Geologic Resources Inventory Scoping Summary
Indiana Dunes National Lakeshore, Indiana

Prepared by Katie KellerLynn
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Geologic Resources Division
National Park Service
U.S. Department of the Interior

The Geologic Resources Inventory (GRI) Program provides each of the 270 identified natural area National Park System units with a geologic scoping meeting, a geologic scoping summary, a digital geologic map, and a geologic resources inventory report. 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. GRI products (maps, scoping summaries, and final reports) are available at http://www.nature.nps.gov/geology/inventory/gre_publications.cfm (accessed November 26, 2010).

On June 28–29, 2010, the Geologic Resources Division held a GRI scoping meeting for Indiana Dunes National Lakeshore at the Bailly Ranger Station, Porter, Indiana (fig 1). Participants at the meeting included NPS staff from the national lakeshore and Geologic Resources Division, and cooperators from Colorado State University, the Indiana Geological Survey, and the U.S. Geological Survey (table 3). Superintendent Constantine Dillon welcomed the group and expressed his interest and support of the geologic inventory by stating, “We don’t have near the mapping I wish we had.” He also highlighted some of the impacts that industry and development have had on the “much manipulated landscape” of Indiana Dunes National Lakeshore. He pointed out two topics that he hopes the inventory can help address: What are the sand sources and are they the same as during initial development of the shoreline? And, where are the “remnant dunes?”

During the meeting, Georgia Hybels (Geologic Resources Division) facilitated the group’s assessment of map coverage and needs, and Lisa Norby (Geologic Resources Division) led the discussion of geologic features, processes, and issues. Todd Thompson (Indiana Geological Survey) presented a geologic overview of Indiana with a focus on the shoreline evolution of Lake Michigan.

During the site visit on June 29, 2010, participants traveled via car to many of the sites discussed during the “features, processes, and issues” portion of the scoping meeting. They also visited selected sites that illustrated the geologic evolution of Lake Michigan. Todd Thompson and park staff led the tour to the following stops: (1) Miller Woods, showing past shorelines, parabolic dunes, the shifting mouth of the Grand Calumet River, and the reestablishment of native dune vegetation; (2) Douglas Environmental Education Center, explaining the wetland-dune systems and beach sediment (fig. 2); (3) West Beach, discussing blowout dunes, optically stimulated luminescence (OSL) as a dating method, ridge-crest association with groundwater highs, sedimentation from Burns Ditch, the geologic story of Tolleston Beach, and past mining/sand extraction from large parabolic dunes that are no longer in existence; (4) Inland Marsh, revealing an east-facing (now vegetated) parabolic dune that formed 3,800 years ago and an oak savanna that now covers the higher, drier parts of the dune; (5) Furnessville with its cemetery and schoolhouse (notably, the cemetery is on sand, which is easier to dig than clay); (6) Kemil Road where participants drove across the Glenwood and Calumet beach ridges (fig. 3); (7) Central Beach with a view of Mt. Baldy and the Northern Indiana Public Service Company (NIPSCO) coal-fired, power-generating station; and (8) extreme erosion at Mt. Baldy, a sand dune that is part of the Tolleston Beach system.

Figure 1. Map of Indiana Dunes National Lakeshore. National Park Service graphic.

Figure 2. Peels of sediment cores from Lake Michigan shoreline. During the site visit, Todd Thompson (Indiana Geological Survey) explained the vibracore technique and the corresponding method for displaying sediments from the beach ridges of ancestral Lake Michigan. Photo by Katie KellerLynn.

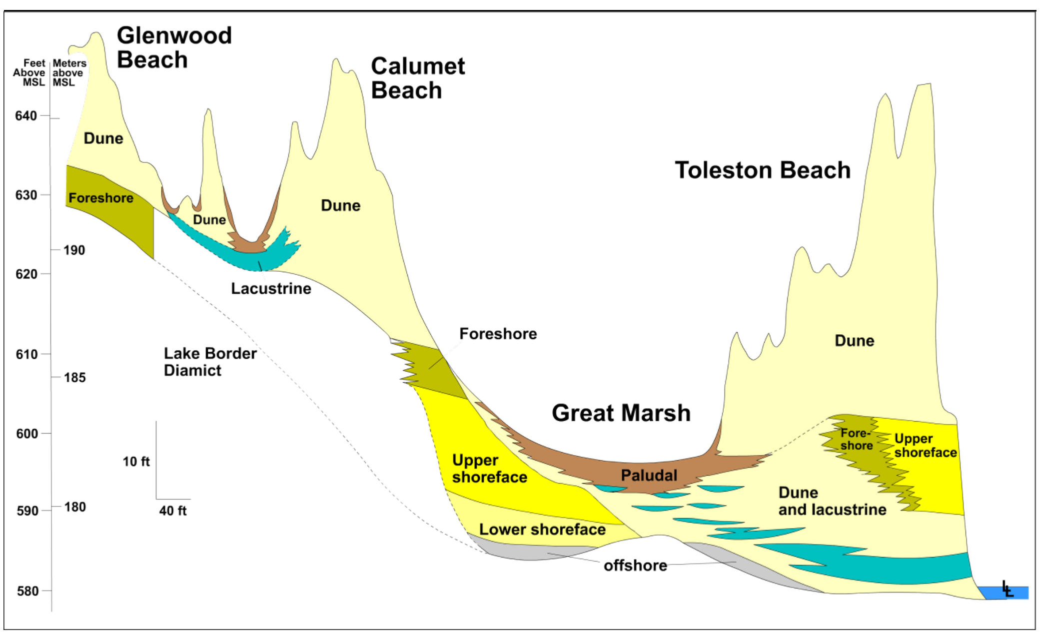

Figure 3. Cross section along Kemil Road. During the site visit, participants drove across ancestral shorelines of Lake Michigan. Toleston (also spelled "Tolleston") Beach is the modern beach. Progressing landward (from right to left on the figure), the beaches get older with the Calumet and Glenwood beaches/shorelines. The Glenwood and Calumet shorelines were built upon the Lake Border Moraine. Graphic by Todd Thompson (Indiana Geological Survey), extracted from GRI scoping PowerPoint presentation, June 28, 2010.

Park Setting

Indiana Dunes National Lakeshore is situated on the southern shoreline of Lake Michigan, which is part of the largest complex of freshwater lakes in the world. With a surface area of more than 57,000 km^2 (22,000 mi^2), Lake Michigan provides habitat for a wide variety of fish, birds, and aquatic organisms. The lake is also a resource for the more than 10 million people living in its watershed, providing food, recreation, transportation, and water for drinking, industry, and agriculture (National Park Service 2006b).

The national lakeshore is a mosaic of natural and disturbed landscapes within an urban setting (see fig. 1). It hosts 24 km (15 mi) of Lake Michigan's shoreline and 6,070 ha (15,000 ac) of beaches, dunes, oak savannas, swamps, bogs, marshes, prairies, rivers, and forests between the industrial centers of Gary and Michigan City, Indiana. Economic interests have determined much of the land use, as witnessed in industrial areas that surround the national lakeshore, but conservation campaigns beginning in the 1900s sought to preserve some areas from development (Government Printing Office 2006). An attempt in 1916 by Stephen T. Mather, director of the newly created National Park Service, to establish "Sand Dunes National Park" failed, but partial success was realized in 1923 with the creation of Indiana Dunes State Park. Fearing that commerce would swallow up the remaining lake front and dunes, Illinois Senator Paul H. Douglas joined the crusade to save the dunes, which Dorothy Buell—a former school teacher and the founder and first president of the Save the Dunes Council of northwestern Indiana—had spearheaded in the 1950s. As an outcome of these efforts, Congress authorized "Indiana Dunes National Lakeshore" in 1966. In recognition of her contributions, Congress designated the principal visitor facility at the national lakeshore as the Dorothy Buell Memorial Visitor Center (Government Printing Office 2006). The Paul H. Douglas Center for Environmental Education honors the efforts of Senator Douglas.

Four national natural landmarks (NNL) and one national historical landmark (NHL) are located in the Indiana Dunes National Lakeshore environs. These landmarks illustrate the natural and cultural resources preserved within Indiana Dunes National Lakeshore:

Pinhook Bog NNL—Designated in 1965 and now part of Indiana Dunes National Lakeshore, Pinhook Bog is a living example of the textbook description of ecological succession from pond to woodland. The site lies within a glacial kettle and is surrounded by wooded hills (National Natural Landmarks Program 2009).

Cowles Bog NNL—The Cowles Bog proper was the first parcel purchased by the Save the Dunes Council in the 1950s and became part of the National Park System when Indiana Dunes National Lakeshore was authorized. While it is named "bog," technically Cowles Bog is a fen complex with the fen portion elevated as a result of the artesian upwelling of ancient water from a confined aquifer. The terms "bog" and "fen" as applied to this site have been controversial in the past (Noel Pavlovic, U.S. Geological Survey, written communication, October 1, 2010). Cowles Bog illustrates marsh and fen habitat, as well as transition to swamp (National Natural Landmarks Program 2009).

Dunes Nature Preserve NNL—Designated in 1974 and owned by the state, the Dunes Nature Preserve is located within Indiana Dunes State Park. It is the best remaining example of undeveloped and relatively unspoiled dune landscape along the southern shore of Lake

Michigan, a portion of which is known as the "Birthplace of American Ecology." The site also contains Ancient Pines Nature Area, a "ghost forest" exposed by dune blowouts (National Natural Landmarks Program 2009). While the forest was thought to be "ancient" at the time of designation, radiocarbon dating has revealed that the trees actually are not ancient at all; rather the trees are "modern" and had been alive within the last 200 years (Noel Pavlovic, U.S. Geological Survey, written communication, October 1, 2010).

Hoosier Prairie NNL—Designated in 1974, Hoosier Prairie is a state-owned site and the last large tract of prairie near the eastern margin of the "Prairie Peninsula" (National Natural Landmarks Program 2009). The site contains a great diversity of community types. When the site was designed, nearly 300 vascular plant species were known to inhabit the prairie, but as study continues, the numbers keep increasing. Wilhelm (1990) reported nearly 475 native plant species, and recent inventories have recorded 561 native plants (Noel Pavlovic, U.S. Geological Survey, written communication, October 1, 2010).

Joseph Bailly Homestead NHL—Designated in 1962, the Joseph Bailly Homestead brings together an unusual combination of vernacular architecture, including an imposing main house that features late-19th century architectural detail, rustic log and brick structures, and the unusual family cemetery (National Park Service 1972). The site is part of Indiana Dunes National Lakeshore.

Geologic Mapping for Indiana Dunes National Lakeshore

During the scoping meeting, Georgia Hybels (Geologic Resources Division) showed some of the main features of the GRI Program'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, Federal Geographic Data Committee (FGDC)–compliant metadata, a help file that captures ancillary map data, and a map document that displays the map and provides a tool to directly access the help file.

When possible, the GRI Program provides large-scale (1:24,000) digital geologic map coverage for each unit's area of interest, which is generally composed of the 7.5' quadrangles that contain NPS-managed lands. 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 resource management begins with the identification of existing geologic maps in the vicinity of the National Park System unit. Scoping participants then discuss mapping needs and select appropriate source maps for the digital geologic data or, if necessary, develop a plan to obtain new mapping. In the lower 48 states, large-scale mapping is usually defined as "one inch to 2,000 feet" or quadrangles produced at a scale of 1:24,000 on a 7.5' × 7.5' base. There are thirty-two 7.5' quadrangles on a 30' × 60' (scale 1:100,000) sheet.

Prior to scoping, there were fifteen 7.5' quadrangles of potential interest for Indiana Dunes National Lakeshore: Gary OE North, Ogden Dunes, Dunes Acres, Michigan City West, Michigan City East, Highland, Gary, Portage, Chesterton, Westville, La Porte West, Saint John, Crown Point, Palmer, and Valparaiso (fig. 4). However, since scoping, GRI staff realized that Gary OE North quadrangle is an OE—"over edge"—map. "OE" is a naming convention that indicates that the quadrangle for this particular area does not have an associated USGS quadrangle number and the data are included on the adjoining map sheet, in this case, the Gary quadrangle. Park managers would like digital geologic data for these remaining quadrangles of interest, including the four quadrangles that do not intersect the boundaries of the national lakeshore (i.e., Saint John, Crown Point, Palmer, and Valparaiso) (tables 1 and 2).

Although a bedrock geologic map is of little use for current resource-management issues at Indiana Dunes National Lakeshore, Schneider and Keller (1970)—the geologic map of the Chicago 1° × 2° quadrangle (scale 1:250,000)—provides bedrock data (table 1). GRI staff could easily digitize these data because the map includes only a few bedrock units in the area of Indiana Dunes National Lakeshore. Such data could be useful for interpretation and potentially management purposes in the future.

Table 1. Source map for bedrock geologic data

Quadrangle of Interest (7.5' quadrangle)	Reference/source	GMAP[1]	Scale	Format
Ogden Dunes	Schneider and Keller (1970)	75403	1:250,000	Paper
Dune Acres				
Michigan City West				
Michigan City East				
Highland				
Gary				
Portage				
Chesterton				
Westville				
La Porte West				
Saint John				
Crown Point				
Palmer				
Valparaiso				

[1]GMAP numbers are identification codes for the GRI Program's database.

Of the fourteen quadrangles desired for a compiled geologic map for Indiana Dunes National Lakeshore, only the Highland, Gary, and Portage quadrangles have surficial data known to be at a scale useful to resource management. Brown and Thompson (2005) mapped the unconsolidated deposits in these quadrangles at a scale of 1:24,000, which were then published at a scale of 1:40,000 (table 2 and fig. 5). According to Todd Thompson (Indiana Geological Survey), surficial geologic data for the remaining quadrangles of interest (i.e., Ogden Dunes, Dune Acres, Michigan City West, Michigan City East, Chesterton, Westville, La Porte West, Saint John, Crown Point, Palmer, and Valparaiso) could come from a publication/map of "geologic terrain data" that at the time of the scoping meeting was undergoing author review at the Indiana Geological Survey. This publication shows the glacial and post-glacial deposits of the area and could potentially be prioritized in the publication queue because of the need by park staff and the GRI Program. This publication/map and Brown and Thompson (2005) could comprise the surficial geologic map for Indiana Dunes National Lakeshore (table 2).

Park staff prefers this plan over digitizing surficial data from Schneider and Keller (1970) because larger-scale data would be more helpful in protecting and managing park resources. Therefore, scoping participants agreed that Todd Thompson (Indiana Geological Survey) should talk with the director of the Indiana Geological Survey about priorities and the potential for publishing these data in the near future.

Table 2. Source maps for surficial geologic data

Quadrangle of Interest (7.5' quadrangle)	Reference/Source	GMAP[1]	Scale	Format
Highland	Brown and Thompson (2005)	75360	1:40,000	Paper & GIS
Gary				
Portage				
Ogden Dunes	Unpublished geologic terrain data (glacial and post-glacial deposits) from the Indiana Geological Survey	TBD	1:40,000 (mapped at 1:24,000)	GIS
Dune Acres				
Michigan City West				
Michigan City East				
Chesterton				
Westville				
La Porte West				
Saint John				
Crown Point				
Palmer				
Valparaiso				

[1]GMAP numbers are identification codes for the GRI Program's database.

Park staff at Indiana Dunes National Lakeshore also expressed the need for digitizing older, shoreline information, which would assist them in their shoreline management plan. Park staff wants to know where the shoreline was prior to construction of the Michigan City Harbor around 1830, and prior to construction of the harbor at Port of Indiana in 1962. This information could come from historic USGS topographic maps, and GRI staff is looking into obtaining these maps for the area. GRI staff plans to incorporate a GIS layer showing past shorelines as part of the completed digital geologic map for Indiana Dunes National Lakeshore.

In addition, park managers are interested in obtaining historical information on former sand mines within Indiana Dunes because of the connection to rare plants, which capitalize on these areas. Again, GRI staff determined that this information could be digitized from a USGS topographic base map and added to the final digital geologic map as a data layer.

Finally, meeting participants discussed the usefulness of aquifer sensitivity terrain maps, which show areas sensitive to contamination, and aquifer level maps, which show a "snapshot" of water level. Generally speaking, these types of maps are not within the scope of the geologic inventory. However, GRI staff obtained, scanned, and provided these maps of La Porte and Porter counties to park staff (Georgia Hybels, Geologic Resources Division, e-mail communication, October 15, 2010).

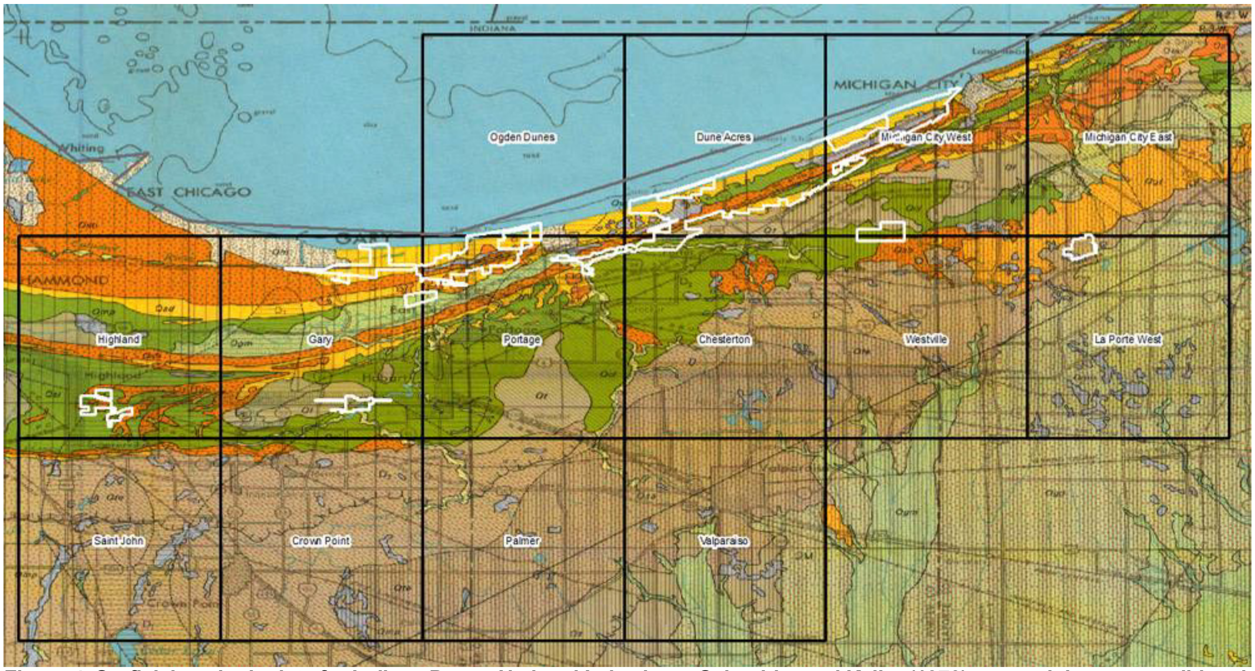

Figure 4. Surficial geologic data for Indiana Dunes National Lakeshore. Schneider and Keller (1970) mapped the unconsolidated deposits in the vicinity of Indiana Dunes National Lakeshore at a scale of 1:250,000. The U.S. Geological Survey 7.5-minute quadrangles are outlined in black and labeled on the figure. The boundary of the national lakeshore is highlighted in white. Graphic from Schneider and Keller (1970), modified by Georgia Hybels (NPS Geologic Resources Division).

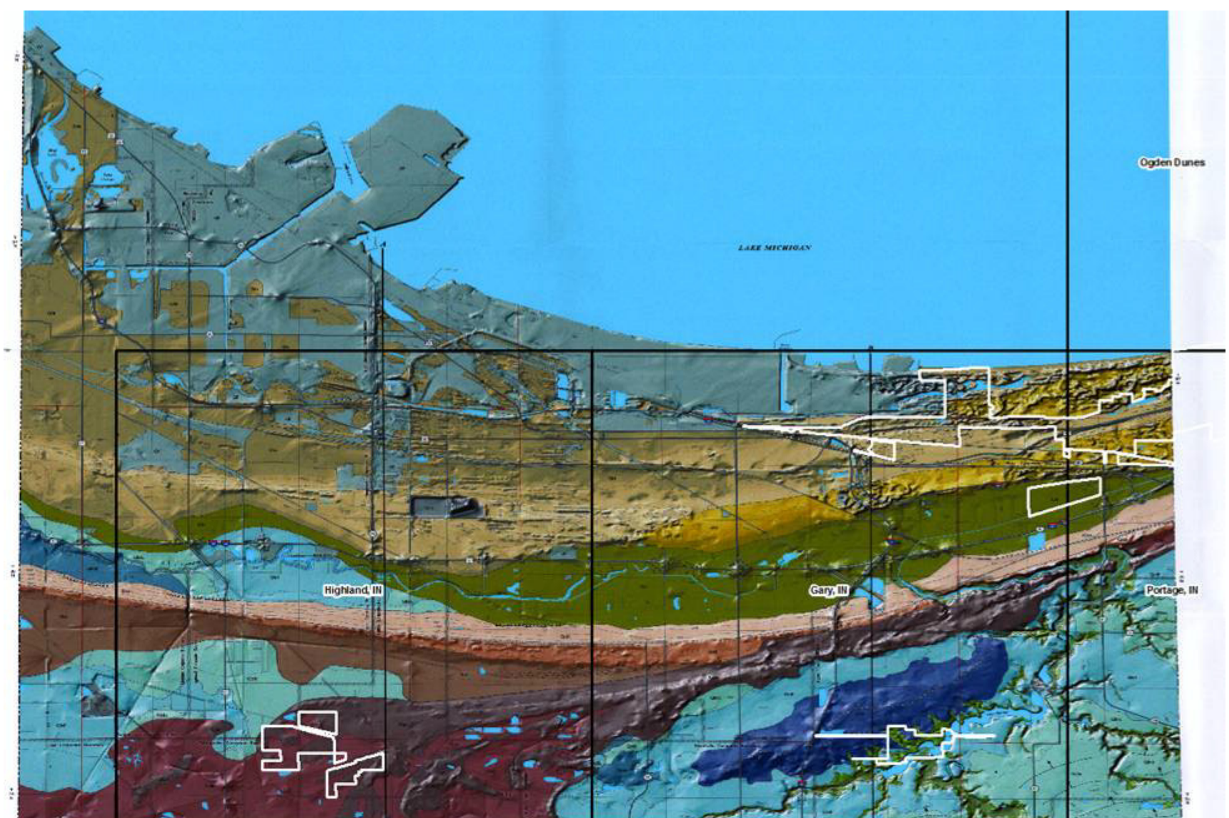

Figure 5. Glacial and post-glacial deposits of northern Lake County, Indiana. In addition to new mapping under review at the Indiana Geological Survey, digital surficial data for the geologic map of Indiana Dunes National Lakeshore will come from Brown and Thompson (2005) (figure image). This map covers the Highland, Gary, and Portage quadrangles. Graphic from Brown and Thompson (2005), modified by Georgia Hybels (NPS Geologic Resources Division).

Geologic Features, Processes, and Issues

The scoping meeting for Indiana Dunes National Lakeshore provided the opportunity to discuss the geologic features and processes occurring at the national lakeshore, which will be further explained in the final GRI report. Many of these features and processes have associated issues of management concern. The "top issues" identified during the scoping meeting were shoreline erosion and restoration of disturbed lands; these issues are discussed first.

Shoreline Erosion

Throughout the year, wind, waves, currents, ice, and storms continually reshape the shoreline of Lake Michigan. Shoreline erosion is exacerbated during lake level highs and November and December storms. The strong winds and high-energy waves of winter create a narrower and steeper beach. At times of stable lake levels in summertime, gentler winds and smaller waves produce a wider, slightly sloping beach (National Park Service 2006b).

During the scoping meeting, participants discussed sand transport, or the lack thereof, as the "big issue" at Indiana Dunes National Lakeshore. Development and installation of navigational harbors and shoreline stabilization structures such as jetties, breakwaters, revetments, and bulkheads have altered the natural east-to-west littoral drift along the shores of southern Lake Michigan, resulting in significant accretion of sands east (up drift) of harbors and the subsequent sand starvation to the west (down drift) of these harbors (Watkins et al. 2010). Coburn (2010) provided an inventory of coastal engineering at Indiana Dunes National Lakeshore. This study identified 40 erosion-control structures, three dredging projects, and three beach/dune construction projects.

Extreme shoreline erosion is a primary driver behind the preparation of a shoreline management plan for the national lakeshore. Planning is in progress, and managers want to have a draft plan / environmental impact statement (EIS) completed by September 2011, with the final plan finished in 2012. Of particular concern are the Mt. Baldy–Crescent Dune and Portage Lakefront–Ogden Dunes areas, but this unnatural accretion-erosion scenario is also occurring at an area of riprap between Dune Acres and Indiana Dunes State Park (see fig. 1).

Under natural conditions, southern Lake Michigan would have two littoral cells with net southerly transport of sediment to a zone of net convergence along the Indiana shore (Chrzastowski et al. 1994). These once-continuous littoral cells of southern Lake Michigan have been segmented by coastal structures that protrude into the lake. According to Chrzastowski et al. (1994), there are now four primary cells along the Indiana shore. Two of these are positioned along the lakeshore of Indiana Dunes: The "eastern Indiana cell" runs for 5.9 km (3.7 mi) from the Michigan–Indiana state line to the Michigan City Harbor. The "Indiana Dunes cell" runs for 35.9 km (22.3 mi) from the Michigan City Harbor to the U.S. Steel lakefill/Gary Harbor. The Indiana Dunes cell is further divided into three secondary cells: (1) Michigan City Harbor to Burns Waterway Harbor, 22.1 km (13.7 mi); (2) Burns Waterway Harbor to Burns Ditch, 1.3 km (0.8 mi); and (3) Burns Ditch to U.S. Steel lakefill/Gary Harbor, 12.5 km (7.8 mi) (Chrzastowski et al. 1994). Other features of a natural setting include sediment deposition at the ends of rivers, creating a "downdrift shadow" of sediment available for transport by littoral drift (artificial harbors and jetties interrupt this process), and ice rafting, which supplies sediment to the system.

Ultimately, managers want to restore natural shoreline processes; however, if restoration is not possible, then replicating natural processes in selected areas to protect park resources is desired. Park managers need to establish management standards based on scientific findings to help direct shoreline restoration efforts at the national lakeshore.

At present, park managers have identified two options for mitigation of erosion: (1) dredging/beach nourishment, and (2) sand bypass. The U.S. Army Corps of Engineers has used a combination of dredging and beach nourishment at the Michigan City Harbor, primarily in an attempt to mitigate erosion at Mt. Baldy (see "Eolian Features and Processes"), but also at Portage Lakefront. However, these activities are costly and a temporary stopgap to a long-term problem (Watkins et al. 2010). Since 1978, the Corps has placed nearly 540,000 m^3 (700,000 yd^3) of sand from inland sources and more than 270,000 m^3 (350,000 yd^3) of material dredged from the Michigan City Harbor in front of Mt. Baldy, yet rapid erosion continues at this location. In addition, the Corps has placed dredged materials at Portage Lakefront from the vicinity of the Burns International Harbor and the NIPSCO Bailly Generating Station intake structure (Watkins et al. 2010).

With respect to sand bypass, the beach at Washington Park is accreting and is, thereby, a potential source of material. However, Michigan City authorities likely would not agree to the removal of sand from the popular beach area, but material could be taken from an area of accreting sand just in front of the visible beach at Washington Park and then bypassed (pumped as slurry) to the shoreline in front of Mt. Baldy (Brenda Waters, Indiana Dunes National Lakeshore, written communication, October 5, 2010).

During scoping, Noel Pavlovic (U.S. Geological Survey) pointed out that the current USGS topographic map of the area shows the 1832 Government Land Survey Office section lines in red (and thereby the shoreline position) prior to construction of the Michigan City Harbor near Mt. Baldy. Todd Thompson (Indiana Geological Survey) made a rough estimate based on the topographic information and found that about 137 m (450 ft) of shoreline was lost to erosion between 1932 and 1980. This number is significant because park managers want to quantify the amount of land loss and restore this amount via the return of natural processes or mitigation techniques.

If mitigation (vs. restoration of natural processes) is required, then identifying lithologic and grain-size characteristic is important for replicating the natural conditions of beach and dune sediments. Park managers also will need to identify appropriate source areas for these sediments. Todd Thompson (Indiana Geological Survey) suggested analyzing his core samples (350 taken during his dissertation field work; see Thompson 1987) as a means for determining natural conditions (i.e., rock and mineral types, grain sizes, and relative quantities of constituent materials). Todd showed peels of some of these cores during the GRI site visit (see fig. 2). In the short term, a sample from the inside floor of the Beach House blowout dune in the Indiana Dunes State park would probably provide a quick "standard" for natural sediment. A key factor in selecting a standard is that much of the natural sediment in the system was capable of undergoing eolian transport. On the other hand, historic evidence of gravel mining on the lakeshore's beaches also suggests a large grain-size component. Moore (1959) reported that the gravel obtained on the Lake Michigan beach consisted of pebbles that ranged in size between a hen's egg and a small marble.

Disturbed Lands

Disturbed lands are those parklands where the natural conditions and processes have been directly impacted by mining, oil and gas production, development (e.g., facilities, roads, dams, abandoned campgrounds, and trails), agricultural practices (e.g., farming, grazing, timber harvest, and abandoned irrigation ditches), overuse, or inappropriate use. The NPS Disturbed Lands Restoration (DLR) Program, administered by the Geologic Resources Division, usually does not consider lands disturbed by natural phenomena (e.g., landslides, earthquakes, floods, hurricanes, tornadoes, and fires) for restoration unless the areas are influenced by human activities. Scoping participants and contributors discussed the following disturbances at Indiana Dunes National Lakeshore either during pre-meeting conference calls or the scoping meeting itself:

Great Marsh

In addition to the "disturbed" process of littoral transport, Indiana Dunes has a number of onshore, disturbed areas, namely the Great Marsh, the largest interdunal wetland on the Lake Michigan shoreline (Government Printing Office 2006). Notably, Cowles Bog—the national natural landmark—is part of the Great Marsh. The general stratigraphy of the Great Marsh is in descending order: peat, sand, and calcareous sand/clayey marl. The peat, which freezes and heaves, gives roads built on the marsh the feel of "driving on a mattress." This extensive wetland is situated between the beach-dune complex of the Calumet shoreline and the modern Tolleston shoreline. The Great Marsh began to form when lake level fell about 3,500 years ago. In present-day, geographic terms, the marsh is south of the primary dunes in the eastern half of the park.

Starting in the latter 19th century and early 20th century, ditching subdivided the Great Marsh and its contiguous watershed into three, separate systems. Although numerous smaller ditches cut the Great Marsh, the primary ones are Kintzele, Derby, Burns, and Brown. Most ditches were constructed between about 1875 and 1925 to drain the marsh for agricultural purposes (Cook and Jackson 1978). Additionally, the construction of roads, levees, factories, and houses segmented the marsh. Drainage and segmentation have resulted in changes in hydrology and loss of habitat. These changes also have made the marsh drier, resulting in an altered plant community and the invasion of nonnative species (National Park Service 2006a).

Another impact of ditches is the addition of unnatural levels of sediment-rich water to Lake Michigan. While at West Beach, scoping participants noted the discharge (i.e., brown, sediment-rich water) emanating from Burns Ditch, which contrasted the blue lake waters. Ditch water is also a prime mover of land-based pollutants.

Restoring the Great Marsh has been a major goal of the National Park Service (National Park Service 2009). The effort is in its third phase with approximately 243 ha (600 ac) in various stages of restoration. Wildlife, including beavers and a variety of birds, has returned to the area. In 2009, park staff and partners removed invasive plants such as reed canary grass, hybrid cattail, common reed, and purple loosestrife and planted 3,400 plants representing 14 native species (National Park Service 2009). From a geologic perspective, the National Park Service is in the process of restoring the hydrologic regime to its natural condition. Restoration includes filling in ditches, plugging culverts, and constructing spillways and levees so surface water can flow without restriction. In 2008, the National Park Service began a two-year project with the U.S. Geological Survey to study groundwater and surface-water levels relative to wetland restoration in and north of the Great Marsh

(National Park Service 2008a). Residents of Beverly Shores, a wealthy development built just north of the Great Marsh, primarily on Tolleston dunes, are concerned that restoration of the wetland is causing flooding of their basements. However, high amounts of precipitation in recent years, which have caused surface-water levels to rise, are a likely cause. The study's findings will primarily help park managers address residents' concerns, but the process—identifying water-table elevations, groundwater divides (often located under dune ridges), and recharge areas (often focused in intradunal depressions)—also will help managers better understand hydrologic conditions and patterns within the Great Marsh. The final report is expected in late 2010 (National Park Service 2009).

Sand and Gravel Mining

During the site visit, scoping participants could only imagine some of the large, parabolic dunes because many of these dunes, which later gave "Indiana Dunes" its name, were consumed in the 1920s and 1930s. For example, once exceeding Mt. Baldy in size, "Hoosier Slide" is now gone. The Ball Company of Muncie, Indiana, mined the quartz sand and made canning jars from the material. In addition, dunes in the Long Lake area were mined and the sand was transported to Chicago where it became lakefront property prior to and after the World's Fair (1893).

In addition, gravel from the beaches of southern Lake Michigan became aggregate and cement used in construction and development of Chicago and other nearby cities. Scoping participants suggested that much of this gravel was gathered locally by citizens during the late 1800s to early 1900s. Users of the gravel raked it out of the shallow water by hand and then carted it beyond the reach of high storm waves. Much of this material was shipped to Chicago for use in roofing and concrete pavements.

Foot Traffic and Blowouts

According to Hill et al. (1991), a seemingly harmless action—foot traffic—can change the face of a dune. As people create footpaths across the dunes, marram grass, which helps to baffle sand and stabilize dunes, is trampled and dies. As a result, wind picks up sand and transports it farther inland, in some cases burying woodlands (Hill et al. 1991). Although Mt. Baldy is the only dune in the national lakeshore where climbing is allowed, foot traffic is also a problem at West Beach and Portage Lakefront, where social trails cut across the dunes to access the beach. Noel Pavlovic (U.S. Geological Survey) has mapped official and unofficial trails across the dunes at West Beach.

As a result of destabilization, large volumes of sand are lost at blowouts and depressions in the dunes. Arbogast and Loope (1999) reported that the large blowouts, which extend a mile or so inland, formed after highstands of Lake Michigan in a fashion similar to the forested parabolic dunes behind them, so claims that these large blowouts are a result of anthropogenic activities are unfounded. Nevertheless, human activities have caused smaller blowouts on the scale of tens of meters (Noel Pavlovic, U.S. Geological Survey, written communication, October 1, 2010).

Todd Thompson (Indiana Geological Survey) suggested that blowouts could be dated using optically stimulated luminescence (OSL). Knowing the timing of the blowout would help park managers identify "natural" vs. "anthropogenic" blowouts.

Of interest for biological resources are the shallow, natural depressions called "pans" that form in blowouts. During wet periods, pans will have standing water that is rich in organic material (see "Inland Lakes"); many state-listed species inhabit pans.

Fly Ash

Fly ash is the residue collected by air pollution control systems (electrostatic precipitators in smokestacks) at coal-fired power plants; it is a byproduct of coal combustion. Fly ash is composed of silt- to clay-sized, silica-glass "beads." When disposed in large piles, these beads exhibit a strong capillary effect (i.e., cause an upward wicking or rise in the water table due to their fine grain size and associated small, interparticle pore spaces) and tend to adsorb metals and metalloids such as molybdenum, arsenic, and boron. When fly-ash deposits are exposed to meteoric flushing by infiltrating surface waters or become saturated from a rising water table, boron is easily desorbed and goes into solution. Although boron is a plant micronutrient, at elevated levels, it is toxic to some plants (Penoyer 2009). In some cases, fly ash is disposed as slurry in pits. Once dewatered, the fly ash is trucked to landfills or used to manufacture cinder block and other building materials.

Two areas adjacent to Indiana Dunes National Lakeshore have been used for fly ash disposal: (1) Yard 520 landfill adjacent to the Town of Pines and upgradient from the Great Marsh, and (2) the settling ponds and a second recently identified landfill near the NIPSCO Bailly Generating Station, southwest of Cowles Bog.

Town of Pines

Yard 520 was an industrial landfill (now superfund site) composed largely of fly ash. It is located at the terminus of County Road 520 (from which it received its name). Prior to the landfill, groundwater flow was southerly and away from the Town of Pines' domestic water wells (private supplies), but the topographically elevated landfill, in conjunction with a hydraulic barrier to flow constructed in association with a newer adjacent landfill on the south portion of Yard 520 (south cell), caused a reversal of groundwater flow. This change in flow direction negatively impacted domestic wells. Much of the Town of Pines is now on the municipal water supply, and the abandoned private domestic wells no longer capture groundwater radiating from Yard 520. In the absence of domestic well capture, however, there is now the potential for uninterrupted plume migration of boron-rich groundwater to the Great Marsh (Penoyer 2009).

Bailly Generating Station

Historically, fly ash produced at the coal-fired plants at the Bailly and Michigan City generating stations were collected from the smokestacks and transported as slurry to a series of landfills or nearby settling ponds. As a result of this procedure, however, contaminated water from the slurry flowed into the Cowles Bog wetland complex and into Blag Slough to the north (Noel Pavlovic, U.S. Geological Survey, written communication, October 1, 2010; see Pavlovic et al. 2009). The primary concern is that current and past discharges to the area's surficial aquifer will increasingly impact park resources in its migration toward Lake Michigan as a concentrated groundwater plume. Cowles Bog is a significant park resource in this flow path (Pete Penoyer, NPS Water Resources Division, telephone communication, June 18, 2010).

Homesites

When the national lakeshore was established in 1966, about 1,000 commercial buildings and homesites were included within the park's boundary (National Park Service 2007). The National Park Service preserved a number of historic structures and renovated some other buildings to create office space, interpretive centers, and other park facilities. However, in order to restore the natural landscape, the National Park Service has removed the majority of these building, associated landscaping, and other nonnative vegetation, as well as farm fields. Approximately 48 ha (118 ac) of former farm fields are slated for prairie restoration (National Park Service 2008b). Restoration includes the removal septic tanks, underground storage tanks, driveways, and roads.

Coastal/Lacustrine Features and Processes

The landscape of Indiana Dunes National Lakeshore contains three major coastal geomorphic features: the Glenwood, Calumet, and Tolleston beaches (fig. 6). Tolleston also has been spelled Toleston, but current usage restores the missing "l" (Todd Thompson, Indiana Dunes National Lakeshore, written communication, October 20, 2010). These barrier and mainland beaches record highstands of ancestral Lake Michigan. The Glenwood Beach formed during the Glenwood phase from about 14,800 to 12,400 years ago. The Glenwood Beach is the highest of the national lakeshore's shorelines and water level is interpreted to have been as high as 195 m (640 ft) and fell to about 190 m (625 ft) during the beach's development. After the Glenwood phase, lake level fell during the Two Creeks phase from 12,400 to 11,800 years ago. After 11,800 years ago, the Calumet Beach formed during the Calumet and Algonquin phases from 11,800 to 10,000 years ago. At this time,water level ranged from as high as 189 m (620 ft) to as low as 184 m (605 ft). The Calumet Beach was abandoned during an extreme low-water phase called the Chippewa. The lowest elevation of this phase is unknown but may have been as low as 116 m (381 ft) (Todd Thompson, Indiana Geological Survey, written communication, October 20, 2010). An extended period of rise starting about 8,000 years ago ended during the peak of the Nipissing phase at 4,500 years ago. The Nipissing reached an elevation of 184 m (605 ft) and formed the landward part of the Tolleston Beach. By 3,500 years ago, lake level had fallen to the elevation of the historical average for Lake Michigan. Today's shoreline is a continuation of the Tolleston Beach from 3,500 years ago with the development of more than 100 beach ridges in the western part of the shoreline and the growth of high dunes in the eastern part of the shoreline. The beach ridges are formed by fluctuations in lake levels with periodicities of roughly 160 and 30 years in duration. The 30-year fluctuation produces individual beach ridges in the Gary area, and the 160-year fluctuation produces groups of ridges consisting of four to six beach ridges per group in the Miller Woods area.

Modern-day lake levels fluctuate naturally over decades, varying by as much as 1.5 m (5 ft) within the last 15 years (National Park Service 2006b). Until the late 1990s, general thinking presumed that precipitation was the cause of 80% of lake-level change. However, in the last 12 years, there has been above-average precipitation but decreased lake levels. Hence, evaporation must be a significant factor. Because Lake Michigan is not "icing over" in the winter, evaporation is now occurring during the winter and spring when ice cover used to inhibit the process.

Inland Lakes

In addition to Lake Michigan, Indiana Dunes National Lakeshore has a number of inland lakes and artificial ponds. One of the larger of these inland lakes is Long Lake, which once extended 13 km (8 mi) along the southern shore of Lake Michigan. The construction of railroads and roads on all sides of Long Lake and the splitting of the lake by County Line Road resulted in changes in drainage and a decrease in the lake's size and depth. Long Lake developed as a result of eolian processes in which wind transported sand out of an expansive, intradunal swale. When the eroded pan dipped below the groundwater surface, water gradually filtered in and a lake formed. Many similar ponds occur in the Miller Woods area of the national lakeshore. Artificial ponds include the three (east, middle, and west) Grand Calumet lagoons, ponds at U.S. Steel, four settling ponds at the Portage Lakefront, and an artificial pond near the NIPSCO property. Many of these ponds are impacted by industrial pollution (see "Disturbed Land").

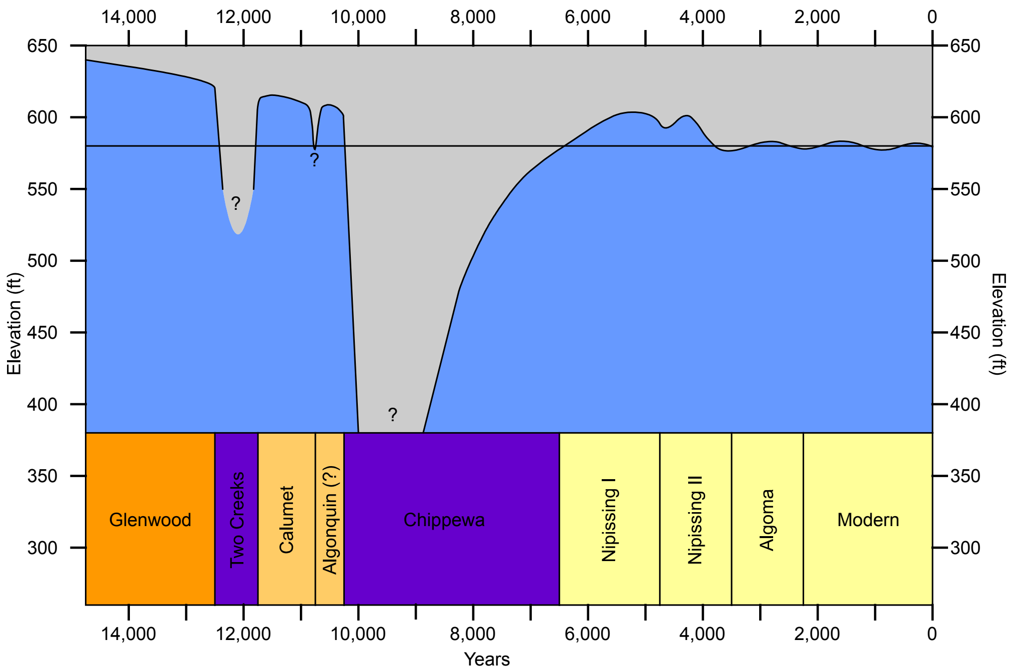

Figure 6. Lake Michigan lake levels. The three shorelines of Lake Michigan record changing lake levels over the past 14,800 years. The Glenwood shoreline encapsulates the Glenwood phase. The Calumet shoreline records the Calumet and Algonquinphases. The Tolleston shoreline documents the Nipissing I and II, the Algoma, and modern levels. Graphic by Todd Thompson (Indiana Geological Survey), extracted from GRI scoping PowerPoint presentation, June 28, 2010.

Eolian Features and Processes

Immediately inland from the beaches, sand dunes rise in a series of ridges, blowouts, and valleys. Extensive wetlands fill many depressions between the dune ridges. High dunes serve as groundwater barriers, trapping water and creating interdunal wetlands.

Three major dune complexes cover Indiana Dunes National Lakeshore. These dune complexes correlate to the three major shorelines in the history of Lake Michigan. Beginning with the modern shoreline and moving inland into progressively older dunes, they are the Tolleston dunes, Calumet dunes, and Glenwood dunes. Glenwood dunes are situated inside (lakeward) of the Lake Border Moraine, representing the departure of glacial ice from the area and the progression from a primarily glacial to a coastal/lacustrine system. The Calumet dunes formed along the shoreline following a major fluctuation (drop) in lake level. The Tolleston dune complex appears as a single dune line at the eastern end of the national lakeshore (east of Miller Woods), fanning to hundreds of dune-capped beach ridges west of Ogden Dunes.

Mt. Baldy

Mt. Baldy—a large sand dune on the southern shore of Lake Michigan—rises 37 m (123 ft) in elevation and is actively migrating. Analysis of past aerial photographs and sketches showed that Mt. Baldy was moving landward at approximately 1.2 m (4 ft) per year prior to 1938. Over the period 1938 to 2005, the dune moved approximately 2.7 m (8.9 ft) to the south and 2.6 m (8.5 ft) to the southeast on average per year (Pranger 2006). In recent years, the rate may be closer to 1.0 m (3.3 ft) per year to the south (Pranger 2006). At a rate of 1.0 m (3.3 ft) to 2.7 m (8.9 ft) per year, the NPS parking lot at Mt. Baldy will be covered in sand in 7 to 20 years; the restroom will be covered in sand in 18 to 50 years (Pranger 2006). Pranger (2006) identified two anthropogenic factors contributing to the landward movement of Mt. Baldy: (1) sediment deficit, and (2) foot traffic (see "Disturbed Lands" section). These impacts may be precluding the development of foredunes fronting Mt. Baldy and thus increasing the eolian transport of sand up and over the parabola, leading to the migration of this large dune (Pranger 2006). Furthermore, some percentage of the sediment migrating over the parabola is coming from the beach and represents a permanent sink (loss) from the coastal sediment budget, which exacerbates shoreline erosion (Hicks 2006) (see "Shoreline Erosion").

In a more recent study, comparison of aerial photographs showed a maximum of 246 m (807 ft) of migration of Mt. Baldy inland between 1938 to 2008, which is 3.5 m (11 ft) per year on average (Kilibarda et al. 2009b). More specifically, between 1938 and 1972, the average annual rates of migration of Mt. Baldy ranged from 1.2 m (4 ft) per year in the western sector of the dune to 5.1 m (17 ft) per year in the eastern sector. From 1973 to 2008, the pattern of dune migration changed, showing a maximum average annual rate of migration in its central and southern sectors, with 3.6 m (11.8 ft) and 3 m (10 ft) per year respectively, while advance of the western and eastern limbs trailed at a rate of 1.1 m (3.6 ft) per year. Moreover, Kilibarda et al. (2009a) documented geomorphic changes, namely that Mt. Baldy changed from a long, 1,470 m (4,823 ft), narrow, 280 m (919 ft), transverse dune to a shorter, 680 m (2,231 ft), but wider, 360 m (1,181 ft), parabolic dune over this time period (Kilibarda et al. 2009a). According to Kilibarda et al. (2009b), autumn and spring have higher rates of sand accretion and dune movement than other times of the year. Also, precipitation and freezing temperatures greatly affect sand movement.

Parabolic Dunes

Mapping of the parabolic dunes in the national lakeshore shows changes in wind direction over time (Thompson 1992; Thompson and Baedke 1997; Thompson et al. 2004). Parabolic dunes migrate parallel to predominant (storm) winds. During the Nipissing (~6,500 to 3,500 years ago) (see fig. 6), the southern shore of Lake Michigan showed predominant westerly winds, followed by a systematic shift of predominant wind direction to the northwest and north. Such a shift in predominant wind direction had an impact on the direction of littoral drift (Thompson et al. 2004). During the Nipissing phases of lake level, littoral drift was from west to east; whereas today, the dominant sediment transport is from east to west in the region east of the southern tip of Lake Michigan.

Fluvial Features and Processes

Significant streams flowing though Indiana Dunes National Lakeshore are the Grand Calumet River, Little Calumet River, and Dunes Creek. Ditches dug for agricultural purposes changed streamflow patterns, in some cases causing completely new drainages into Lake Michigan (see "Disturbed Lands"). Before 1870, the Grand Calumet and Little Calumet rivers were the same river with two mouths that discharged into Lake Michigan, one in Illinois and the other near today's Marquette Park in Gary, Indiana. Development of a harbor at the Illinois mouth in 1870 resulted in increased discharge there and the closure of the Indiana mouth (Cook and Jackson 1978). Dunes Creek is a natural drainage, although artificial ditches feed into it. Markowitz Ditch, which drains into Dunes Creek, was constructed in the early 1950s to improve septic-tank operation for local residents (Cook and Jackson 1978). Portions of Dunes Creek are currently undergoing restoration by the National Park Service.

Fluvial processes along Lake Michigan are driven by lake levels. For example, when the level of Lake Michigan is high, the lower reach of the west fork of the Little Calumet River may flow west rather than east. Furthermore, coastal processes during times of high lake levels erode the shoreline, and the eroded sediment is, in turn, available to form spits and beach ridges. These landforms can then direct the location of stream channels. About 1,700 years ago, high lake levels resulted in a series of Tolleston beach ridges that gradually forced the mouth of the Calumet River 35 km (22 mi) to the east. This pattern of beach-ridge development continued along the shoreline until humans began modifying sediment-transport patterns in the late 1800s and early 1900s (Thompson 1998a).

Recreational use, namely on the Little Calumet River, have altered fluvial features and processes. In order to reduce the number of portages and facilitate canoeing on the river, people remove trees from the banks and within the stream, which changes streamflow, sedimentation patterns, and the formation of riparian habitat. Scoping participants noted that the Little Calumet River downstream from Chesterton is a segment of the river where there is pressure from the canoeing community to remove trees both within and outside the national lakeshore.

Glacial Features and Processes

About 14,800 years ago, the basin of Lake Michigan formed in the thick glacial drift deposited by the retreating glaciers. As the lobe of the glacier that occupied Lake Michigan began to pull back from the Lake Border Moraine, much of its meltwater was trapped between the glacier's snout to the north and the moraine material on the west, south, and east (Schoon 2003). Since glacial retreat, the levels of ancestral and now present-day Lake Michigan have fluctuated.

Although the glaciers seem "old" and the lake seems "new" in Indiana geology, glaciers were still in the area during the Glenwood and Calumet shoreline phases. The Lake Border Moraine was deposited during the same time period as the Glenwood phase. This moraine and the older Valparaiso Moraine to the south form the dominant landscape of much of the area, extending from Wisconsin south through Lake, McHenry, DuPage, western and southern Cook, and Will counties in Illinois; through central Lake, Porter, and LaPorte counties in Indiana; and northeast into southwestern Michigan. After the Valparaiso Moraine was formed, the Lake Michigan lobe of the glacier retreated some distance north and then advanced again to build the Lake Border Moraine on the lakeward flank of the Valparaiso Moraine. The Valparaiso Moraine does not intersect Indiana Dunes National Lakeshore, but park headquarters rest on the Lake Border Moraine. The Glenwood and Calumet beach-dune complexes rest on sediment of the Lake Border Moraine and comprise platforms in deeper parts of the lake.

Glaciers deposited huge amounts of material, covering the area in more than 100 m (350 ft) of sediment. Generally, moraines are made of a heterogeneous mixture of rock of varying sizes and shapes called till, but the "till" of the Valparaiso Moraine is composed almost entirely of sand (Schoon 2003). Till of the Lake Border Moraine is more clay rich (Todd Thompson, Indiana Geological Survey, written communication, October 20, 2010). Glaciers piled this material into long, curved ridges and hills (moraines), but meltwater from the glaciers also spread material across the terrain as outwash. The Kankakee outwash plain, south of the Valparaiso Moraine (and the lakeshore), is the result of large-scale deposition, extending across seven counties in Indiana and Kankakee County, Illinois (Schoon 2003). The 1° × 2° geologic map for the area (i.e., Schneier and Keller 1970) shows the extent of outwash material in the vicinity of Indiana Dunes. Scoping participants pointed out that Pinhook Bog formed as a kettle (depression) in outwash material.

Another glacial feature, perhaps still affecting the lakeshore today, is isostatic rebound. Scientific debate continues as to the amount of actual rebound (uplift), especially in the northern part of Lake Michigan, but investigators agree that after the glaciers receded, the land surface began to rebound without the weight of glacial ice weighing it down. Isostatic rebound is linked to the rise in lake level. By 8,300 years ago, water was rising quickly, drowning oak trees about 14 km (9 mi) north of the modern shoreline. By 6,300 years ago, the elevation of the lake was near its current position but surpassed this position by more than 6 m (20 ft) around 5,500 years ago (Thompson 1998b).

Paleontological Resources

Hunt et al. (2008) completed a baseline paleontological inventory for the Great Lakes Network, including Indiana Dunes National Lakeshore. This inventory documented paleontological resources from the geologic formations beneath the national lakeshore and within park collections. The bedrock underlying the national lakeshore are from the Paleozoic Era, namely the Silurian and Devonian periods (443 million to 359 million years old), and include the Wabash Formation (limestone and dolomite), Muscatatuck Group (dolomite, sandstone, and limestone), Antrim Shale (noncalcareous shale), and New Albany Shale (shale with limestone lenses). Of these, the Silurian Wabash Formation and Middle Devonian Muscatatuck Group are the most abundantly fossiliferous.

Exposed bedrock is essentially absent along the Indiana shoreline, but the Illinois shoreline, which was exposed during Pleistocene (2.5 million to 11,700 years ago) highstands, yields fossils. These fossils from Illinois occasionally wash up along the shoreline of the national lakeshore. The crinoids within the park's collections likely came from these exposures of limestone in Illinois.

While fossils washing up along the Indiana Dunes shorelines is rare, the lakeshore has a well-documented Pleistocene (2.5 million years ago to 11,700 years ago) and Holocene (starting 11,700 years ago) fossil record that holds important information regarding post-glacial changes in flora and fauna in the area. Holocene material includes post-glacial, spruce pollen and wood. Paleoecological studies at Pinhook Bog documented 8,000-year-old *Sphagnum* moss (floating mat), sedges, heath shrubs, white pine, and larch (Futyma 1988; Davis et al. 1998). Studies at Cowles Bog found 7,000-year-old floating, leaved aquatics; the algae *Pediastrum*; and abundant grass pollen, as well as 2,000-year-old grass-dominated marsh, containing *Sphagnum*, larch, and white pine. Following shortly thereafter conifer swamp hosted tamarack (*Larix laricina*), eastern white pine (*Pinus strobes*), winterberry (*Ilex verticillata*), and/or mountain holly (*Nemopanthus mucronata*), speckled alder (*Alnus rugose*), Polypodiaceous ferns, royal fern (*Osmunda* spp.), and *Sphagnum* moss (Futyma 1988). In addition, vibracores from Cowles Bog recovered 6,000-year-old mollusks (Miller and Thompson 1990; Miller et al. 1996).

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Table 3. Scoping Meeting Participants and Contributors

NAME	AFFILIATION	TITLE	PHONE	E-MAIL
Bob Daum	Indiana Dunes National Lakeshore	Chief of Resource Management	219-395-1571	bob_daum@nps.gov
Constantine Dillon	Indiana Dunes National Lakeshore	Superintendent	219-926-7561	constantine_dillon@nps.gov
Georgia Hybels	NPS Geological Resources Division	GIS Specialist	303-969-2173	georgia_hybels@nps.gov
Katie KellerLynn	Colorado State University	Geologist, Report Writer	801-608-7114	katiekellerlynn@msn.com
John Kwilosz	Indiana Dunes National Lakeshore	Natural Resources Program Manager	219 395-1565	john_r_kwilosz@nps.gov
Dan Mason	Indiana Dunes National Lakeshore	Botanist	219 926-7561	daniel_mason@nps.gov
Chales Morris	Indiana Dunes National Lakeshore	Environmental Protection Specialist	219-395-1552	charles_morris@nps.gov
Lisa Norby	NPS Geological Resources Division	Geologist	303-969-2318	lisa_norby@nps.gov
Noel Pavlovic	U.S. Geological Survey	Ecologist	219-926-8336 x428	npavlovic@usgs.gov
*Pete Penoyer	NPS Water Resources Division	Hydrologist	970-225-3535	pete_penoyer@nps.gov
Todd Thompson	Indiana Geological Survey	Senior Scientist	812-855-4400	tthomps@indiana.edu
Brenda Waters	Indiana Dunes National Lakeshore	Assistant Chief of Natural Resources	219-395-1552	brenda_waters@nps.gov

*Pre- and post-scoping contributor.