A GEOLOGIC OVERVIEW OF CAPE COD:

A GUIDE FOR THE SIGMA XI FIELD TRIP

SEPTEMBER 26, 1992

BY

ROBERT N. OLDALE[1]

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[1]U.S. Geological Survey

Woods Hole, MA 02543

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INTRODUCTION

This overview presents a generalized account of the geology of Cape Cod, demonstrated by scenic overlooks from the Cape Cod Canal to the Provincelands dunes. This generalized approach is necessary because I have not done field work on the Cape since about 1972 and much of my work here was completed by 1967, 25 years ago. The outcrops studied in the distant past have no doubt changed greatly or disappeared completely, the result of shore erosion and development. However, the general aspects of the geology, stratigraphy, and geologic history remain relatively unchanged, and can best be demonstrated from broad vistas.

Although the complete geologic history of Cape Cod spans more than 600 million years, the Cape Cod we will view today has a much shorter history. This history encompasses the last glacial stage of the ice age, the Wisconsinan, and the present interglacial stage, the Holocene. The cape was initially shaped by the Laurentide ice sheet, which formed in Canada about 75,000 years ago. For much of its existance, the ice sheet remained north of New England. About 25,000 years ago the Laurentide ice sheet advanced southward and reached the vicinity of Cape Cod and the Islands a few thousand years later. Retreat of the ice sheet followed within a thousand years or so, and the glacial deposits on Cape Cod were formed by 18,000 years ago.

The next great event in the geology and geologic history of Cape Cod was the submergence by the rising sea. The sea-level rise was the result of water being returned to the ocean basins from the melting Laurentide ice sheet. Initial submergence of Cape Cod probably occurred about 8,000 years ago and the development of the spits and marshes about 4,000 to 6,000 years ago. Sea-level rise, upland erosion, and barrier island erosion and progradation are the most important processes shaping Cape Cod today.

The geology and the basic the shape of Cape Cod was established by lobation of the Laurentide ice sheet during its retreat. The lobes, from west to east, were the Buzzards Bay lobe that established the arc of the Elizabeth Islands and the

shape of the eastern shore of Buzzards Bay, the Cape Cod Bay lobe that built the upper arm of the cape, and the South Channel lobe, that occupied the western Gulf of Maine east of Cape Cod and shaped the cape's forearm.

Retreat of the lobes was not synchronous; the Buzzards Bay lobe retreated first and the South Channel lobe, last. As a result, the glacial deposits on Cape Cod, in general, become younger towards the east and the youngest glacial deposits occur on the lower cape.

Among the earliest visitors to Cape Cod were Gosnold, in 1602, Champlain in 1605 and 1606, Hudson in 1609, and John Smith in 1614. There is no evidence that the Vikings were the first to visit, but they could have been. Many of these early visits ended in violence between the Indians and Europeans, including killing and kidnaping. The Pilgrims, in 1620, first landed at the tip of the cape. They explored as far south as Eastham where their first contact with the Indians, a fight, occurred. During the expedition they stole whatever Indian possessions they wanted. Some natives and year rounders may think that the unhappy situation that existed between the Indians and Europeans has a modern counterpart when the summer visitors invade Cape Cod.

U. S. Geological Survey map I-1736 (Oldale and Barlow, 1986), a geologic map of Cape Cod and the islands, will be the major reference for the field trip. The book Cape Cod and the Islands: The geologic story (Oldale, 1992) provides an easily understood account of the geology and geologic history of the cape. A booklet (Oldale, 1981), currently being reprinted by the U.S. Geological Survey, provides a simple account of the geologic history of the cape. This field guide is modified from an earlier guide written for the American Quaternary Association (Oldale, 1988a).

ROUTE 6 CANAL OVERVIEW

The first stop of the field trip is on the east end of the Sandwich moraine and is an overlook of the Cape Cod Canal. The Sandwich moraine and Buzzards Bay moraine form the so-called back bone of Cape Cod. The Buzzards Bay moraine, not visible from this point, parallels the Buzzards Bay shore and forms the Elizabeth Islands chain southwest of Woods Hole. A short distance south of the canal, the Sandwich moraine deposits overlie the Buzzards Bay moraine deposits (Mather et al., 1940, 1942).

The canal is located in a through valley that was originally occupied by two streams, the Scussett River that flowed northeast

into Cape Cod Bay and the Monument or Manomet River that flowed southwest into Buzzards Bay. The divide between the two streams was at an altitude of about 29 feet (9 m) (Farson, 1977). The through valley is thought to have formed as water from a glacial lake in Cape Cod Bay escaped to the Buzzards Bay valley. The outlet may have had an initial altitude of about 80 feet (24 m), about the surface altitude of the earliest deltas associated with the lake. Erosion lowered this threshold and consequently the level of the lake. The outlet was abandoned when lower outflow routes developed as the ice retreated from Cape Cod Bay.

The through valley and the two rivers provided an easy portage between Cape Cod and Buzzards Bay. By 1627, colonists had established a trading post in the valley for trade between the English settlers of New England and the Dutch settlers of New Amsterdam. Miles Standish of Alden and Mullens fame proposed a canal between Cape Cod Bay and Buzzards Bay to avoid the dangerous shoals southeast of the cape (Farson, 1977). More than a century later, a canal was proposed by George Washington, among others, as a way to avoid sea blockades such as those imposed by the British during the Revolutionary War and the War of 1812. After numerous false starts, by various companies who were licensed by Massachusetts to dig the canal, the canal was completed in 1914 by a company headed by August Belmont--a feat commemorated by the glacial boulder at this site. Following World War I, the canal was bought by the United States and improved by the U. S. Army Corps of Engineers to what you now see. It is the widest canal in the world.

EN ROUTE TO SCARGO HILL TOWER

Route 6 runs along the crest of the Sandwich moraine with Cape Cod Bay to the north and Vineyard and Nantucket Sounds to the south. The moraine consists of a veneer of till and boulders underlain by stratified drift, including sand and gravel and rhythmically bedded silt and clay. Both the Sandwich moraine and the Buzzards Bay moraine have been interpreted to be glaciotectonic features (Oldale and O'Hara, 1984) formed as the lobes readvanced and thrust previously deposited drift. This stop is located on the crest of the moraine. To the south of the moraine lie the upper Cape outwash plains and the kames along the Nantucket Sound shore. The kames are the oldest surficial glacial deposits on Cape Cod. The upper cape outwash plains were deposited by meltwater from the Cape Cod Bay lobe. They are, from west to east, the Mashpee pitted plain, the Barnstable outwash plain, and the Harwich outwash plain. The Mashpee and Barnstable outwash plains are older than the Sandwich moraine and the Harwich outwash plain is younger than the moraine.

SCARGO HILL TOWER

Scargo Hill tower is located on one of two kames that rise slightly above the Harwich outwash plain. Glacial deposits located between the kames, the Harwich outwash plain, and the Sandwich moraine and the shore are interpreted to be ice-contact deltas and shallow water sediments of the Cape Cod Bay glacial lake. The deltas along this part of the shore generally have altitudes of about 60 feet (18 m) while to the west, older deltas have altitudes of closer to 80 feet (24 m). The latter may have formed during the earliest high stage of the Cape Cod Bay lake. Initially, the lake was very narrow as the ice pulled away from the upper cape, but it became a significant body of water when the large outwash deltas developed on lower Cape Cod and along the west shore from Plymouth to Duxbury.

Postglacial deposits including spits, beaches, marshes, and dunes formed as the Holocene rise in sea level drowned the glacial cape. Sandy Neck and the Barnstable marshes can be seen to the west. Both features began to develop about 4,000 years ago, when sea level was about 25 feet (7.5 m) below the present level (Redfield, 1965; Redfield and Rubin, 1962). Provincelands spit, seen at the outer end of the cape if it is very clear, started to form about 6,000 years ago (Zeigler et al, 1965).

EN ROUTE TO CHATHAM LIGHT

On the way to Chatham Light the route crosses the much collapsed Harwich outwash plain. Large and small kettle holes and shallow valleys interrupt the outwash plain. Many of the large kettle lakes have bottoms well below present sea level and represent ice blocks as much as 200 feet (60 m) thick. Valleys occur on all of the cape outwash plains. They are relict because many are dry. They cross kettle holes and were thus cut early, before the ice blocks buried by outwash melted. These valleys were probably cut not by glacial meltwater because they do not start at the ice-contact head, but by rain water and water from melting snow before the outwash plains became vegetated. Permafrost could have prevented the surface water from percolating into the sandy outwash plain deposits. However, there is no evidence of permafrost and the outwash deposits themselves provide evidence for abundant meltwater and a temperate climate during deglaciation. Robert Thorson (oral commun., 1987) has suggested that an unvegetated or poorly vegetated outwash plain surface may have been sufficient to favor runoff over percolation. Runoff may have been encouraged by the ubiquitous layer of wind deposited silty sand that caps the coarser, more permeable, outwash sand and gravel. Spring sapping has also been suggested as an origin for the valleys. More on this hypothesis later.

CHATHAM LIGHT

Cape Cod is a dynamic environment and ever changing. The dominant factor in the changing landscape is the sea. Where the cape is unprotected from wave attack, sea cliffs have formed in the glacial deposits. In places, barrier beaches protect the glacial deposits from erosion. However, the protection is temporary as the barriers can change form or wash away, mostly during major storms. The breach in this barrier was first developed during a northeast storm in January 1987. The continuing impact of the still widening breach includes increased tidal range and flow within the lagoon, shoaling of the harbor as flood-tidal deltas develop, and erosion along the mainland shore. Changes in the barrier system protecting the mainland from wave attack appear cyclic, as does erosion of the mainland when changes in the barrier system occur. Evidence of a breakdown in the barrier system and erosion of the mainland that occurred in 1851 is shown by the inactive sea cliff below Chatham Light. During the time the Chatham shore was exposed to wave attack, roads and houses were destroyed and as much as 100 feet (30 m) of cliff retreat occurred (Leatherman, 1988). The erosion following the latest breach has claimed a number of houses and, unless hard protective measures are taken, will probably claim more. A laissez faire attitude prevailed for a short time after the recent break, but as expensive land and houses began to go, that changed. The willingness to live with nature gave way to screams for engineering structures to protect the mainland shore from wave attack or to close the breach in the barrier.

FORT HILL

The glacial features seen from this stop on were deposited by the South Channel lobe. From Chatham Light the route crossed the deeply embayed eastern flank of the Harwich outwash plain. The large embayments, Pleasant Bay and Little Pleasant Bay, represent sublobes of South Channel ice, against which the Cape Cod Bay lobe outwash was deposited.

Fort Hill overlooks Nauset Harbor, an embayment formed by a sublobe of South Channel ice. The Nauset sublobe is thought to have been larger initially and to have occupied the site of the Eastham plain. Fort Hill is part of the Eastham plain and across the harbor, to the southeast, are the Nauset Heights ice-contact deposits. The Nauset Heights deposits may be contemporaneous with, or somewhat younger than, the Harwich outwash plain deposits and are the oldest of the South Channel lobe units. The Eastham plain deposits are considered to be the youngest South Channel lobe outwash unit.

Nauset Harbor is bordered on three sides by sea cliffs cut into the glacial drift. The cliff erosion may have occurred before the barrier spit formed or when the embayment was much larger and the mudflats and marshes had not yet developed. The embayment is the result of the Nauset sublobe and was here when the sea transgressed; the cliffs may originally have been ice-contact slopes that were later modified by wave erosion. The opening in the barrier is presently migrating northward and the southern spit is about 1/2 mile (.8 km) longer than it was in 1962. Nauset Harbor spit changed greatly in the 1978 February storm. Previous to the storm, dunes up to 40 feet (12 m) high occupied the spit north of the inlet.

Samuel de Champlain visited Nauset Harbor and made the first map of the region in 1605. The map shows the headlands and barrier spits up to a mile seaward of their present position. The distribution of the marsh and sand flats on the map is remarkably similar to the present distribution.

MARCONI SITE

This is the site from which the first transatlantic wireless transmission between the United States and Europe was made in 1903. Offshore is the site of the pirate ship Whydah, wrecked in a storm in 1717 and now being excavated. The ship's bell, cannon, gold, silver, and other artifacts have been found. The presence of the Whydah probably explains the gold coins occasionally found in the beach deposits along this shore.

Geologically the Marconi site is located at the southern end of the Wellfleet outwash plain deposits, the largest and next to oldest of the South Channel lobe drift units. Its southern flank was deposited against the Nauset sublobe. Following the retreat of the sublobe, the Eastham outwash plain was deposited against the ice-contact slope of the Wellfleet plain. The difference in elevation between the plains and the general westerly slope of the outwash plain surfaces can be clearly seen. The latter unequivocally establishes the presence of ice to the east and is the primary evidence for ice in the Gulf of Maine during late Wisconsinan time, a point that advocates of the late Wisconsinan minimal ice sheet model need to be reminded of periodically.

The great cliff along the "back side" of "lower" Cape Cod, local terms that mean "out back" and "northeast" (as in downwind to Maine), demonstrates dramatically the erosion that will eventually reduce the cape to a series of low islands and broad sand shoals. Erosion along this shore, although sporadic and local in nature, averages about 3 feet/year (1 m/year). The eroded material is transported, by longshore drift, southward to nourish the barriers from Eastham to Chatham and northward to

build the Provincelands spit. Major erosion along the east shore of the cape and the southwest and west shore of Cape Cod Bay occurs mostly during severe winter northeast storms. In contrast, major erosion along the south shore and the Buzzards Bay shore occurs during summer and fall hurricanes.

PAMET VALLEY

Route 6 crosses a number of large dry valleys eroded into the Wellfleet outwash plain. The valleys in the Wellfleet outwash plain, called hollows, are probably the large end member of all the outwash plain valleys. Within the Wellfleet plain, they represent significant erosion, which occurred shortly after the plain was built.

The Pamet is the largest outwash plain valley on Cape Cod. If not blocked by beach and dune on the Atlantic end, the Pamet River would be a seaway, completely separating the lower cape into two parts and making the northern part an island. In addition, unlike all the other valleys, the glacial drift floor of this valley is well below sea level over its entire length.

The valleys were probably cut shortly after the outwash plain surface became inactive. Clearly they were cut before the kettle holes developed and when base level was below present sea level. The origin of the dry valleys is not certain. Hypotheses involving permafrost, to change the permeability of the outwash deposits, or a lack of vegetation that would encourage runoff are possibilities. However, the hypothesis I favor the most involves spring sapping. Under this scenario, the outwash plains would act as leakey dams holding back glacial lakes with altitudes considerably above present sea level. The lakes would raise the water table well above its present level and springs would breakout part of the way down the outwash plain. Spring sapping would cause headward erosion to form the valleys.

At first, the Pamet probably had a history similar to the other dry valleys, that is headward erosion by spring sapping. However, final cutting of this large and deep valley may have been catastrophic. I hypothesize that headward erosion caused the valley to breach the outwash plain dam. The glacial lake drained rapidly and the rushing water widened and deepened the valley.

Where the dry valleys, called hollows on lower Cape Cod, interrupt the great cliff, they provide access to the beach. They were a vital means of escape for sailors stranded on the beach and also made it easier for wreckers to save lives and then scavenge the wrecks.

HIGHLAND LIGHT

One of the early classic Quaternary sections in New England is exposed in the cliffs below the lighthouse. The section consists of gravel overlain by rhythmically laminated clay capped by fine sand. These latter two deposits are lacustrine and provide evidence of a glacial lake to the east of lower Cape Cod, perhaps the one that may have drained through the Pamet Valley. The beds were correlated to the pre-Wisconsinan stratigraphy of Long Island and Martha's Vineyard by Fuller (1914) and Woodworth and Wigglesworth (1934). Zeigler considered the Highland plain deposits to be early Wisconsinan in age (Zeigler et al., 1964). These age assignments and regional correlations are no longer considered valid because the units exposed in the cliff are quite restricted and overlie the Wellfleet plain deposits. The deposits are now inferred to be glaciolacustrine in origin, laid down in a glacial lake, unrelated to the Cape Cod Bay lake, that developed between the Cape Cod Bay and South Channel lobes and the ice-contact flank of the Wellfleet plain.

Three late Wisconsinan outwash plains can be seen from this overlook. We are standing on the surface of the lake deposits that form the Highland plain. The ice-contact slope of the higher Wellfleet plain can be seen to the south marked by the granite tower, a memorial to Jenny Lind, a famous Gay Nineties song bird. To the north is the lower Truro plain. The Wellfleet and Truro plains were formed as deltas, graded to different levels of the Cape Cod Bay glacial lake. The Wellfleet plain is the oldest and the Truro plain is next to the youngest feature related to the lake. The Eastham plain, to the south of the Wellfleet plain, is considered to be the youngest because, above sea level, its deposits are entirely fluvial and the plain was graded to a lower and, most likely, younger level of the lake.

Highland Light is the most powerful light on the New England coast and can be seen from more than 20 miles (32 km) at sea. The light is threatened by the retreat of the cliff which, in the last 10 years, has averaged about five feet (1.5 m) per year (Leatherman, 1988). The retreat is facilitated by landslides in the lake clay and overlying sand.

PROVINCELANDS VISITOR CENTER

The route from Highland Light to the final overview leaves the glacial cape at High Head. The scarp just to the east of Pilgrim Lake is a sea cliff that was eroded in the glacial drift before the Provincelands spit was formed. Just beyond Pilgrim Lake, a lagoon now artificially closed from the sea, the dune sand is burying trees and encroaching on the road. The sand must be removed to keep the road open. Dark layers within the dune

sand are old soil horizons. The beach and dune deposits of the Provincelands rest on late Wisconsinan strata deposited in the sea during the final retreat of the ice. The marine deposits are in part equivalent to the glaciomarine mud that crops out above sea level along the New England coast from Boston northward. They indicate that during the final stages of ice retreat from the vicinity of Cape Cod, the crust was isostatically depressed below the late Wisconsinan low sea level (Oldale, 1988b). As a result, the sea level history of lower Cape Cod is complex and includes a transgression followed by regression during latest Wisconsinan time. The Holocene transgression may not have started until after about 11.0 ka. The Provincelands spit began to form about 6,000 years ago as the sea transgressed the glacial cape. The longshore current carried sand eroded from the glacial deposits northward and westward into deep water off the tip of the glacial cape to form a recurved spit. As sea level rose, new spits were developed along the Atlantic shore, each one recurving toward Cape Cod Bay (Zeigler et al., 1965). The oldest beach deposits occur along the Cape Cod Bay shore and they become progressively younger toward the Atlantic Ocean. As the barrier beach grew toward the Atlantic Ocean, erosion along the Cape Cod Bay side has removed, at least in part, the oldest spits. Wind erosion and deposition continue to move and modify the dunes and, except for the foredune along the Atlantic shore, the dunes may be unrelated in age to the beach deposits beneath them.

Although Cape Cod is a fragile land, its ability to adjust to sea-level rise is well shown by the developing spits and shoals. If sea level continues to rise, Cape Cod may persist in some form long after the rock-bound coast of New England and its port cities are drowned.

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ROAD LOG

Cape Cod can be approached in several ways. From Amherst, the Massachusetts Turnpike connects with I-495 south, which ends at U. S. Route 6, the basic route for the trip. From the Boston area, there are two ways to reach the cape. Route 128, the circumferential highway around Boston, connects with Route 24, which connects with I-495/Route 25. Route 28 also connects with Route 3 which connects with Route 6 at the Cape Cod Canal. **ROUTE 6 CANAL OVERVIEW** The overview is east of Route I-495/25, about 2.0 miles, and west of Route 3, about 1.7 miles. From Route I-495 it is the third pulloff on the right and from Route 3 it is the second pulloff on the left.

Leaving the Route 6 canal overview, turn east on Route 6. Continue east on Route 6 to Union Street (exit 8). Turn north on Union Street to Route 6A in Yarmouth. Turn east on 6A. At the cemetery in Dennis (its on the right) turn right onto Scargo Hill Road. Shortly after the turn Scargo Hill Road bears left at the fork with Old Bass River Road. **SCARGO HILL TOWER** Continue on Scargo Hill Road to a left turn that goes to Scargo Hill tower (Stop 3). Climb the tower for this overview.

Return to Scargo Hill Road and turn left. Continue east on Route 6A to Brewster. In Brewster, turn right onto Route 137. At Route 28, turn left and continue on to Chatham. At the rotary, take Main Street to where it takes a sharp left. Turn right to Chatham Light. **CHATHAM LIGHT**

Go north on Shore Road and Route 28 to Orleans, where Route 28 joins Route 6A. Continue northward to the Eastham rotary. Take Route 6 north to Governor Prence Road, a left fork. Turn right onto Fort Hill Road to Fort Hill overview. **FORT HILL**

Return to Route 6 and turn right. Continue on the entrance road for the Cape Cod National Seashore headquarters. Turn right and carefully follow signs for the Marconi site. **MARCONI SITE**

Return to Route 6 and continue north. The road drops down into the Pamet River Valley. Take Truro exit. **PAMET VALLEY**

Return to Route 6 and continue north. Turn right onto South Highland Road to the Highland Light Road and Highland Light. **HIGHLAND LIGHT**

Return to Route 6 by taking a right on to South Highland Road and a left onto Highland Road. Turn north on

Route 6. At High Head, the road crosses from glacial deposits to the deposits of the Provincelands spit. Continue northward to Point Road. Turn right into the Provincelands Visitor Center. **PROVINCELANDS VISITOR CENTER**

To leave Cape Cod, return to Route 6 and turn left.

DISTANCES BETWEEN MAJOR POINTS

	Miles
Canal overview to Shootflying Hill	15.0
Shootflying Hill to Union Street	7.3
Union Street to Route 6 A	1.4
Route 6A to Scargo Hill Road	3.5
Route 6A/ScargoHill Road intersection to Scargo Hill	1.0
Scargo Hill Road/Route 6A intersection to Route 137	4.6
Route 137 to Route 28	7.2
Route 28 to Main Street, Chatham	3.3
Shore Road, Chatham/Route 28 intersection to Eastham Rotary	9.2
Eastham Rotary to Governor Prence Road	1.4
Governor Prence Road to Park Headquarters Road	6.5
Park Headquaters Road/Route 6 intersection to Pamet Bridge	7.6
Pamet Bridge to South Highland Road	2.5
Highland Road/Route 6 intersection to High Head	1.9
High Head to Point Road	4.5