Geologic Resource Evaluation Scoping Summary
Cape Cod National Seashore, Massachusetts

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The Geologic Resource Evaluation (GRE) Program provides each of 270 identified natural area National Park Service units with a geologic scoping meeting, a digital geologic map, and a geologic resource evaluation report. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity for discussion of park-specific geologic management issues and, if possible, include a site visit with local experts. The purpose of these meetings is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and potential monitoring and research needs. Outcomes of this scoping process are a scoping summary (this report), a digital geologic map, and a geologic resource evaluation report.

The National Park Service held a GRE scoping meeting for Cape Cod National Seashore on June 12-13, 2008 at Cape Cod National Seashore headquarters. Bruce Heise (NPS – GRD) led the discussion regarding geologic processes and features at the Cape Cod National Seashore, and Melanie Ransmeier (NPS – GRD) facilitated the discussion of map coverage. Steve Mabee (MGS) presented an overview of geologic mapping in Massachusetts, Byron Stone (USGS) presented an overview of Quaternary stratigraphy and origin of Cape Cod, John Masterson (USGS) explained the role of geology in water resources studies on Cape Cod, and Mark Borrelli (Texas A&M) reviewed the National Park Service's interest in mapping submerged resources associated with coastal park units. On Friday, June 13, Graham Giese, Byron Stone, Steve Mabee, and Mark Adams led participants on a field trip of the national seashore. Participants at the meeting included NPS staff from the park and Geologic Resources Division, as well as cooperators from the Massachusetts Geologic Survey (MGS), United States Geologic Survey (USGS), Provincetown Center for Coastal Studies, Texas A&M, and Colorado State University (see table 2). This document highlights the GRE scoping meeting for Cape Cod National Seashore including the geologic setting, the plan for providing a digital geologic map, a 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

Cape Cod National Seashore is located about 110 km (65 miles) southeast of Boston at the end of the distinctive peninsula that defines the Massachusetts coastline. The classic Cape Cod Hook forms a sandy extension of land known as a spit that curves around nearly on itself creating an ideal harbor near Provincetown.

Igneous and metamorphic rocks form the foundation of Cape Cod and are buried by glacial deposits ranging from 61-183 m (200-600 ft) thick. These granites, schists, and gneisses are similar to rocks in parts of the northern Appalachians, and like the rocks in the Appalachians, they are related to - and were once connected with - the rocks of Morocco in northern Africa. When Africa split apart from the large landmass known as Pangaea about 200 million years ago (Ma), these rocks remained sutured to the North American tectonic plate.

By Late Cretaceous time (99.6-65.5 Ma), a coastal plain environment formed in the Cape Cod region. Deltaic, swamp, and marine clay deposits formed and are now exposed on Martha's Vineyard and probably underlie Nantucket and Cape Cod. Tertiary coal deposits exposed beneath the sands near Provincetown and other nearby deposits record alternating marine and nonmarine conditions through the Tertiary Period (65.5-1.81 Ma).

In the Pleistocene Epoch beginning about 1.8 Ma, great ice sheets advanced from the north into the temperate regions of North America. These continental glaciers advanced and retreated several times during the Pleistocene Ice Age. Sea level lowered during glacial advance and rose when the ice melted. Between 25,000 and 16,000 years ago the advance of the glaciers into Cape Cod stopped on what is now Nantucket and Martha's Vineyard. Most of the Cape Cod landscape is composed of sand and gravel deposited in braided streams as meltwater flowed from receding glaciers. These outwash deposits formed deltas in glacial lakes.

As the glaciers retreated, sea level rose. Hills became islands and then shoals as rising water levels and erosion by waves impacted these areas. Drowned stumps found off the coast of Provincetown were once part of forests that have been submerged by rising sea level. The glacial features and history of Cape Cod along with its constantly changing shoreline as sea level rises makes Cape Cod a unique landform along the Atlantic Coast. Today, the continuous beach facing the sea on the east side of lower Cape Cod and the wave-cut cliff behind the beach are retreating at a rate of approximately 0.8 m (2.6 ft) each year.

Overview of Mapping in Massachusetts

In 2002, a rejuvenated mapping program, driven by population growth along the I-495 corridor, focused on updating the bedrock map of Massachusetts, finishing and publishing all the surficial geologic mapping in the state, and digitizing all available maps. All of the bedrock maps have been updated, and the published paper geologic maps for Massachusetts have been digitized.

The USGS is currently preparing a seamless compilation of the glacial and postglacial units on the six published, 1:24,000-scale quadrangles – North Truro, Wellfleet, Orleans, Harwich, Chatham, and Monomoy Point. The compilation will include the unpublished Provincetown quadrangle, as well, and will resolve not only the mismatched lines across map borders but also the glacial and postglacial units that vary slightly on each map. For example, units of glacial meltwater deposits on the published quadrangles include Qtr – Truro outwash plain, Qh – Highland outwash plain, Qw – Wellfleet outwash plain, and Qe – Eastham outwash plain. The compilation will combine these units into one unit referred to as "coarse stratified deposits" (sd-c). However, while units may be lumped together, the original detail in the linework will be maintained so that, if desired, the lumped polygons may be subdivided into individual units such as outwash plains, beach deposits, or dune types.

Quaternary Stratigraphy of Cape Cod (Byron Stone)

Cape Cod is the largest glacial peninsula in the world, and its thick glacial and postglacial deposits make it one of the "jewels" of worldwide Quaternary geology. Coarse-grained glaciofluvial, glaciolacustrine, and glaciomarine sediments are principal high-yielding groundwater aquifers for municipal and industrial use. Mapping the glacial aquifer system is now a major focus in Massachusetts.

Different stratigraphic methods can be used to map and date glacial deposits. “Lumped stratigraphy” can be useful when comparing similar glacial deposits from different areas. For example, till, glacial lake deposits, glacial stream deposits, glacial moraines, and postglacial moraines in Illinois can be compared with those in Michigan. “Diachrono-stratigraphy” dates glacial deposits using C14 dates so, for example, the Michigan Lobe can be correlated to the Hudson-Champlain Lobe. In general, the primary purpose of “chronostratigraphy” is to determine stage-age dates of strata. The location and age of different ice lobes can be mapped, also (“lobe stratigraphy”). In the Cape Cod region, four ice lobes have been mapped: 1) Cape Cod Bay (CCB) Lobe, 2) South Channel Lobe (east of CCB Lobe), 3) Charles-Merrimack Lobe (northwest of CCB Lobe), and 4) Narragansett Bay-Buzzards Bay Lobe (west of CCB Lobe). “Biostratigraphy” uses the remains of organisms to date deposits. Quaternary stratigraphy is generally useful for dating postglacial deposits and for determining past climates. “Lithostratigraphy” packages strata into specific formations, facies, or groups of layers. Finally, “allostratigraphy” is used to map and define stratigraphic layers based on bounding discontinuities, which are noticeable interruptions in sedimentation. This method uses an informal nomenclature, informal terms, and is based on good stratigraphic principles.

Allostratigraphy has proven invaluable for mapping the complex glacial stratigraphy of Cape Cod. In Massachusetts, glacial meltwater sediments deposited in glacial lakes, glacial streams, and the sea in front of the retreating ice margin are the primary stratified surficial material. Using allostratigraphic concepts, meltwater deposits have been arranged in “morphosequences.” A meltwater morphosequence includes a continuum of landforms that grade from ice-contact forms (eskers, kames) to non-ice-contact forms (valley terrace, delta plains) that were deposited simultaneously at and beyond the margin of a glacier. Within a morphosequence, which occupies a known position within a basin, a sedimentary facies, the smallest sedimentary unit that can be mapped based on lithologic characteristics, can be 3-D mapped in detail and may be utilized directly as a hydrostratigraphic unit.

Mapping the Quaternary geology of Cape Cod dates back to the 1934 map by Woodworth and Wigglesworth. In 1966, Arthur Strahler wrote A Geologist’s View of Cape Cod. In the 1960s, the USGS-NPS Cape Cod mapping program followed the classic stratigraphy from Shaler and Woodworth. The maps were precise and included large morphosequences, recognition of glacial lakes, and cross sections.

In 2008, the USGS plans to finish compiling surficial digital geologic maps for Cape Cod at a scale of 1:24,000. Future work may include a revised stratigraphy, a history of the glacial lakes, a subsurface 3-D stratigraphic model, moraine stratigraphy and processes, kettle deformation and kettle stratigraphy, the age of terminal and recessional moraines, and the integration of terrestrial geology with offshore geology.

The Role of Geology in Water Resources Studies: CACO (John Masterson)

Cape Cod is not a sandbox. The geology of Cape Cod needs to be understood in order to understand groundwater flow patterns and to develop an accurate 3D hydrologic model. For example, the Wellfleet Plain is an old delta; the Truro Plain, which is younger than the Wellfleet Plain, consists of foreset beds; and the Eastham Plain, the youngest of the three, is composed of outwash sediments. The hydraulic conductivity of these different lithofacies can be measured and used to help define groundwater flow.

Water tables can also be measured. The depth to the water table from the surface may be used to predict the depth of the freshwater/saltwater interface. In general, the closer the water table is to the surface, the deeper the saltwater lense. The maximum depth to the fresh water/salt water interface is 137 m (450 ft). At Nauset, the water table is about 5 m (17 ft) below the surface and groundwater flows into the ocean about 0.4 km (0.25 mi) offshore. Information concerning the water resources on Cape Cod is available through the Water Resources Division (WRD) of the NPS, the U.S. Geological Survey, Woods Hole Oceanographic Institute, and in *Ground Water*, a leading technical journal for groundwater hydrogeologists.

Geologic Mapping for Cape Cod National Seashore

During the scoping meeting Melanie Ransmeier (NPS GRD) showed some of the main features of the GRE Programs digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of GIS compatibility. The NPS GRE Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation set for the GRE Program. Staff members digitize maps or convert digital data to the GRE 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, a Windows HelpFile that captures ancillary map data, and a map document that displays the map and provides a tool to access the HelpFile directly.

When possible, the GRE 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 management because they capture most geologic features of interest and are positionally accurate within 40 feet. The process of selecting maps for management use begins with the identification of existing geologic maps and mapping needs in vicinity of the park. Scoping session participants then select appropriate source maps for the digital geologic data to be derived by GRE staff. Table 1 lists the source maps chosen for Cape Cod National Seashore.

Table 1. GRE Mapping Plan for Cape Cod National Seashore

Covered Quadrangles	GMAP[1]	Citation	Scale	Format	Assessment	GRE Action
Provincetown		Unpublished	1:24,000	Scribe sheet & photo positive	Most comprehensive geologic map known for area	The GRE team will facilitate publication of this quadrangle as an OF by digitizing it in cooperation with the Mass. Survey and USGS
Orleans	1614	Oldale, R. N., Koteff, C., Hartshorn, J. H. 1971. Geologic map of the Orleans quadrangle, Barnstable County, Cape Cod, Massachusetts. Scale 1:24,000. GQ-931. U.S. Geological Survey.	1:24,000	Digital & paper	Most comprehensive geologic map known for area	Both formats acquired by GRD
Chatham	1612	Oldale, R. N. 1970. Geologic map of the Chatham quadrangle, Barnstable County, Cape Cod, Massachusetts. Scale 1:24,000. GQ-911. U.S. Geological Survey.	1:24,000	Digital & paper	Most comprehensive geologic map known for area	Both formats acquired by GRD
Harwich	1611	Oldale, R. N. 1969. Geologic map of the Harwich quadrangle, Barnstable County, Cape Cod, Massachusetts. Scale 1:24,000. GQ-786. U.S. Geological Survey.	1:24,000	Digital & paper	Most comprehensive geologic map known for area	Both formats acquired by GRD
Monomoy Point	1609	Koteff, C., Oldale, R. N., Hartshorn, J. H. 1968, Geologic map of the Monomoy Point quadrangle, Barnstable County, Cape Cod, Massachusetts. Scale 1:24,000. GQ-787. U.S. Geological Survey.	1:24,000	Digital & paper	Most comprehensive geologic map known for area	Both formats acquired by GRD
Wellfleet	1613	Oldale, R. N. 1968. Geologic map of the Wellfleet quadrangle, Barnstable County, Cape Cod, Massachusetts. Scale 1:24,000. GQ-750. U.S. Geological Survey.	1:24,000	Digital & paper	Most comprehensive geologic map known for area	Both formats acquired by GRD
North Truro	1608	Koteff, C., Oldale, R. N., Hartshorn, J. H. 1967, Geologic map of the North Truro quadrangle, Barnstable County, Massachusetts. Scale 1:24,000. GQ-599. U.S. Geological Survey.	1: 24,000	Digital & paper	Most comprehensive geologic map known for area	Both formats acquired by GRD

[1]GMAP numbers are unique identification codes used in the GRE database.

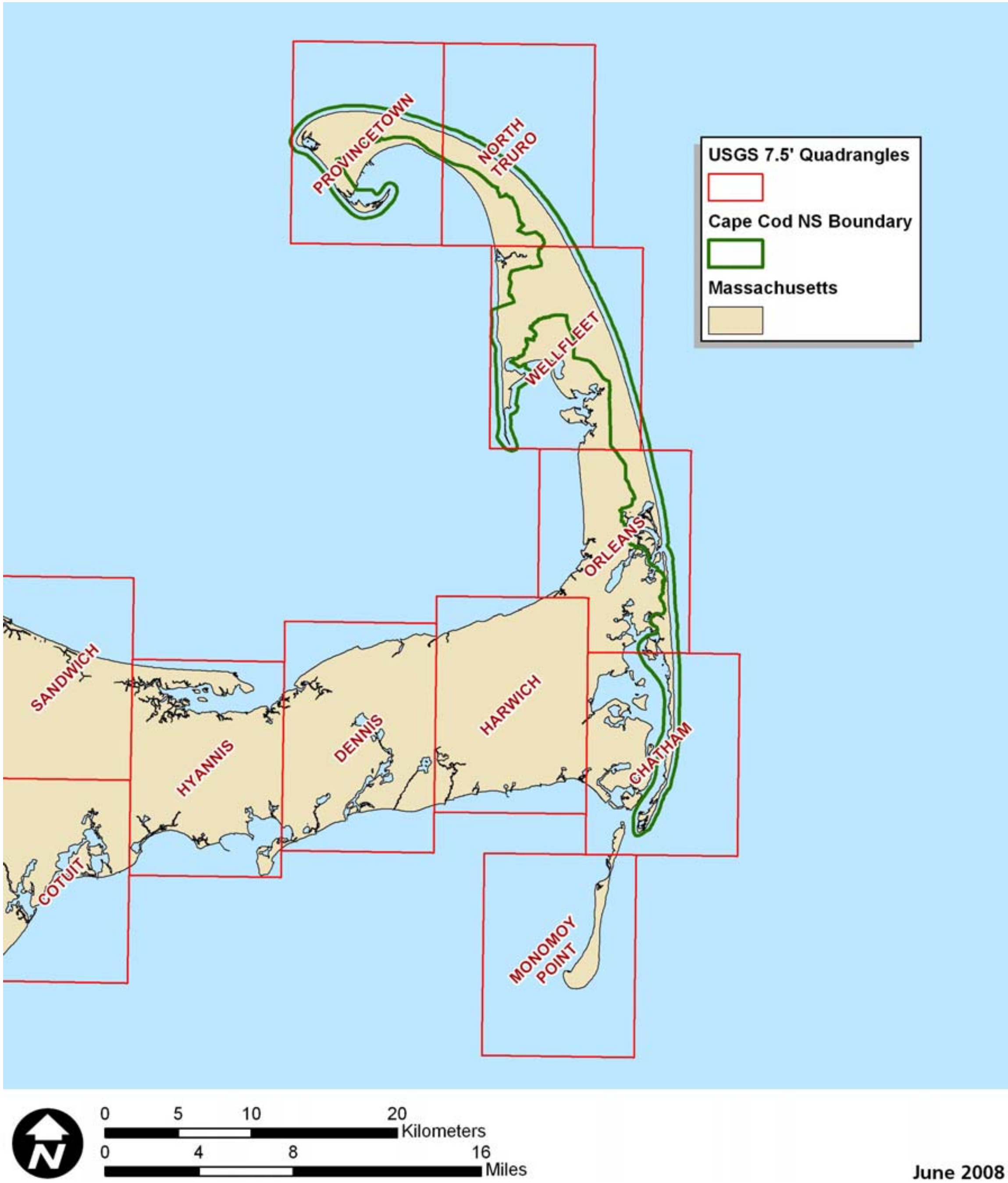

Figure 1. Area of interest for Cape Cod National Seashore, Massachusetts.

In order to obtain complete digital geologic map coverage for Cape Cod National Seashore, GRD plans to convert existing digital geologic maps of the Orleans, Chatham, Harwich, Monomoy Point, Wellfleet, and North Truro Quadrangles to the NPS GRE Geology-GIS Geodatabase Data Model. Source maps identified in the table above were originally generated by Oldale, Koteff, and Hartshorn and published by the USGS in the late 1960's and early 1970's. They are considered the best geologic mapping available in the area and provide sufficient detail for use by resource management. These maps have already been digitized through a cooperative agreement with the USGS and Massachusetts Geological Survey. Conversion of these data to the GRE data model should be fairly straightforward and will ensure consistency with other NPS units and provide the added benefit of Helpfiles to the park. Steve Mabee has agreed to provide the necessary data for this conversion project to GRE staff.

The Provincetown Quadrangle presents a bigger challenge because it has never been published. However, Byron Stone of the USGS has obtained the original scribe sheet map of this quadrangle and produced a photo positive. In order to facilitate publication of this quadrangle as a USGS Open File report GRE team has agreed to digitize the Provincetown Quadrangle. Byron Stone has agreed to provide a digital photo positive of the original Provincetown map and GRE team will work closely with Byron to ensure that the USGS is satisfied with the digital product. Once these data are published, seamless digital geologic map coverage of Cape Cod National Seashore will be accomplished. The GRE team could begin the digitizing process for Provincetown in the first quarter of FY09 as long as source data are provided in time. An assessment of projected time for project completion will take place once the team evaluates the source photo positive.

Mapping Submerged Resources at Cape Cod National Seashore

Cape Cod National Seashore is one of 97 National Park units with coastal features. The park has 177 km (110 mi) of shoreline and extends for one-quarter mile off shore. Of the park's 43,600 acres, 16,700 acres (38%) are submerged. A baseline inventory and map of these resources may be important for political as well as resource management issues. For example, because of the changing shoreline, the spit offshore of Chatham will eventually attach itself to the mainland. Chatham's town charter states that all of the land to the shoreline belongs to Chatham. Currently, the spit is part of Cape Cod National Seashore. It is not clear if the park will loose this land. A baseline inventory of offshore resources may aid park managers in discussions regarding potential power lines, liquid natural gas (lgn) pipelines, and other offshore development. These inventories will also allow the park to project how future projects may impact park recourses and assess how past projects have impacted those resources.

Scoping participants were concerned with how to map the white zone, which is that area between low tide and about 20 m (66 ft) offshore. Byron suggested using old photographs on which the bottom is visible. Raw data from Woods Hole combined with ortho-images may be useful to distinguish and map different lithologies, for example, sand from fine-grain till. Local fishermen may be hired to identify hazardous areas such as boulder areas. Offshore areas between the hazards may be mapped as extensions of the low tide sedimentology and morphology. Fishermen, however, may not be willing to give up their favorite fishing locations, which are generally associated with irregular seafloors. While offshore of the beaches is probably straightforward at Cape Cod, the embayments are more complex. Side-scan sonar may be useful for mapping these areas.

Issues related to global warming may also become important with regards to purchasing properties that may eventually be converted to open water and to the landward migration of the shoreline from rising sea level. An essential first step toward understanding marine resources would be an inventory of known submerged data, maps, and research. The recently formed Ocean and Coastal

Resources Program of the NRPC Water Resources Division will begin to address many of these mapping and potential impact questions.

Geologic Resource Management Issues

The scoping session for Cape Cod National Seashore provided the opportunity to develop a list of geologic issues that may be important to park management. These issues will be further explained in the final GRE report. The more significant geologic issues include:

- Coastal erosion
- Sea level rise and climate change
- Groundwater/sediment interaction

Other potential geologic resource management issues discussed included:

- Seismic activity (earthquakes)
- Dredging
- Disturbed lands needing restoration

Coastal Erosion

The dynamic open ocean shoreline of Cape Cod erodes at an average rate of 0.8 m/yr (2.6 ft/yr). The rate doubles from north of the nodal point to the south. Sand to the north of the nodal point is transported north, and sand south of the nodal point replenishes beaches to the south. Because erosion is faster on the southern end of the Cape than farther north, the orientation of the shoreline is rotating slowly clockwise. Approximately 6,000 years ago, long shore current began to transport eroded sand from the bluffs to the south, forming the barrier beach system of Nauset Beach and Monomoy Island. Sea level has risen about 10 m (30 ft) over the last 6,000 years, and the water over Georges Bank has deepened. As a result, the nodal point, which was once located north of the bluffs, has moved south to its present position near Coast Guard Beach. Evidence suggests that the overwhelming majority of sand eroded from the bluffs is transported to the north, effectively shutting off the primary source of sand to Nauset Beach and Monomoy Island. Sand transported to the north provides sediment to the Provincetown Hook.

Erosion at the foot of the Pleistocene bluffs during spring high tides and storm events increases the potential for landslides. Mass wasting due to bluff failure is a threat to infrastructure and visitor safety. Management has posted signs warning visitors of the potential danger. Bluff erosion also leads to changes in habitat for vegetation. Submerged trees in life position near Provincetown attest to the change in topography due to both sea level rise and coastal erosion.

Sea Level Rise and Climate Change

Rising sea level changes the wave energy regime along Cape Cod. Increases in the frequency and/or intensity of storm events may impact infrastructure and cause more damage than historic storms of equal intensity due to decreasing barrier volume resulting from declining sediment supply. Along with sea level, the water table may rise, thus changing the freshwater/saltwater interface. As sea level rises, salt marshes are migrating landward causing channels to narrow. Rising sea level has also impacted once-dry pamets, which were periglacial valleys that are now filling with seawater.

Saltwater intrusion is impacting freshwater systems. Flapper gates were installed on the Pamet River to restrict high tide and preserve the freshwater system. However, the flapper gates have caused the hydraulic head to change and now the system is being contaminated by salt water. Dams have been installed in the Herring River in an attempt to maintain its freshwater system rather than converting to a salt marsh. Salt pond, near Provincetown, had been a typical freshwater kettle, which underwent saltwater inundation. The salt marsh boundary is migrating landward. The landward migration and narrowing of Nauset spit with sea level rise is anticipated. Once the spit is attached to the mainland, jurisdictional questions will arise over who owns the spit, the NPS or the town of Chatham.

Groundwater/Sediment Interaction

All precipitation on Cape Cod is intercepted by the porous sediments and infiltrates into the groundwater system. Cape Cod has negligible overland runoff and no integrated runoff patterns. All potable water on Cape Cod comes from groundwater stored in unconsolidated glacial material. Multiple sources may affect groundwater quality including septic systems, groundwater withdrawal, military activities, and saltwater intrusion. For example, algal blooms in Salt Pond may indicate potential contamination from the town's landfill or septic system. Monitoring groundwater quality, therefore, is extremely important. Detailed information is available from the Water Resources Division of the NPS and John Masterson's group at the USGS.

Other Geologic Issues

Seismic Activity: A 1755 earthquake in Boston caused as many as 1500 chimneys to topple and church bells to ring. The earthquake had an estimated magnitude of 6.0 to 6.3 on the Richter Scale, and the quake's epicenter was located about 40 km (25 mi) east of Cape Anne. Shaking lasted for more than one minute and was felt in coastal communities from Portland, Maine, to south of Boston. If a similar earthquake were to occur today, Boston could sustain billions of dollars of earthquake damage, with many thousands injured or killed, because much of the city is built on artificially created landfill. Several smaller earthquakes have been detected in this area during the past 30 years (Ebel 2005). The unconsolidated sediment that overlies the bedrock surface in the Cape Cod region poses a significant threat of mass wasting and possibly liquefaction. A seismic risk map is available from the USGS for this area, and earthquake information for this area is available on the Weston Observatory web site at www.bc.edu/westonobservatory.

Dredging: Chatham Harbor is home to a 70-vessel fishery fleet. Sediment dredged from the navigational channel in Chatham Harbor is deposited on town beaches impacting sediment transport. Dredging may be one unintended consequence of hard structures built in the bay in 1987 that may have contributed to the formation of the inlet in 2007. Dredging also is occurring in Hatches Harbor and East Harbor, and is planned for Herring River, in order to restore tidal functions.

Sand Migration: Because sand dunes are dynamic features, blowing sand tends to migrate onto roads, especially in the Provincetown area. The park moves sand from roads in the direction it was naturally trending. The state and town take the sand away.

Disturbed Lands Needing Restoration: Rock groins, seawall berms, and an old asphalt road at Herring Cove Beach are relict structures from the 1950s. Erosional processes have caught up with the structures and they are not viable today. An old mining site is present in the park where sand was mechanically removed and transported to Boston for use in factories. The park is an access point for remote cabins, many of which have been reclaimed by nature. A large rotary at the end of Highway 6 was abandoned in the 1980s but scars from the old highway remain in the Province Lands dunes. About 50% of Province Lands still has disturbances. Dunes and successional dunes are threatened by all-terrain vehicles (ATVs), social hiking trails, horse trails, and mountain bike activity. Horse trails have proven to be more susceptible to erosion than the bike trails. Cape Cod is an intensely used landscape, and often, visitors enter the park without knowing.

Features and Processes

The scoping session for Cape Cod National Seashore provided the opportunity to develop a list of geologic features and processes, which will be further explained in the final GRE report. Several of these geologic features and processes were observed on Friday's (06/13/2008) field trip. The park includes a variety of recent (Holocene) and Pleistocene geologic features.

Holocene Aeolian Dunes

These modern dunes include excellent examples of parabolic dunes in Province Lands, perched or "bluff top" dunes common on the ocean side of the Pleistocene bluffs, and longitudinal dunes that form an axis on the barrier beach starting at Eastham and extending south to Monomy Point and providing protection to the interior of the Cape. Old dunes, created by northerly winds, and young dunes, deposited by northwesterly winds, may exist in the park. Mapping or aerial photography may show the differences in wind direction. Dune surfaces have been extensively disturbed since the arrival of Europeans to the area.

Pleistocene Bluffs

The glacial bluffs behind the beach are the second highest bluffs (glacial or otherwise) on the east coast of the United States. They are composed of unconsolidated outwash from the Pleistocene ice sheet. The high point of Cape Cod National Seashore is south of Pamet on the ocean side.

Tidally Influenced Fluvial System

Because meteoric waters are nearly 100% absorbed, no overland flow or integrated drainage system exists on the Cape. Rather, drainage is influenced by groundwater, elevation, and tides. In the past, Native Americans artificially connected several ponds to create a surface flow that still supports a complex area of wetlands and islands.

Salt Marsh Processes

Fluctuations in sedimentation driven by tidal flow or overwash events contribute to healthy salt marsh and island systems. Overwash events deposit sediment in marshes, increasing the elevation of the march, which allows them to keep pace with sea level rise. Subsidence due to the construction of dikes in some areas may have resulted in salt marsh die back although this die back is still not well understood.

Lacustrine

The lakes and ponds in Cape Cod National Seashore are primarily kettle features. Some of the shallow, nearshore ponds are at risk due to erosion and may become springs. Salt water intrusion has impacted some of the ponds and put pressure on some public water supplies, especially in Provincetown. The Cape has both commercial and natural cranberry bogs.

Glacial and Periglacial Features

Outwash plains, delta deposits, pamets, ice contact slopes, and erratics are some of the glacial and periglacial features on Cape Cod. Excellent examples of outwash plains are dotted with small to large kettles. The large kettle lakes may be 0.8 – 1.6 km (0.5 – 1 mi) in diameter. These large kettle holes probably contained blocks of ice at least 150 m (500 ft) thick when they were buried in the lake bottom sediments. Cape Cod kettles are a topic of upcoming research.

A collapsed outwash plain at the top of a deltaic system is also present. Representative sections of glacial-deltaic deposits in the bluffs include foreset beds and glacial ponds that have filled with sediment.

Pamets are valleys cut by flowing water following the disappearance of glacial lakes. They are possibly related to seasonal melt, permafrost, and/or groundwater sapping. The Pamet River is an example of a Pleistocene pamet that is now filling with seawater. The Pamet River flows to the west into a flooded Pleistocene lowland.

Ice contact slopes have been mapped on Cape Cod. The Billingsgate Shoal in Cape Cod Bay may show evidence of glacial readvance. This area is now totally submerged, but it was emergent 6,000 years ago.

The massive Doane Rock is the largest glacial erratic on Cape Cod. The erratic is too big to roll down an outwash slope. A more plausible explanation for its origin suggests that the rock rolled off kettle ice that was so thick and extensive that it lay upon the outwash plain.

Some paleo permafrost features may be preserved in the park, but these are currently not mapped. They are known in Massachusetts and may be present in this area, also.

Coastal and Marine Features

Cape Cod National Seashore contains excellent coastal features such as barrier spits, barrier islands, salt marshes, inner tidal flats, coastal bluffs, ebb and flood tidal deltas, flood tidal deltas in Chatham Harbor that are world-class, tidal inlets, the Hook at Provincetown, beach/dune complexes, submerged and emerged shorefaces, nodal plains, nearshore bars, offshore bars, and rip channels.

Washover fan deposits indicate extreme events that caused major changes over a short time frame. Coastal processes and rising sea level have also drowned valleys and some kettles.

Other Features

Ventifacts: Faceted by wind, these pebbles are common at High Head and indicate strong periglacial winds and may have been frozen "in place" in the permafrost

Paleosols: Buried soils within the dunes may be significant for paleo climate research

Fulgurites: Lightning strikes might fuse sand grains together into irregular, glassy, rod-like structures called fulgurites.

Paleontological resources: Two kinds of fossils are found on the Cape: 1) transported Tertiary microfossils in glacial deposits, and 2) 12-18 thousand years of fossil pollen, seeds, twigs, gastropods, pinecones and microfossils that fill kettle bowls. Shells within the body of the Provincetown Hook deposit have been dated and indicate the Hook formed approximately 6,000 years ago. These fossils are a valuable scientific resource but not a management issue.

Friday the Thirteenth Field Trip

We were fortunate to have participants at the scoping workshop who had many years of experience with the geology of Cape Cod. On Friday, they led an exceptionally informative field trip from the Province Lands south to Chatham Harbor.

Stop	Features
1. Ballston Beach	• Type section for a pamet • Washover location of 1991 Perfect Storm • Dune fencing for protection from trampling • House being moved due to cliff collapse • Sedimentary features in cliff face: paleosol, ripples, foresets, slump • Anthropogenic features in cliff face: asphalt road • Small scale avalanche slopes at toe of cliff
2. Herring Cove Visitor Center	• Relict road • Blocks of peat • Dune migration • Bi-modal direction sand transportation patterns
3. High Head	• Wave cut Pleistocene cliff • Intersection of 2 systems: winter sand movement to south; summer sand movement to north • View of Provincetown Hook • Historical explanation of railroad and Old King's Road
4. Oversand Beach	• Parabolic dunes • Blowout, or Deflation dune

	• Salt & pepper beach sand from magnetite, garnet, hornblende, metabasalt
5. Doane Rock	• Glacial erratic (also called Enos Rock)
6. Nauset Light Beach	• Glacial erratics left along ice contact margin • Cross-bedding in Holocene slope deposits
7. Coast Guard Beach	• Bluff features • Pleistocene fluvial beds in outwash plain channels • Diamicton (matrix supported conglomerate) from ice contact • Bluff erosion – undercutting; collapsed concrete blocks from abandoned structure
8. Chatham Lighthouse	• Mesotidal inlet • Storm breached barrier in 1987 at narrowest point; approximately 140 year cycle • Prior to breaching, barrier extended to south • Discussion of jurisdictional issue when spit attaches to land • Discussion of hydraulic efficiency, dredging, and inlet migration

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Table 2. Scoping Meeting Participants

Name	Affiliation	Position	Phone	E-Mail
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