Geologic Resources Inventory Scoping Summary
Saint Croix National Scenic Riverway

Prepared by Trista L. Thornberry-Ehrlich
August 7, 2010

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 Saint Croix National Scenic Riverway on July 19, 2010 at the headquarters building for Mississippi National River and Recreation Area in St. Paul, Minnesota. A site visit and further scoping discussion occurred at the riverway the following day. 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. Jamie Robertson from the Wisconsin Geological and Natural History Survey presented a brief geologic overview of the park and surrounding area. Participants at the meeting included NPS staff from the park and Geologic Resources Division, geologists from the Minnesota Geological Survey and Wisconsin Geological and Natural History Survey, and cooperators from Colorado State University (see table 2). 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, U.S. Geological Survey, and Minnesota Geological Survey; and cooperators from Colorado State University (see table 2). This scoping summary highlights the GRI scoping meeting for Saint Croix National Scenic Riverway 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

The Saint Croix National Scenic Riverway encompasses 37,534 ha (92,749 ac) of which 16,385 ha (40,487 ac) are Federally owned along 406 km (252 mi) of the Saint Croix River and its tributary, the Namekagon River, to its confluence with the Mississippi River downstream of Minneapolis and St. Paul, Minnesota. The St. Croix National Scenic Riverway was established under two separate pieces of legislation, the upper miles 99.5 miles of the St. Croix between Gordon Dam and the St. Croix Falls Dam and the entire 99.5 miles of the Nameakgon River were established on October 2, 1968. Together they are among the eight original rivers designated under the Wild and Scenic Rivers Act. The lower 52 miles of the St. Croix were designated by a 1972 amendment to the Act. The state governments of Minnesota and Wisconsin manage the lowermost 40 km (25 mi) of the river. The lower 52 miles were designated under the Act for outstanding scenic, aesthetic, recreational, and geologic values. The national scenic riverway contains numerous state and locally owned areas including Saint Croix Boomsite, Saint Croix Islands Wildlife Area, Minnesota and Wisconsin Interstate State Parks, Governor Knowles State Forest, Saint Croix State Park, and many others. Features at the park include the Saint Croix and Namekagon rivers; several smaller tributaries including the mouths of the Trade and Snake rivers; riparian and wetland habitat flanking the waterways; steep bedrock bluffs; broad floodplain areas; dams, landings, and bridges; and cascading rapids and waterfalls.

Bedrock in Wisconsin is from three chapters of geologic history: the Precambrian, Paleozoic (Cambrian through Devonian), and the Cenozoic (Tertiary through Quaternary). At Saint Croix National Scenic Riverway, Cambrian sandstones and Ordovician carbonate rocks dominate the bedrock. The geologic story of this area includes the Midcontinent rift, a failed Precambrian extension event, Paleozoic cover rocks, and much more recent glacial activity during the Pleistocene ice ages. Along the Saint Croix and Namekagon river corridors, there are also driftless areas that display no evidence of glacial ice sitting atop or moving across them. This area of Wisconsin was underneath the Superior Lobe during the last glacial maximum at 18,000 years ago. During glacial retreat approximately 10,000 years ago, a series of proglacial lakes formed at the retreating front of the glaciers. Glacial deposits include moraines, outwash, till, and glacial lake clays.

Geologic Mapping for Saint Croix National Scenic River

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 Saint Croix National Scenic River

Extent	Relationship to the park	Citation	Format	Assessment	GRI Action
Port Wing, Solon Springs, and parts of the Duluth and Sandstone 30x60 quadrangles	Intersects ~14 of the 42 7.5 minute quadrangles that cover the park boundary	Nicholson, S.W., Cannon, W.F., Woodruff, L.G., and Dicken, C.L., 2004, Bedrock geologic map of the Port Wing, Solon Springs, and parts of the Duluth and Sandstone 30' X 60' quadrangles, Wisconsin, U.S. Geological Survey, Open-File Report OF-2004-1303, 1:100000 scale	Digital	Yes - bedrock	Convert into GRI data model
All of Pierce County, Wisconsin	Intersects ~1 of the 42 7.5 minute quadrangles that cover the park boundary	Evans, T.J., Cordua, W.S., and LePain, D.L., 2007, Preliminary geology of the buried bedrock surface, Pierce County, Wisconsin, Wisconsin Geological and Natural History Survey, Wisconsin Open-File Report 2007-08 OF 2007-08, 1:100000 scale	Paper	Yes - bedrock	Digitize
All of Saint Croix County, Wisconsin	Intersects ~3 of the 42 7.5 minute quadrangles that cover the park boundary	LePain, Dave L., 2006, Preliminary Geologic Map of the Buried Bedrock Surface of Saint Croix Co., Wisconsin, Wisconsin Geological and Natural History Survey, Wisconsin Open-File Report 2006-04, 1:100000 scale	Paper	Yes - bedrock	Digitize
All of Chisago County, Minnesota	Intersects ~5 of the 42 7.5 minute quadrangles that cover the park boundary	Boreboom, T.J. and Runkel, A.C., 2009, Bedrock geology of Chisago County, Minnesota, Minnesota Geological Survey, County Atlas Series C-22 Part A, Plate 2, 1:100000 scale	Paper	Yes - bedrock	Digitize
Seven-County Twin Cities Metropolitan Area	Intersects ~5 of the 42 7.5 minute quadrangles that cover the park boundary	Mossler, J.H.; Tipping, R.G., 2000, Bedrock geology and structure of the Seven-County Twin Cities Metropolitan Area, Minnesota, Minnesota Geological Survey, Miscellaneous Map Series M-104, 1:125000 scale	Digital	Yes - bedrock	Convert into GRI data model
All of Pine County, Minnesota	Intersects ~4 of the 42 7.5 minute quadrangles that cover the park boundary	Boerboom, Terrence J., 2001, Geologic atlas of Pine County, Minnesota, Minnesota Geological Survey, County Atlas Series C-13, part A, 1:100000 scale	Digital	Yes – County Atlas, contains both bedrock and surficial data	Convert into GRI data model –
Hastings 30x60 quadrangle	Intersects ~3 of the 42 7.5 minute quadrangles that cover the park boundary	Hobbs, H.C., 1999, Surficial geology of the Hastings 30 x 60 minute quadrangle, Minnesota, Minnesota Geological Survey, Miscellaneous Map Series M-96, 1:100000 scale	Digital	Yes - surficial	Convert into GRI data model – also being converted for MISS – use for both
Stillwater 30x60 quadrangle	Intersects ~4 of the 42 7.5 minute quadrangles that cover the park boundary	Meyer, G.N., 1999, Surficial geology of the Stillwater 30 x 60 minute quadrangle, Minnesota, Minnesota Geological Survey, Miscellaneous Map Series M-95, 1:100000 scale	Digital	Yes - surficial	Convert into GRI data model

Extent	Relationship to the park	Citation	Format	Assessment	GRI Action
All of Saint Croix County, Wisconsin	Intersects ~3 of the 42 7.5 minute quadrangles that cover the park boundary	Koska, S.J., Hinke, H.J., Mickelson, D.M., and Baker, R.W., 2004, Preliminary Quaternary geologic map of Saint Croix County, Wisconsin, Wisconsin Geological and Natural History Survey, Wisconsin Open-File Report 2004-22, 1:62500 scale	Paper	Yes - surficial	Digitize
All of Chisago County, Minnesota	Intersects ~2 of the 42 7.5 minute quadrangles that cover the park boundary	Meyer, G.N., 1993, Quaternary geologic map of Chisago County, Minnesota, Minnesota Geological Survey, Miscellaneous Map Series M-78, 1:100000 scale	Paper	Yes - surficial	Digitize features outside of the Stillwater 30x60 quadrangle
All of Polk County, Wisconsin	Intersects ~3 of the 42 7.5 minute quadrangles that cover the park boundary	Johnson, M.D., 2000, Pleistocene Geology of Polk County, Wisconsin, Wisconsin Geological and Natural History Survey, Bulletin 92, 1:100000 scale	Paper	Yes - surficial	Digitize

During the meeting, the following possible quadrangles of interest were reviewed with regards to park resource management needs: Iverson, Sawyer, Cromwell East, Cromwell West, Wright, Frogner, Wrenshall, Atkinson, Barnum, Cromwell SE, Heikkila Creek, Automba, Delta, Drummond NW, Island Lake, Lake Minnesuing, Bennett, Lyman Lake, Amnicon Lake, Patzau, Foxboro, Holyoke, Nickerson, Hanging Horn Lake, Moose Lake, Kettle River, Ronald, Split Rock Lake, Thor NE, Thor, Marengo Lake, Grand View, Diamond Lake, Drummond, Upper Eau Claire Lake, Ellison Lake, Metzger Lake, Solon Springs, **Buckety Creek**, Empire Swamp, Moose Junction, Black Lake, Holyoke SW, Kerrick, Bruno, Willow River, Denham, Arthyde, Solana, Thor SE, Thor SW, Clam Lake, Namekagon Lake, Lake **Tahkodah**, **Cable**, **Totagatic Lake**, Chittamo NE, Chittamo, Gordon, **Minong Flowage**, **Scovils Lake**, **Dairyland**, Cloverton, Ox Creek, Duxbury, Askov Lookout Tower, Sandstone North, Finlayson, Giese, Kroschel NW, McGrath, Isle, **Seeley**, **Hayward**, **Stanberry East**, Stanberry West, Minong, **Horseshoe Lake**, **Frog Lak**e, **Webb Lake**, **Danbury East**, **Danbury West**, Wilbur Lake, Cloverdale, Sandstone South, Hinckley, Kroschel, Pomroy Lake, Warman, Isle SW, Wahkon South, **Reserve**, **Bean Lake**, **Springbrook**, **Trego**, **Dunn Lake**, McKenzie Lake, Birch Island Lake, Webster, **Yellow Lake**, Monson Lake, **Lake Clayton**, **Saint John's Landing**, Cedar Lake, Beroun, Brook Park, Quamba, Mora North, Ann Lake, Milaca NE, Stone Lake, Potato Lake, Spooner Lake, Spooner, Poquettes Lake, Hertel, Siren East, Siren West, Falun, **Grantsburg**, **Bass Creek**, Pine City, Henriette, Grasston, Mora South, Ogilvie, Bock, Sarona, Shell Lake, Timberland, Indian Creek, Clam Falls, Frederic, Trade Lake, Trade River, **Randall**, **Rush City**, Rush Lake, Braham, Springvale, Dalbo, Cumberland, McKinley, Big Round Lake, Luck, Milltown, **Cushing**, **Sunrise**, **North Branch**, Stark, Cambridge, Turtle Lake, Range, Centuria, **Saint Croix Dalles**, Lindstrom, Stacy, Typo Lake, Isanti, Clayton, Wapogasset Lake, Nye, **Osceola**, **Scandia**, Forest Lake, Linwood, Coon Lake Beach, Graytown, Forest, Deer Park, New Richmond North, **Somerset North**, **Marine On Saint Croix**, Hugo, Centerville, Glenwood City, Emerald, Jewett, New Richmond South, **Somerset South**, **Stillwater**, White Bear Lake East, Baldwin East, Baldwin West, Roberts, **Northline**, **Hudson**, Lake Elmo, Martell, River Falls East, **River Falls**

West, **Prescott**, Saint Paul Park and **Hastings** 7.5 minute quadrangles. 42 quadrangles (shown in bold above) of the total 199 intersect the park boundary (fig. 1).

Sufficient bedrock and surficial mapping required to provide complete coverage for the Saint Croix National Scenic River area of interest does not exist. Additionally, because the Saint Croix River defines part of the boundary between Minnesota and Wisconsin and because most of the mapping in the area is published by the respective state geological surveys, providing mapping coverage for one 7.5 minute quadrangle along the river often requires two different maps.

Meeting participants agreed that providing mapping coverage for the 42 quadrangles that intersect the park boundary (identified in bold above) would be adequate, at least initially, for park needs. Source maps that extend beyond those 42 quadrangles will be included in entirety.

Existing bedrock mapping covers, at 1:100,000 scale, roughly 32 of the 42 7.5 minute quadrangles that intersect the park boundary (fig. 2). Meeting participants and park personnel agreed that 1:100,000 scale bedrock data is adequate for park needs. The holes in geologic mapping are located on the Wisconsin side of the Saint Croix River and are within the Spooner, Grantsburg and Stillwater 30x60 quadrangles. While the Wisconsin Geological and Natural History Survey (WGNHS) has no immediate plan to produce bedrock mapping for those areas, the USGS is currently producing a map of rocks related to the Midcontinent rift that ties into 1:100,000 scale geologic map data which, when published, could potentially fill some or all holes in bedrock mapping for Saint Croix National Scenic River. Currently, a 1:500,000 digital bedrock map that encompasses the entire area is available from the USGS - http://pubs.usgs.gov/of/1997/of97-455/. Alternatively, the northwest sheet for the Geologic Map of Wisconsin (Mudrey, 1987) could fill in mapping holes but, at 1:250,000 scale, this may not match the detail of surrounding 1:100,000 scale data so further review of this dataset is needed.

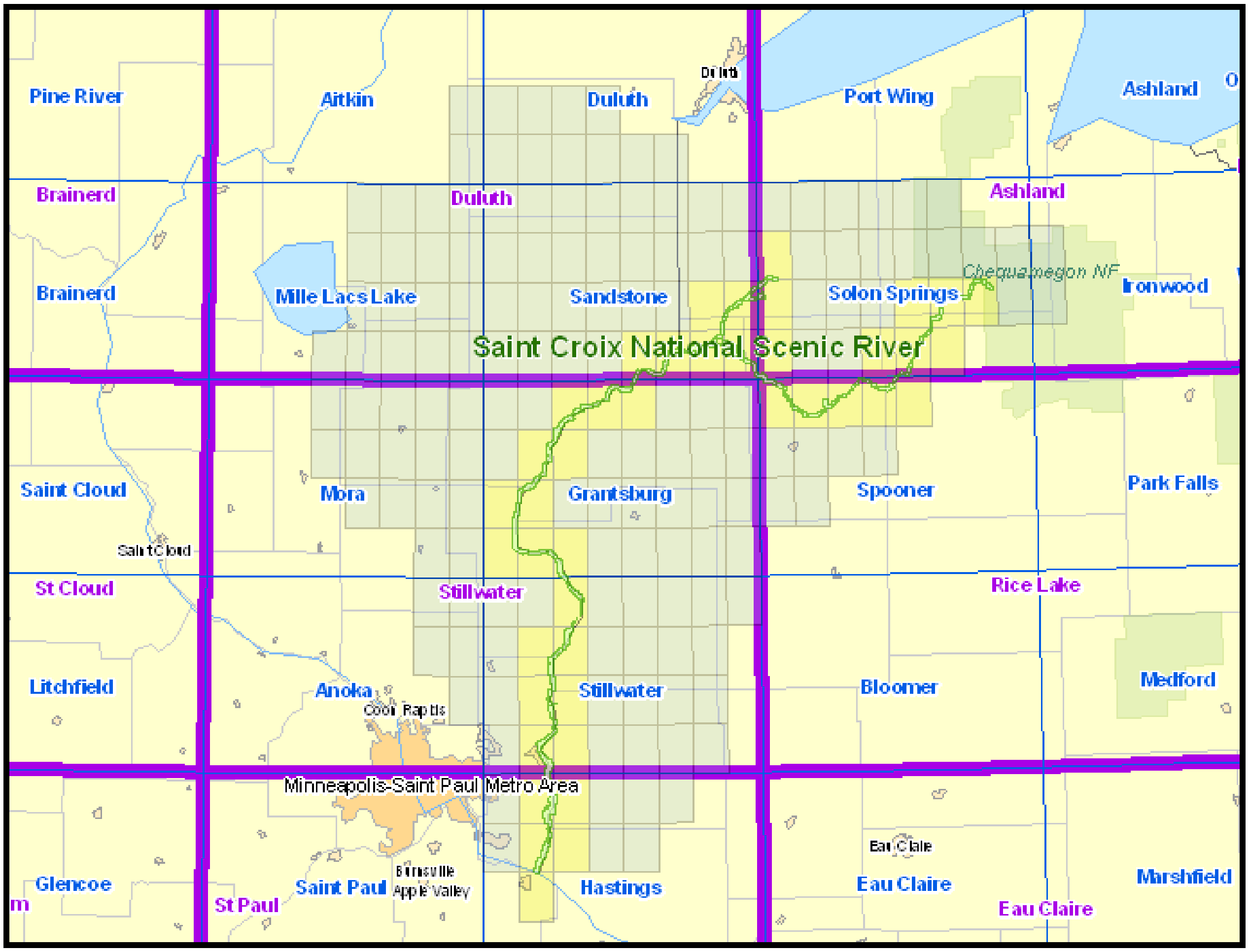

Figure 1. Area of interest for SACN. 7.5-minute quadrangles of interest shown in olive shade with quadrangles that intersect park boundary shown in darker yellow shade; names and lines in blue indicate 30x60-minute quadrangles; 1x2 degree quadrangles shown with purple text and purple boundaries. Green outlines indicate park boundaries.

There is no large scale (greater than 1:100,000 scale) surficial mapping for the Saint Croix National Scenic River area of interest. Existing 1:100,000 scale surficial mapping does not provide complete coverage for the Saint Croix National Scenic River area of interest (fig. 3) and potentially lacks the detail needed for resource management needs at the park. While there are no plans by the WGNHS to provide more detailed surficial mapping for the area, James Robertson (Wisconsin State Geologist) expressed interest in providing a river-mile surficial map for Saint Croix National Scenic River. Further discussion is needed between the WGNHS and the GRI to determine the feasibility of such a project.

The GRI will digitize and convert the mapping data listed in Table 1. Further work is needed to fill holes in mapping coverage that are outlined in this document as well as to explore possible ways to provide more detailed surficial mapping.

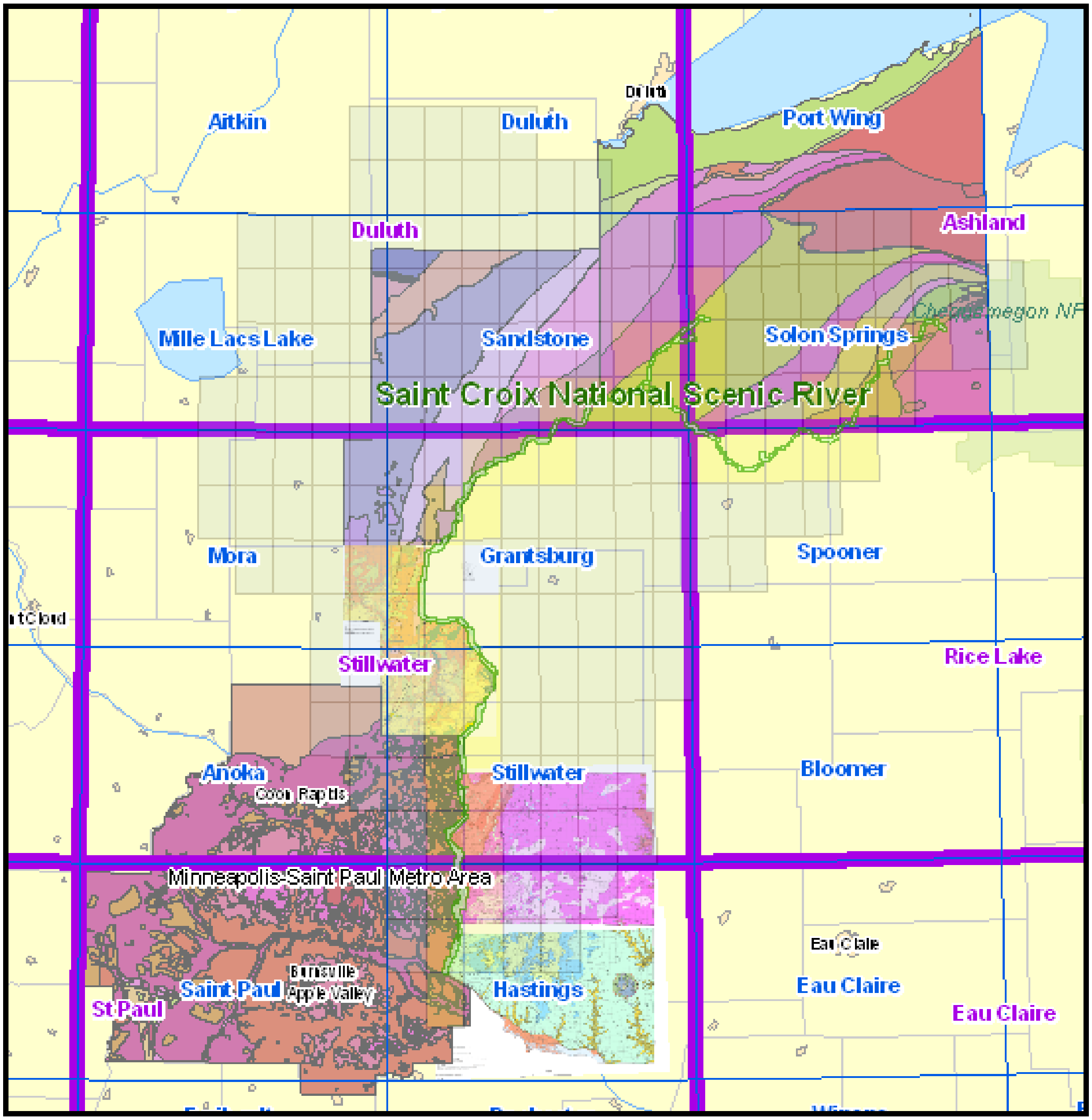

Figure 2. Available 1:100,000 scale bedrock mapping of the Saint Croix National Scenic River area of interest; green outlines indicates park boundary. Note 7.5-minute quadrangles (shaded darker yellow) in the Spooner, Grantsburg and Stillwater 30x60 quadrangles (blue outline, blue text) that intersect the park boundary but do not have associated geologic data.

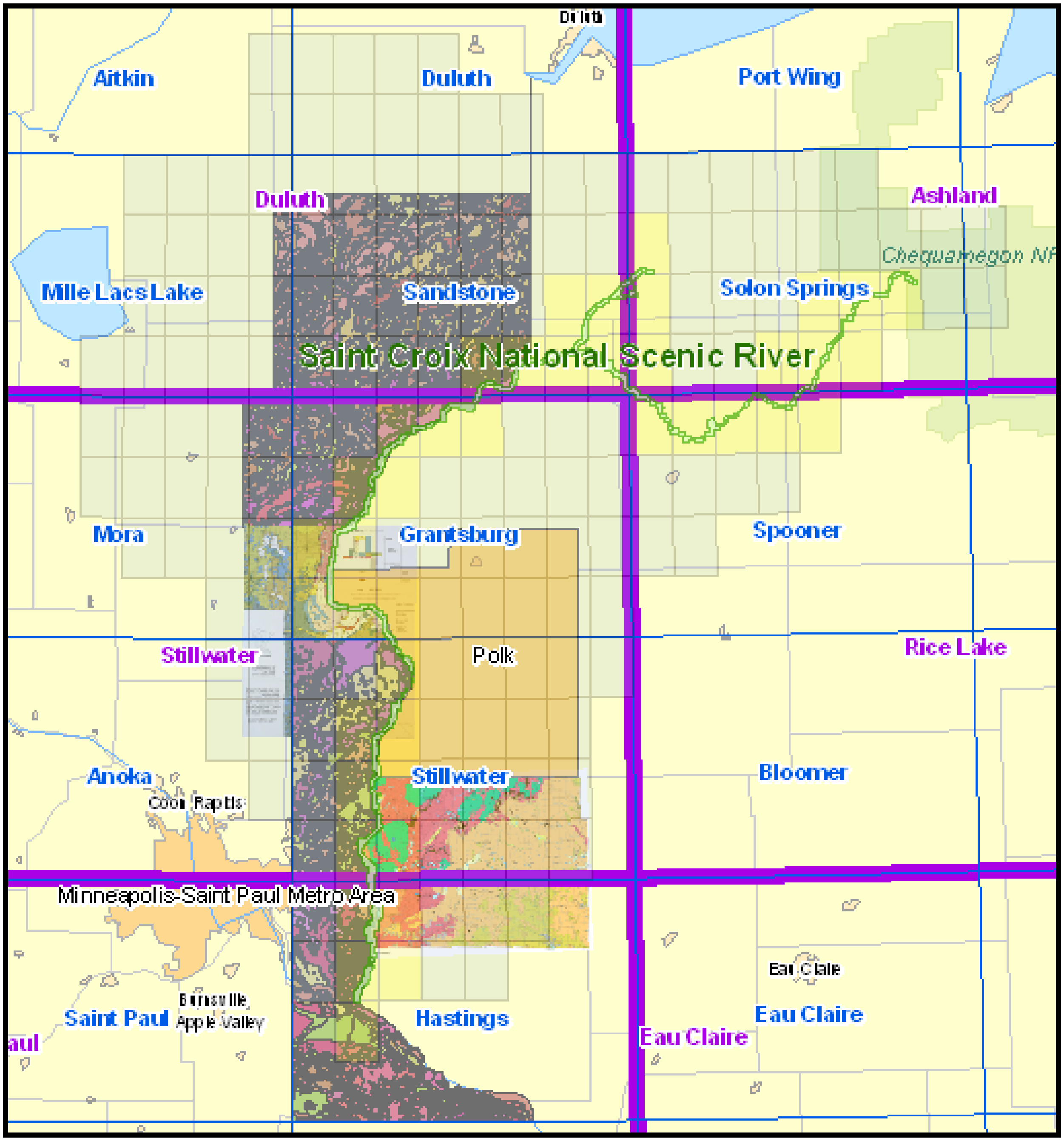

Figure 3. Available 1:100,000 scale surficial mapping of the Saint Croix National Scenic River area of interest; green outlines indicates park boundary. Note 7.5-minute quadrangles (shaded darker yellow) in the Spooner, Grantsburg, Hastings, Solon Springs and Sandstone 30x60 quadrangles (blue outline, blue text) that intersect the park boundary but do not have associated geologic data.

For surficial map coverage, the NRCS soils maps may provide a base from which to interpret some surficial geology of the area. LiDAR data would really aid in this surficial mapping effort. The GRI will investigate the U.S. Geological Survey's surficial U.S.A. 1:5,000,000-scale map (contact: Dave Soller; http://pubs.usgs.gov/ds/425/). The state of Wisconsin has 1:500,000-scale surficial coverage, but will need to determine if it is digital or not.

The park is interested in potentially developing a geologic river log that could be used by visitors (especially those on watercraft) to interpret geologic features of interest along the waterway. The Wisconsin Geological and Natural History Survey's website has a 1:500,000-scale landforms map available for the entire state.

Geologic Resource Management Issues

The scoping session for Saint Croix National Scenic Riverway provided the opportunity to develop a list of geologic features and processes, which will be further explained in the final GRI report. During the meeting, participants prioritized the most significant issues as: fluvial features and processes. Other geologic resource management concerns discussed include slope processes, seismicity, and disturbed lands.

Fluvial features and processes

The Saint Croix and Namekagon rivers and their associated fluvial features such as tributaries, tributary deltas (Apple River splits into 3 channels at its deltaic confluence with the Saint Croix) , terraces, riparian zones, floodplains, sand bars, and flanking bluffs dominate the landscape within Saint Croix National Scenic Riverway. Following three years of low flow and drought, the river water levels are rebounding to normal status. The water quality of the St. Croix and Namekagon rivers is generally good. In fact, the high water quality has resulted in both Wisconsin and Minnesota designating them as "outstanding resource waters," the highest designation possible. There is, however, growing concern about phosphorous and nutrient loading from runoff within the watershed. This is particularly true for the lower reaches of the St. Croix. Some smaller streams have bedload that appears stained bright orange. This type of staining is typical of acid mine drainage, but there are no mines nearby and no sources of the minerals responsible for iron oxide (rust) precipitates. This staining may be due to bacteria, but this remains to be researched.

The rivers vary along their lengths. At Boomsite, the Saint Croix River has a nearly imperceptible current due to the presence of a natural impoundment downstream forming Lake Saint Croix (fig. 4). In the upstream reaches of the lake, depths are approximately 2 to 3 m (8 to 10 ft) deep. Downstream, depths can reach up to 18 to 24 m (60 to 80 ft) deep. Upstream from Boomsite, the Arcola sand bar prevents most power boats from cruising beyond it. Upstream at the Dalles area of Interstate Park, the river narrows and flows through bedrock cliffs and benches (fig. 5). The cliffs are made of basalt flows and the river forms rapids here. A local fault zone may have caused the presence of a sharp bend in the river course at the base of which is a large eddy.

Visitor use of the fluvial resources at Saint Croix National Scenic Riverway is of utmost importance to park resource managers. The park protects one of the most diverse natural mussel populations in the National Park System. (or the most diverse mussel population in the upper Mississippi Basin). There are about 40 different species. Each mussel filters a liter of water per hour making them vital to maintaining high water quality in the park. These native populations are under threat from zebra mussels imported on visitors' boats. These invasive mussels attach to the hard shell of the native mussel and compete for nutrients. Another exotic mussel, imported from the Black Sea, the quauga mussel, feeds on zebra mussels, but could pose on the threats to the ecosystem.

Visitor use of islands within the river is also a source of resource management concern. Heavy visitation of the islands causes devegetation along the shoreline and increased erosion. Between 1 and 2 m (4 and 5 ft) of soil is missing in some areas. The park is using repeat measurements of buried rebar (using metal detectors) to monitor shoreline erosion and soil loss from areas of no traffic, some traffic, and heavy traffic for comparison. Boat wake also contributes locally to erosion along streambanks.

The Saint Croix River and its tributaries periodically flood, inundating flanking riparian zones and floodplains. Picnic areas, campsites, boat landings, and other visitor use facilities along the river corridor are prone to damage during flood events.

Other geologic resource management issues

Slope processes

Hillslope issues at Saint Croix National Scenic Riverway include pervasive erosion, blockfall, and slumping. At a rest area near Boomsite, steep bluffs of Tunnel City Formation sandstone flank a narrow riparian zone along the river. This outcrop exhibits trace fossil burrows, crossbeds (deposited in an old tidal flat environment), and honeycomb weathering (fig. 6). Weathering along joints is creating local zones of weakness potentially prone to blockfall. Along the Potholes Trail at Interstate State Park, rock climbers frequent the steep, sheer cliffs for recreation. At a formation known as Devil's Oven, rock bolts are in place to prevent the rock from falling. Certain hazards may be associated with these sheer cliffs including blockfall and landslides.

Minor slope failures and sloughing occur all along the river corridor especially during spring thaw and high precipitation events. Rockfall and slumping near roads is exacerbated when developers remove the talus toe at the base of the slope. Park managers do not consider the ongoing slope processes at the park to be a threat to infrastructure or visitor safety.

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 fractures that cross the state in the subsurface. In 1994, near Wilmer, Minnesota, a magnitude-3.5 earthquake occurred. Otherwise there is very little seismicity locally. 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).

Disturbed lands

Many portions of the landscape within the park are reclaimed homesteads, cabin sites, and other anthropogenic features, including landings, which could be considered disturbed lands. However, few of these features are targets for remediation. There are enigmatic pits on the upper Namekagon River that might have been copper prospecting pits or early American Indian excavations. There are several active sand and gravel pits, early copper mine features, and clay mines (yellow and red clays excavated at Paint Mine were used for paint color). Active quarries are excavating high glacial outwash areas and can create dust, noise, and excess sediment.

Figure 4. Lake Saint Croix near Boomsite. View is to the south. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 5. The Dalles area on the Saint Croix River at Interstate State Park. View is to the east. Note the presence of a gap in the cliffs that may represent a fault zone, which influenced the sharp bend in the river here. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 6. Honeycomb weathering in steep sandstone bluffs near Boomsite along the Saint Croix River. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Features and Processes

Fluvial system evolution

The evolution of the Saint Croix River system is closely tied to the glacial history of the area. Prior to glaciation, the presence of a buried bedrock valley attests to a river draining eastern Minnesota. A sublobe of the Des Moines glacial lobe (the Grantsburg lobe) dammed this early eastward course. The present, relatively young Saint Croix River course formed as that ice receded and flow southward was restored. A series of proglacial lakes formed landward of the large continental glacier during its Pleistocene retreat from central Wisconsin. Locally, the Superior lobe descended south from the Lake Superior basin and Canada, blanketing the area beneath a thick sheet of ice. Glacial Lake Duluth influenced the location of Glacial River Saint Croix as it was the lake's outlet prior to the opening of the modern outlet on the eastern end of Lake Superior. This glacial lake formed at 335 m (1,100 ft) above sea level approximately 9,900 years ago. Its outlet was at Bois Brule into the Brule River (the modern headwaters of the Saint Croix River). When sequential outlets were lowered by even a single foot, many acres of water flooded down the glacial river channels. Glacial Lake Duluth left a series of sloped abandoned lakeshores around Lake Superior.

For some of its length, the Saint Croix River flows through a pre-glacial buried bedrock valley. It appears to be underfit, or a small river within a broad valley. Because the river underfits its valley, broad riparian and floodplain zones flank certain stretches. Thick sediments fill the valley and the river is currently downcutting through these thick units. It is unlikely one large river ever entirely filled this large valley with a single channel. More likely, it probably contained a series of sediment-laden, braided stream systems that were typical after the glacial maximum.

Lacustrine features

Lacustrine features of myriad scales exist along the river corridors within Saint Croix National Scenic Riverway including Lake Pacwawong. Some dammed stretches exist along the rivers impounding lakes including Trego Lake, Hayward Lake, and Indianhead Flowage. These lakes provide habitat for trumpeter swans and bald eagles, and suitable substrate for growing wild rice. Wetlands and bogs flank the rivers along broad riparian zones. Cutoff meanders and back channels are ephemeral lacustrine features formed by the natural migration of the river within its valley. Kettle ponds frequently appear along the Namekagon River; however, most of these are already filled in with sediment.

Caves and karst features

Humans have long excavated cavities in the soft, friable sandstones that crop out along rivers such as the Saint Croix and Mississippi rivers. Some of these cavities were originally quarries for sand to make glass; other caves were used for cold storage. A manmade cave exists at the base of bluffs in the Tunnel City Formation sandstone near the rest stop upstream from Boomsite (fig. 7). This was a mid-1800s winter shelter. Knapps Cave, on the Cedar Bend stretch of the St. Croix River, is the second most frequently visited cave in the park area behind the manmade cave. There is also a natural cave about 19 km (12 mi) upstream from the manmade cave. Locally, caves developed in sandstone tend to be relatively small and primarily present along preexisting fracture zones. These cavities provide bat habitat and are largely hidden from view of the river.

Karst topography is a landscape created by dissolution of rock by groundwater. Rocks considered especially prone to karst processes include soluble limestone. Karst features can include caves, sinkholes, springs, and sinking streams. Karst processes can cause sinkholes to form that may impact roads, buildings, and other infrastructure. Karst features can also strongly affect the hydrogeologic system by funneling runoff and stream flow underground through vast networks of conduits. Along the Saint Croix Rivers, karst development seems restricted to the upland areas.

Paleontological resources

According to the paleontological resource inventory and monitoring report prepared by the Geologic Resources Division for Saint Croix National Scenic Riverway, the park contains fossiliferous bedrock units. There are Paleozoic rocks exposed throughout the park area and Pleistocene glacial deposits that have the potential to host fossil remains. Near Taylors Falls, outcrops of a basalt boulder conglomerate in a Cambrian sandstone matrix contain trilobite and brachiopod fossils. There are trace fossil burrows in the Paleozoic sandstones near Boomsite. The Curtain Falls area has notable fossil resources as does the area near the Sooline Railroad High Bridge. North of Stillwater, there are cliffs of fossiliferous Jordan Sandstone. Typical fossils found in the Paleozoic rocks include brachiopods, trilobite hash, assorted fragments, and trace fossils (burrows).

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 Saint Croix National Scenic Riverway area. The Grantsburg sublobe of the Des Moines lobe deposited a vast moraine deposit. The Saint Croix River gives its name to the Saint Croix moraine that runs through St. Paul near the mouth of the Saint Croix River. Moraines, till, glacial lake deposits and outwash underlie much of the park area. Kettles (most of which are filled with sediment) exist along the Namekagon River corridor. Two glacial tills—a lower red till sourced from the Lake Superior basin, and an older, underlying gray till sourced from the northwest in Manitoba and transported by the Grantsburg sublobe of the Des Moines lobe—exist throughout much of the park area. There are relict permafrost features in the park including probable ice wedge casts. Other glacial features include eskers; potholes (many of which are scoured in ancient basalt flows at Interstate State Park, see fig. 8); widespread erratics; dunes at the mouth of the Namekagon; and a kame at Mt. Telemark (outside of the park). Glacial lake beds and terraces including meanders, are present throughout the area. In certain areas, glacial sediments containing varved layers are exposed.

Aeolian features

Aeolian features at Saint Croix National Scenic Riverway include some dunes derived from sediments of Glacial Lake Grantsburg. These dunes were active during the Pleistocene and today are totally vegetated and stable. At Saint Croix State Park (Kettle River confluence), studies of the depositional environment indicate paleo-aeolian features within the Bayfield Group. There may be some windblown silt (loess) deposits covering isolated areas on glacial outwash. These types of deposits formed prior to extensive revegetation following glacial retreat. They are easily eroded and do not crop out on bluffs as at nearby Mississippi National River and Recreation Area.

Midcontinent rift

During the Precambrian, upwelling caused by a mantle plume resulted in the development of the Midcontinent rift, a major tectonic feature stretching from Kansas through the Lake Superior region, and into southern Michigan. All the rock units related to the rift are called the Keweenaw Supergroup. The rift developed in three stages over some 50 million years from around 1100 million years ago to 1060 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 series of centrals graben (sag basins) bounded by normal faults. Following the end of significant volcanism, the second stage was continued sagging within the rift because of thermal subsidence, with accompanying sedimentation and no volcanism. In the deepest part of the rift under Lake Superior, rift rocks have been imaged nearly to the Moho at 30 km (19 mi), with about 20 km of basalt flows overlain by about 10 km of sediment. The third stage in rift history occurred when the extensional regime shifted to compression at the onset of the Grenville Orogeny (mountain building event) to the east of the rift. This late-stage compressional event, that may have begun about 1080 million years and culminated about 1060 million years, changed the sense of motion along the rift-bounding normal faults, and uplifted the central rift grabens relative to their flanks.

Volcanism within the central rift basin began with voluminous eruptions of molten rock (basaltic magma) at about 1109 million years with waning activity lasting until about 1086 million years ago. Large volumes of magma erupted as lava flows from vents along the center of the rift, spreading laterally towards the rift margins. The earliest lavas are the basalts of the Powder Mill Group (1108 to 1099 Ma), overlain by basalts of the Bergland Group (1099 to 1086 Ma), which includes the Portage Lake Volcanics in Michigan and the Chengwatana Volcanics in Wisconsin. One flow, the Greenstone flow dated at 1094 million years, is more than 305 m (1,000 ft) thick and can be traced for approximately 80 km (50 mi) across the Lake Superior basin. Thick sedimentary units, including sandstone, conglomerate, and shale, overlie the volcanics within and adjacent to the rift basins. These sedimentary units are the interbasinal Oronto Group (Copper Harbor Conglomerate, Nonesuch Formation, and Freda Sandstone) and the extrabasinal redbeds of the Bayfield Group (Orienta, Devils Island, and Chequamegon formations).This sedimentary section in general fines upwards as the slopes and sediment supply from surrounding areas decreased.

Along the Saint Croix River, basalts of the Clam Falls Volcanics (equivalent to the Chengwatana Volcanics) are exposed. In several particular areas such as Taylors Falls and the greater Interstate Park area, outcrops contain evidence of Cambrian, marine shore sediments lapping onto Precambrian lava cliffs (highlands or islands). These so-called basalt “islands” crop out at Wisconsin’s Interstate State Park. During high energy events, blocks of basalt spalled off the cliffs and tumbled down to the Cambrian shoreline below. These exposures consist of large, rounded blocks of basalt in a Cambrian fine-grained, sandy matrix (fig. 9). The matrix contains some brachiopod fossils. These clast-supported exposures exist along the Saint Croix River because during the Cambrian, the local sea was deeper with infrequent storms and some hospitable areas for life to flourish. More shallow areas would have experienced more frequent storms (high energy events) and less hospitable conditions to support life or preserve fossils.

Unique features

The basalt conglomerate in the Cambrian sandstone is one of the very few places in North America where conglomerate marks the base of the Upper Cambrian era.

At Interstate State Park, the Pothole Trail winds amongst massive potholes in basalt scoured by rocks and eddies during extremely high flow events associated with draining Glacial Lake Duluth. Some potholes are more than 3 m (10 ft) across and tens of meters deep. They contain an invaluable paleoclimate record stored in the pollen and other organic sediments trapped within them over the centuries.

These massive basalt flows become more vesicular towards their tops as lavas degassed while flowing over the surface (fig. 10). These filled gas bubbles are called amygdules, and contain a range of minerals typical of low temperature hydrothermal fluids. Abundant geochemical data is available on these flows. Compositions include trachyandesite, andesite, icelandite, and rhyolite. Similar to most basalts of the Midcontinent rift, these basalts typically contain traces of copper. The Portage Lake Volcanics in northern Michigan contain world-class native copper deposits which were mined from the 1840s to the 1970s. Copper in the Lake Superior region was also mined as early as 5,000 B.C. by American Indians and traded throughout the region. This is the only large native copper area in the world. Coppermine Dam, constructed to help with the movement of logs on the river, gets its name from a local copper exploration site (located along Crotte Creek) active from about 1840 to 1968(?). Native copper throughout the area may also be found in basalt erratics brought in by glaciers

The park protects certain unique ecosystems and flora and fauna communities. As mentioned previously, the intact native mussel population is among the last and most diverse in the country. Near Potholes Trail, buttonbush (one of the approximately 35 rare plant species known from the park) thrives in one of only five known localities. Wetland bogs sit atop uplands underlain by basalt flows at the Interstate State Park area.

Figure 7. Manmade cave in sandstone bluffs near Boomsite. View is to the west. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 8. Flooded potholes scoured into basalt flows at Interstate State Park, Minnesota. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 9. Outcrop of Precambrian basalt boulders in a scant, Cambrian, sandstone matrix. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 10. Vesicular lava flows at Interstate State Park, Minnesota. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Recommendations

1. Access the "onegeology" global portal interface.
2. Consult the Wisconsin Geological Survey's website for geologic information(http://www.uwex.edu/wgnhs/).
3. Visit the National Fossil Day (October 13) website prepared in partnership between the NPS and American Geological Institute.

Action Items

1. GRI report author will consult the Wisconsin Geological and Natural History Survey's website for pertinent publications (http://www.uwex.edu/wgnhs/).
2. GRI report author will obtain a copy of the Wild and Scenic River designation justification for geologic references.

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. Saint Croix National Scenic Riverway. www.nps.gov/sacn (accessed August 7, 2010).

Table 2. Scoping Meeting Participants

Name	Affiliation	Position	Phone	E-Mail
Eric Carson	Wisconsin Geological Survey	geologist	608.890.1998	eccarson@wisc.edu
Jim Chappell	Colorado State University	geologist	970-491-5147	jrchapp@lamar.colostate.edu
Nancy Duncan	NPS, MISS	resource management	651.290.3030, ext. 237	nancy_duncan@nps.gov
Bruce Heise	NPS, Geologic Resources Division	geologist	303.969-2017	Bruce_Heise@nps.gov
Howard Hobbs	Minnesota Geological Survey	geologist	612.627.4780	hobbs001@umn.edu
Steve Johnson	NPS, MISS	resource management chief	651.290.3030, ext 223	steven_p_johnson@nps.gov
Jason Kenworthy	NPS, GRD	report coordinator	303.987.6923	jason_kenworthy@nps.gov
Robin Maercklein	NPS, SACN	biologist	715.483.2282	robin_maercklein@nps.gov
Richard Ojakangas	University of Minnesota (Duluth)	geologist	218.721.3026	Rojakang@d.umn.edu
Jamie Robertson	Wisconsin Geological Survey	geologist	608.263.7384	jmrober1@wisc.edu
Harvey Thorleifson	Minnesota Geological Survey	director	612.627.4780	thorleif@umn.edu
Trista Thornberry-Ehrlich	Colorado State University	geologist	406.837.2274	tthorn@warner.cnr.colostate.edu
Laurel Woodruff	USGS	geologist	763.783.3291	woodruff@usgs.gov
Stan Zabel	NPS,	IT technician	651.290.3030, ext. 224	stan_zabel@nps.gov