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Trips A-8 & B-8

SEDIMENTARY AND GEOMORPHIC ORIGIN AND DEVELOPMENT OF PLUM ISLAND, MASSACHUSETTS: AN EXAMPLE OF A BARRIER ISLAND SYSTEM

by

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- and -

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INTRODUCTION

The origin and development of barrier islands has received much attention over the last decade as geologists and geographers have become more concerned with man's coastal environments (e.g., Hoyt, 1967; Fisher, 1968; Dolan, 1973; Schwartz, 1973). This field trip and guide will examine many of the geomorphic, sedimentary and vegetational features of Plum Island, Massachusetts, which exemplifies a coastal barrier system.

Plum Island is 8 miles long and varies from 1/4 to 1 mile in width (Fig. 1). It is composed mainly of well-sorted beach and dune sands and marsh deposits. Glacial till, outwash and marine clays are also present at its southern end (Nichols, 1964, p. 32; Sammel, 1963). Some of the features of this island are formed by daily low energy conditions that can usually be observed on a field trip while others are formed during high energy storms. The latter retain their characteristics during the more prevalent lower energy conditions.

Plum Island also represents the dramatic differences which exist between the altered and the natural sections of a barrier environment. These differences will become apparent when the altered northern end of the island is contrasted with the unaltered Parker River National Wildlife Refuge at the southern section of the island. Dolan (1973) made similar observations and comparisons between altered and natural barrier island systems along the North Carolina coast. An active surf zone will be found along the Plum Island shoreline. As waves break along this shoreline, sediment movement can be observed within the swash zone. In the northern, altered section, a steep-sloped, coarse sediment-bearing, high energy littoral zone may be contrasted with the natural beach of the southern section which is gently sloped, less energetic, and composed of finer grained sands.

A well-defined berm is developed in the refuge, and the backshore slopes from this berm into the foredunes. The development of foredunes is believed to be related to the migration of sand accumulation in the backshore area caused by wind action (King, 1973). When these dunes reach a zone of less active energy, pioneer plants may become established and stabilize the foredunal area (Godfrey and Godfrey, 1973). The entire dunal field is an area of less active energy (Coastal Research Group, 1969; Jones, 1974). Many plant species are capable of existing and establishing themselves in a dunal area (Brown, 1959; Jerome and

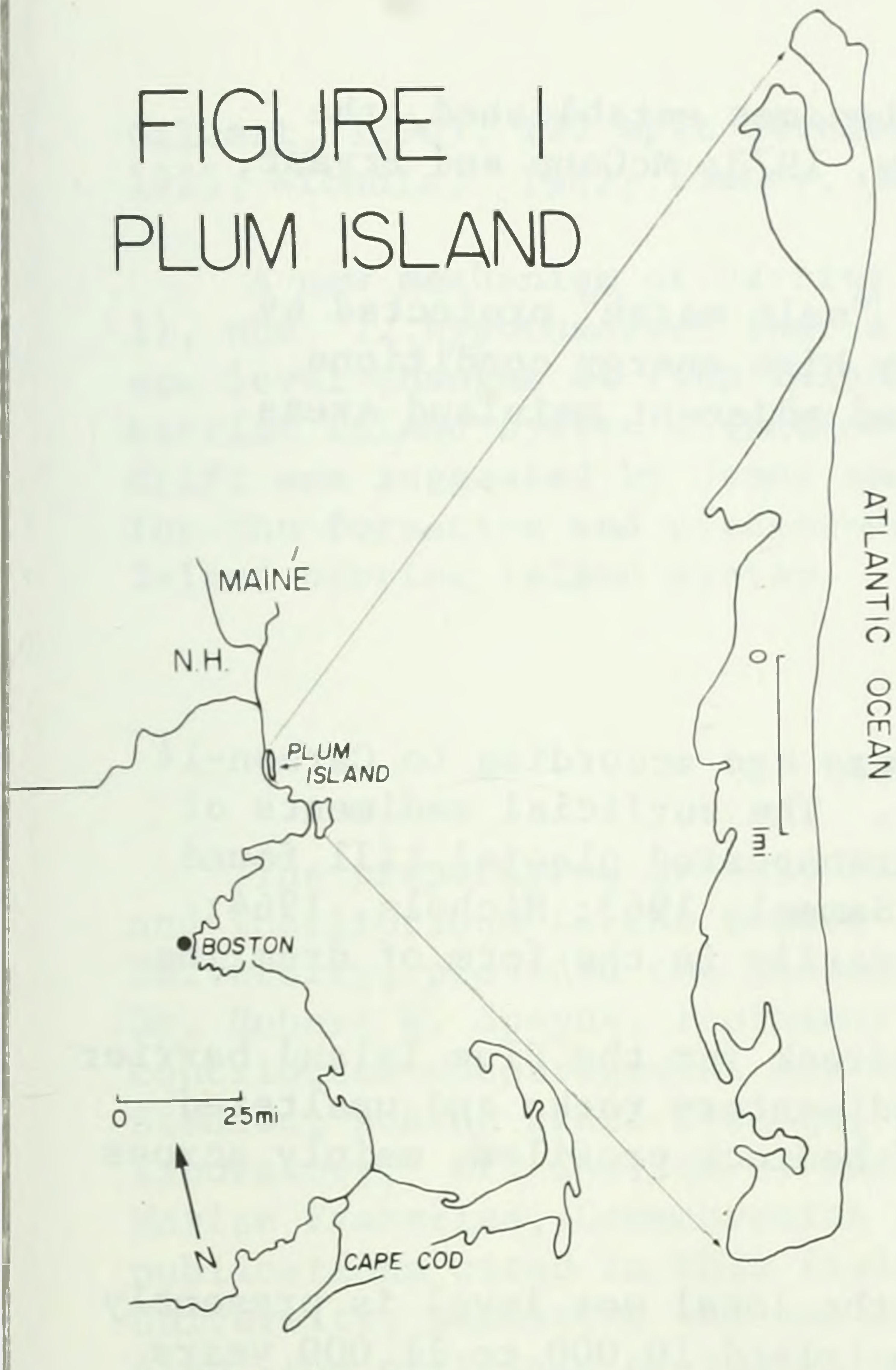

Figure 1. Location map of Plum Island.

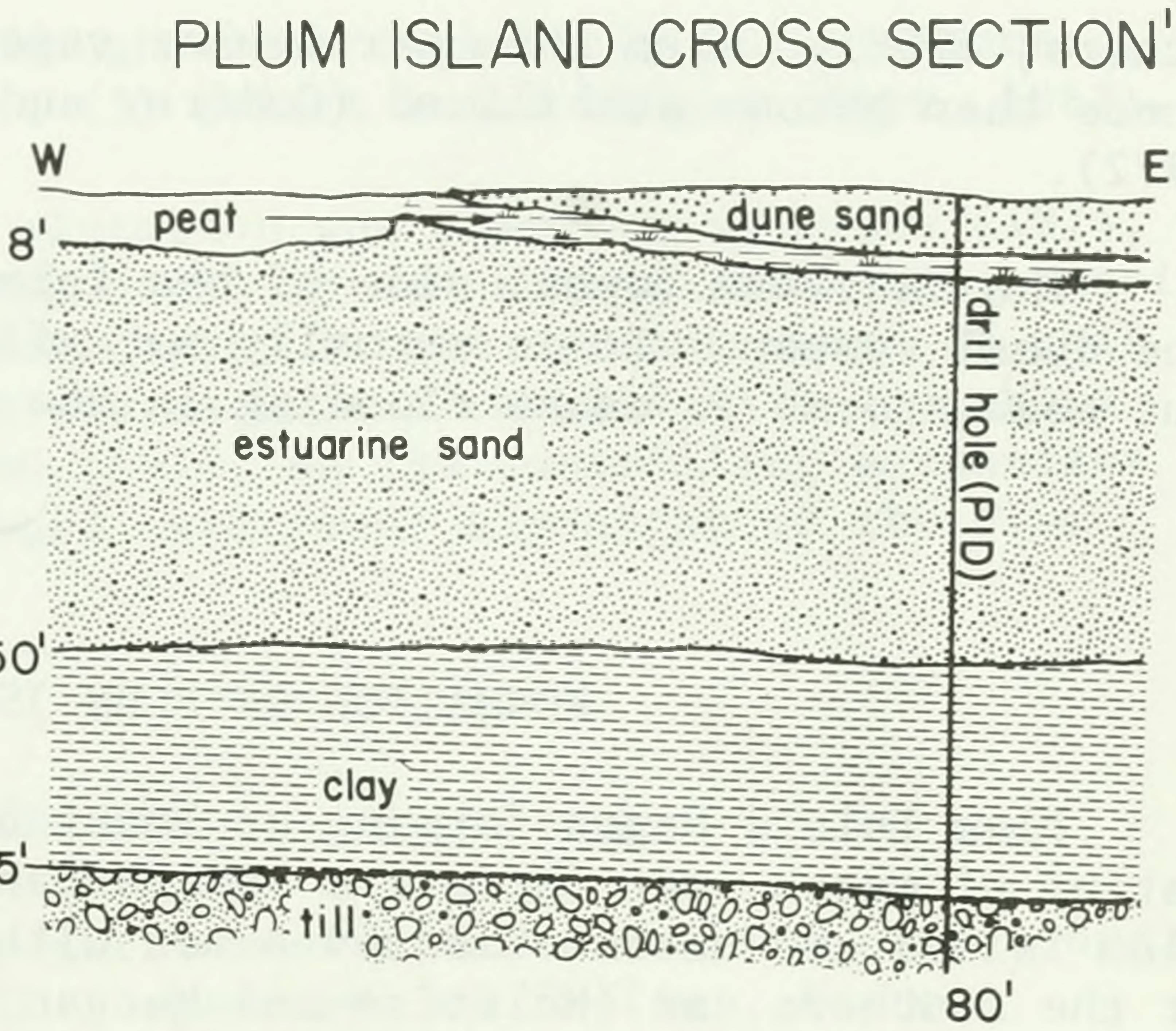

Figure 2. East-west cross-sectional interpretation of southern Plum Island, as proposed by Rhodes (1973).

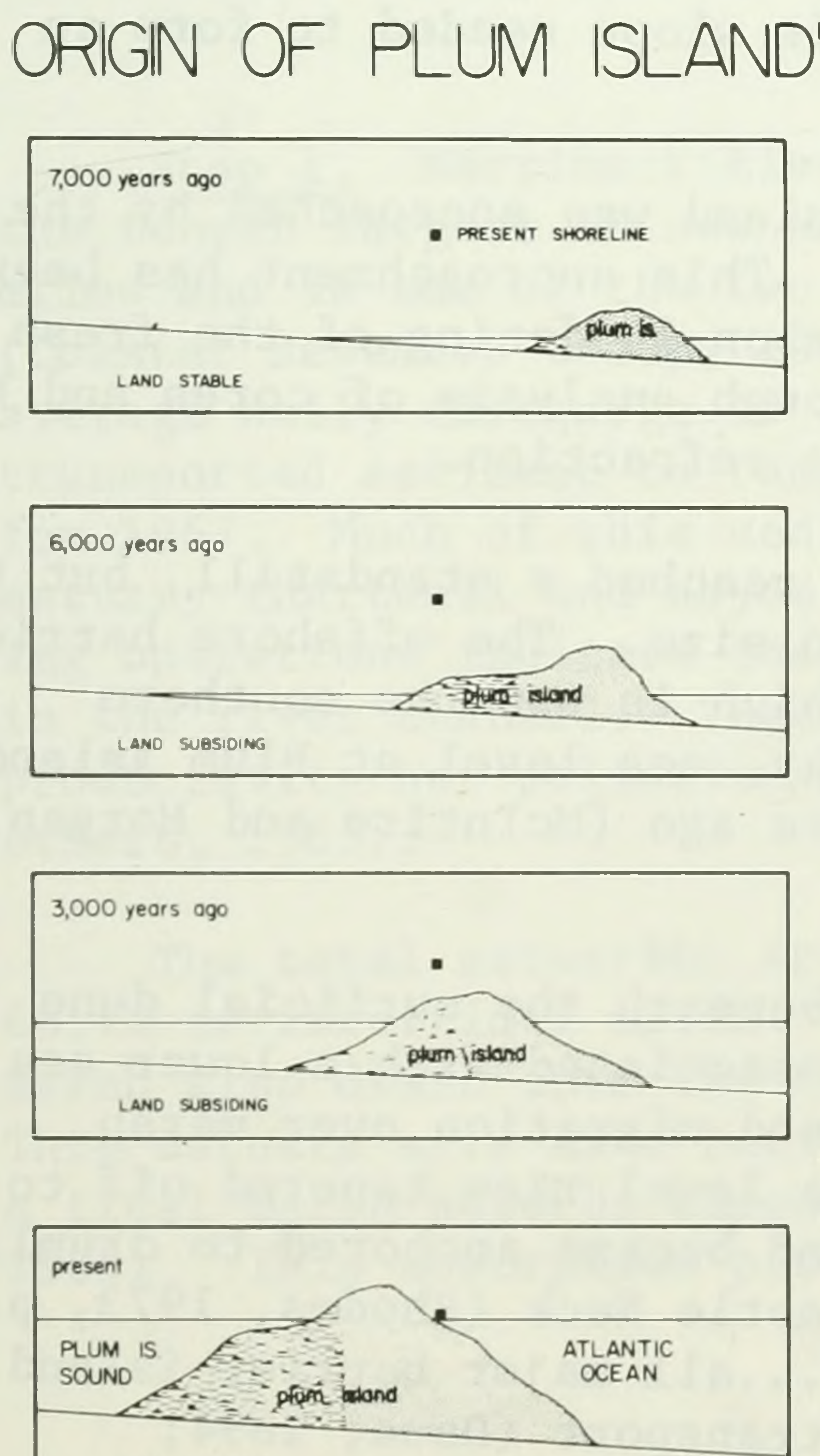

Figure 3. Origin of Plum Island as proposed by McIntire and Morgan (1963). They hypothesized that the rise in sea level appears to have been greater than glacial rebound for this area 7000 years B. P. The beach ridge (Plum Island) was encroached by the ocean until an equilibrium was reached about 3000 years B. P. Plum Island then developed southward through longshore sediment transport processes.

others, 1968). When this particular vegetation becomes established, the dunes then become stabilized (Godfrey and Godfrey, 1973; McCann and Bryant, 1972).

The landward (west) side of the island is a "salt marsh" protected by the dunal system. It is normally not affected by high energy conditions, but some storms do cause flooding in the marsh and adjacent mainland areas.

FORMATION OF PLUM ISLAND

Plum Island began forming at least 6,200 years ago according to Carbon-14 dating of marsh peat (McIntire and Morgan, 1963). The surficial sediments of Plum Island are unconsolidated sands with some transported glacial till found at the southern end (McIntire and Morgan, 1963; Sammel, 1963; Nichols, 1964; Coastal Research Group, 1969; Rhodes, 1973), primarily in the form of drumlins.

According to Clapp (1921) the underlying bedrock for the Plum Island barrier system is Paleozoic metamorphosed igneous and sedimentary rocks and unaltered igneous rocks. See Rhodes (1973) for a study of bedrock profiles, mainly across Castle Neck to the south (Fig. 2).

McIntire and Morgan (1963) postulated that the local sea level is presently higher than during the early development of Plum Island 10,000 to 11,000 years ago at the end of the Wisconsin Glaciation (Fig. 3). With the retreat of this last continental glacier, vast amounts of water and sediment were released and transported to the sea by fluvial processes. According to their theory, the deposition of sediment was greater than the subsequent rise in sea level, thereby forming an offshore bar. The land was also rebounding because of the ice retreat which appears to contribute to the gentle slope needed to form an offshore bar-barrier island complex (Hoyt, 1967).

The fresh water swamp area adjacent to the mainland was encroached by the transgressing sea, eventually forming a salt marsh. This encroachment has been documented by McIntire and Morgan (1963) through Carbon-14 dating of the fresh water and salt marsh peats, by McCormick (1969) through analysis of cores and by Rhodes (1973) through wash-bore sampling and seismic refraction.

About 3,400 years ago sea level at Plum Island reached a standstill, but the offshore bar-barrier island continued to increase in size. The offshore barrier island complex then became attached to a drumlin, which is now the southern end of the island (McIntire and Morgan, 1963). Today, sea level at Plum Island is approximately at the same level it was 2,000 years ago (McIntire and Morgan, 1963).

Rhodes (1973, p. 30-31) found a layer of peat beneath the surficial dune sand which he thought represented a pre-dune marsh associated with a lower sea level (Fig. 2). This supports the theory of dune sand migration over marsh (peat). Rhodes (p. 58) considered that when the sea level rise tapered off to the present 0.3 feet/century the migrating barrier island became anchored to drumlins. He also found bedrock highs under Plum Island and Castle Neck (Rhodes, 1973, p. 38). He (p. 55) concluded that his findings gave "...all major barrier-island theories some support ...," including (1) littoral transport (Dana, 1894;

Gilbert, 1890), (2) spit development through waves cutting drumlins (Johnson, 1925; Nichols, 1942; Fisher, 1968), and (3) relict beach ridges (Hoyt, 1967).

A new mechanism of barrier island migration was proposed by Jones (1974, p. 1), who "...hypothesized that a migrating dunal system rather than transgressive sea level changes at Plum Island, Massachusetts, is the current cause of this barrier island system migration." This new mechanism coupled with longshore drift was suggested by Jones and Cameron (1975) as the controlling mechanisms for the formation and present-day landward (westward) migration of the Plum Island barrier island system.

ACKNOWLEDGEMENTS

The preparation of this field trip guide was dependent on many individuals and institutions in the Boston area. The Department of Geology, Boston University, provided the photographic materials and a sedimentation laboratory, Dr. Robert W. Spayne, Professor of Physical Geography at Boston State College, contributed encouragement and valuable suggestions. The Department of Regional Studies, Boston State College, granted permission to use their cartographic laboratory, Mr. Charles O. Anderson, Jr., Assistant Director, Division of Marine Fisheries, Commonwealth of Massachusetts, was helpful in obtaining some publications cited in this field guide. The Department of Geography, Boston University, permitted the use of their dark room and reproduction facilities, Also, the officials of the Parker River National Wildlife Refuge were most cooperative by granting permission to conduct field trips and research on Plum Island, Massachusetts.

STOP DESCRIPTIONS

Stop 1. Merrimack River estuary (Fig. 4) - The Merrimack River, which is the fourth largest in New England, has a drainage basin of over 5,000 square miles and is one of the two sources of sediment for the Plum Island system (Coastal Research Group, 1969). The U. S. Geological Survey (1968) found the average daily discharge of the river to be about 7,000 cfs. and the amount of transported sediment to range from 2,860 tons in April to 46 tons in September for 1967. Much of this sediment is deposited on the Joppa Flats section of the estuary (Hartwell and Hayes, 1969) along the immediate shoreline. Recent dredging operations indicate that some of this transported sediment is also deposited in the river channel. These flats were once an area of high soft-shell clam productivity but pollution has closed this area to shellfish digging (Jerome and others, 1965).

The total estuarine area at mean high water is almost 4,000 acres of which 46.7% is intertidal marsh. An additional 2,300 acres of rarely submerged marsh also drain into the Merrimack River estuary (Jerome and others, 1965). This estuary acts as a buffer zone between Plum Island and the mainland because a tidal marsh absorbs excess water during storm conditions (Burton and others, 1965). This absorption process prevents many floods from reaching the lowlying

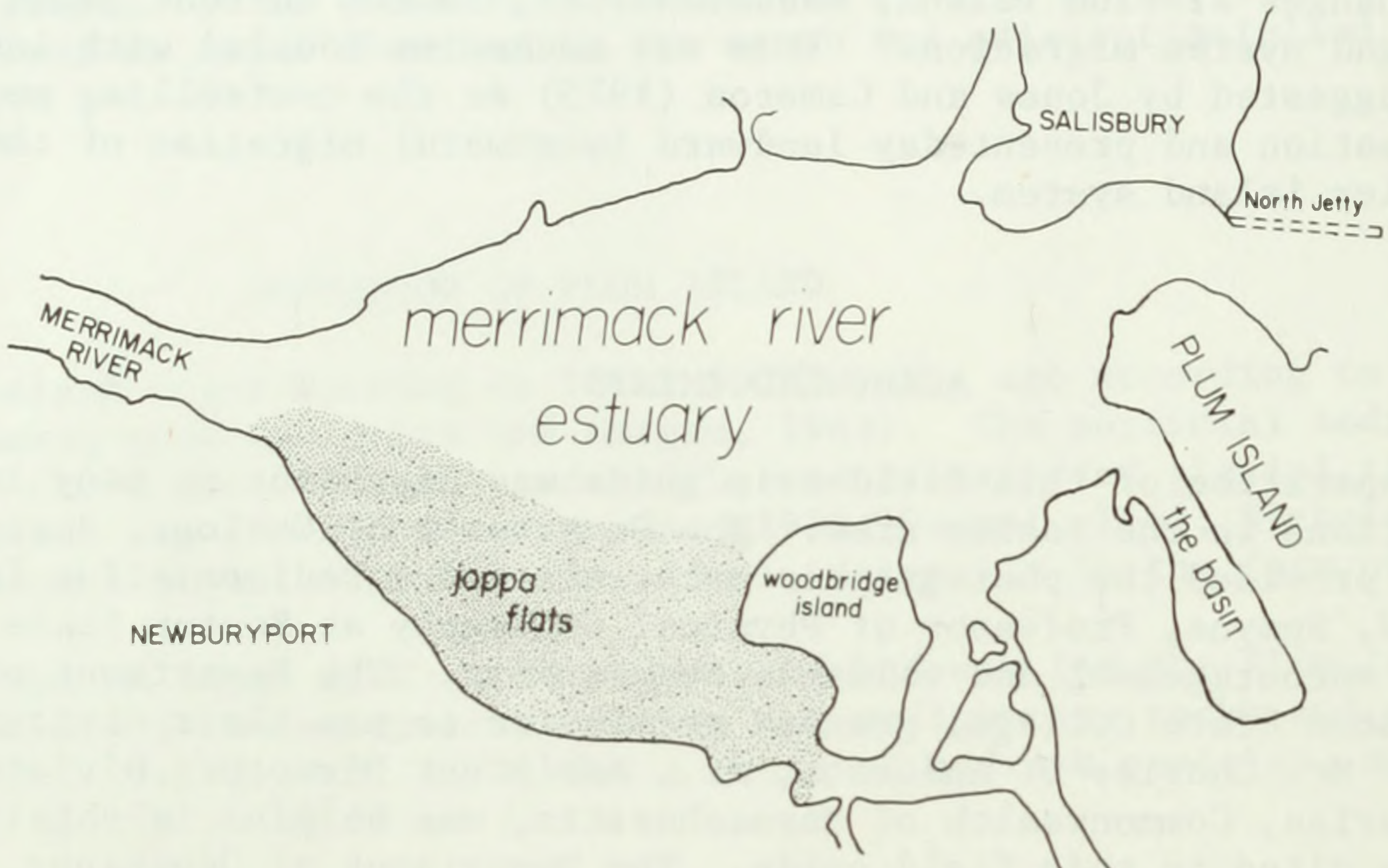

Figure 4. Merrimack River Estuary, a major sediment source for Plum Island. Joppa Flats are viewed at Stop 1.

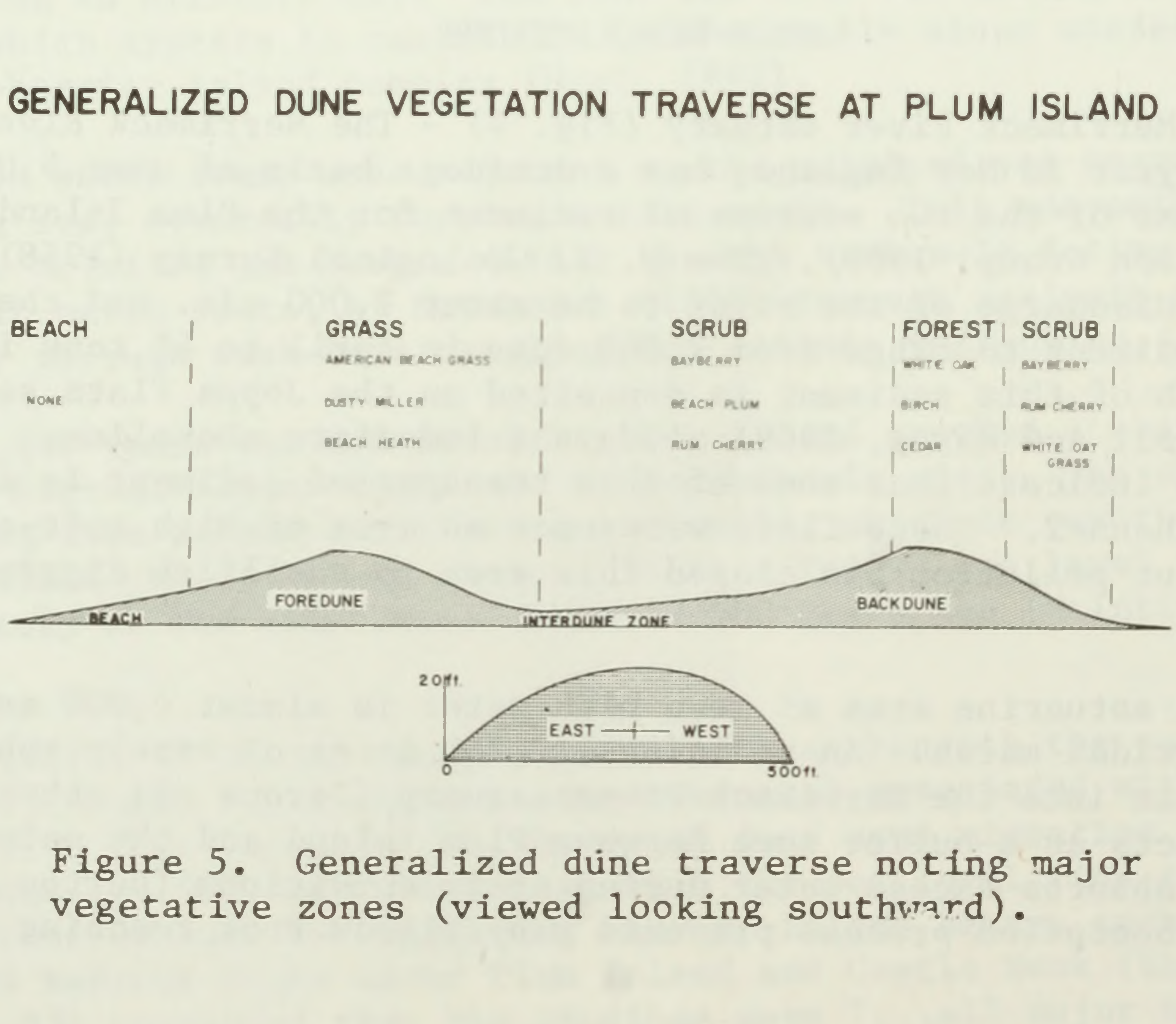

Figure 5. Generalized dune traverse noting major vegetative zones (viewed looking southward).

coastal towns. The estuary also provides nursery grounds for the many anadromous finfish inhabiting the North Atlantic (Jerome and others, 1965; 1968).

Stop 2. The South Jetty Area - The north end of Plum Island exhibits the greatest amount of shoreline change during the past 150 years (Chute and Nichols, 1941; Nichols, 1942, 1964). The development of this northern section is closely related to the offshore bottom topography and dependent on storms (Hayes and Boothroyd, 1969).

The predominant direction of the storm waves is from the northeast, but according to Hayes and Boothroyd (1969) the offshore bottom topography, which consists of a series of sand bars, causes these northeast storm waves to refract so that they then approach from the southeast. This refraction process produces erosion at areas not protected by the jetties or groins. A view of this refraction process can usually be seen off the south jetty.

This northern tip suffered severe erosion in February, 1969, and again during many storms in 1972. The February, 1969, storm caused a loss of over 200 feet of shore-front property along this beach. The effects of the storms on the northern section of Plum Island caused the Army Corps of Engineers to declare this area a "critical erosion zone" in 1971.

Evidence of these high energy conditions is seen in the dunal bedding along this beach. There are two distinct layers of sediment present: a fine-grained layer of quartz sand and a coarse layer composed of coarse quartz sand and clam shell fragments. The vegetation fronting these foredunes is sparse and the dunes are not stabilized. The absence of vegetative cover is related to the high energy conditions present at the northern end of Plum Island (Jerome and others, 1968). Some vegetation is established behind this frontal dune and this appears to be related to the lower energy conditions found in the area adjacent to the Coast Guard Station.

Historically, this part of Plum Island has been subject to dramatic shoreline changes. It has been suggested by Hayes and Boothroyd (1969) that this area will continue to erode, and it appears there is very little man can do to prevent this erosional process from occurring.

Stop 3. Plum Island Center - Plum Island Center beach is another location which is a "critical erosion zone" (U. S. Army Corps of Engineers, 1971). This area is densely populated in contrast to northern Plum Island which is primarily non-residential government land.

Storms that buffet this area not only remove sediment, but destroy many homes on the upper beach face. The February, 1969, storm undercut this upper shoreline, causing cottages to topple downward onto the beach. A storm in February, 1972, which caused widespread coastal damage in Massachusetts, also caused heavy losses to cottages and property at Plum Island Center (Jones, personal observations, 1972).

As a result of these high energy storm conditions, Plum Island Center beach exhibits well-developed erosional features. The slope along this beach is the steepest found at Plum Island (Coastal Research Group, 1969). The average sediment size is large and most sand deposition occurs on the south side of the groin due to storm wave refraction. There are also many beach cusps visible at this stop.

The Commonwealth of Massachusetts and the Town of Newbury in conjunction with the Federal Government have replenished the sand at this site during the last few years. This replenished sediment is distinguished from the indigenous sand by its textural characteristics, e.g., its larger size. However, immediately north and south of this location, the natural sand is coarser than along the far southern end of Plum Island because of the higher energy erosional and sorting conditions along the northern end.

In North Carolina beach replenishment projects and other stabilization attemps are more erosionally detrimental to a barrier environment than allowing the natural wave overwash process to occur (Dolan, 1973). It would then seem likely, from the conclusions of Dolan's study (1973), that the beach replenishment project at Plum Island Center beach will only contribute to erosion, will continue to need seasonal sand refill, and, due to the resultant higher energy conditions, will introduce coarser sand into the system.

Stop 4. Low Energy Beach - The beaches along the shoreline of the Wildlife Refuge differ dramatically from the northern beaches. When a southern beach is contrasted with a northern beach, the southern beach exhibits a lower beach slope, smaller sediment size and the development of accretionary features. Beach profiling also shows that these southern beaches restore their equilibrium slope more rapidly after storm conditions (Coastal Research Group, 1969).

The most common accretionary features seen along the shoreline are ridges and runnels. King (1973) concluded that their development on a low energy beach indicates progradation or non-erosion.

This low energy beach also exhibits a well-developed foredune. The sediment size at this location becomes progressively smaller from the beach to the foredune environment (Anan, 1969; Jones, 1974). Some of these dune segments are well stabilized by American beach grass (*Ammophila breviligulata*). The complex root system of the dune vegetation is exposed in cross-sections of some dunes. These dune grasses represent the pioneer plants in the vegetative succession on a barrier island. These grasses are highly adaptive and exhibit a high salt tolerance. They are also capable of storing moisture which rapidly percolates downwards through the porous dunes (Jerome and others, 1968).

Contrary to other coastal areas along the Atlantic coast, there has not been an attempt to artificially stabilize these dunes with exotic grasses. Time has proven that stabilization attempts by man can be more harmful to the system than allowing natural processes to take place (Dolan, 1973; Godfrey and Godfrey, 1973). Man's absence from the southern part of Plum Island has an advantage in that protection for his structures is not necessary. (For example, compare this location to that of Stop no. 3.) The foredunes act as a buffer between the surge waves and the area behind the dunes. According to Dolan (1973, p. 263):

> Natural barrier islands are much better adapted to steady-state processes and extreme events than are the man-manipulated islands. Since there is little resistance to the storm surge movement across the natural barriers, wave energy is dissipated across

the wide berm, among the low dunes, and finally in the grasslands and marshes behind. These islands actually gain material from the beach as the surge moves across the islands, and such deposits serve as sources of supply for new dune growth.

Although the southern end generally does not exhibit erosional features, high energy winds do, sometimes, breech the foredune barrier causing blow-outs, but rapid re-adjustment usually takes place. Blow-outs are caused by unusually high winds. It is not uncommon to experience wind speeds exceeding 50 mph along the Plum Island Shoreline (Coastal Research Group, 1969; Jones, personal observations, 1972).

Stop 5. Kettle Hole Nature Trail - This area is not a glacial feature. Its "kettle-like" form in the dunes has been designated a self-guiding nature trail. This site was selected as a stop because it exhibits the adaptability of dunal vegetation to adverse factors. The sediment is very fine throughout this area and continues to become fine southward along the dunal belt (Coastal Research Group, 1969; Jones, 1974). The presence of garnet might suggest a northern New Hampshire-Maine source for the sand.

Vegetation appears to be the greatest stabilizing control of the dunes, especially due to its entrapping root system. There are many vegetative species represented in this depression. The height of the trees does not exceed the rim of the "kettle". This tree height shows the relatively low salt spray tolerance of the tree species found in this coastal environment (Brown, 1959). An idealized example of vegetative succession for Plum Island is illustrated in Figure 5.

Examples of sand encroachment are seen on the frontal kettle dunes. The fine sand has been moved by the wind, so that now the trees are surrounded by it. An example of a blow-out where vegetation is sparse can be seen northeastwardly from the crest of the dune. This naturally stabilized dunal belt continues southward paralleling the shoreline.

Stop 6. Hellcat Swamp Nature Trail - This field stop coincides with another self-guiding nature trail and was selected because it exhibits relationships among a stabilized dunal system, a fresh water swamp and a salt marsh. A view of this area from the observation tower provides an opportunity to see these three systems (see road log directions). This stop shows a subclimax community. A man-made dike parallels the marsh shoreline which is artificially maintained to provide a breeding pond for waterfowl. The adjacent salt marsh is also a breeding area for waterfowl.

A consensus regarding the formation of the marsh is that the present marsh area was a fresh water swamp some 7,000 years ago. About 6,000 years ago sea level rose to encroach upon the fresh water swamp. The mixing of the two water masses created an estuarine environment. Evidence for these events is well recorded in the stratigraphic sequence of the marsh (McIntire and Morgan, 1963; Sammel, 1963; Hartwell, 1969; McCormick, 1969; Rhodes, 1973).

The substrate of the Hellcat Swamp varies from fine sand to clay. Much of the marsh is mixed clay-sand sediments while the swamp is composed of organic debris, sand and silt (Jerome and others, 1968). The sediment in the adjacent dunes is fine-grained quartz sand (Anan, 1969).

There appears to be evidence of dunal encroachment into the salt marsh area. Unvegetated lobes of sand can be observed from recent (1973) aerial photographs and from the observation tower. Thses features provide an opportunity to study vegetative succession through time.

Stop 7. Bar Head Drumlin and Beach - This area is the southern end of the longshore-transported sediments of an earlier geomorphic history (McIntire and Morgan, 1963). The large hill to which the barrier island is attached, is mapped as a drumlin (Sammel, 1963). This drumlin is partially eroded and provides an opportunity to study the cross-section of a glacially deposited feature. A drumlin boulder pavement is exposed on this beach at low tide one-half mile to the north. An excellent example of wave refraction can frequently be seen around this boulder pavement which forms a natural "groin." The rock types and mineral composition of the till clasts in both drumlins correlate with the bedrock of northern and western regions (Hartshorn, 1969).

The beach sediment is composed of very fine-grained quartz sand (McIntire and Morgan, 1963; Coastal Research Group, 1969). The cross-stratified dune sand is the finest sediment within the entire dunal system (Anan, 1969; Jones 1974). Frequently, there are thick layers of purple, garnet-rich, heavy minerals present at the swash zone. Hayes and others (1969) have observed heavy mineral layers throughout the Plum Island beach face. The commonly observed heavy minerals are biotite, garnet and hornblende.

Wind generated linear ripples appear to be the most common type of primary sedimentary structures found in this area. The Coastal Research Group (1969) observed an abundance of rill marks in the intertidal zone at this beach in addition to the ripples.

Stop 8. The Recurved Spit - This spit area is the most evident example of beach accretion at Plum Island. According to Farrell (1969) the spit has progressively grown since 1965. This growth is seen by comparing the 1966 Ipswich, Massachusetts, quadrangle to recent aerial photographs.

Hayes and others (1969) concluded that this spit receives the sediment supply from longshore drift and that the recurving results from wave refraction and tidal currents at the Parker River estuary. Farrell (1969) also observed a neep ridge and runnel system in the intertidal zone of this area.

Sediment in this system is very fine and lenses of organic debris are present a few feet down from the surface of the spit (Farrell, 1969). High energy conditions, however, introduce a coarse sand onto the spit face and Farrell (1969) observed that samples from these coarser beach faces were bimodal, indicating the possibility of a dual sediment source.

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DIRECTIONS AND MILEAGE LOG

The computed log starts at Stop 1 of this field guide and continues through Stops 7 and 8. The field stops included in this guide are found on Figure 6. Individulas using this field guide can choose the route most convenient for them to reach Plum Island, however, the best route from Newbury Center is Route 113 East, which coincides with Route 1A South. Follow 113 East - 1A South until the Newbury Common is on the right. Turn left at the flashing light onto Rolfe Lane. Stop 1 is at the intersection of Rolfe Lane with Seawall Street.

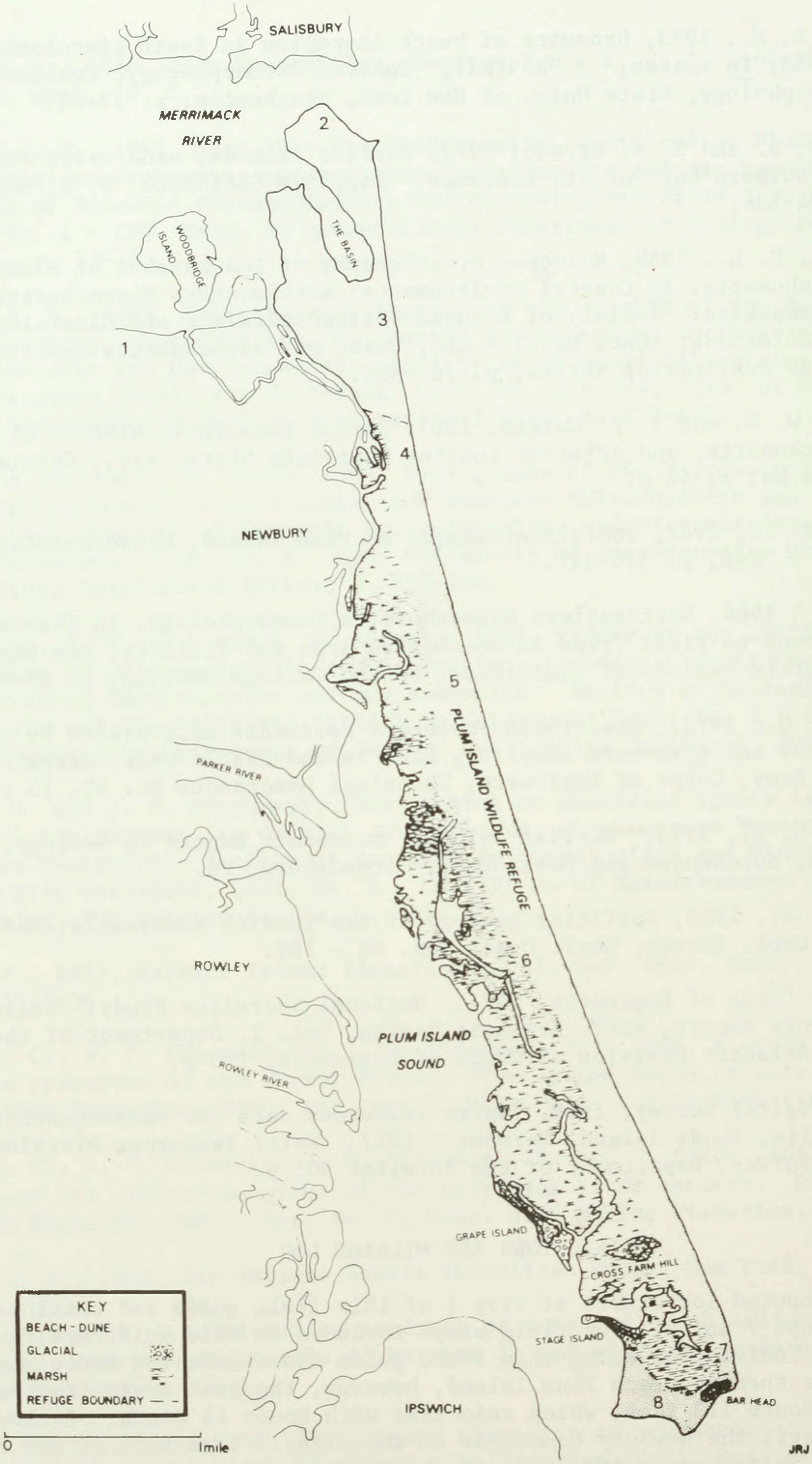

Figure 6. Location map of field trip stops at Plum Island.

Plum Island is included in the Newburyport East (1966), Massachusetts, and the Ipswich, Massachusetts (1966), Quadrangles published by the United States Geological Survey. In addition, the Surficial Geology of the Ipswich, Massachusetts, Quadrangle (GQ 189) has been mapped by E. A. Sammel (1963) of the U. S. G. S.

0.0*	0.0^x	After turning left at the intersection of Rolfe Lane and Seawall Street, park the cars on the left side of Seawall Street near the white cottage.
		Stop 1. Merrimack River estuary - This area is Joppa Flats. Note the High Water cord grass above the marsh high tide line. The red-roofed building at the northern end of Plum Island is near the mouth of the Merrimack River. The North Jetty is seen to the left across from this point.
		Return to the cars and continue straight ahead to Plum Island.
1.0	1.0	The cottages at the left are built on stilts because of flooding in the marsh. The vegetation is primarily High Water cord grass. Seawall Street now becomes Plum Island Turnpike.
1.5	0.5	Crossing over the Plum Island River.
2.0	0.5	This is Plum Island Center. The land use found in this area is primarily residential and small service stores.
2.2	0.2	Intersection of Plum Island Turnpike with Northern Boulevard. Turn left.
2.5	0.3	Northern Boulevard parallels the shoreline. There is a noticeable paucity of vegetation along the discontinuous dune on the right. The residential development appears to control the environment.
3.6	1.1	Bear right and turn into the parking area to the right, parking near the red-roofed Coast Guard building. Walk between this building and the fence on the right. Continue to the beach which is about 75 yards straight ahead.
		Stop 2. South Jetty area - At the beach turn right and follow the shoreline toward the mouth of the river. About 150 yards along the shoreline there is a dune segment. Walk up to the dune segment and continue along its base. The dune terminates at the beginning of the abandoned Coast Guard Station. You may wish to walk to the South Jetty; if so, the jetty is in sight 500 yards to the left. If you wish to return to the cars, turn right at the end of the dune and walk between this dune and the fence on the left. The parking area is about 150 yards straight ahead.

* Cumulative mileage
x Incremental mileage

		Return to the cars and leave the parking area, turning left back onto Northern Boulevard. Proceed toward Plum Island Center.
4.5	0.9	The Basin is to the right. This feature was formed when the Merrimack River changed its course after 1827.
5.1	0.6	Turn left into the parking lot at the intersection of Northern Boulevard and Plum Island Turnpike. Park cars and walk 30 yards to the beach.
		Stop 3. Plum Island Center Beach - See stop description no. 3 above.
		Return to the cars and proceed west on Plum Island Turnpike.
5.3	0.2	Intersection of Plum Island Turnpike with Sunset Drive. Turn left and proceed south on Sunset Drive.
5.5	0.2	Note the development of the dunes and the amount of vegetation in this area. This area exhibits the relationship between the dune and vegetative stabilization and is contrasted with the northern end.
6.1	0.6	Proceed through the gatehouse into the Parker River National Wildlife Refuge. (OBEY ALL RULES AND REGULATIONS.)
6.2	0.1	Turn left into the first parking lot. Park cars as close to the beach as possible, but still within the parking lot.
		Stop 4. Low Energy beach - Walk to the beach. Note the dunes and the slope of the beach. These dunes continue southward along the beach.
		Return to the cars and turn left out of the parking lot back onto Island Road.
6.7	0.5	Far to the right is a bedrock outcrop (Pine Island).
7.1	0.4	Note the continuously stabilized dune on the left and the expanse of marsh on the right.
7.3	0.2	The pool at the right provides a feeding area for many species of birds.
7.7	0.4	Turn left into parking lot #6. This is Kettle Hole Nature Trail. Park the cars and walk to the beginning of the nature trail.
		Stop 5. Kettle Hole Nature Trail - Follow the self-guiding nature trail to the left (DO NOT FOLLOW THE SIGN: "TO THE BEACH"). This trail slopes upward into the stabilized dunes. About half-way up this dune, note the garnet sands off to the left under a cover of Jack Pines (*Pinus banksiana*). Continue along the trail into the depression. An example of

a blow-out is seen from the summit of the rear dune, forming the back of the "kettle." Follow the trail around the depression.

Return to the cars. Turn back onto Island Road so that you are proceeding in the same direction as before (south).

8.4	0.7	Vegetative succession is seen in this area (Figure 5).
8.8	0.4	Bear left at this fork in the road. The Refuge sub-headquarters is at the right.
9.0	0.2	The end of North Pool Dike is on the right.
9.3	0.3	This area on the right is a meadow used by migrating birds as a feeding ground.
9.4	0.1	On the left is a pine forest.
10.0	0.6	Note the height of the dunes to the left.
10.1	0.1	Turn right into parking lot #9. This is Hellcat Swamp Nature Trail. Park cars and proceed 100 yards to the observation tower.

Stop 6. Hellcat Swamp Nature Trail - From the observation tower look northward (Merrimack River estuary). The water below is the North Pool Dike. The area to the right of the dike is Hellcat Swamp. Turn around 180°; the water just below is the South Pool Dike and in the distance is the well-forested area of the "Pines."

Return to the parking lot. Follow the self-guiding nature trail from the parking lot into the Hellcat Swamp. Bear to the right 30 yards after the trail starts. Stay on this pear-shaped trail.

Note the vegetation along the trail. Continue on the trail until a circular clearing. Stay on the trail; there is another circular clearing within 50 yards. Follow the nature trail to the parking lot.

Return to the cars and proceed back to Island Road and turn right.

10.4	0.3	To the left is Camp Sea Haven (A summer camp for children with polio).
10.6	0.2	The "Pines" is on the right.
10.8	0.2	Note the expanse of salt marsh on the right.
11.2	0.4	The dunes to the left are well stabilized.
11.8	0.6	The dunes to the left are well stabilized by American beach grass.
12.0	0.2	Cross Farm Hill - This feature is mapped as a drumlin (Sammel, 1963). These fields are planted with grain for migrating bird

species. The beach dunes exhibit an expanse of American beach grass. This is another example of pioneer plants stabilizing the Plum Island dune fields. The upland area to the southwest is also a glacial feature; it was mapped as ground moraine and estuarine deposits (Sammel, 1963).

12.3 0.3 The Stage Island Pool complex is at the right. This area was mapped as ground moraine by Sammel (1963) (Fig. 2).

12.9 0.6 Turn right into parking lot #15. Park cars and follow trail from parking lot to the observation tower.

Stop 7a. From the tower, the Atlantic Ocean is to the East (the larger water mass). Bar Head drumlin is to the south, and Crane's Beach is directly across from this point. Plum Island Sound is to the west.

Return to parking lot #15. Directly across from this parking lot is a wooden walkway; proceed along this wooden walkway for 100 yards to the beach. Turn left (north) at the junction with the beach and walk toward the exposed rocks.

Stop 7b. Bar Head Drumlin Area - These exposed rocks are the boulder pavement described in stop description 7. Proceed southward toward the large hill. Examine the ripples found along this beach area and look for cross-stratification in some breeched dunes. The large hill is the Bar Head drumlin. Continue around the drumlin so that Crane's Beach is visible to the left across Plum Island Sound.

Stop 8. Recurved Spit - The recurved spit begins at the left just beyond the western end of the Bar Head drumlin. See stop description 8.

Return to the cars by following the western side (base) of the drumlin in a clockwise direction around (northwestward) until the intersection of the dirt road and the drumlin occurs. Turn right onto this road so that the drumlin is on the immediate right. Stay on this road for about 250 yards until the sign, "Entering Parker River National Wildlife Refuge." Turn left onto Island Road. Continue along Island Road for about 100 yards until you reach parking lot #15. Drive northward along Island Road, which becomes Sunset Drive, to Plum Island Turnpike. Turn left and return to Boston.

* END OF THE FIELD TRIP *