Geologic Resources Inventory Scoping Summary
Grand Portage National Monument

Prepared by Trista L. Thornberry-Ehrlich
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Geologic Resources Division
National Park Service
US Department of the Interior

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

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

Park and Geologic Setting

Established as a national historic site on September 15, 1951, and redesignated September 2, 1958, Grand Portage National Monument encompasses 287 ha (710 ac) including the 13.7-km (8.5-mi) portage between western Lake Superior at Grand Portage Bay and Fort Charlotte at the Pigeon River in northern Minnesota along the border with Ontario, Canada. The park owns between 30 and 91 m (100 and 300 ft) on either side of the portage trail. There is abundant cooperation between the NPS and the Grand Portage Band of Lake Superior Chippewa (Ojibwe).

The bedrock at Grand Portage consists of Precambrian rocks of two separate ages and types. Much of Grand Portage area is underlain by sedimentary rocks of the Rove Formation, formed about 1.85 billion years ago. At about 1.1 billion years ago, diabase dikes related to igneous activity of the Midcontinent rift were emplaced into the Rove Formation. These dark colored igneous rocks are of two separate generations separated by a short time interval. The oldest are known as the Grand Portage dike swarm and are generally east-trending features no more than a few tens of feet thick. Slightly younger dikes of the Pigeon River swarm are much more voluminous and support the higher ridges of the region such as Mt. Rose and Mt. Josephine. The dikes form a roughly orthogonal array of NE-trending and NW-trending bodies. Bedrock has been eroded by successive glacial advances and the differing resistance to erosion of the two rock types further accentuated the orthogonal topography. With retreat of the final Superior lobe out of the Lake Superior basin about

10,000 years ago, the Grand Portage emerged from a succession of pro-glacial lakes, creating wave-washed sediments, erosional bluffs, and old beaches and bars.

Geologic Mapping for Grand Portage National Monument

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

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

Table 1. GRI Mapping Plan for Grand Portage National Monument

Covered Quadrangles	Relationship to the park	Citation	Format	Assessment	GRI Action
Pigeon Point quadrangle	Covers one QOI – does not intersect park	Mudrey, M.G., Jr., 1977, Geologic map of Pigeon Point quadrangle, Cook County, Minnesota, Minnesota Geological Survey, Miscellaneous Map Series M-36, 1:24000 scale	Paper	Yes	Digitize
The Cascades, Pigeon Point OE N, Pigeon Point, Grand Portage OE N, Grand Portage, and Mineral Center 7.5 minute quadrangles	Covers all of park and QOI	Nicholson, S. et al, 20xx, Bedrock Geologic Map of the Superior Region (unpublished), USGS, 1:100,000 scale.	Digital	Yes - bedrock	Convert to GRI data model – clip to QOI

During the meeting, the following quadrangles of interest (fig. 1) were determined to be necessary for park resource management needs: The Cascades, Pigeon Point OE N, Pigeon Point, Grand Portage OE N, Grand Portage, and Mineral Center 7.5 minute quadrangles.

The only large scale mapping for the area is the map of the Pigeon Point quadrangle (Mudrey, 1977), which covers part of the area of interest but does not intersect the park. Meeting participants concluded that the best bedrock mapping for the area, with regards to coverage and detail, is the

USGS bedrock map of the Superior region (Table 1) that is being produced at 1:100,000 scale by USGS (hopefully available 2011). This map will not only provide the best detail of existing maps for the area, but also contains mapping for the area of interest in Canada. Park personnel requested that the more detailed map of the Pigeon Point quadrangle be included in the GRI GIS data.

Detailed surficial geologic mapping for the area does not exist. Brandon Seitz stated that a contact of his, Brian Phillips, has completed research in the area and might be a possible resource for surficial mapping – Brandon stated he would follow up with Brian Phillips and put him in contact with the GRI. Brandon also conveyed the park's desire to acquire fluvial geomorphologic data for the area, making it clear that more surficial and recent processes mapping is needed. Currently, the GRI is set to digitize and convert data listed in Table 1, when available, and will clip data to the area of interest for Grand Portage National Monument.

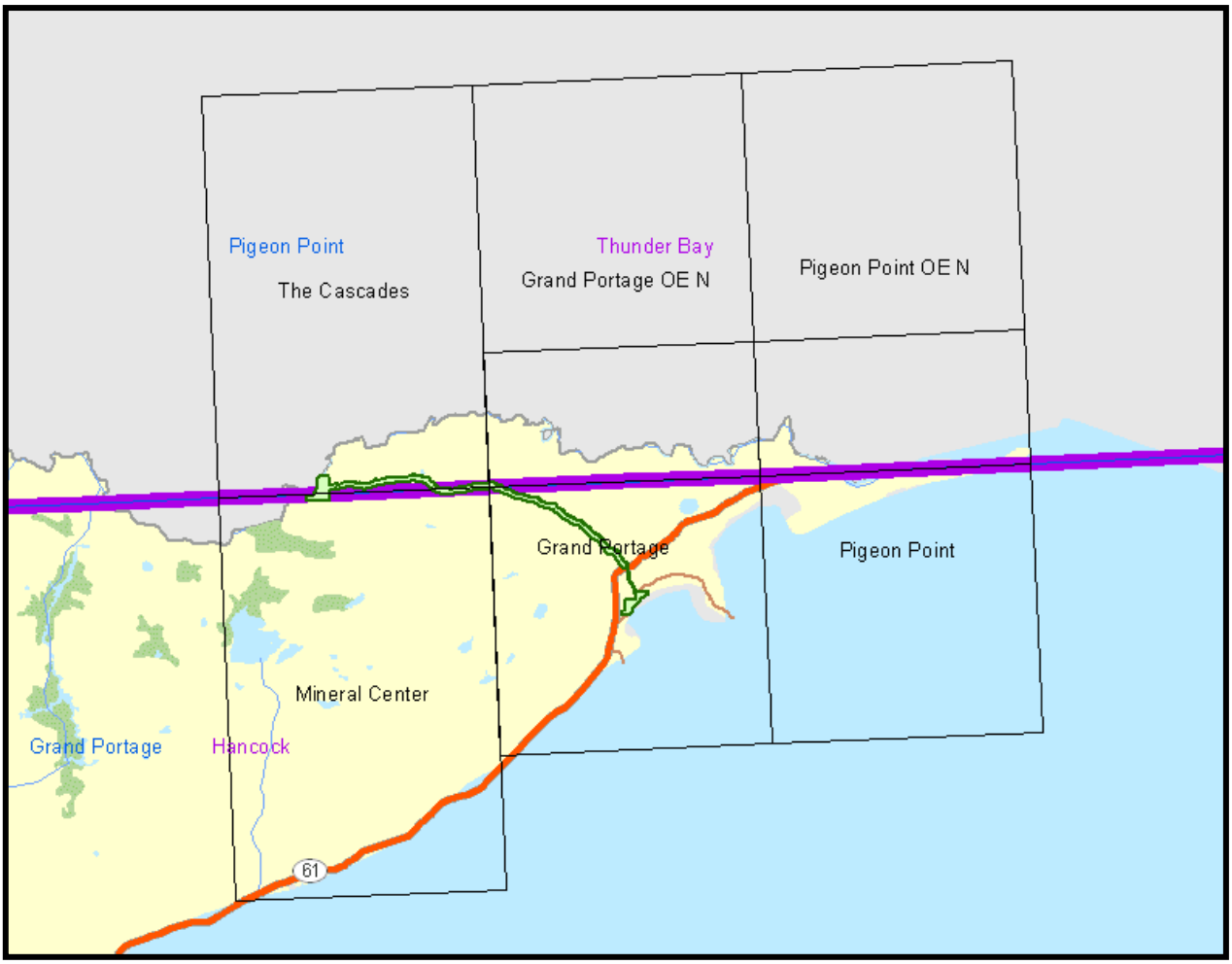

Figure 1. Area of interest for GRPO. 7.5-minute quadrangles are labeled in black; names and lines in blue indicate 30x60-minute quadrangles; 1x2 degree quadrangles shown with purple text and purple boundaries. Green outlines indicate park boundary.

Additionally, the GRI will fund a Geological Society of America GEOCORPS intern to map stream terraces along Grand Portage Creek from its headwaters to Lake Superior. The mapping will be integrated into USGS Water Resources Division shoreline mapping currently in progress.

[September, 2013 Mapping Update – the above mentioned USGS bedrock map of the Superior region remains delayed due to issues relating to mapping on the Canadian side of the border. At the 2011 Geological Society of America (GSA) annual meeting in Minneapolis, MN, USGS geologists recommended using these maps instead for source material:
Mudrey, M.G., Jr., 1977, Geologic Map of Pigeon Point Quadrangle, Cook County, Minnesota, Minnesota Geological Survey, Miscellaneous Map Series M-36, 1:24000 scale (M-36).

Miller, J.D., Jr., Green, J.C., Severson, M.J., Chandler, V.W., and Peterson, D.M., 2001, Geologic Map of the Duluth Complex and Related Rocks, Northeastern Minnesota, Minnesota Geological Survey, Miscellaneous Map Series M-119, 1:200000 scale (M-119).
The GRI program funded a GSA GeoCorps interns in 2011 to map terraces in the park: *Rosenthal, Jeff, 2012, Fluvial Terraces of Grand Portage Creek, Grand Portage National Monument, GeoCorps, 1:24000 scale.*
The GRI team subsequently converted all three of these referenced maps into a GIS and delivered it to the park in June, 2012.
In 2012 the GRI program funded a second GeoCorps intern to lead a field crew in geomorphic assessment of one of the park's principal rivers in 2012. This intern continued to work in the park, and in 2013 was employed as a Physical Scientist for NPS partner the Grand Portage Band of Lake Superior Chippewa.]

Geologic Resource Management Issues

The scoping session for Grand Portage National Monument provided the opportunity to develop a list of geologic features and processes, which will be expanded upon in the final GRI report. During the meeting, participants discussed geologic resource management concerns including shoreline erosion and fluvial features, slope processes, disturbed lands, potential energy and mineral development, and seismicity. The park is in the process of revising its trail guide. Geologic information could add to the interpretive content about the history of the area and the role natural features played in the development and use of Grand Portage.

Shoreline erosion and fluvial features

The park contains 400 m (1,312 ft) of Lake Superior shoreline. Hat Point, a local landmark is just outside park boundaries. The shoreline system has erosional and depositional areas controlled by the interaction between longshore currents, wave action, sediment supply, and incoming streams. Grand Portage Creek runs adjacent to the Grand Portage near its mouth into Lake Superior. This stream experiences seasonal flooding and is causing erosional issues near historic structures as mentioned below. There was a delta into the lake at the mouth of Grand Portage Creek. In 1910, the construction of a road drastically changed the delta. Scraped fill inundated up to one-third of the former deltaic area. Up the shoreline from the creek mouth was a feature called Premiers Point. This featured in circa 1790s historical accounts of the area. It formed from the interaction between longshore erosion, creek flow to create a depositional area that resembles a cobble spit.

The shoreline was the focus on a 1988 erosion mitigation project. The engineering efforts included placement of cobbles, geotex, and plantings. Since that time, the geotex has pillowed out and broken up. The continual movement and interaction of ice and water has reworked many of the structures; once again, the area is in threat from flooding and erosion. At the depot area on Grand Portage Creek, revetments were installed in 1988. These are also in the process of degrading from intense weathering.

Shoreline erosion threatens the fort structure at Grand Portage National Monument. There are also issues with erosion stemming from visitor use and fluvial erosion from Grand Portage Creek. In the 1970s, when fluvial erosion threatened the fort, developers place stone revetments and car-sized rip rap along critical areas to protect the shoreline. The river has since shifted away from this area. The 1933 Civilian Conservation Corps stone bridge on Grand Portage Creek is causing localized eddying and erosion on one side of the structure and may require intervention in the near future. During high flows, the bridge creates a backwater area and mid-channel bar. These features interact with a downstream revetement causing unstable areas along the shoreline. In general, high flows rapidly change the channel morphology and cause a break in grade in the park. The Pigeon River flows through a bedrock channel and is relatively stable. Poplar Creek crosses the portage near the half-way point. This stream has an elevated sediment load due to its course eroding through areas that were clearcut adjacent to the park. Numerous unnamed, often ephemeral tributaries and ravines also cross the portage.

Numerous stream terraces, floodplain areas, and riparian zones flank local waterways at Grand Portage National Monument. Given the amount and variety of land use changes over the last 100 years including logging and grazing, these features are probably not pristine. Erosion is occurring along most streambanks and is the focus of a GRD erosion mitigation case, which will need to be further investigated. According to park staff, infrastructure would be damaged or destroyed if a 30-year flood occurred. Not to be confused with fluvial terraces, there are also glacial lake terraces that formed as glacial lakes flanked the fronts of retreating glaciers during the Pleistocene. These notable features along Grand Portage have red clay and loamy sediment caps.

Slope processes

Mount Rose, underlain by resistant igneous dikes, rises over 91 m (300 ft). On the front side of Mount Rose are accumulations of diabase block talus. The fissile argillite of the Rove Formation also spall off slopes to accumulate as talus at the base of local slopes. The portage crosses many ravines that are prone to mass wasting during seasonal runoff. Some mass wasting could locally threaten American Indian gravesites and funerary objects. A new park building could potentially be damaged during an extreme mass wasting event. The banks along the Grand Portage River are prone to mass wasting. This is threatening part of the original Grand Portage trail (portions of today's trail are not entirely original) where it crosses an enigmatic deltaic area upstream of its mouth into Lake Superior. Here, the park boundary bisects the river bank and only half of the area is inside park boundaries.

Disturbed lands

Because of its long history of human use and occupation, all anthropogenic features including the portage itself could be considered disturbed lands. However, few of these features are targets for remediation, and most are part of the cultural interpretive story at Grand Portage National

Monument. Despite lead and zinc shows in local rocks (the Mineral Center quadrangle is nearby), there are no mines inside the park. Prior to the establishment of the park, the area experienced heavy grazing and logging. Early settlers denuded the landscape in the 1700s, and it was later logged and burned as part of early 1800s settlement. At one time, Mount Rose had no forest on it due to logging. Logging occurred in two phases: one for settlement, and one for commercial enterprises. The local landscape was pastoral with fences and pastures in the early 1900s. Early grazing along the riparian corridor and river terraces left lasting impacts that may still persist today. The park is reclaiming some these areas to a cultural landscape state in the lower portions of the portage. Other areas are naturally revegetating to a forest environment.

Potential energy and mineral development

Though not allowed within the park, energy and mineral development could proceed in surrounding areas and impact natural resources at Grand Portage National Monument. There are currently four or five companies exploring the region for copper, nickel, and platinum group elements (PGEs) in the basal rocks of the Duluth Complex to the south of the portage. Mineral exploration for copper, nickel and PGEs is occurring across the international border in Canada in rocks of a similar age and setting as the rocks at Grand Portage. The area experienced local hydrocarbon exploration in 1992 but nothing of economic significance was identified. Local vermillion deposits, used in paints and cosmetics, may also be a source of mercury.

There is some discussion about the potential to use sedimentary units within the Great Lakes Network for carbon sequestration. This involves injecting condensed carbon dioxide into deep sedimentary rocks for storage. Requirements for this type of operation include some pore space at depth and a suitable impermeable cap layer. Midcontinent rift contains thousands of feet of sedimentary rocks, which are likely unsuitable for carbon sequestration. None of the rocks units in northeastern Minnesota are under consideration for carbon sequestration. The carbon dioxide is generated by coal fired power plants and condensing it requires vast amounts of energy and money.

There is some local discussion about constructing wind farms on ridgetops in the Grand Portage Area and along the Lake Superior shore. This would impact the park's viewshed. Transmission lines from these farms would not be allowed to cross the park.

Seismicity

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

Features and Processes

Geology and history connections

Grand Portage is almost synonymous with a long record of human use. The earliest records include American Indian sites. They would shoot arrows to the top of local cliffs as a game of skill. The Grand Portage Band of the Lake Superior Chippewa (Ojibwe) people still have a prominent presence in the Grand Portage area. There are American Indian gravesites at the park. The area was significantly important to the fur trade from Montreal into the northwestern area of the continent. Historians surmise that the 13.7-km (8.5-mi) Grand Portage (and its annual August Rendezvous) was the single most important fur trade location in North American history. Fur trade traffic funneled through this area because waterfalls on the Pigeon River, a major access waterway to the northwest, made it non-navigable between Lake Superior and the end of the portage at Fort Charlotte. Traditionally, porters had to bring 2 packs, each weighing more than 180 pounds, back and forth on the rough trail. Today, more than 100 people complete the portage with canoes in tow each year. The crossing is difficult with the trail traversing slippery, wet clay areas and boardwalks, tree roots, and significant topography. Mafic dikes within the Precambrian Rove Formation underlie ridges along the trail within the park. As much as possible, the trail stays on the high ground on the western end; however, the remainder of the trail crosses the valleys between diabase dike ridges. Glacial deposits of till and glacio-lacustrine clays fill these valleys. These tend to be marshy and wet areas.

The intrusive igneous rocks of the dikes are more resistant to erosion than the surrounding sedimentary rocks. Resistant, 27-m-high (90-ft-high) diabase dikes underlie Pigeon Falls—the ultimate reason for the development of Grand Portage. The southern portion of the portage follows the trace of the Grand Portage Fault, which may have provided a zone of weakness for preferential weathering and erosion forming a natural passage.

Historians suggest there may be remains of other forts or outposts (possibly from the American Fur Company, or the XY Fort) on park land on the eastern or southwestern side of the monument. The remains may also exist on the Ojibwe Indian Reservation. These archaeological features are still buried and remain to be excavated and/or interpreted.

Paleontological resources

According to the paleontological resource inventory and monitoring report prepared by the Geologic Resources Division for Grand Portage National Monument, the Rove Formation may contain evidence of microorganisms that are among the earliest life forms on Earth. Mysterious “crinoids” have been reported from rocks of the Rove Formation. These cannot be true fossils, but remain a topic of research interest. The park may contain fossiliferous clasts (erratics) in the glacial drift from elsewhere and there may be paleoecological remains such as a pollen record in glacial lake deposits. Paleontological resources may have been a traded material among American Indians locally.

Glacial features

During the Pleistocene, episodic cooler climates led to global glaciation events. Of these, the Illinoian and later Wisconsinan events strongly influenced the development of the landscape in the

Grand Portage National Monument area. Locally, the Rainy lobe (and St. Louis sublobe) descended south from Canada in the west and the Superior lobe excavated the Lake Superior basin in the east. Glacial ice was thicker in the Lake Superior basin and retreated later. Glacial rebound is thus greater there and this results in tilted beaches dipping toward the west. Glacial lobes descending into the Great Lakes area became progressively thinner with distance.

Glaciers left vast deposits till, outwash, and lake clays amidst small bedrock outcrops at Grand Portage National Monument. Ice contact features are visible on the landscape as well. Glacial erratics from the Hudson Bay area dot the park's landscape. These erratics, especially those of Ordovician and Silurian age may contain fossils. The park does not contain any kames or kettles.

A complex series of proglacial lakes formed landward of the large continental glacier during its Pleistocene retreat from northern Minnesota. Locally, the Superior lobe descended south through the Lake Superior basin, blanketing the area beneath a thick sheet of ice. Glacial Lake Duluth, one of a series of progressively lower lakes, formed as this glacier retreated northward. Glacial Lake Duluth collected vast amounts of clay-rich, lacustrine deposits. Resistant diabase dikes persisted as island ridges within the lakes. Glacial lake deposits and subsequent lake terraces occur along the portage. These contain red clay and loamy sediments that crop out as terrace caps. The glacial tills contribute to clay-rich soils locally. An enigmatic, abandoned deltaic fan in the Grand Portage River corridor between Grand Portage Bay and Highway 61 may indicate a higher lake level associated with a particular glacial lake stage. Glacial lake terraces may be a target for interpretation.

Regional geology

The oldest formation present in the Grand Portage area is the Rove Formation, estimated to be about 975 m (3,200 ft) thick. The Rove is a series of graywackes and argillites deposited between 2.0 and 1.7 billion years ago. These units were deposited in deep, quiet waters by a series of tubidite currents. The exact source of the Rove Formation remains enigmatic as paleocurrent information indicates a north to south transport direction; however, dated zircons from the formation are from 1,750 to 1,850 million years ago. The Archean rocks in the area north of Grand Portage are not a suitable source for the Rove, but a southern source would contradict the paleocurrent data.

About 650 million years after deposition of the Rove Formation, upwelling caused by a mantle plume resulted in the development of the Midcontinent rift, a major tectonic feature stretching from Kansas through the Lake Superior region, and into southern Michigan. All the rock units related to the rift are called the Keweenaw Supergroup. The rift developed in three stages over some 50 million years from around 1,100 million years ago to 1,060 million years ago. The first stage was the initial rifting of the continental rocks and accompanying volcanism that spanned close to 14 million years. The rift developed as a central graben (sag basin) bounded on either side by normal faults. Following the end of significant volcanism, the second stage was continued sagging within the rift because of thermal subsidence, with accompanying sedimentation and no volcanism. In the deepest part of the rift under Lake Superior, rift rocks have been imaged nearly to the Moho at 30 km (19 mi), with about 20 km (12 mi) of basalt flows overlain by about 10 km (6 mi) of sediment. The third stage in rift history occurred when the extensional regime shifted to compression at the onset of the Grenville Orogeny (mountain building event) to the east of the rift. This late-stage compressional event, that may have begun about 1,080 million years and culminated about 1,060

million years, changed the sense of motion along the rift-bounding normal fault, and uplifted the central rift graben relative to its flanks.

The diabase dikes swarms that intrude the Rove Formation are related to the Midcontinent rift. The two dike swarms are the Grand Portage diabase dikes and the Pigeon River diabase dikes. The Grand Portage diabase dikes are present throughout the region. This set of dikes cuts rift basalts that are 1,105 million years old and are reversely polarized, which constrains their age to between 1,105 to 1,100 million years. The Pigeon River dikes are younger and normally polarized, which means they must be younger than 1,100 million years, and are probably about 1,095 million years old. Intrusion of both sets of dikes resulted in contact metamorphism of adjacent Rove Formation. Near the contact, the metamorphic mineral assemblage in the Rove is assigned to the pyroxene- and hornblende-hornfels facies. Local pink stringers rich in sodium and containing significant sulfide are the result of introduction of hydrothermal fluids with dike emplacement.

Unique features

Volcanic features within the diabase dikes of the park include chill zones and contact metamorphism with the surrounding Rove Formation. The contact zone contains the mineral cordierite which geologists use to determine the degree of heating of the country rock during the metamorphic event. Some of the dikes display columnar jointing that is visible near the road at the new Visitor Center. The dikes are of two separate generations separated by a short time interval. The oldest, the Grand Portage dike swarm, are generally east-trending features no more than a few tens of feet thick. Slightly younger dikes of the Pigeon River swarm are much more voluminous and support the higher ridges of the region such as Mt. Rose and Mt. Josephine. The dikes form a roughly orthogonal array of NE-trending and NW-trending bodies.

The region surrounding the park contains some local age date and geochemical sampling points. The U.S. Geological Survey will be publishing data from these points on the 2011 map (see mapping plan above). The Rove Formation is notoriously difficult to date, so any age dates available are invaluable to understanding the geologic history of the area.

Recommendations

1. Access the “onegeology” global portal interface.
2. Consult the Minnesota Geological Survey’s website for geologic information (http://www.mngs.umn.edu/index.html).
3. Visit the National Fossil Day (October 13) website prepared in partnership between the NPS and American Geological Institute.
4. Contact the Minnesota Geological Survey and/or the Wisconsin Geological and Natural History Survey for information about potential carbon sequestration operations.

Action Items

1. GRI report author will obtain copy of Dick Ojakangas’ 2009 cross section.

References

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

National Park Service. 2010. Grand Portage National Monument. www.nps.gov/apis (accessed August 15, 2010).

Table 2. Scoping Meeting Participants

Name	Affiliation	Position
Eric Carson	Wisconsin Geological Survey	geologist
Jim Chappell	Colorado State University	geologist
Ulf Gafvert	NPS, GLKN	Data manager
Bruce Heise	NPS, Geologic Resources Division	geologist
Jason Kenworthy	NPS, GRD	report coordinator
Richard Ojakangas	University of Minnesota (Duluth)	geologist
Jamie Robertson	Wisconsin Geological Survey	geologist
Brandon Seitz	NPS, GRPO	Biological science technician
Trista Thornberry-Ehrlich	Colorado State University	geologist
Julie Van Stappen	NPS, APIS	Natural resources branch chief
Laurel Woodruff	USGS	geologist