not crop out on Isle Royale, but appear both north and south of Lake Superior (Huber 1975). The region of northern Wisconsin, northeast Minnesota, and the Upper Peninsula of Michigan, forms part of the Canadian Shield and is the largest surface exposure of Archean and Proterozoic rocks (2.6 to 1.6 billion years old) in the United States (Vigil 2000).

Deformation and metamorphism have obscured many of the original features as well as the complex history of the Archean basement rocks. Shallow seas covered part of the ancient peneplain in which a thick sequence of marine sedimentary rocks were deposited. These units included impure graywackes, sandstone, shale, dolomite, and iron- rich deposits (Huber 1975). Once deposited, they were deformed and metamorphosed into alternating belts of greenstone- granite and gneiss, and subsequently eroded (LaBerge 1994). During the Early Proterozoic, the Archean rocks, composing a large continental mass, fractured into smaller fragments (fig. 9a).

The Middle Proterozoic rocks at Isle Royale, including the Portage Lake Volcanics and the overlying Copper Harbor Conglomerate, are part of the larger Keweenawan Supergroup. In fact, the period of time when these rocks were deposited is locally referred to as the Keweenawan (~1,100 to 1,000 Ma).

The supergroup is divided into lower, middle, and upper parts. Below the Isle Royale units of the middle Keweenawan, are the Bessemer Formation (a basal sandstone and conglomerate), an unnamed volcanic sequence, and dikes and sills of gabbro including the Duluth Complex. Geologists interpret these sediments to have formed in a shallow- water, near- shore environment. At some point during the deposition of the unnamed volcanic sequence, the basin was likely filled and all later Keweenawan deposits are thought to be terrestrial (Huber 1975).

The Portage Lake Volcanics are roughly the upper half of one of the largest deposits of lava ever recorded.These lavas erupted from fissures in a rift system that formed the long axis of an arc- shaped trough in what is now the center of Lake Superior (fig. 9b). This rift was extensive and probably extended southwest at least as far as Kansas, possibly to the Gulf of Mexico, and southeast into the Lower Michigan peninsula (Huber 1975). As the lava continued to erupt, followed intermittently by sedimentary deposition, the rift basin began to subside, both from the weight of the accumulation of deposits and from deflation of the magma chamber supporting the extrusion of the lava (LaBerge 1994).

Basin- wide subsidence continued after the extrusion of lava ceased. Deposited over the basalt flows were the Copper Harbor Conglomerate and younger Keweenawan rocks (sandstones) forming a thick sedimentary rock cap (fig. 9c). The direction of sediment transport was generally northeast to southwest and the sediments were derived from predominantly felsic cobbles and pebbles of the earlier pre- Portage Lake volcanics (Wolff and Huber 1973).

Near the end of the Keweenawan, hot fluids from lower volcanic units likely percolated upwards carrying dissolved minerals. These fluids under pressure altered the overlying rocks and precipitated some interesting secondary minerals in cavities, joints, and fissures at Isle Royale including native copper, chlorastrolite (pumpellyite), prehnite, and agate (Huber 1975 and 1983). Because the lava extruded primarily subaerially, the flows were highly vesicular, making them ideal for secondary mineralization (Woodruff et al. 2003).

The downwarping of the basin altered stream patterns resulting in an inward flow of streams and rivers carrying mostly pebbles and cobbles. The basin thus formed a bowl- shaped syncline, called the Lake Superior syncline, with upturned beds exposed on the Keweenaw Peninsula to the southeast (bedding dips northwest) and on Isle

Royale to the northwest (bedding dipping southeast) (figs. 4- 5). The axis of the syncline trends between Isle Royale and the Keweenaw Peninsula along the length of Lake Superior.

Late Proterozoic through Early Cambrian

The syncline initially formed by subsidence rather than by tectonic compression. During the Late Proterozoic to Early Cambrian (~1,080 to 1,040 Ma) however, a local compressional event reactivated the reverse Isle Royale and Keweenaw faults (previously rift- bounding faults), and steepened the strata near the basin margins, accentuating the synclinal structure (fig. 10a) (Huber 1975; Woodruff et al. 2003).

The rocks on Isle Royale reflect the movement of the Isle Royale thrust fault just west of the island. Strata dip from between 10° and 50° to the southeast, with steeper dips on the north side. The Isle Royale fault pushed up the volcanics, sedimentary interbeds, and conglomerates. When the less resistant sedimentary rocks preferentially eroded into valleys, the volcanics (now metamorphosed to greenstones) formed the elongate ridges along the length of the island (Huber 1973). This fault movement also established the present geologic structure of the Isle Royale, thrusting the resistant volcanic rocks in an elongate ridge surrounded by less resistant sedimentary rocks that eroded away (Huber 1975).

The Missing Record

Erosion beveled most of the craton to a relatively flat surface prior to any Paleozoic, Mesozoic, and Cenozoic age deposition (Huber 1975). As a relatively stable landform, the craton has been exposed to millions of years of continuous erosion. The rocks of the Paleozoic, Mesozoic, and Cenozoic Eras, beginning with the sandstones of the upper part of the Keweenaw Supergroup in the Late Proterozoic to early Cambrian, were either never deposited or were eroded away from the landscape at Isle Royale. The next unit in the rock record is glacial till from the Pleistocene Epoch overlying the Late Proterozoic Copper Harbor Conglomerate leaving a gap (hiatus) of 570 million years as a mystery at Isle Royale.

Surrounding areas give some clues as to the sequence of events for the 570 million years missing from the rock record at Isle Royale. The Lake Superior region, part of the Canadian Shield or craton, has been relatively stable geologically since the Precambrian (Huber 1975). In the Late Cambrian, deposition of a thick sequence of sediments extending to at least the Keweenaw Peninsula in the failed continental rift resulted in subsidence, which developed into the Michigan Basin, presently southeast of Isle Royale.

The Michigan Basin is a typical interior cratonic basin bounded by a series of structural highs including, counterclockwise from the west, the Wisconsin Arch, the Kankakee Arch, the Findlay Arch of Ohio, Algonquin Arch of Ontario, and the Canadian Shield (Dolton 1995). The Michigan Basin has been a depositional center since the beginning of the Paleozoic Era. Sedimentary strata include various types of marine deposits such as dolomites, limestones and mixed calcareous shales interlayered with nearshore deposits such as sandstones, and reefal limestones as well as subaerial deposits including red beds and evaporites (Dolton 1995). Several periods of non- deposition and erosion punctuate the thick deposits of the basin, notably during the Lower Ordovician, Lower Silurian, Lower Devonian, late Mississippian to early Pennsylvanian, and the Permian to Triassic (Dolton 1995). The depositional sequence in the Michigan Basin attests to long- term tectonic stability of the area.

Quaternary Period

Prior to glaciation, broad river valleys occupied the failed continental rift valley and Michigan structural basin. Deformation associated with regional faults may have locally concentrated erosion by rendering the rocks weaker than surrounding areas. These valleys probably also served to exert a major influence on the direction of ice movement, focusing the successive lobes of ice through the topographic lows, and subsequently lowering them even further by glacial erosion

In the Pleistocene Epoch, glacial advance and retreat significantly modified the topography at Isle Royale (fig. 10b). Evidence indicates that glaciers overrode the island during all major Pleistocene advances and the final advance and retreat during the Wisconsin event, called the Marquette readvance (culminating at about 10,025 years ago) obliterated nearly all evidence of the previous episodes on the island. The ice moved generally parallel with the prevailing bedding direction, so pre- existing landforms were accentuated. They scoured out the softer sedimentary rock layers leaving a valley- and- ridge topography, and also left many glacial features such as striations, ice margin deposits such as drumlins, moraines, glacial erratics, and layers of till (concentrated on the southwestern part of the island) (Huber 1973b). When the ice finally retreated from the axis of the basin, it left behind a large trough with Isle Royale remaining a ridge of more resistant rock (fig. 10c) (Huber 1975; Woodruff et al. 2003).

Glacial advance and retreat controlled many of the paleolakes of the Lake Superior region. During warm periods, as the ice melted and the glaciers retreated, the corresponding lake levels rose from the addition of meltwater. Retreating glaciers also uncovered lower outlets for the meltwater that would have the effect of lowering lake levels. Upon the final glacial retreat, isostatic rebound of the Great Lakes region from removal of the enormous weight of the glacial ice resulted in uplift and a relative lowering of water level.

The results of these fluctuations are several tilted paleoshorelines that correlate with certain paleolakes named from oldest to youngest: Lake Duluth, Lakes Washburn and Beaver Bay (~9,800 – 9,700 years before present (B.P.)), Lake Minong (~9,500 B.P), Lake Houghton (~8,000 B.P.), Lake Nipissing (~5,000 – 4,700

B.P) and modern Lake Superior (Huber 1975; McRae et al. 1998). The first glacial lake, the highest at 331 m (1,085 ft) above sea level, was Lake Duluth; this lake is inferred from features around the Lake Superior basin and is not well preserved on Isle Royale (Huber 1973b). Similarly, Lake Houghton paleoshorelines features are submerged in the Isle Royale area (John Anderton, written comm. 2007).

Several of these different paleolakes left shoreline features that are remarkably preserved on Isle Royale, especially Lake Minong and Lake Nipissing (Huber 1975). Examples of these features include a 2 km (~1 mile) long barrier beach near Feldtmann Ridge, some 240 m (800 ft) above the present lake level, probably from Lake Minong. A wave- cut cliff south of Washington Harbor sits at 247 m (810 ft) elevation. Other paleoshoreline landforms include Suzy's Cave, Monument Rock, and Amygdaloidal Arch (John Anderton, written comm. 2007).

The paleoshoreline features possibly associated with Lake Beaver Bay persist around 90 m (300 ft) above the present lake level including a cliff of conglomerate at the west end of Feldtmann Ridge (Huber 1973b). Paleoshorelines appear best developed along the southwest end of the island where unconsolidated glacial till and other reworked glacial moraine and outwash deposits are readily available for the development of beaches, terraces, and wave- cut benches (McRae et al. 1998).

Since the last glacial retreat, weathering and erosion have been active on Isle Royale. Soils developed on the island promoting vegetation including southern boreal forests and northern hardwoods (Edstrom 1994; Woodruff et al. 2003). Sediment is filling glacial ponds and inland lakes (42 of which are named) are shrinking (Edstrom 1994).

Eon	Era	Period	Epoch	Ma		Life Forms	N. American Tectonics
Phanerozoic (Phaneros = "evident"; zoic = "life")	Cenozoic	Quaternary	Holocene	0.01	Age of Mammals	Modern humans	Cascade volcanoes (W)
			Pleistocene	1.8		Extinction of large mammals and birds	Worldwide glaciation
		Tertiary	Pliocene	5.3		Large carnivores	Uplift of Sierra Nevada (W)
			Miocene	23.0		Whales and apes	Linking of N. and S. America
			Oligocene	33.9			Basin-and-Range extension (W)
			Eocene	55.8		Early primates	Laramide Orogeny ends (W)
			Paleocene	65.5			
	Mesozoic	Cretaceous		145.5	Age of Dinosaurs	**Mass extinction** Placental mammals Early flowering plants	Laramide Orogeny (W) Sevier Orogeny (W) Nevadan Orogeny (W)
		Jurassic		199.6		First mammals **Mass extinction** Flying reptiles	Elko Orogeny (W) Breakup of Pangaea begins
		Triassic		251		First dinosaurs	Sonoma Orogeny (W)
	Paleozoic	Permian		299	Age of Amphibians	**Mass extinction** Coal-forming forests diminish	Supercontinent Pangaea intact Ouachita Orogeny (S) Alleghenian (Appalachian) Orogeny (E)
		Pennsylvanian		318.1		Coal-forming swamps Sharks abundant Variety of insects	Ancestral Rocky Mts. (W)
		Mississippian		359.2		First amphibians First reptiles	Antler Orogeny (W)
		Devonian		416	Fishes	**Mass extinction** First forests (evergreens)	Acadian Orogeny (E-NE)
		Silurian		443.7		First land plants	
		Ordovician		488.3	Marine Invertebrates	**Mass extinction** First primitive fish Trilobite maximum Rise of corals	Taconic Orogeny (NE)
		Cambrian		542		Early shelled organisms	Avalonian Orogeny (NE) Extensive oceans cover most of N. America
Proterozoic ("Early life")		Precambrian		2500		First multicelled organisms Jellyfish fossil (670 Ma)	Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
Archean ("Ancient")				≈4000		Early bacteria and algae	Oldest known Earth rocks (≈3.96 billion years ago)
Hadean ("Beneath the Earth")				4600		Origin of life?	Oldest moon rocks (4-4.6 billion years ago) Earth's crust being formed
						Formation of the Earth	

Figure 8: Geologic time scale; adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/). 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.

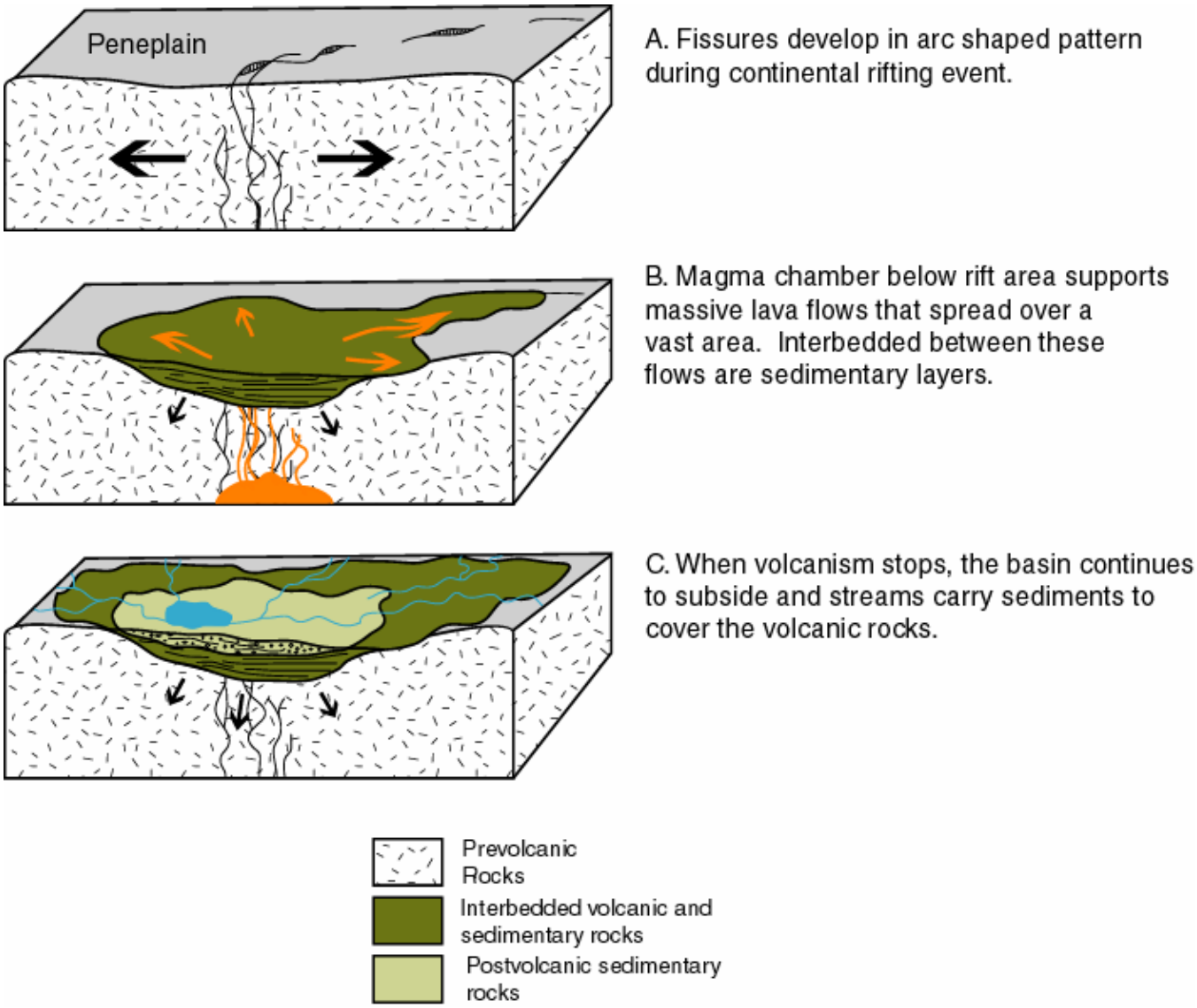

Figure 9a-c. Evolution of the landscape in the Isle Royale area from the Precambrian rifting and volcanism through the early Paleozoic deposition of post-volcanic sediments. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University).

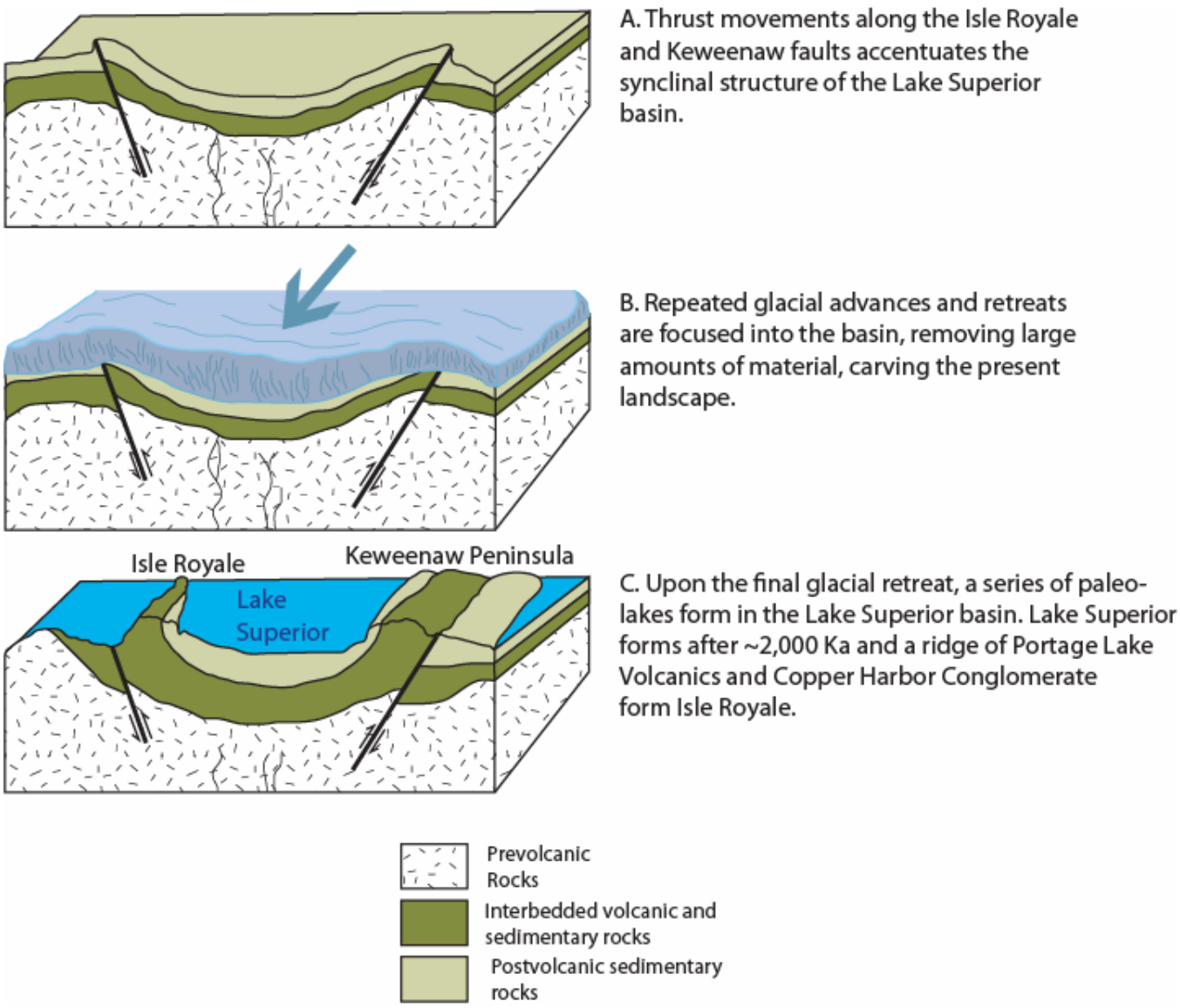

Figure 10a-c: Evolution of the landscape in the Isle Royale area continued from the Late Precambrian – Early Cambrian thrust faulting through the Pleistocene ice ages to the present day landscape. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University).

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.

alluvial fan. A fan- shaped deposit of sediment that accumulates where a high gradient stream flows out of a mountain front into an area of lesser gradient such as a valley.

alluvium. Stream- deposited sediment that is generally rounded, sorted, and stratified.

alpine glacier. A glacier occurring in a mountainous region; also called a valley glacier.

amygdule. A gas cavity or vesicle in an igneous rock which is filled with such secondary minerals as zeolites, calcite, quartz, or chalcedony.

aquifer. Rock or sediment that are sufficiently porous, permeable, and saturated to be useful as a source of water.

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

axis (fold). A straight line approximation that when moved parallel to itself generates the shape of a fold (see and use hingeline)

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.

beach. A gently sloping shoreline covered with sediment, often formed by action of waves and tides.

bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above.

bedrock geology. The geology of underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.

block (fault). A crustal unit bounded by faults, either completely or in part.

chemical weathering. The dissolution or chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances.

clastic. Rock or sediment made of fragments or pre-existing rocks.

clay. Clay minerals or sedimentary fragments the size of clay minerals (<2 cm).

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.

continental shield. A continental block of Earth's crust that has remained relatively stable over a long period of time and has undergone only gentle warping compared to the intense deformation of bordering crust

craton. The relatively old and geologically stable interior of a continent (also see continental shield).

cross-bedding. Uniform to highly- varied sets of inclined sedimentary beds deposited by wind or water that indicate distinctive flow conditions.

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).

dike. A tabular igneous intrusion that cuts across or is at an angle to the orientation of adjacent rocks.

dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.

erratic. A rock fragment carried by glacial ice to a location distant from its original outcrop.

extrusive. Of or pertaining to the eruption of igneous material onto the surface of Earth.

fault. A subplanar break 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.

graben. A down- dropped structural block bounded by steeply- dipping, normal faults (also see horst).

horst. An uplifted structural block bounded by high-angle normal faults.

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.

joint. A semi- planar break in rock without relative movement of rocks on either side of the fracture surface.

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

lava. Magma that has been extruded out onto Earth's surface, both molten and solidified.

magma. Molten rock generated within Earth that is the parent of igneous rocks.

mechanical weathering. The physical breakup of rocks without change in composition (syn: physical weathering).

metamorphism. Literally, "change in form". Metamorphism occurs in rocks with mineral

alteration, genesis, and/or recrystallization from increased heat and pressure.

normal fault. A dip- slip fault in which the hanging wall moves down relative to the footwall.

ophitic. The texture of igneous rocks having plagioclase laths surrounded by pyroxene grains.

orogeny. The tectonic process of mountain building usually accompanied by folding, faulting, thrusting, igneous activity, and metamorphism.

outwash. Glacial sediment transported and deposited by meltwater streams.

pebble. Generally, small, rounded, rock particles from 4 to 64 mm in diameter.

pegmatite. An exceptionally coarse- grained igneous rock with interlocking crystals, often containing rare minerals, derived from the most hydrous portion of a magma.

peneplain. A geomorphic term for a broad area of low topographic relief resulting from long- term, extensive erosion.

pillow lavas. Lavas displaying pillow structures (discontinuous bun- shaped masses) formed by the extrusion of basalt or andesite under water.

pyroclastic. Particles of rock material formed by volcanic explosion or ejection from a volcanic vent; size ranges from ash to large boulders.

rift. A long, continental depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone where extensional forces are pulling the crust apart..

sandstone. Clastic sedimentary rock of predominantly sand- sized grains.

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

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

shale. A clastic sedimentary rock made of clay- sized particles that exhibit parallel splitting properties.

sill. A tabular, igneous intrusion that is concordant with the country rock.

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

siltstone. A variable- lithified sedimentary rock with silt-sized grains.

slump. A generally large, coherent mass movement with a concave- up failure surface and subsequent backward rotation relative to the slope.

strata. Tabular or sheetlike masses or distinct layers (e.g., of rock).

striations. Scratches or lines that are usually parallel formed by the scraping action of glaciers, faults or streams.

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.

suture. The linear zone where two continental landmasses become joined due to obduction.

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

tholeiite. A basalt characterized by the presence of orthopyroxene and/or pigeonite in addition to clinopyroxene and calcic plagioclase. Olivine may be present.

thrust fault. A contractional, dip- slip fault with a shallowly dipping fault surface ($<45^{\circ}$) where the hanging wall moves up and over relative to the footwall.

trace (fault). The exposed intersection of a fault with Earth's surface.

transgression. Landward migration of the sea due to a relative rise in sea level.

trend. The direction or azimuth of elongation or a linear geological feature.

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

unconformity. A surface within sedimentary strata that marks a prolonged period of nondeposition or erosion.

vent. An opening at the surface of Earth where volcanic materials emerge.

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 is a preview or snapshot of the geologic map for Isle Royale National Park. For a poster- size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resource Evaluation publications Web page (http://www.nature.nps.gov/geology/inventory/gre_publications).

Geologic Map of Isle Royale National Park

Geologic Contacts

- known or certain
- approximate
- concealed
- gradational
- shoreline
- shoreline, approximate

Geologic Units

- Qal - alluvium
- Qts - talus, slopewash, and glacial drift
- Qg - glacial till
- cu - Copper Harbor Conglomerate, undivided
- cc - Copper Harbor Conglomerate, chiefly conglomerate
- cb - Copper Harbor Conglomerate, boulder and cobble conglomerate
- cp - Copper Harbor Conglomerate, pebble conglomerate
- cs - Copper Harbor Conglomerate, chiefly sandstone
- pu - Portage Lake Volcanics, lava flows, undivided
- psc - Portage Lake Volcanics, sandstone and conglomerate
- pp - Portage Lake Volcanics, pyroclastic rocks
- psp - Portage Lake Volcanics, Scoville Point Flow
- pel - Portage Lake Volcanics, Edwards Island Flow
- pmp - Portage Lake Volcanics, Middle Point Flow
- pli - Portage Lake Volcanics, Long Island Flow
- pth - Portage Lake Volcanics, Tobin Harbor Flow
- pwi - Portage Lake Volcanics, Washington Island Flow
- pg - Portage Lake Volcanics, Greenstone Flow
- pgi - Portage Lake Volcanics, Grace Island Flow
- pm - Portage Lake Volcanics, Minong Flow
- ph - Portage Lake Volcanics, Huginnin Flow
- php - Portage Lake Volcanics, Hill Point Flow
- pai - Portage Lake Volcanics, Amygdaloid Island Flow
- water

Geologic Attitude and Observation Localities

- strike and dip of beds
- strike and dip of lava flows
- downthrown side of fault

Mine Feature Localities

- prospect pit
- mine shaft
- diamond drill hole

Paleoshorelines

- beach crest, known or certain
- wave-cut cliff, known or certain
- wave-cut cliff, approximate

Glacial Line Features

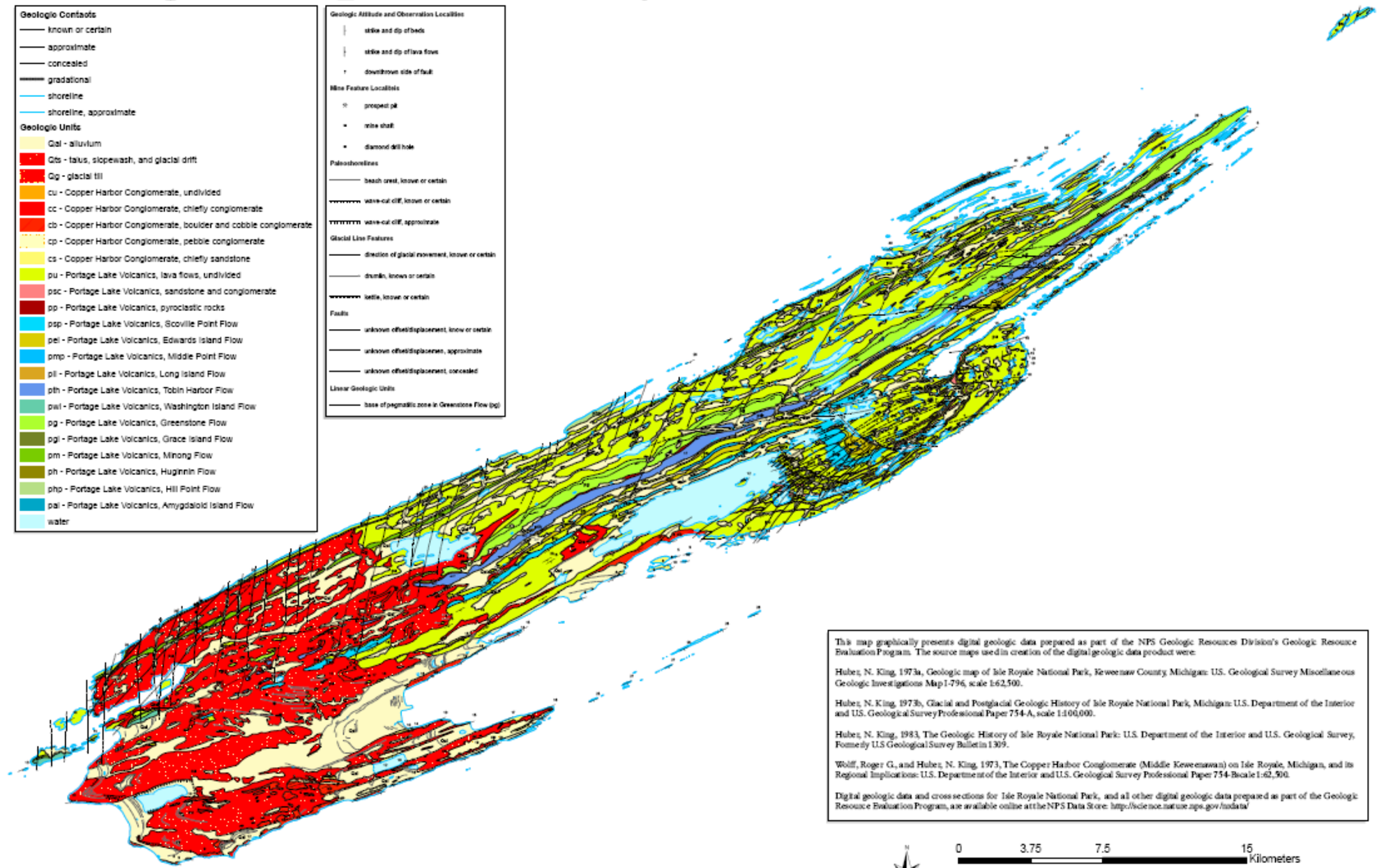
- direction of glacial movement, known or certain
- drumlin, known or certain
- kettle, known or certain

Faults

- unknown offset/displacement, know or certain
- unknown offset/displacement, approximate
- unknown offset/displacement, concealed

Linear Geologic Units

- base of pegmatitic zone in Greenstone Flow (pg)



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:

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Digital geologic data and cross sections for Isle Royale 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/

0 3.75 7.5 15 Kilometers

0 2.5 5 10 Miles

Produced by Geologic Resources Division

May 2008

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Isle Royale National Park. The scoping meeting was on June 16, 2004; therefore, the contact information and Web addresses referred to in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

A Geologic Resource Evaluation scoping meeting for Isle Royale National Park was held at park headquarters on Mott Island June 16, 2004. The scoping meeting participants identified the following as the most significant geologic resources management issues.

1. Park wants to know the submerged geomorphology using lidar and other appropriate techniques.
2. Identify ancient shorelines in an effort to study early history.
3. Identify old mining sites
4. Park would like a new source of drinking water, preferably from a water well.

Introduction

The purpose of the meeting was to discuss the status of geologic mapping in the park, the associated bibliography, and the geologic issues in the park. The products to be derived from the scoping meeting are: (1) Digitized geologic maps covering ISRO; (2) An updated and verified bibliography; (3) A scoping summary (this report); and (4) A Geologic Resources Evaluation Report which brings together all of these products.

There are 19 quads of interest covering Isle Royale National Park. From northeast to southwest they are: Passage Island OE ("Over Edge") North, Passage Island, Rock Harbor Lodge, Belle Harbor, Mott Island, McCargoe Cove, Lake Richie, Lake Richie OE South, Todd Harbor, Malone Bay, Little Todd Harbor, Point Houghton, Point Houghton OE South, Sugar Mountain, Feldtmann Ridge, Windigo, Feldtmann Lake, Windigo OE West, and Feldtmann Lake OE West. Of these, Passage Island OE N, Passage Island, Windigo OE W and Feldtmann Lake OE W are entirely off- shore.

Four known geologic maps cover ISRO, three in 1973 by N. King Huber: map I- 796, scale 1:62,500 (Huber 1973), Professional Paper 754- A, scale 1:120,000 (Huber 1973), and Professional Paper 754- B, scale 1:62,500 (Wolff and Huber 1973). Open- File Report OF- 03- 276, scale 1:100,000, is a map of the bedrock, soil and lichen geochemistry (Woodruff, et al. 2003). The NPS Geologic Resources Division will digitize the Huber map of glacial deposits (Professional Paper 754- A) as well as the I- 796, for basic geologic coverage. By using the two maps together, the locations of the Copper Harbor Conglomerate can be plotted more accurately. A third order soil survey was done in the 1980s and published in June 1991. At present ISRO contracts with Michigan Tech in Houghton to produce all of their data layers for their park. There is also a need to look at available bathymetric data.

Significant Geologic Resource Management Issues at Isle Royale National Park

Identify and study submerged geomorphology

About two- thirds of the park is below lake level. Therefore, it is important to understand the bathymetry and geology of the submerged areas. There are critical fish habitats that need study. USGS maps extend to only 15 feet depth offshore. Many shoals and other fish habitats are not mapped. The method of choice is lidar, which is being used by the Natural Resources Conservation Service (NRCS) for terrestrial studies. lidar can measure through the leaf cover, but the best time for these studies would probably be after the leaves drop but before the first snow – probably September.

Lidar for benthic studies use a different sensor than for soils. Two lasers are used, one infrared (IR) for the surface and one blue- green for the bottom. Cost is estimated to be about $44,000. The Army Corps of Engineers (ACE) in the ENG Shoals Program uses 2mX2m, the highest resolution, down to 150 feet. The cost for this resolution is estimated to be $630,000. For 4mX4m resolution, the cost is estimated at $225,000. The planning, mobilization, and demobilization alone would cost about $65,000. It may be more realistic to survey only the trout spawning areas rather than the whole coast.

Identify ancient shorelines

Identifying and mapping ancient shorelines can not only provide the history of the relative rise and fall of the lake level in response to glaciation, but also pinpoint the location of settlements and human artifacts. Some of this mapping was done by Huber, but much more remains to be done. Huber mapped the paleo- shorelines of glacial Lake Minong and Nipissing, published in USGS Professional Paper 754- A, but only in the southwest part of the park. These areas have a high potential for having archeological sites. Furthermore, Huber apparently was not aware at the time of the "Marquette advance." Soils mapping by the NRCS could complement the surficial map by Huber. The NRCS is prepared to begin the process by late May 2005. John Anderton, Associate Professor of Geography at Northern Michigan University would like to accompany the soil survey either in Fall 2005 or the following year.

The oldest known archeological sites are about 4,000 to 5,000 years old. There could be older sites (8,000 to

9,000 years old) along some Minong shorelines. Some have been found at Thunder Bay, Ontario. These sites could be under water now. Stumps have been found at Grand Island at over 200 feet depth that are believed to be 8,000 years old.

Identify old mining sites

Historic mining, mainly for copper, occurred at three periods in time: 1840s- 1850s, 1870s, and 1890s. There is also evidence that there was some prehistoric mining by Native Americans. Unlike the Keweenaw Peninsula and other areas of the Great Lakes, Isle Royale did not have abundant deposits of copper. Native copper is widely distributed but there are no large lode deposits (Huber 1983). A survey of old mining sites was done in the late 1980s, mostly along trails and near campgrounds, but about 80% of the park is unsurveyed. There is also a need for bat surveys as well.

Two mines of note are the Island Mine and the Minong Mine, both of which were financial failures. The Island Mine is near the west end of Siskiwit Bay. Native copper occurs in the matrix of a conglomerate. At the Minong Mine copper occurs as nodules and irregular masses in fractures in altered rock. About 250 tons of copper was produced from the Minong Mine (Huber 1983).

Water quality and supply

Currently, all drinking water comes from Lake Superior. It is expensive to pump, clean, and purify the water. There are some mineral springs that animals (e.g. moose) use, but most are too high in mineral content. The park would like to put down a water well, but the characteristics of the groundwater aquifer system are not well known. The water table is high and there may be some contamination from human wastes as well as from petroleum spills, especially at Rock Harbor, Mott Island, Amygdaloidal Island and Windigo. There may be residual PCBs, mercury, and other toxins in the surface and groundwater.

Other issues

- Species Isolation: When was the island isolated from the mainland? When Lake Superior freezes over, there is opportunity for some animals to migrate to the island. Once the ice thaws, the animals are isolated. Why are there plants native to the Pacific Northwest on the island? The island used to have caribou and lynx, but now there are more moose and wolves. Populations of some species periodically collapse.
- State Gem: Isle Royale is known as the home of the state gem chlorastrolite, also known as "Isle Royale greenstone." However, this is not greenstone in the petrologic since, but actually a variety of the mineral pumpellyite [$Ca_2MgAl_2(SiO_4)(Si_2O_7)(OH)_2 \cdot H_2O$]. The mineral was discovered on Isle Royale by C.T. Jackson and J.D. Whitney in 1847. It was later identified as pumpellyite from a similar mineral first described on the Keweenaw Peninsula in 1825 by Raphael Pumpelly (Huber 1983). The chlorastrolite variety on Isle Royale has a characteristic mosaic or mottled pattern know as turtleback.

  Since this variety is thought to occur only on Isle Royale, any specimens found elsewhere probably were removed illegally from the island. As visitation to the island increases, specimen theft may become a problem.
- Surface Water Issues: There has been no watershed mapping in ISRO. There is a need for stream profile data as well. Human waste disposal in shallow privies has the potential to contaminate both surface and groundwater. There have been petroleum spills as well as lead contamination (on Passage Island).There is a need to identify and map the near surface fracture system to help understand surface and groundwater flow regimes.
- Wetlands: There has been monitoring of aquatic vegetation in wetlands and no major changes in wetland extent have been observed. No coring of wetlands has been done, even though this could provide a wealth of information on the sediment, climate, cultural, and fire history of the island. How will drawing groundwater affect the springs and wetlands?

Scoping meeting participants

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- Anne Poole, Geologist, NPS, Geologic Resources Division
- Phyllis Green, Superintendent, NPS, Isle Royale National Park
- Jean Battle, Chief, Natural Resources Mgt., NPS, Isle Royale National Park
- Mark Romanski, Biological Technician, NPS, Isle Royale National Park
- John Anderton, Assoc. Professor of Geography, Northern Michigan University

On ferry:

- Liz Valencia, Chief, Cultural Resources Mgt., NPS, Isle Royale National Park

Via conference call:

- Pete Biggam, Soil Scientist, NPS, Natural Res. Information Div.
- Ulf Galvert, GIS Specialist, NPS, Great Lakes Network
- Larry Carey, Soil Scientist, USDA, NRCS

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Isle Royale National Park

Geologic Resource Evaluation Report

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