A GEOLOGIC OVERVIEW OF CAPE COD AND A GEOLOGIC TRANSECT OF WELLFLEET FROM THE ATLANTIC OCEAN TO CAPE COD BAY

by

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INTRODUCTION

This field trip guide is for the October 30, 1993 NAGT field trip EVOLUTION OF CAPE LANDSCAPES: MARINE AND GLACIAL FIELD TECHNIQUES APPLIED TO CAPE COD to be conducted in association with the Geological Society of America 1993 Annual Meeting at Boston, Massachusetts. The guide is based, in part, on two previous Cape Cod field trip guides (Oldale, 1988; Oldale, 1992a).

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 Wisconsin, 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 existence, the ice sheet remained north of New England. About 23,000 years ago, however, the Laurentide ice sheet advanced southward and reached the vicinity of Cape Cod, Martha's Vineyard, and Nantucket a few thousand years later. Retreat of the ice sheet followed within a thousand years or so. Radiocarbon dates on foraminifera in glaciomarine mud in the Gulf of Maine indicate that glacial Cape Cod was completed by about 18,000 years ago (Schnitker, 1988).

The next great event in the geology and geologic history of Cape Cod was submergence by the rising sea. The sea-level rise was the result of water being returned to the ocean basins from the melting Laurentide and Eurasian ice sheets. Unlike much of the Atlantic Coast, the sea was never very far from Cape Cod and the eastern shore of New England. The Gulf of Maine, the large embayment that lies between New England and Nova Scotia and north of Georges Bank, has an average depth of 492 feet (150 m) and was occupied by the sea as soon as the ice retreated. Initial submergence of glacial Cape Cod probably occurred about 6,000 years ago. The development of the spits and marshes began about 4,000 years ago, when sea level was about 26 feet (8 m) below its present level. 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 (Fig. 1). The lobation in southeastern Massachusetts was controlled and shaped by basins in the bedrock surface, with the shallowest basin to the west and the deepest basin to the east. The lobes, from west to east, were the Buzzards Bay lobe, the Cape Cod Bay lobe, and the South Channel lobe. The Buzzards Bay lobe established the arc of the Elizabeth Islands and the shape of the eastern shore of Buzzards Bay. The Cape Cod Bay lobe built the inner arm of the Cape. The South Channel lobe occupied the western Gulf of Maine east of Cape Cod and shaped the Cape's outer arm (Fig. 2).

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 outer arm of the 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 firm evidence that the Vikings were the first to visit, but they could have been[1]. 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 (Fig. 2) where, in 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.

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[1] See "The Expedition of Thorfinn Karlsefni (1007-11)" in Gordon (1957), p. 48): "There was a ness (peninsula) which they came to. They sailed near the wind along the coast and put the coast on the starboard side. There was a harborless coast and long beaches and sand. They went by the boat to shore and found a keel of a ship, and called it (the peninsula) Kjalarnes ("Keel Ness" = Cape Cod?). They also gave a name to the beach and called it Furdustrandir ("Wonder Sands"), because it was a long way to sail along." (Translated from the Old Norse by Richard S. Williams, Jr.)

U. S. Geological Survey map I-1736 (Oldale and Barlow, 1986), a geologic map of Cape Cod and the islands and U. S. Geological Survey map GQ-750 (Oldale, 1968) will be good references for the field trip and transect. The book Cape Cod and the Islands: The geologic story (Oldale, 1992b) provides an easily understood account of the geology and geologic history of the Cape. Six books that address the geography, geology, and natural history of Cape Cod have been written by Thoreau (1984), Chamberlain (1981), Strahler (1988), Beston (1974), Brownlow (1979), and O'Brien (1990).

The route to the first stop crosses the Cape Cod Canal (Fig. 2). The canal is located in a trough that was originally occupied by two streams, the Scussett River that flowed northeast into Cape Cod Bay and the Monument (the Indians called it the Manomet River) 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 that occupied it, 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. Following World War I, the canal was bought by the United States and improved by the U. S. Army Corps of Engineers. The land cut for the canal is 8.1 miles (13 km) long and 480 feet (146 m) wide (Farson, 1977) making it the widest canal in the world. It has a depth of 32 feet (9.7 m) and the clearance beneath the two highway bridges and the railroad bridge, when raised, is 135 feet (41 m) (Farson, 1977), too low for the tallest of the tall ships.

EN ROUTE TO SCARGO HILL TOWER

After crossing the Cape Cod Canal, Route 6 runs along the crest of the Sandwich moraine. The moraine, along with the southwest trending Buzzards Bay moraine, forms the so-called back bone of Cape Cod (Fig. 3). On the Cape, the Buzzards Bay moraine is a short distance inland of the Buzzards Bay shore. To the southwest of the Cape it forms the Elizabeth Islands chain. A short distance south of the canal, the Sandwich moraine deposits overlie the Buzzards Bay moraine deposits (Mather et al., 1940, 1942), indicating that the Buzzards Bay moraine was formed first.

Route 6 runs along the crest of the Sandwich moraine; Cape Cod Bay lies to the north and Vineyard and Nantucket Sounds lie to the south (Fig. 2). 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. To the south of the moraine lie the inner Cape outwash plains and the kames along the Nantucket Sound shore (Fig. 3). 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 large kames that rise slightly above the Harwich outwash plain (Fig. 3). Glacial deposits located between the kames, the ice-contact head of the Harwich outwash plain, and the Sandwich moraine and the shore are interpreted to be ice-contact deltas and shallow water sediments of Glacial Lake Cape Cod. 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 closer to 80 feet (24 m). The latter may have formed during the earliest high stage of Glacial Lake Cape Cod. Initially, the lake was very narrow as the ice pulled away from the inner cape, but it became a significant body of water when the large outwash deltas developed on outer Cape Cod and along the west shore from Plymouth to Duxbury (Chute, 1965; Larson, 1982).

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 Route 137 crosses the much collapsed Harwich outwash plain (Qhw, Fig. 3). Large and small kettle holes and shallow valleys interrupt the outwash plain. The kettle holes mark the site of ice blocks, which were buried by the outwash deposits. 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.

About 0.4 of a mile east of the intersection with Route 137, Route 28 drops into a depression that is not a kettle hole. The road crosses one of the valleys that interrupt the surface of all of the Cape outwash plains. The valleys are not being eroded today and are enigmatic. Several hypotheses on their origin have been put forth and the valleys will be discussed in more detail during the Wellfleet transect.

CHATHAM LIGHT

Cape Cod is a dynamic environment that is 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 because 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 (Fig. 4). 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 and erosion of the mainland when changes in the barrier system occur have been considered to be cyclic (McClennen, C.E., 1979, and Giese, 1988), but episodic is a more likely description of the process. The sea cliff below Chatham Light was inactive before the new break, protected by a prograding beach. The inactive cliff was evidence of the previous breakdown in the barrier system and erosion of the mainland that occurred in 1851. At that time as now, 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 attitude changed. Understandably, the willingness to live with nature gave way to requests, by the property owners whose houses were threatened, for engineering structures to protect the mainland shore from wave attack or to close the breach in the barrier. An attempt to close the breach has not been given much attention, but property owner's requests for permission to build seawalls to protect the mainland shore have, in many cases, been denied. These denials, may indicate a flaw in the wetlands law of the state. The law prohibits protecting coastal dunes by seawalls, but allows seawalls for the protection of coastal banks composed of upland materials. In the case of the Chatham shore, the coastal bank is capped by thin and discontinuous bank top dunes. Permission was denied for properties where dune sand occurred atop upland materials. The uneven permitting lead to adjacent properties, one with permission and one without permission for a seawall. This would result in a coastal bank protected by seawalls in some places and not in others, and will insure, in the long run, that the isolated seawalls will fail and leave the coastal bank unprotected.

EN ROUTE TO FORT HILL

From Chatham Light, the route crosses the deeply embayed eastern flank of the Harwich outwash plain. The large embayments, Pleasant Bay and Little Pleasant Bay, represent sublobes of the South Channel lobe, against which the Cape Cod Bay lobe outwash was deposited. Between the large embayments the Harwich outwash plain deposits are mostly collapsed, resulting in the very irregular kame and kettle topography, smaller bays and coves, and kettle ponds.

FORT HILL

The glacial features seen from this stop and the Wellfleet transect were formed by the South Channel lobe. Fort Hill overlooks Nauset Harbor, an embayment formed by a sublobe of South Channel ice. Initially, the Nauset sublobe was much larger and 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 (Qnh, Fig. 3). 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 (Qep, Fig. 3) are considered to be the youngest South Channel lobe outwash unit.

Nauset Harbor is bordered on three sides by ice-contact slopes that have been modified somewhat by marine erosion. The 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 opening in the barrier is presently migrating northward and the southern spit is about 0.5 mile (0.8 km) longer than it was in 1962. Nauset Harbor spit changed greatly in the 1978 February storm. {Henry Beston's "Outermost House" was also destroyed during the storm (Beston, 1974)] Previous to the storm, dunes up to 40 feet (12 m) high occupied the spit. The present Nauset Harbor spit is easily overwashed and is undergoing rapid change that may dramatically change Nauset Harbor. There are now two inlets, the southern one formed more recently.

Samuel de Champlain visited Nauset Harbor and made the first map of the region in 1605 (Fig. 5). The map (Ganong, 1922) 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 geography; however, a comparison of the shoreline position on the Champlain map with maps of the present shoreline position provides an estimate of the rate of shoreline retreat, about 4 feet/yr (1.2 m/yr), for roughly the past 400 years. Other estimates of the average rate of shoreline retreat, based on field measurements, range from 2.6 to 3.2 feet/yr (.8 to 1.0 m/yr (Zeigler et al., 1964).

EN ROUTE TO NEWCOMB HOLLOW

The route from Fort Hill to Newcomb Hollow beach, the starting point of the Wellfleet transect, crosses the Eastham plain roughly parallel to strike. The road undulates as it enters and leaves depressions in the outwash plain. The depressions are either the result of collapse or valleys cut into the outwash plain. Salt Pond, adjacent to the National Seashore Visitor Center, is a kettle hole that has been submerged by the postglacial rise in sea level. A short distance north of the Salt Pond Visitor Center another kettle hole, Minister Pond, indicates that the watertable beneath this part of outwash plain has an altitude of about 14 feet (4.3 m).

En route we will pass the entrance to the Headquaters of Cape Cod National Seashore, Marconi Beach, and Marconi Station. Marconi Station is the site from which the first transatlantic wireless transmission between the United States and Europe was made in 1903. The pirate ship <u>Whydah</u> was found a short distance offshore of the Marconi site. The <u>Whydah</u> was wrecked in a storm in 1717 and is now being excavated. The ship's bell, cannon, gold, silver, and other artifacts have been found. The presence of the <u>Whydah</u> probably explains the gold coins occasionally found in the beach deposits along this shore.

At Blackfish Creek, named after the pilot whales that frequently strand in the shallow water of Cape Cod Bay, Route 6 crosses the contact between the Eastham plain deposits and the Wellfleet plain deposits (Qw, Fig. 3). Shortly beyond the contact, the route turns east to run up Lacount Hollow. Hollow is the local term for valleys that transverse the outer cape outwash plains. They are also called pamets, a name taken from the Pamet Valley, which is located in Truro and is the largest and deepest of all outwash plain valleys. A left turn puts us on Ocean View Drive, which runs parallel to the marine scarp cut into the east or upstream side of the Wellfleet plain.

THE WELLFLEET TRANSECT

The Wellfleet transect will begin at Newcomb Hollow on the Atlantic Ocean(Gulf of Maine) shore and end at the Cape Cod Bay shore. This route will take us down the westerly slope of the Wellfleet outwash plain. The fact that this outwash plain, the Eastham plain, and the Truro plain, to the north of the Wellfleet plain, slope to the west unequivocally establish the presence of ice to the east in the Gulf of Maine during late Wisconsinan time. Although we will cross the Wellfleet plain from ocean to bay, it is important to realize that our observations will only involve the middle part of this feature. Both the upstream part and downstream part of the plain have been removed by marine erosion. Thus, we do not know whether or not the plain had an ice-contact head or whether it was bordered by an end moraine.

In addition, the coarser more poorly sorted ice proximal deposits have been eroded away, and we are left with only the better sorted pebbly sand and finer-grained deposits characteristic of the middle and lower part of the outwash plain.

NEWCOMB HOLLOW BEACH

Newcomb Hollow lies about in the middle of the 15 mile (24 km) long marine scarp and strand that runs from Coast Guard beach in Eastham to Head of the Meadow Beach in Truro. The deposits exposed in the cliff face underlie the Wellfleet plain and were deposited in Glacial Lake Cape Cod to form a delta. For the most part the Wellfleet plain deposits consist of pebbly sand with sparse gravel beds and widely scattered boulders. Of particular interest at Newcomb Hollow is the large dome-like structure that consists mostly of highly deformed very fine sand, silt and clay. The dome is interpreted to be a sediment diapir consisting of glaciolacustrine deposits, including drop stones and till, which were laid down on the floor of Glacial Lake Cape Cod. After burial by fluvial and deltaic sand and gravel the water saturated lake bottom deposits deformed plastically and migrated laterally to a place where upward relief was available. At that place the lake bottom deposits flowed upward to fold the overlying sand and gravel.

The great cliff along the "back side" of "lower" Cape Cod, local terms that mean "out back" (the front side was the Cape Cod Bay side) 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 3.2 ft/year (~1 m/year) (Zeigler et al., 1964). The material eroded from the southern part of the sea cliff is transported southward by longshore drift and longshore currents to nourish the barriers from Eastham to Chatham and Monomoy Island. The material eroded from the northern part of the cliff is transported northward by these same processes to build the Provincelands spit. Major erosion along this shore occurs mostly during severe winter northeast storms. Unlike hurricanes, which are fast moving and very limited in geographic extent, northeasters move slowly and batter long sections of the Atlantic shore for several days at a time. Recent northeasters that have caused significant erosion along the back side of the Cape include the Halloween storm of 1991, the December storm of 1992, and the "storm of the century" in March of 1993.

Newcomb Hollow and the other hollows in the Wellfleet plain are important because they provide passage to the beach through the great sea cliff. Historically they were the routes off the beach for shipwrecked sailors and routes to the beach for the rescuers and wreckers. Today, the hollows provide access to the beach for swimmers, fishermen, and off road vehicles. The transect will use Newcomb Hollow as a route to Gull Pond and for the return to Route 6.

The large dry valleys eroded into the Wellfleet outwash plain represent a significant period of erosion, which probably occurred shortly after the outwash plain ceased to be an active surface of deposition. They are interrupted by kettle holes, which are clearly younger. Their lower reaches are drowned so they were cut when base level was below present sea level. The origin of the dry valleys is not certain. Hypotheses include the following: permafrost, change in permeability of the outwash deposits, and lack of vegetation to encourage runoff. However, the hypothesis in present favor involves spring sapping (Uchupi and Oldale, in press). Under this hypothesis, 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 the spring head to erode, forming the valleys.

GULL POND

Gull Pond occupies one of a group of kettles that pit the Wellfleet plain. Kettle holes are a major feature of the glacial landscape and were formed when ice blocks left behind by the retreating glacier were buried by glacial drift, mostly outwash. As the ice melted, the deposits atop and around the ice collapsed to form a depression. The closely spaced kettles in this part of the Wellfleet plain may have formed over separate ice blocks or over a single large ice block of variable thickness. In the latter case, the ice block may have been up to 1.5 miles (2.5 km) long and .6 miles (1 km) wide. The maximum thickness of the ice block, estimated from the total depth of the kettlehole, was on the order of 160 feet (50 m).

Deeply buried ice blocks were well insulated from the warmer temperatures of the postglacial climate and may have taken thousands of years to melt. The oldest radiocarbon date on vegetation from the bottom of Duck Pond, one of a cluster of kettle ponds about .9 miles (1.5 km) south of Gull Pond, indicates that Duck Pond formed above a melting ice block about 12,000 years ago (Winkler, 1985). This would have been about 6,000 years after the retreat of the Laurentide ice. A less reliable, but more intriguing, indication of the persistence of ice buried by outwash comes from Indian folklore. The story tells of how the Indians observed the formation of Walden Pond, a kettle pond in Concord, Massachusetts. If the story is true, this event could not have occurred before the arrival of the Paleoindians, about 10,000 years ago.

The shore of Gull Pond is influenced by waves and currents in the same manner as the sea shore. Cliffed headlands occur along the shore, cut by wave attack. The material eroded from the cliff is transported by longshore currents and longshore drift to where it is redeposited to form beaches, baymouth bars (across small coves), and the nearshore sandy bottom. These processes tend to smooth the shoreline and make the pond nearly circular.

The surface altitude of Gull Pond indicates that the water table (the top of the aquifer) beneath this part of the Wellfleet plain is at an altitude of 6 feet (1.8 m) above sea level. The pond has no inlet or outlet. However, the water is not stagnant, as ground water continuously flows down the aquifer towards the sea much like a stream, but at a much slower rate. The slowly moving ground water constantly refreshes the water in the pond.

WELLFLEET HARBOR

The route to Cape Cod Bay travels down Gull Pond Road, which runs along the south side of Newcomb Hollow. The route turns north on Route 6 for about a mile and then turns west down Pamet Point Road, a small dry valley. West of Route 6, the Wellfleet plain is characterized by isolated kames, locally called islands (for example, Bound Brook Island, Merrick Island, and Griffin Island). It is likely that they are called islands because they are isolated elevations surrounded by salt marsh. The lows between the islands may be the result of the erosion that occurred during the formation of the dry valleys. Others may be the result of collapse over ice blocks, some of which may have been quite large. The very large depression that contains Wellfleet Harbor may have been occupied by the Nauset sublobe of the South Channel lobe, thus precluding deposition or causing the

Wellfleet plain deposits that overlay the ice to collapse to below sea level.

GRIFFIN ISLAND AND DUCK HARBOR

The Cape Cod shoreline is mostly moving landward, but in a few places the shoreline is moving seaward. For example, the mostly east trending shoreline at the tip of Cape Cod prograded at an average rate of about 3 feet (1 m) a year between 1938 and 1974 (Gatto, 1979). Predictions indicate that the progradation of this shore will continue and by the year 2030 the shoreline will be about 100 feet (30 m) further seaward (Cornillon, 1979). The northwest corner of Griffin Island shows a clear, although somewhat less dramatic, example of a shoreline moving seaward. There, a once eroding sea cliff is now up to 650 feet (200 m) from the shore, the result of beach deposits prograding into Cape Cod Bay. The beach deposits form the tombolo that connects Griffin Island to Bound Brook Island. Other tombolos connect Bound Brook Island to the mainland and tie together the islands south of Griffin Island. Duck Harbor is now the name of the salt marsh between Bound Brook Island and Griffin Island. In the past, it was the name of a small harbor just to the north of Griffin Island with an opening directly to Cape Cod Bay.

Not too long ago, there was another island about 3.5 km south of Great Beach Hill (the last of the islands in the chain). The island was called Billingsgate and, in the middle 1800's, it was about a mile long and about half a mile wide. It had about

30 homes, a schoolhouse, and a lighthouse. Billingsgate Island supported farming and an important fishing industry. Today it is a shoal exposed only during the very lowest tides. (Fig. 6). The fate of Billingsgate Island is a likely precursor for all of Cape Cod as the sea continues to erode the fragile land.

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FIGURE CAPTIONS

Figure 1: Map of southeastern Massachusetts showing the lobes of the Laurentide ice sheet during its maximum advance, probably about 20,000 years ago.

Figure 2: Index map of Cape Cod and the Islands.

Figure 3a: Explanation and correlation of geologic units for the geologic map of Cape Cod.

Figure 3b: Geologic map of Cape Cod.

Figure 4: The break in North Beach off Chatham. The break occurred on the second of January 1987. This photograph by Kelsey and Kennard was taken two days later.

Figure 5. Champlain's map made in 1605 (Ganong, 1922).

Figure 6a: Billingsgate Island Light about 1910. Note riprap on the right side of the photograph.

Figure 6b: Billingsgate Shoal at extreme low tide. The riprap can be seen in the lower left with the base of the lighthouse behind it.

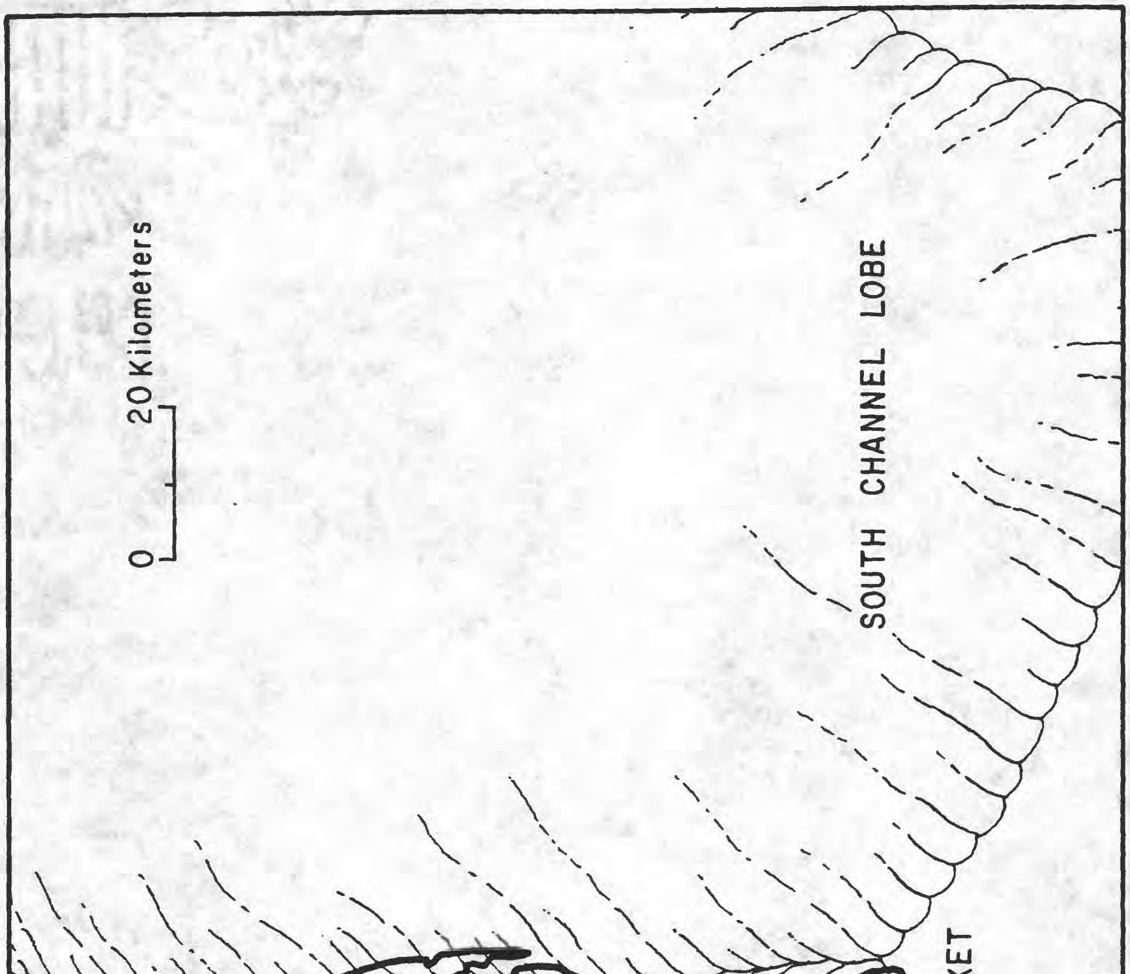
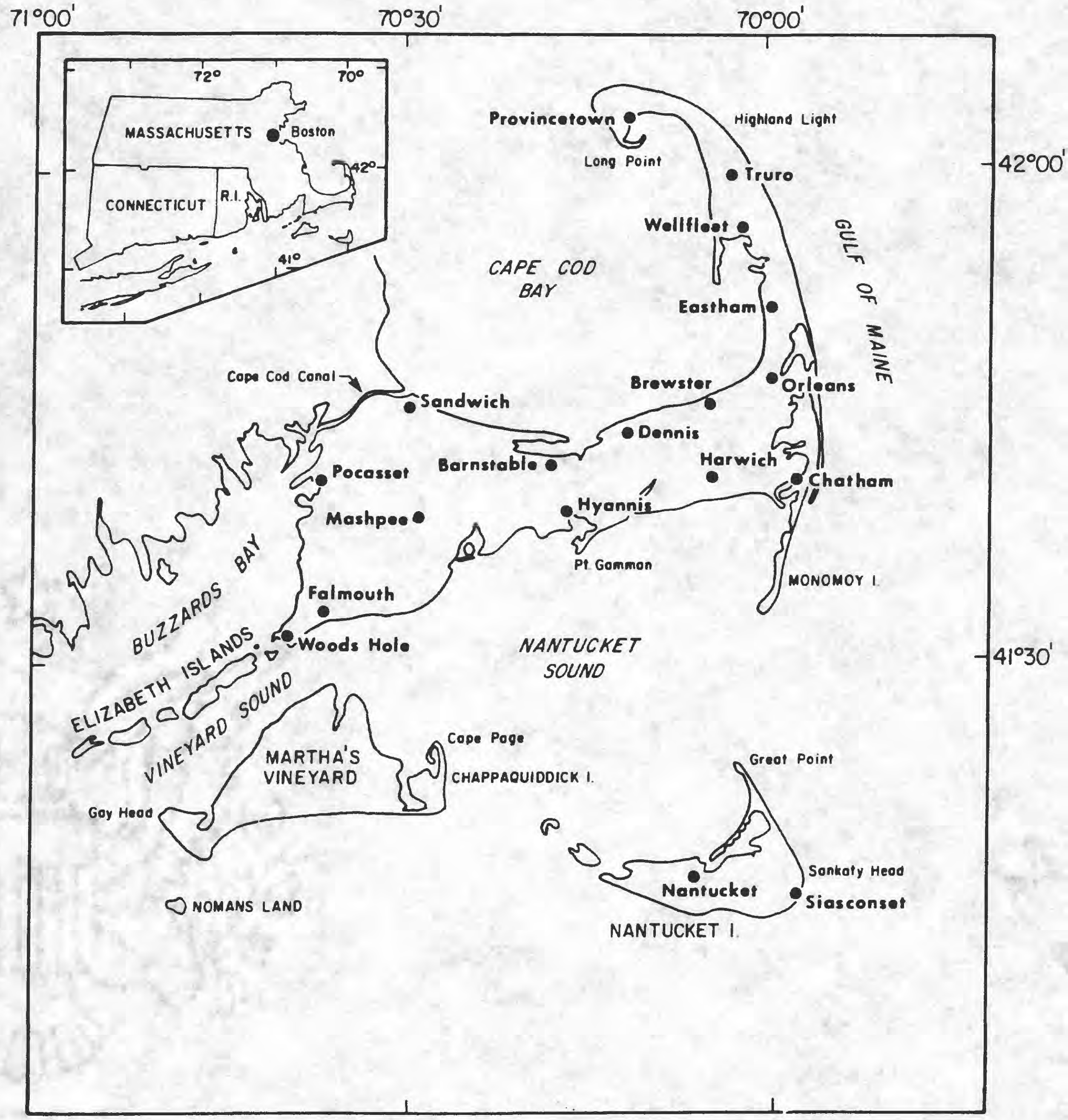

0 20 Kilometers
SOUTH CHANNEL LOBE
CAPE COD
CAPE COD BAY LOBE
NANTUCKET
MARTHA'S VINEYARD
BUZZARDS BAY LOBE

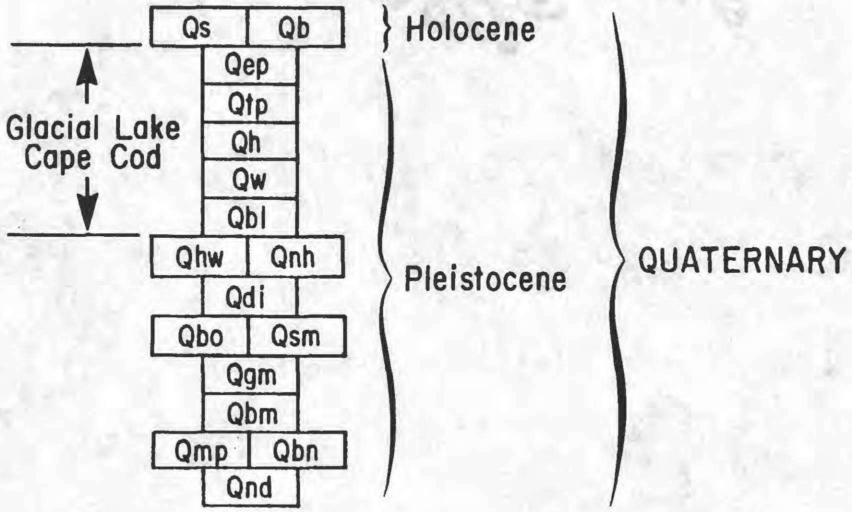
Fig. 1



71°00'
70°30'
70°00'
42°00'
41°30'
72°
70°
MASSACHUSETTS
Boston
42°
CONNECTICUT
R.I.
41°
Provincetown
Highland Light
Long Point
Truro
Wellfleet
CAPE COD BAY
GULF OF MAINE
Eastham
Brewster
Orleans
Cape Cod Canal
Sandwich
Dennis
Harwich
Barnstable
Chatham
Pocasset
Hyannis
Mashpee
Pt. Gammon
MONOMOY I.
BUZZARDS BAY
Falmouth
Woods Hole
NANTUCKET SOUND
ELIZABETH ISLANDS
VINEYARD SOUND
Cape Page
MARTHA'S VINEYARD
CHAPPAQUIDDICK I.
Great Point
Gay Head
Sankaty Head
Nantucket
Siasconset
NOMANS LAND
NANTUCKET I.

Fig. 2

CORRELATION of MAP UNITS



EXPLANATION

Qb	BEACH and DUNE DEPOSITS
Qs	SWAMP and MARSH DEPOSITS
Qep	EASTHAM OUTWASH PLAIN DEPOSITS
Qtp	TRURO OUTWASH PLAIN DEPOSITS
Qh	HIGHLAND PLAIN DEPOSITS
Qw	WELLFLEET OUTWASH PLAIN DEPOSITS
Qbl	BARNSTABLE LAKE DEPOSITS
Qnh	NAUSET HEIGHTS ICE-CONTACT DEPOSITS
Qhw	HARWICH OUTWASH PLAIN DEPOSITS
Qdi	DENNIS ICE-CONTACT DEPOSITS
Qsm	SANDWICH MORAINE DEPOSITS
Qbo	BUZZARDS BAY OUTWASH DEPOSITS
Qgm	BUZZARDS BAY GROUND MORAINE DEPOSITS
Qbm	BUZZARDS BAY MORAINE DEPOSITS
Qbn	BARNSTABLE OUTWASH PLAIN DEPOSITS
Qmp	MASHPEE PITTED PLAIN DEPOSITS
Qnd	HARWICH OUTWASH PLAIN DEPOSITS

Fig. 3a

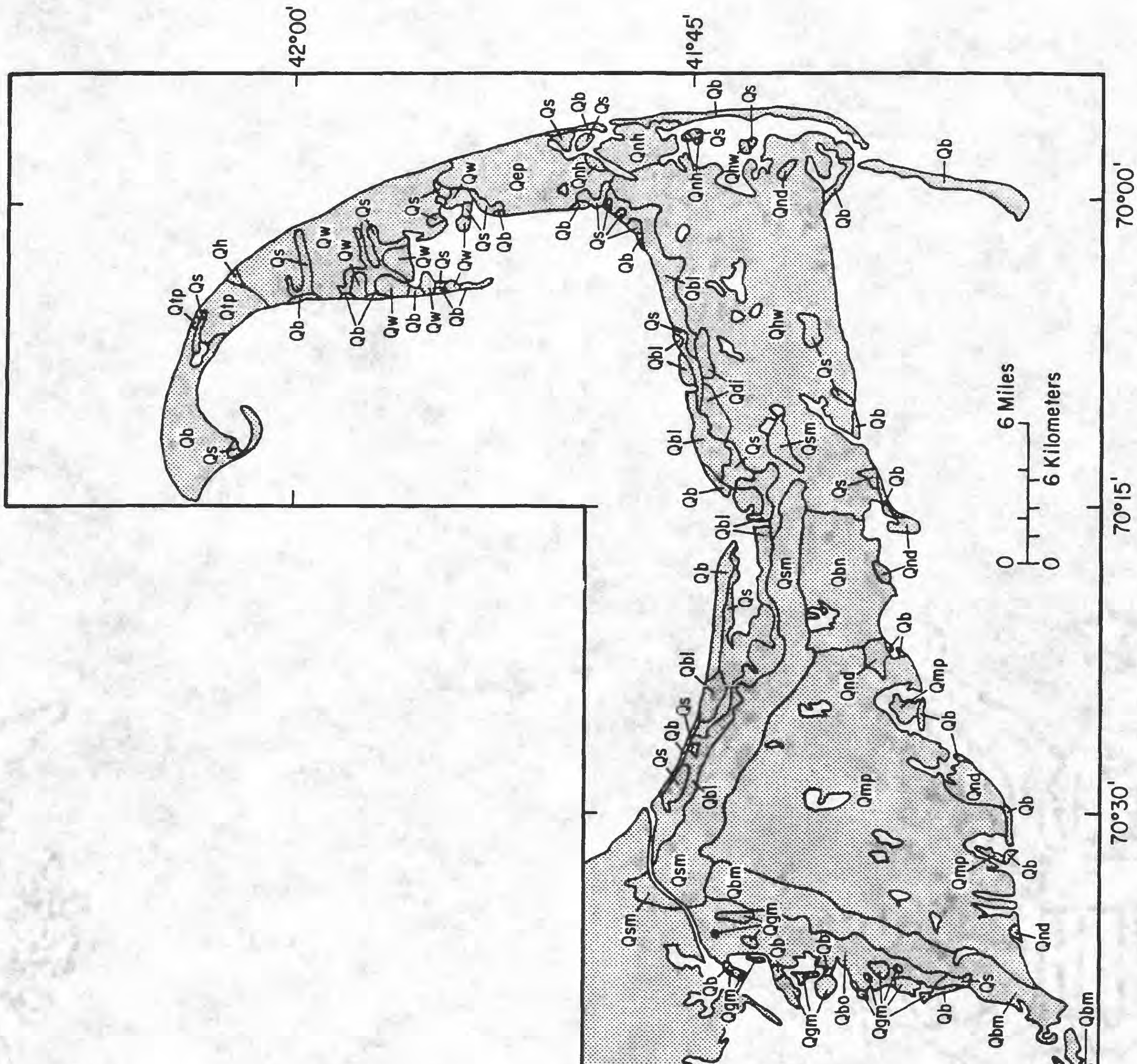


Fig. 3b

Fig. 4

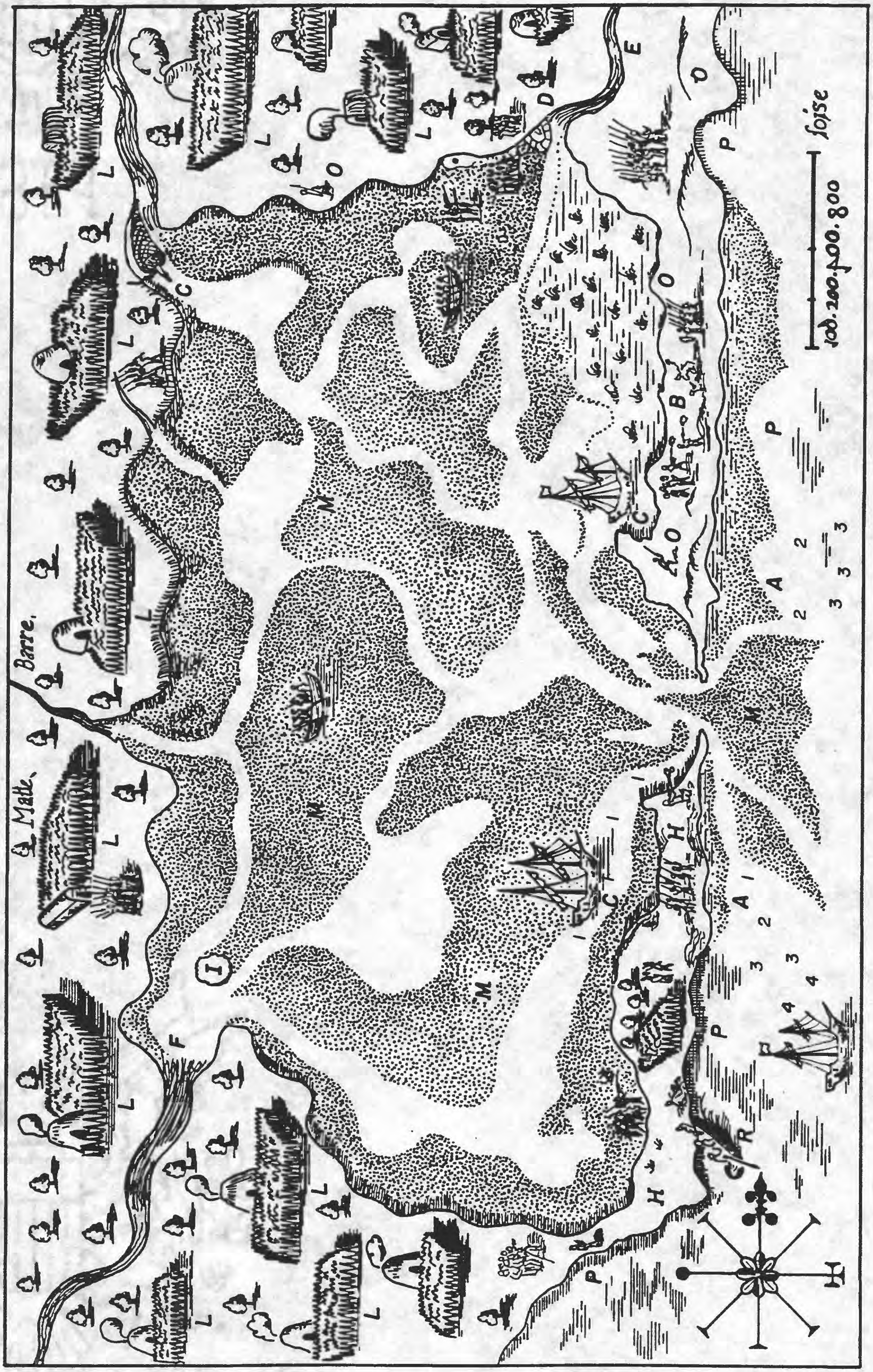


Fig. 5

Fig. 6a

Fig. 6b