

*Bloom*

THE PLEISTOCENE GEOLOGY OF MARTHA'S VINEYARD, MASS.

Itinerary for the  
FRIENDS OF THE PLEISTOCENE

27th Annual Reunion

May 23 and 24, 1964

Katama, Martha's Vineyard

Massachusetts

by

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## ITINERARY

SATURDAY, MAY 23

7:45 a.m.--Buses leave from the Dunes, Katama

### EN ROUTE TO STOP 1.

The hotel is situated on the outwash plain of the early Wisconsin ice sheet whose terminal moraine makes up the northeast and northwest coasts of the island. The composition of the upper part of the outwash here is mostly medium to coarse sand with some beds of gravel. Conspicuous among the larger pebbles are gray sideritic nodules derived from Upper Cretaceous coastal plain sediments. Some of these nodules contain poorly preserved marine mollusks. The pebbles are commonly encrusted with brown iron-cemented sand and many of them have been leached of carbonate, leaving either a void or a soft clay residue within the sandy iron shell. This early Wisconsin outwash can be seen in the spoil pile at the south end of the rectangular pit that has been excavated in front of the hotel (examine this on our return to the hotel this evening).

About a mile north of the hotel, at about the edge of Edgartown, we leave the outwash plain and enter the moraine. The moraine is not very conspicuous here, consisting of a few knobs rising not more than 25 feet above the outwash plain.

We will make a brief sight-seeing detour through Edgartown. This is one of the best preserved, early 19th century towns in New England. Most of the houses were built when the town enjoyed considerable prosperity as one of the three home ports (along with Nantucket and New Bedford) of the American whaling fleet. Today, the harbor is used only by pleasure craft. The island of Chappaquiddick is on the opposite side of the narrow harbor, across which a small motorized, 2-car ferry plys. Chappaquiddick is considered to be part of Martha's Vineyard.

From Edgartown we travel northwest to Vineyard Haven. The road follows the low hummocky topography of the early Wisconsin moraine. From scattered exposures in sea cliffs, roadcuts, and pits the moraine seems to consist largely of well-stratified sand and gravelly sand, not noticeably different from the deposits in the outwash plain and, as can be seen from the road, boulders are scarce. Sandy till, perhaps not unlike the material seen in Stop 1 may occur in the higher parts of the moraine. The rock types present in the pebbles are similar to those found in eastern Cape Cod and indicate a source somewhat east of north. The moraine along this stretch outlines the southwestern side of a broad ice lobe whose southern extremity is marked by the island of Nantucket, about 10 miles east-southeast of Martha's Vineyard. The eastern margin of the lobe is not known and is not evident on bathymetric charts of the waters east of Nantucket.

STOP 1. Sand pit behind Coca-Cola bottling plant, west edge of Vineyard Haven (20 minutes).

A deposit that is midway in sorting and structure between sandy till and stratified sand occurs in this pit which is located in the early Wisconsin moraine of the eastern lobe. The material is too poor in both the fines and

coarse fraction to be called a till without substantial qualification, yet the stratification is not as well developed as in the obviously water-deposited sand in both outwash plain and in the moraine to the east of here. Farther west, the material making up the moraine of the western lobe of the early Wisconsin ice becomes more till-like, and at the western extremity of the island typical compact, well-graded till is found. The moraine is probably partly made up of unsorted drift; but from exposures and topographic form it seems clear that much of it represents the headward extension of the outwash plain which, during the later stages of ice wastage, was deposited superglacially.

#### EN ROUTE TO STOP 2.

From the Coca-Cola pit the road dips down into a narrow valley formed by the collapse of superglacial moraine into a system of ice tunnels, which at an early stage of ice wastage discharged meltwater to the outwash plain to the south. The highway leaves the moraine and enters onto the northern edge of the outwash plain about a mile beyond the collapse-valley. The head of the outwash plain is at altitude 100 ft. here and is somewhat higher than the slightly hummocky moraine in back of it. This inversion of the usual topographic relationship reflects the superglacial origin of the moraine and the collapse that occurred when the underlying ice melted. The road follows the northern margin of the outwash plain. We turn north on Indian Hill Road and climb the lower slope of the eroded late Illinoian moraine.

#### STOP 2. Harold Rogers sand pit (30 minutes).

We are in the eroded late Illinoian moraine which makes up most of the hilly country in western Martha's Vineyard. The pit is excavated in one of the low (10-25 feet in height) northeast-trending ridges that are found widely in this moraine. From scattered exposures, such as in this pit and in Gay Head Cliff, we can see that the moraine consists largely of deposits older than late Illinoian that are disposed in a great series of imbricated thrust sheets. The low ridges appear to be erosional cuestas produced by outcrops of more resistant beds, principally the till of early Illinoian age.

The following section occurs in this pit (north to south). The beds and faults dip steeply northwest.

1. Greenish gray micaceous, slightly glauconitic fine sand (upper Cretaceous; possibly Magothy Formation but may be younger).
2. Thrust fault
3. Compact reddish brown pebble till, scattered small boulders interbedded with thin bedded sand (early Illinoian). (Note: the till had been removed and only the sandy section remained when seen in April, 1964).
4. Angular unconformity
5. Medium-coarse sand, scattered glauconite grains, some angular gravel. More fine-grained at base. Pronounced current bedding in upper part. (early Illinoian).
6. Fine-very fine light gray sand, some thin interbedded silty sand. Crossbedded in lower part. (early Illinoian).
7. Very compact till, capped by several feet of interbedded coarse sand and silty fine sand. The till is greenish gray at top, below which is a reddish brown semi-indurated zone overlying olive drab unoxidized(?) till with iron-stained joints. Some boulders are decomposed. This till has some of the characteristics of Kansan

till found in good exposures in the sea cliff north of here at Lamberts Cove but the depth of oxidation here is considerably less.

8. Thrust(?)
9. Red clay (Upper Cretaceous, Raritan Formation?)

The Pleistocene part of this section, consisting essentially (top to bottom) of pinkish till, medium sand becoming coarser at top, very fine sand and interbedded silt, and till, is found repeatedly throughout the late Illinoian moraine and will be seen in Gay Head Cliff.

#### EN ROUTE TO STOP 3.

We drop back onto the outwash plain of the early Wisconsin ice. A dry shallow meltwater channel can be seen immediately north of the road as we enter the village of North Tisbury. This channel heads to where a bulbous lobe of early Wisconsin ice breached the late Illinoian moraine, about 1 mile northeast of here. As we shall see tomorrow, the early Wisconsin outwash plain is scored by many dry channels similar to this. West of North Tisbury the road (North Road) follows one of the longitudinal (subsequent) northeast-trending valleys eroded in the late Illinoian moraine during Sangamon time. For several miles the valley is floored with early Wisconsin outwash. The origin of this outwash was several small projections of early Wisconsin ice that had pushed through narrow transverse gullies in the ridge of late Illinoian moraine forming the north side of the valley (the main mass of early Wisconsin ice came to rest against the north flank of this ridge). We leave the North Road, turn south on Tabor House Road. We cross a major erosional ridge of the late Illinoian moraine and drop down to the Middle Road--a road that follows the southern of the 2 main longitudinal valleys in the moraine. Many of the very large boulders in this part of the moraine are a coarse porphyritic granite. These are found on the surface of all but the eastern part of this moraine and were possibly transported by the late Illinoian ice. They are not found on the early Illinoian moraine at Squibnocket (Stop 8), which lay south of the late Illinoian ice margin, nor are they found on the middle Wisconsin moraine of the Elizabeth Islands, about 6 miles to the northwest of Martha's Vineyard.

#### STOP 3. Summit of Peaked Hill (20 minutes).

This is one of the highest points on the late Illinoian moraine (Alt. 298 feet). From it we have a good view of the late Illinoian moraine to our south. The low sag to the west was occupied by early Wisconsin ice. The ice excavated the basins of Menemsha and Squibnocket ponds by bulldozing proglacial clays and sands into the high windrow to the south (into which Wequob-sque Cliff has been eroded). The point in the distance to the southwest is Squibnocket; this lay just south of the late Illinoian ice margin. The island to the southwest, in the far distance, is Nomans Land. Both Nomans Land and Squibnocket are segments of the deeply lobate early Illinoian moraine. The higher land to the west, beyond Menemsha Pond, is the town of Gay Head and is a continuation of the same late Illinoian moraine on which we are standing.

#### EN ROUTE TO STOP 4.

The road leaves the late Illinoian moraine and enters the sag that was occupied by early Wisconsin ice at the crossroads called "Beetlebung Corners," about a mile west of Stop 3. We turn south and the road follows approximately the margin of the early Wisconsin ice (there is no topographic or depositional

evidence to mark this important junction here). To the left one can see the eroded late Illinoian moraine.

#### STOP 4. Eastern part of Wequobsque Cliff (2 hours).

Exposed in the easternmost end of this cliff are structural deformations produced by late Illinoian ice and earlier glaciation. These consist of variegated and gray clays (Upper Cretaceous Raritan Formation) striking east northeast, dipping north, and very much sheared. A wide fault zone with predominantly vertical beds striking northwest, which I call the Point of Rocks fault, marks the margin of the early Wisconsin ice. This is a marginal shear zone separating the subglacial and proglacial deformation of the early Wisconsin ice from the older terrain. In this fault zone are greensands and quartzose gravels that are probably Aftonian Interglacial in age. A few hundred yards further west, we will also see greensand of Miocene age and also Late Cretaceous (Magothy or post-Magothy) age. The Pleistocene quartzose gravel and greensand overlies a very compact light-medium gray till that is almost devoid of boulders and cobbles. Over 95 percent of the pebbles in this till consist of rocks derived from the Upper Cretaceous sediments and the Miocene greensand (quartz pebbles, siderite and limestone nodules, phosphorite nodules, and fossil bone). About 2 percent of the pebbles are of the metamorphic and igneous rocks of the New England uplands. In later tills these rocks are volumetrically more important. In places the upper part of this till is much weathered to a light tan to nearly white regolith that is rich in kaolinite. The till is probably Nebraskan in age. It has not been recognized elsewhere on the island.

The higher part of Wequobsque Cliff to the west consists entirely of a series of thick thrust plates of the early Wisconsin proglacial clays and sands. This material originally filled the basin of Menemsha Pond. The thrusts strike northeast and can be distinguished from the east-northeast thrusts produced here by the late Illinoian ice.

The lower slopes of the cliff are mantled with thick solifluction deposits. These are much weathered and, in places, capped by a deep, very mature podsol. These deposits and paleosols have been faulted and partially removed by glacial planation. This solifluction and soil-forming interval appears to have occurred between the retreat of early Wisconsin ice and the brief advance of late Wisconsin ice.

#### EN ROUTE TO STOP 5.

For about 3 miles the road crosses the lowland occupied by early Wisconsin ice. A lobate series of push-ridges in the southern part of the area outlines the lobate form of the ice front as it advanced through the sag. The road winds among these push-ridges. One steep-sided push-ridge can be seen edge on out the front window of the bus where the road climbs and then bears sharply to the right. An excellent view of the late Illinoian moraine east of the Menemsha sag can be had by looking to the rear.

We traverse the town of Gay Head. The road rises back onto the late Illinoian moraine which continues to the western tip of the island, Gay Head Cliffs.

#### LUNCH AT THE LIGHTHOUSE, GAY HEAD.

## STOP 5. Gay Head Cliffs.

The cliffs provide a deep cross section of the late Illinoian moraine. Early Wisconsin till mantles the north slope up to an altitude of about 100 ft. The rest of the cliff is entirely a product of imbrication by late Illinoian ice and consists of deposits that are pre-Wisconsin in age.

Most of the cliff consists of Upper Cretaceous sediments (Raritan Formation and a lesser amount of Magothy Formation). These are white, red, gray, black and yellow sands, clays, gravels and lignites. Hard nodular rocks up to 8 feet across occur in them and litter the beach in some places. These include siderite (mostly from the Magothy Formation), limestone, dolomite, and calcareous sandstone (mostly from the Raritan Formation). The Tertiary is represented by a fossiliferous greensand of middle Miocene age (probably equivalent to the Calvert Formation of Maryland) in the northern part of the cliff, the same greensand seen in Stop 4. Overlying this is a massive ferruginous clay and a fossiliferous and somewhat glauconitic sand which may be either Pliocene or early Pleistocene (Aftonian). Paleontologic studies of the sand are still being made in order to resolve the problem of age.

Starting our tour in the southern part of the cliff we will cross about a dozen large low-angle thrust faults and several boundary faults of east-west trending grabens as we proceed to the north end of the cliff in the course of the afternoon. There are innumerable smaller faults and the complexity of the structure is compounded by the faulting and plastic deformation of the recent landslides, both those that are now active and earlier ones now mostly removed by cliff erosion. Structural complexity increases towards the north end of the cliff where complex folds become important. The structural imbrication has resulted in the telescoping together of deposits that were originally as much as five miles apart. It is the piling up of thrust plates that makes it possible to study in this small area the remarkable variations in the pre-Pleistocene coastal plain sediments.

The Pleistocene units to be seen in the cliffs include the Aquinnah Conglomerate, a curious lithologic analog of the Miocene greensand (though much poorer in glauconite) and which, indeed, was thought to be Miocene until a bone of a Pleistocene horse was found in it. It is probably an early Pleistocene (Aftonian) talus derived from outcrops of Miocene greensand and gravelly sand of the Raritan Formation. Overlying the Aquinnah Conglomerate in the southern part of the cliff are quartzose gravels and greensand, the same as those seen in Wequobsque Cliff. The oldest obviously glacial unit in Gay Head is probably Kansan in age and overlies the Aquinnah Conglomerate. In places it is a deposit of pebbles, cobbles, and boulders, in others a thin, medium-dark gray till. The cobbles and boulders are largely of crystalline rocks (granite, gneiss, schist) plus some unusual masses of vein quartz and, for the most part, are decomposed in varying degrees. Near the north end of the cliff, this unit is represented by a thin pavement of pebbles and a few large boulders, all of which are well faceted, polished, and fluted by wind action.

Above the Kansan till and boulder pavement are crossbedded, light gray (pepper and salt) very fine sands overlain by coarser sands and gravel. The upper part of this unit is generally well oxidized and in places cemented by iron and manganese oxide. In a few places thin early Illinoian till, much

oxidized, overlies the gravel. At the northern end of the cliff, early Wisconsin till overlies all the older deposits with a pronounced angular unconformity.

Notice the many fine ventifacts on the beach and cliff, including some of the very large boulders. There were two times when ventifacts were formed: at the onset of Illinoian time when the lag gravel of Kansan age was very deeply windcut, and during early and middle Wisconsin time. The higher parts of Gay Head appear to have been free of ice during the early Wisconsin and deep sand cutting took place at that time of the boulders that were strewn on the surface of the "nunatak."

#### EN ROUTE TO END OF SATURDAY TRIP.

On our return to Katama we will take the North Road, the road that follows the northern of the 2 longitudinal valleys in the late Illinoian moraine. If time permits, we will make a short sightseeing detour to Menemsha, a quaint fishing port at the mouth of Menemsha Pond.

#### SUNDAY, MAY 24.

7:45 a.m.--Buses leave from the Dunes, Katama.

#### EN ROUTE TO STOP 6.

From Edgartown we travel west on the West Tisbury road. This road leaves the low hummocky early Wisconsin moraine about a mile west of town and crosses the outwash plain, dipping and rising as it crosses a number of dry meltwater channels.

#### STOP 6. Quampache Bottom (10 minutes).

This is one of the dry meltwater channels that head up to the early Wisconsin moraine. The outwash plain is dissected by a series of these. The lower reaches of these valleys are ~~not~~ drowned and the estuaries are closed by the series of bay mouth bars, comprising South Beach. The channels are dry today because the water table beneath the pervious plain is lower than their floors. It can be appreciated in a rough, qualitative way that the amount of meltwater produced by the early Wisconsin ice must have been considerable to result in a water table that was high enough for these channels to flow bank-full.

#### EN ROUTE TO STOP 7.

We travel due west across the outwash plain, dropping down into a succession of dry channels. At the little village of West Tisbury (notice the old mill pond with its proprietors, the swans) we travel south and then west on the South Road. The road follows approximately the northern edge of the outwash plain and the late Illinoian moraine is to the right, just beyond the trees. About 2 miles out of West Tisbury the road rises onto the late Illinoian moraine. At the road intersection of Chilmark (Beetlebung Corner) we again enter the sag that was occupied by early Wisconsin ice. We leave the highway and travel a short distance on a private road to the western end of Wequobsque Cliff.

STOP 7. West end of Wequobsque Cliff (25 minutes).

The western end of the cliff is cut in solifluction deposits. These deposits are particularly well developed here but are found on the lower slopes of many cliffs around the island, indicating that they form collars around the base of hills. Their low lying position is due in part to their origin--they represent downward creep of surface material--but also in part to their removal from higher places by later ice. Evidence for this last glaciation (late Wisconsin) will be examined this morning.

The solifluction deposits and mature podsol that we see at the stop are of the same age (post-early Wisconsin) as those seen yesterday in the eastern part of the cliff. The lower part of the deposit here consists largely of angular rock fragments in a rough imbricated arrangement. This coarse rubble grades up into a laminated, slightly greenish gray, compact silt and sand mixture. The top of this deposit is marked by a thin pavement of cobbles, many of which are broken along their basal surface. Above this is a thin and somewhat obscurely stratified sand with some large involuted structures. A thick and very prominent podsol is developed on this sand (and on the underlying rubble bed where the sand is absent). The gleyed A<sub>2</sub> horizon is 30 inches thick in places. The underlying B horizon is deep red to black and indurated in places.

As we move along the cliff we will see compact early Wisconsin till overlying proglacial outwash gravel that grades down to uniform medium sand. The paleopodsol disappears but small stretches of it can be seen at the top of the cliff at several places. A deep wedge structure cuts the entire cliff section, continuing below beach level. It is capped by the paleopodsol and contains collapsed beds of sand and clay. It is possibly an ice-wedge structure, but a very large and complex one. Further east there is a broad wedge shaped area of the cliff face that exhibits the type of gleying normally found beneath peat deposits (Stop 8). The early Wisconsin till and underlying sand are an ashy gray color below which there is a prominent zone of red iron oxide. However, here there are no organic soils on the surface. We can only conclude that a peat filled depression once occurred but that it has been scraped away. The ice sheet responsible for this was also responsible for the removal of the paleopodsol from most of the surface.

EN ROUTE TO STOP 8.

The road crosses some of the push ridges of the early Wisconsin ice, crossing the southernmost of these, and follows behind the barrier beach at the mouth of Squibnocket Pond. We enter the rolling, poorly drained tract of Squibnocket, whose topography and underlying materials are very like those on Nomans Land. Both of these are thought to be remnants of the early Illinoian moraine.

STOP 8. Squibnocket (60 minutes).

We will walk along the shore. In the cliff is the very compact, somewhat reddish, and interestingly stratified till, typical of the early Illinoian moraine. Notice the absence of porphyry boulders generally associated with the late Illinoian moraine. Many boulders of ferruginous sandstone, some bearing Cretaceous marine fossils, litter the beach. These are only rarely found in the late Illinoian moraine. The origin of the stratification of this till



should be discussed here. Underlying the till in one section of the cliff is fine to medium sand and gray silty clay. These deposits are the same as those seen in the southern part of Gay Head but are thought to be older than those making up much of Wequabsque Cliff.

We will stop to study the hanging bog at Squibnocket Point. Notice the gleyed zone in the very compact stratified till beneath the bog sediments. The bog section was recently described by Ogden (Am. Jour. Sci., 1963, p. 344-353) and Kaye (Science, 1962, p. 906-907). The lowest unit, overlying the early Illinoian till, is a thin diatomaceous gyttja with a tundra-type pollen flora. A very thin sample at the base of this was radiocarbon dated as  $12,700 \pm 300$  years B.P. (Rubin and Alexander, Radiocarbon, 2, sample W-710). The overlying fibrous peat contains leaves of arctic willow, spruce cones, beetle carapaces, and many sticks of beaver-cut wood. The massive woody section at the western end of the bog may be a beaver lodge. Two pieces of beaver-cut wood were radiocarbon dated at  $11,650 \pm 250$  years B.P. (Humble, O-766) and  $11,352 \pm 211$  years B.P. (OWU-6).

The 12,700-year date of the thin basal sample should give a minimum date for the retreat of the last ice from here--assuming that the depression was not simply the result of a beaver dam having been put across a small valley at that time.

#### EN ROUTE TO STOP 9.

We continue along the road to Gay Head, crossing the push-ridges of the early Wisconsin ice, and then turn south along Moshup Trail. We cross a series of low elongate ridges and mounds that on aerial photographs somewhat resemble the ice-fracture-filling topography of an ablation moraine (Kaye, C. A., 1960, U. S. Geol. Survey Bull. 1071-I, p. 341-396). The road-cuts show that the ridges are essentially anticlinal, another characteristic of this type of topography.

#### STOP 9. Zacks Cliff (60 minutes).

The peat on the beach at the point of entry formed in a swamp, similar to those just in back of the cliff. Its position on the beach today is the result of cliff recession. The peat is probably fairly recent and no radiocarbon dates have been obtained from it.

The very compact till just west of the entry onto the beach may be early Illinoian or early Wisconsin in age. About 100 yards to the west it is overlain by a coarse solifluction rubble.

The most interesting thing about the cliff are the foreset bedded sands and associated silty gray clays that overlie the compact till and solifluction rubble. The clays rest directly on the solifluction rubble and are seen to grade into the foreset bedded sand providing a textbook illustration of delta structure and facies. This delta formed in a basin whose outlines are now obscured or, more probably, have been removed by erosion. At one place the lower part of the silty clay contained carbonized leaves, mostly of small arctic willows and other tundra plants. These were radiocarbon dated at  $15,300 \pm 800$  years B.P. (W-1187, Washington laboratory, U. S. Geological Survey).

As we follow the cliff to the northwest the sand and clay sequence is much faulted and is capped by a poorly compacted rather stony till. The same till and the underlying sand can be examined in the small anticlinal roadcut where the buses are parked and in other road cuts along here. This, then, appears to be the drift of the ice that was responsible for the partial erosion of paleosols of Waquoagsue Cliff. It also apparently scraped all organic deposits out of such depressions as existed on the early Illinoian moraine. The age of the glaciation would therefore appear to be bracketed by the Squibnocket and Zacks Cliff dates and from evidence in the Boston area (Kaye and Barghoorn, 1964, Geol. Soc. America, p. 63-80) occurred between 14,000 years B.P. and about 13,000 years B.P. This is approximately contemporaneous with the Port Huron ice advance in the Great Lakes area.

EN ROUTE TO VINEYARD HAVEN.

We will take the Middle Road which follows the southern of the 2 longitudinal (subsequent) valleys eroded in the Illinoian moraine. We enter the early Wisconsin outwash plain at West Tisbury and travel due east along this plain to Edgartown.

NOTICE: BUSES WILL LEAVE THE DUNES FOR THE FERRY AT 1:15 SHARP.

Outline of Pleistocene geology  
of Martha's Vineyard, Massachusetts

By Clifford A. Kaye, Boston, Mass.

Abstract. Six drifts and the deposits of one interglaciation are recognized on Martha's Vineyard. It is thought that these represent Nebraskan Glaciation, Aftonian Interglaciation, and Kansan, early Illinoian, late Illinoian, early Wisconsin and late Wisconsin Glaciations. In addition, the terminal moraine of middle Wisconsin Glaciation is nearby, at the Elizabeth Islands, and the periglacial effects of this ice sheet are preserved on Martha's Vineyard. The Pleistocene stratigraphy was worked out independently of earlier work and is in remarkably close agreement with the conclusions reached by Fuller and Woodworth a half century earlier.

The following pages and the diagram in Figure 1 summarize the major conclusions the author has reached concerning the stratigraphic divisions of the Pleistocene deposits of Martha's Vineyard. This is the result of a field study that began in 1957, and which will be reported on more fully in a Professional Paper of the U. S. Geological Survey.

Earlier work on the glacial deposits of the southern New England islands recognized the existence of a complex stratigraphic sequence of drifts. Fuller (1914) distinguished seven drift units and one interglacial unit on Long Island comprising all 4 glacial stages of the Pleistocene.

The writer approached the geology of Martha's Vineyard with few preconceptions, working independently of the results of earlier writers. He soon became convinced, however, that deposits and structural effects of several ice sheets that apparently represent a wide time range are present. The problem of arranging the drifts in stratigraphic order was complicated by the fact that most of the deposits are fragmentary. No single exposure contains the entire section, and the stratigraphic sequence had to be put together piecemeal by a series of comparisons between widely separated outcrops. Moreover, the deposits are almost everywhere very much deformed by glacially produced thrust faulting and some folding. Thus, deposits that were laid down as much as several miles apart have been telescoped together by the glacial imbrication. This complicated the recognition of facies differences and variations of the type to be expected within a single drift. A series of value judgments had to be made as to whether differences in adjacent deposits were due to faulting, differences in age, or compositional and textural variations within a single drift.

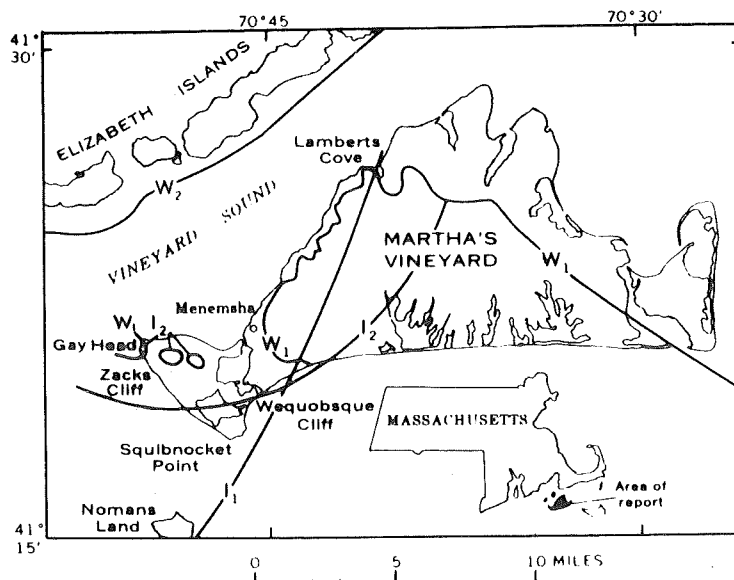


Fig. 1 — Map of Martha's Vineyard and surrounding islands showing inferred ice margins and moraines of Illinoian and Early and Middle Wisconsin ice sheets.

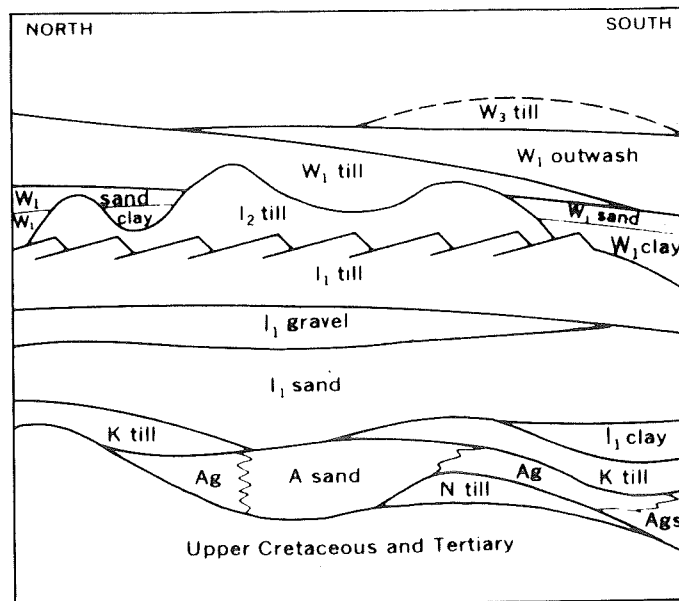


Fig. 2 — Diagrammatic north-south cross-section through Martha's Vineyard, showing succession of drifts and their spatial relationships. Symbols: N, Nebraskan; A, Aftonian; K, Kansan; I<sub>1</sub>, early Illinoian; I<sub>2</sub>, late illinoian; W<sub>1</sub>, early Wisconsin; W<sub>3</sub>, late Wisconsin; gs, greensand; g, gravel.

When all the fragments were pieced together, however, there was strong evidence of 6 drifts and the periglacial effects of a 7th glaciation, thought to be that which produced the nearby Elizabeth Islands moraine several miles to the northwest (fig. 1). Moreover, sediments deposited during an interglaciation are present, and the weathering and erosional effects of several other interglaciations have been deduced. This confirms the deductions of Fuller (1914) and Woodworth and Wigglesworth (1934) as to the number of drifts and interglacial deposits present. The writer differs with these earlier workers, however, on the stratigraphic position of some of the deposits; therefore in the following brief account only stage names are used.

The drifts were assigned ages by matching them with all the known major glacial stages and substages of the upper Mississippi Valley, working back from the late Wisconsin and taking into account the lengths of interglacial intervals as suggested by weathering effects and interglacial deposits. It is recognized that this method leaves much to be desired as a means of correlation, and therefore must be considered as a provisional interpretation, at best. Nonetheless, it is apparent that Martha's Vineyard possesses one of the most complete sections of Pleistocene deposits known, and possibly the most complete and varied within the confines of such a small area (81 sq. mi.).

#### Nebraskan drift

Nebraskan drift consists of a till that has been recognized at only one locality on Martha's Vineyard, the eastern part of Wequobsque Cliff (fig. 1), where it overlies greensand of Miocene age and attains a maximum exposed thickness of 20 feet. It is very compact and well graded in the clay to fine-gravel size range; clasts larger than 3 inches are very rare. It is light gray (dry) or medium gray (moist), and is massive in the upper part but thinly banded or stratified in the lower part. About 97 percent of the coarse clasts in the till consist of quartz pebbles and nodular rocks derived from Tertiary and Cretaceous coastal-plain sediments, which are exposed in Martha's Vineyard; thus only 3 percent are derived from crystalline rocks of the New England upland. This is significant because the percentage of crystalline rocks of New England upland provenance increases in successively younger tills. The sand, silt, and clay show by their mineral composition that they, too, are largely reworked coastal-plain sediments.

At two places in the cliff the upper part of the till has been profoundly altered by weathering to a maximum depth of 13 feet beneath sand of early Illinoian age. This old truncated regolith (which, like most interglacial weathering profiles, has been partially to completely removed by later glacial erosion) is nearly white. Study of the clay mineralogy by John Hathaway, U. S. Geological Survey, showed that the regolith is considerably richer in kaolin-ite than the unweathered till from which it was derived. Little can be deduced about the direction of movement of the Nebraskan ice, although dark-gray phyllite pebbles in the till, which resemble rocks in southern Rhode Island, suggest southeast or east-southeast movement. There is no evidence indicating the maximum extent of the ice sheet. This till was not recognized by Woodworth and Wigglesworth and may not have been exposed in their day.

### Aftonian deposits

Deposits of probable Aftonian age consist of several bodies of quite dissimilar sediments that are thought to represent both marine and nonmarine depositional facies in a coastal area (fig. 2). In eastern Wequobsque Cliff there is a bright pistachio-colored greensand interbedded with quartzose gravel (the content of crystalline rock pebbles is about 2 percent of the total pebbles) containing reworked Miocene shark teeth and other fossils. In Wequobsque Cliff these sediments overlie the Nebraskan till. The greensand does not resemble the Miocene greensand or the glauconitic fine sand of Late Cretaceous age, both of which crop out on the island. The glauconite may therefore be authigenic; an attempt is being made to date it by the potassium-argon method. Cropping out in the central part of Gay Head sea cliff is a massive bed that consists mainly of reworked Miocene and Cretaceous sand, gravel, and fossils, which in part is loosely cemented by phosphate. This peculiar bed was called the Aquinnah Conglomerate by Woodworth and Wigglesworth (1934), and although it strongly resembles the Miocene deposits of Gay Head, its Pleistocene age was established by the finding of the bone of a Pleistocene horse. This odd sediment is probably talus that accumulated on the lower slopes of a sea cliff that was cut into Miocene and Upper Cretaceous sediments in Aftonian time. In the southern part of Gay Head it can be seen grading into greensand and quartzose gravel very similar to those of Wequobsque Cliff. In south and central Gay Head these sediments unconformably overlie white clayey coarse sand of the Raritan Formation of Late Cretaceous age, and in some places they underlie Kansan till and in others sand of early Illinoian age.

The Aquinnah Conglomerate and the greensand-quartzose gravel complex are not found in the northern part of Gay Head. Instead, a massive ferruginous clay and fossiliferous glauconitic sand lie between Miocene greensand and Kansan drift. Mollusks from the sand were studied by Dall (1894) who dated them as Pliocene. More recently Raup and Lawrence (1963), working with another collection of shells, considered the fauna to be Pleistocene. Further study is being carried on to resolve the difference of opinion. At this stage of the study, one can only suggest that if these deposits are Pleistocene in age they probably are equivalent to the greensand and gravel to the south.

### Kansan drift

Kansan drift is found at several places in Gay Head Cliff overlying the Aquinnah Conglomerate, the Pliocene or Pleistocene fossiliferous sand, or where this is missing, Upper Cretaceous or Miocene sediments. It is also exposed in the cliff in the northern end of Lamberts Cove and in several sand and gravel pits in the interior of the western part of the island. It is a compact medium-gray to greenish-gray till that is poor in cobbles and boulders. However, a lag deposit of boulders, mostly of crystalline rocks (termed the "Dukes boulder bed" by Woodworth and Wigglesworth, 1934), marks the stratigraphic position of the Kansan drift in a few places in Gay Head. The content of crystalline rocks in the till is higher than in the Nebraskan till, but nodular sedimentary rocks (siderite, dolomite, limestone, and phosphorite) from the coastal-plain sediments make up 60-80 percent of the clasts larger than 1 inch.

In the lag gravel the content of crystalline rocks is higher, mainly because these rocks are generally harder and more durable than the nodular rocks. In Lamberts Cove cliff, Kansan till is oxidized beneath its contact with overlying sand of the Illinoian drift to a depth of more than 40 feet. In the northern part of Gay Head, lag pebbles and boulders of Kansan till are deeply wind cut and polished where they are overlain by basal fine sand (eolian?) of the Illinoian drift. In other places, some of the crystalline boulders are much decomposed. The direction of movement of Kansan ice is deduced from very tenuous evidence as having been almost due south. There is no evidence as to the maximum extent of the Kansan ice sheet.

### Illinoian drift

The patchy Kansan till is overlain by a widespread and varied sequence of sediments that are thought to be Illinoian in age. The Illinoian drift is divided into a lower unit of sorted, stratified sediments overlain by till, believed to be of early Illinoian age, and an upper till that may represent late Illinoian Glaciation. In the central and northern part of Gay Head Cliff and in several pits in the interior of the island the basal Illinoian drift consists of fine-grained, light-gray laminated sand that grades up into cross-bedded, somewhat glauconitic, uniform fine to medium sand and finally up into a somewhat quartzose gravel. In the southern part of Gay Head and in Lamberts Cove, the basal Illinoian consists of glauconitic sand and quartzose gravel that somewhat resemble the Aftonian sequence of Wequobsque Cliff. In the southern part of Gay Head, in Squibnocket cliff, and in the cliff of Nomans Land (fig. 1), the basal Illinoian is brown to gray clay and silt overlain by fine to medium sand. There is no evidence of weathering of any of these basal deposits beneath Illinoian till.

These sorted, basal sediments are unfossiliferous (except for fossils that were obviously reworked from Miocene beds) and for the most part are probably nonmarine. The glauconite is probably reworked from older greensand. Indeed, in texture and type of bedding and crossbedding, some of the deposits resemble outwash sand and gravel, and eolian sand. The thick clay-sand sequence may be marine and quite comparable to the clay-sand sequence at the base of the Wisconsin drift, which is thought to be a marine deposit made up of rock flour and sand derived from the advancing ice sheet. Because of these reasons and the absence of a pre-till weathering profile it seems more reasonable to consider these sediments as Illinoian rather than Yarmouth in age.

The early Illinoian till is best exposed in cliffs at Squibnocket Point and in the cliffs on the south shore of Nomans Land,  $3\frac{1}{2}$  miles to the south. It also is found at the north end of Lamberts Cove and in pits in the interior of the western part of the island. It is an exceedingly compact well-graded till, eroding into "badland" forms. In places it is strikingly stratified. The color is slightly mauve to pinkish gray. More than 60 feet of till is present in the cliffs of Nomans Land and Squibnocket. This very compact stratified till was called the Montauk Till Member of the Manhasset Formation in Long Island by Fuller (1914), and the name Montauk was extended to Martha's Vineyard and Block Island by Woodworth and Wigglesworth (1934).

Unlike the Kansan and Nebraskan tills, but in common with all later tills, the pebbles, cobbles, and boulders of the early Illinoian till are predominantly of crystalline rock. Much of the deep pre-Pleistocene regolith had been removed from the New England crystalline terrane by the two earlier ice sheets, and by Illinoian time a large expanse of unweathered rock lay exposed for the glacial ice to quarry. From rock types in the till the direction of movement of the early Illinoian ice is thought to have been toward the east-southeast. The thick till exposed at Squibnocket Point and Nomans Land probably represents parts of the terminal moraine, and the limits of the ice are inferred to have been a deep lobe, the edge of which trended southwest from Lamberts Cove through Nomans Land, curving northward to the west to include Block Island, where this till is also well exposed (Kaye, 1960, fig. 51). The bathymetry of open waters between the islands gives evidence of this lobate ice margin. Hydrographic charts and recent surveys show that a broad ridge marked here and there by boulder concentrations follows this alignment.

The late Illinoian till can be seen in only a few small exposures in the eastern part of Wequobsque Cliff. The former widespread presence of this till, however, is deduced from the marked structural effects that the ice sheet had on all older deposits and from the widespread occurrence of a lag concentration of large boulders of a characteristic type that were carried by the ice and that may have once been part of a till sheet. Where exposed in Wequobsque Cliff, the till is medium to dark gray and has an abundance of cobbles and boulders. Two rather distinctive rock types are found in the clasts: a coarsely porphyritic granite containing large pink to red microcline phenocrysts, and a dark-gray diorite. Boulders of these rocks, commonly of very large size, litter the surface of much of western Martha's Vineyard. Their greatest concentration is in areas of pronounced structural imbrication, and they are particularly abundant in the hilly western section of the island. These hills are the remains of a great pushed, or imbricated, terminal moraine of the late Illinoian ice. The intervening valleys are erosional, cut by streams in Sangamon time. The lobate outline of the late Illinoian terminal moraine is suggested by the change in strike of the thrust sheets produced by it. It is also shown by the topographic axis of the western part of the island. The southernmost point reached by this lobe was just north of Squibnocket.

No deposits of Sangamon age have been recognized. Sangamon time was, however, a time of considerable erosion and profound weathering. Deep oxidation developed during this interval is found on Sangamon erosion surfaces in all the cliffs.

#### Early Wisconsin drift

The earliest Wisconsin deposit is thick gray clay overlain by sand. The sequence very much resembles the clay and sand of the early Illinoian drift and probably formed under similar conditions. The early Wisconsin clay and sand crop out in the high central and western part of Wequobsque Cliff where they have been repeated by a series of thrust faults, and in the cliffs on the north side of the island where they were pushed up from Vineyard Sound against the north flank of the eroded Illinoian moraine by early Wisconsin ice. In Wequobsque Cliff the lower 10 feet of the clay is varved, grading up into an unfossiliferous medium-gray massive clay. Pollen studies of this clay indicate a fairly mild climate at the outset of deposition, becoming colder



as clay was deposited toward the top of this zone. The sediment probably represents a proglacial deposit formed by rock flour coming from the distant early Wisconsin ice. As the ice advanced, crustal subsidence caused by ice loading produced a relative rise of sea level. This changed the estuarine or lacustrine depositional environment (varved clay) to a marine environment (massive clay). The overlying uniform sand is in effect a deltaic continuation of the same deposition and marked the approach of the ice front. In western Wequobsque Cliff the sand grades up into gravelly outwash, which in turn is overlain by compact early Wisconsin till.

The morainic deposits of the early Wisconsin ice range from a well-graded till containing interstratified thin lenticular sand and gravel, on the west, to a stratified medium to coarse sand containing minor amounts of gravel in the eastern part of the island. In the central part of the island the two types of deposits tend to grade into each other. In the westernmost part of the island the cobbles and boulders in the till consist of an unusually wide variety of rock types and include many that are recognized as coming from distant outcrops to the northwest, in Massachusetts and Rhode Island. The erratics in the eastern part of the island lack the diversity of type and the distinctive and sometimes traceable rocks that are found in the till to the west. This is very probably due to differences in the direction of ice movement as suggested by the bilobate configuration of the ice front (fig. 1).

The broad triangular outwash plain making up the central section of Martha's Vineyard is a product of the early Wisconsin glaciation. The plain was fed mainly by the eastern lobe of the ice, although some sediment was contributed by the western lobe where small tongues of ice broke through the north ridge of the eroded Illinoian moraine (fig. 1).

#### Middle Wisconsin glaciation

Martha's Vineyard was probably free of ice during the middle Wisconsin. It was during part of this interval that the large moraine of the Elizabeth Islands, only 4 miles to the northwest, was formed. Some oxidation of earlier deposits and the development of podsol soil took place on Martha's Vineyard during the interval between early Wisconsin glaciation and the maximum advance of middle Wisconsin ice. Later, when the ice front stood at the Elizabeth Islands moraine, solifluction and other frost action occurred on Martha's Vineyard. Large soil involutions, ice-wedge structures, and deeply cut and polished ventifacts are found on the early Wisconsin moraine, outwash plain, and the uplands. Even the previously developed podsol soil was involuted. Solifluction carried surface material downslope; characteristic deposits of iron-stained solifluction debris can be seen rimming the lower flanks of hills in many sea cliffs.

#### Late Wisconsin drift ?

The presence of late Wisconsin drift on Martha's Vineyard, dating from about 13,000-14,000 years B.P., is inferred from several lines of evidence. A radiocarbon date of 15,300 $\pm$  800 years B.P. (W-1187, Washington laboratory, U. S. Geological Survey) was obtained from leaves of tundra plants embedded in clay in Zacks Cliff, a low sea cliff about midway between Squibnocket

Point and Gay Head. The clay overlies middle Wisconsin solifluction gravel and compact early Wisconsin till. The clay is overlain by foreset bedded sand. The outlines of the body of water in which this material was deposited are no longer evident and probably were removed by erosion. At two places the clay and sand are overlain by till, or a till-like deposit (cobbles, gravel, in a silty sand matrix). Inland from here, low roadcuts show similar till(?) interbedded with sand.

About 2 miles southeast of Zacks Cliff, about 10 feet of postglacial peat and organic sediment is exposed in the upper part of the sea cliff at Squibnocket (Kaye, 1962; Ogden, 1963). The lower 2 feet of this deposit contains fossils of tundra plants, and pollen studies indicate that a tundra flora existed when the earliest sediments were deposited here. A radiocarbon date of  $12,700 \pm 300$  years B.P. (W-710, Washington laboratory, U. S. Geological Survey, Rubin and Alexander, 1960) was obtained from a very thin sample at the base of the section resting on early Illinoian till.

The two Martha's Vineyard dates viewed in isolation do not in themselves provide a very strong basis for deducing the presence of an ice sheet of intermediate age. However, such an interpretation is given strong support by the fact that no basal material from postglacial organic sediments in eastern Massachusetts and Rhode Island has yielded a date older than that at Squibnocket. The deposition of sediment in depressions seems to have begun sometime after 13,000 years B.P. In the Boston area the earliest date obtained is 12,170 years B.P. (Kaye and Barghoorn, 1964); on Block Island, 12,090 years B.P. (Kaye, 1960). All of these are thin samples collected in open exposures. In Boston a date of 14,000 years B.P. was obtained from shells in marine clay, but these clays have been preconsolidated to considerable depth, and it is believed that this is the result of overriding by an ice sheet, presumably the same glacial advance that reached Martha's Vineyard.

Another line of evidence for glaciation that was approximately contemporaneous with the Port Huron ice advance of the Great Lakes area (Flint, 1963) is that the middle Wisconsin solifluction deposits of eastern Wequobsque Cliff are faulted and the entire surface has been planed smooth, removing the up-thrown scarps of the faults. The faulting may be the result of ice shove, as are so many of the structures exposed in the cliffs, and the smoothly truncated surface may have been caused by glacial erosion. Other examples of surface planation have been noted in the cliffs. An interesting one is in the western part of Wequobsque Cliff where an undrained depression has been entirely removed and only the well-developed gley zone that formed beneath it is preserved.

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Illinoian and early Wisconsin moraines  
of Martha's Vineyard, Massachusetts

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Abstract. Three well-defined morainic systems are present on Martha's Vineyard. Remnants of an early Illinoian moraine occur at the southernmost point of the island and on Nomans Land, a nearby island. Hydrographic surveys show a deeply lobate submarine continuation to the west. The hills and valleys of western Martha's Vineyard are the eroded remains of a very large moraine pushed up by late Illinoian ice. Early Wisconsin ice was partly stopped by this moraine in the western part of Martha's Vineyard but overrode it in the eastern parts. The entire eastern half of the island consists of the early Wisconsin moraine and its outwash plain.

Six drifts, very probably representing Nebraskan, Kansan, two Illinoian, and two Wisconsin Glaciations are found on Martha's Vineyard. The two earliest drifts, the Nebraskan and Kansan, and the late Wisconsin do not give evidence of the maximum extent of their respective ice sheets, and it is very likely that the ice terminated well south of the island. However, study of the two Illinoian and the early Wisconsin drifts, and their respective topographic characteristics, indicates that the drifts are terminal moraines. By some curious coincidence, therefore, the terminal moraines of three successive continental glaciations appear to have crossed what is now western Martha's Vineyard.

Early Illinoian moraine

The oldest moraine is probably early Illinoian in age. It is made up mainly of exceedingly compact mauve to pinkish-gray till that is commonly strikingly stratified. The topography is low and hummocky with many shallow swampy depressions. The depressions, however, may be partly the result of erosion by late Wisconsin ice, which seems to have occupied the area but which left only a very thin and fragmentary drift cover. On Martha's Vineyard the early Illinoian moraine as such is restricted to Squibnocket Point (fig. 1), the southernmost tip of the island. In the interior of the western part of Martha's Vineyard, pinkish compact early Illinoian till is found within the moraine of the succeeding late Illinoian ice sheet where it had been faulted up, along with earlier deposits, in an imbricated series of thrusts.

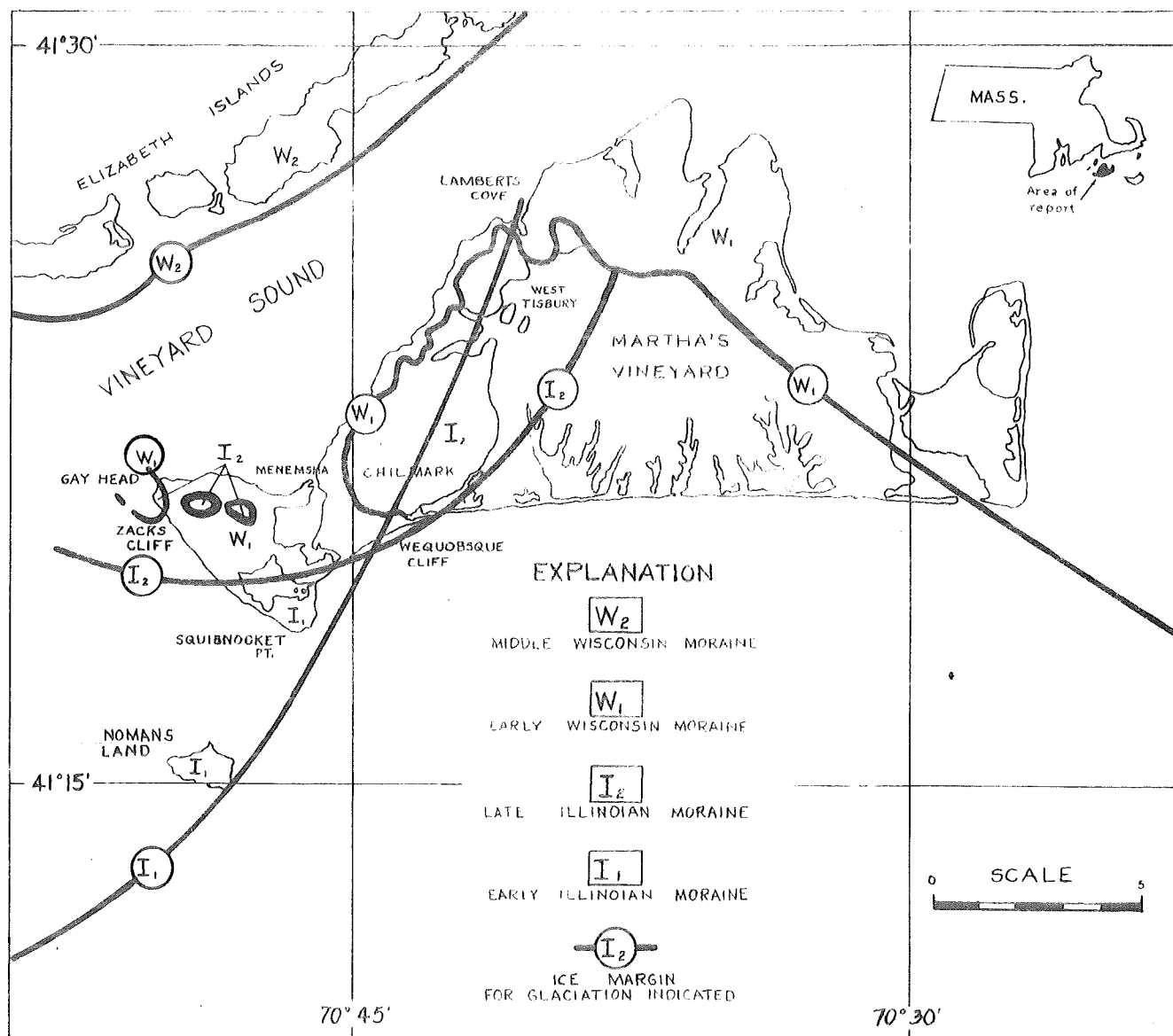


Fig. 1 -- Map of Martha's Vineyard and surrounding islands showing inferred ice margins and moraines of Illinoian and early and middle Wisconsin ice sheets.

The same type of thick till and similar terrane features as at Squibnocket are found on Nomans Land, a small island  $3\frac{1}{2}$  miles south-southwest of Squibnocket. Hydrographic charts show a low, interrupted submarine ridge of broadly lobate form connecting Nomans Land and Block Island, lying about 40 miles to the west, where similar very compact stratified till crops out with considerable thickness in the cliffs. The same type of very compact stratified till also occurs in eastern Long Island, where it was called the Montauk Till Member of the Manhasset Formation by Fuller (1914). The probable ice margin of the early Illinoian ice in the Martha's Vineyard area is shown in figure 1.

#### Late Illinoian moraine

The high-standing, hilly western section of Martha's Vineyard is the terminal moraine of late Illinoian ice. Northeast of Menemsha the moraine has been much eroded, both by stream action and by landsliding. Two rather deep northeast-trending valleys and a number of tributary valleys and gullies have been cut into it, producing a pleasant hill-and-dale topography with a relief of up to 175 feet. To the west the moraine is interrupted by a low sag occupied by two large ponds between Menemsha and Squibnocket Point; farther west the moraine occurs in the high land near Gay Head.

The interior of the moraine is well exposed in Gay Head Cliff, the high sea cliff at the western tip of Martha's Vineyard. Here the moraine is seen to consist of Late Cretaceous, Miocene, and pre-late Illinoian Pleistocene deposits, broken by a great number of faults and, at several places, distorted into complex folds. These structures continue below sea level, and there is no evidence of how thick the morainic complex is here. A detailed study of the structure exposed in the cliff shows that the moraine is mainly made up of imbricated thrust sheets pushed from the north. Distortions of the thrust plates--presumably formed as they piled up in front of the ice--created secondary fault structures and large-scale rumpling. The impression conveyed by Gay Head, that the structure is an imbrication of thrust plates moved from the north, is confirmed by detailed mapping and study of exposures in the hilly section of the moraine northeast of Menemsha. Here, the same imbrication of thrust plates, with individual plates attaining thicknesses of 100 feet or more, can be seen. Upper Cretaceous deposits are repeatedly thrust over Pleistocene.

The major thrust sheets in Gay Head Cliff strike nearly east. East of Menemsha the strike is northeast; this shift in orientation reflects the lobate form of the moraine. A study of aerial photographs shows that the eroded moraine northeast of Menemsha is marked by a series of low parallel ridges. From exposures in some of these ridges, one can see that they parallel the strike of the thrust sheets and are, in fact, small erosional cuestas produced by the outcrops of more resistant beds (mostly of early Illinoian till) within the thrust sheets. They therefore are useful in outlining the deformational structure of the moraine and they nicely indicate the form of the ice lobe that produced the deformation.

Over most of this moraine late Illinoian till is absent. At many places, however, there is an impressive concentration of boulders. Many of these are of a characteristic coarsely porphyritic granite with pink to red euhedral phenocrysts of microcline, 2 inches or more in length, that is not found in

older drifts. These boulders are thought to have been transported by the late Illinoian ice and in part, may represent a lag concentration left after whatever late Illinoian till that may have been deposited on or in the moraine had been removed by interglacial erosion.

The late Illinoian ice was not unique in producing thrust or push structures. All the glaciations appear to have deformed to varying degrees the preexisting sediments. In Gay Head and other cliffs, there is a problem of distinguishing the deformation produced by the several ice sheets. It is clear, however, that the late Illinoian ice produced the most important deformation.

The mechanism responsible for the imbricated moraine was probably the shearing off of broad flat fragments of the ground surface lying in front of the ice and the piling up of these plates as the ice moved forward. Plates were successively added at the base, rather than the top, of the pack, and the moraine in effect was built from the base upwards. Something of the sort can be seen if one pushes his hand horizontally against the surface of a sandy beach on which there is a thin crust of salt-cemented sand. The essential condition is that the surface plates have greater rigidity and strength than the substrata along which they shear. Perhaps, therefore, the ground in front of the ice was frozen and the thrust plates may therefore largely represent the permafrost zone existing at the time, and the thickness of each thrust sheet may measure the thickness of the carapace of frozen ground. The stripping and bulldozing effect was probably facilitated by the existence of weak clayey beds beneath the permafrost. Moreover, the piling from the base upwards may have been aided by a thawed surface (the active zone) on the frozen ground. This would have reduced frictional resistance to the movement of the heavy morainic pile as it was pushed out over the ground surface.

The late Illinoian moraine appears to have had a deep sag in the area now occupied by ponds between Menemsha and Squibnocket Point. Elements of the moraine are now lacking in this lowland, a fact that cannot be entirely explained by erosion by the early Wisconsin ice known to have passed through here. More likely the absence of the moraine is a result of a low point in the pre-late Illinoian surface.

The lack of porphyry boulders and of characteristic deformational structures in the Squibnocket area suggests that the southern margin of the late Illinoian moraine probably passed immediately north of here. Using this as a point of control, the lobate southern margin of the moraine has been drawn (fig. 1).

#### Early Wisconsin moraine

The next ice sheet to have reached Martha's Vineyard was probably early Wisconsin in age. The moraine of this ice probably correlates with the Ronkonkoma moraine of Long Island (Fuller, 1914). Many of the physiographic features produced by this ice are still evident on Martha's Vineyard and can be best appreciated on aerial photographs. In the western part of Martha's Vineyard, the ice was stopped by the late Illinoian moraine. North-east of Menemsha the ice lapped up against the north flank of the northernmost of the three erosional ridges, generally reaching no higher than the present

150-foot contour. Till deposited by this ice rarely exceeds 25 feet in thickness, and the ice left little in the way of an actual moraine.

One effect of the glaciation was the rumpling and thrusting up of the early Wisconsin proglacial deposits into ridges. These consisted of thick marine clay overlain by sand that had been deposited in Vineyard Sound, in the Menemsha sag, off the south coast, and in fact, in all low-lying places. Besides the resulting push ridges and thin till, another topographic effect of the glaciation was the erosion of the late Illinoian moraine and the removal of many of its more delicate features. For example, the thrust ridges were destroyed, and today we can see many of these ridges truncated at the margin of the early Wisconsin moraine.

The strip occupied by the early Wisconsin moraine along the northwest coast of the island is narrow, averaging about half a mile in width. However, where low cols or small transverse valleys had cut across the crest of the northern ridge of the late Illinoian moraine, the ice front was able to project south for short distances into the erosional valley beyond. The largest of these projecting tongues of ice was south of Lamberts Cove, where a bulbous lobe of ice reached about a mile south of the main front.

West of the main late Illinoian moraine the ice pushed through the Menemsha sag and then spread east and west. The ice also flowed south through Vineyard Sound, around the highlands of Gay Head, joining the ice pushing through the Menemsha sag. The highest land near Gay Head rose above the ice as low nunataks. Today three patches of high ground, including the higher part of Gay Head Cliff and the land immediately behind it, give evidence of having been ice free. The early Wisconsin ice may have reached as far south as Momans Land. Thin drift that may be early or late Wisconsin in age caps all but the highest ground of this small island.

In the eastern part of Martha's Vineyard the early Wisconsin ice was able to push south across the entire width of the late Illinoian moraine and to form a very broad lobe. The entire eastern half of Martha's Vineyard is the product of this lobe, as is most of Nantucket Island to the east. On Martha's Vineyard the moraine of this lobe is a belt of low hummocky ground, about 2 miles wide, that follows the northeastern shore. From many good exposures in cliffs it is clear that much of the moraine is made up of horizontally stratified sand with some interbedded gravel. This material is not noticeably different from the sand and gravel in the outwash plain that spreads from the foot of the moraine to the south shore of the island. The morainic sand may represent a superglacial, headward continuation of the outwash plain. However, the moraine stands higher than the outwash plain. This relationship is difficult to explain in terms of the topographic inversion to be expected in superglacial deposits (Kaye, 1960, p. 358). The manner in which the early Wisconsin moraine in eastern Martha's Vineyard was built is therefore a question that merits further study.

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| C. S. Denny<br>U. S. G. S.        | C. E. Miller<br>U. R. I.             | J. A. Sinnott<br>Sinnott Geol. Service  |
| W. J. Eden<br>N. R. C. Canada     | W. S. Motts<br>U. Mass.              | L. Sirkin<br>Adelphi                    |
| R. L. Farnsworth<br>Bates         | E. H. Muller<br>Syracuse             | H. T. U. Smith<br>U. Mass.              |
| R. F. Flint<br>Yale               | W. S. Newman<br>Queens               | Mrs. Smith                              |
| Mrs. Flint                        | D. R. Nichols<br>U. S. G. S.         | J. C. Tharin<br>Wesleyan                |
| J. L. Forsyth<br>Ohio G. S.       | R. L. Nichols<br>Tufts               | F. C. Ugolini<br>Rutgers                |
| D. S. Fullerton<br>Yale           | J. G. Ogden, III<br>Ohio Wesleyan U. | J. E. Upson<br>U. S. G. S.              |
| J. G. Fyles<br>G. S. Canada       | R. N. Oldale<br>U. S. G. S.          | F. J. E. Wagner<br>G. S. Canada         |
| N. R. Gadd<br>G. S. Canada        | J. P. Owens<br>U. S. G. S.           | C. Waldron<br>Boston Mus. of Sci.       |
| R. P. Goldthwait<br>Ohio State U. | W. N. Palmquist<br>U. S. G. S.       | A. L. Washburn<br>Yale                  |
| J. C. Goodlett<br>Johns Hopkins   | E. Penner<br>N. R. C. Canada         | Mrs. Washburn                           |
| D. J. Hagar<br>U. Mass.           | F. Pessl<br>U. S. G. S.              | G. W. White<br>U. Ill.                  |
| L. N. Hart<br>San Diego, Cal.     | S. J. Pollock<br>U. S. G. S.         | S. E. White<br>Ohio State U.            |
| Mrs. Hart                         | E. S. Deevey<br>Yale                 | W. E. Wilson<br>U. S. G. S.             |
| R. Z. Gore<br>U. S. G. S.         |                                      | C. Hickox<br>Colby                      |

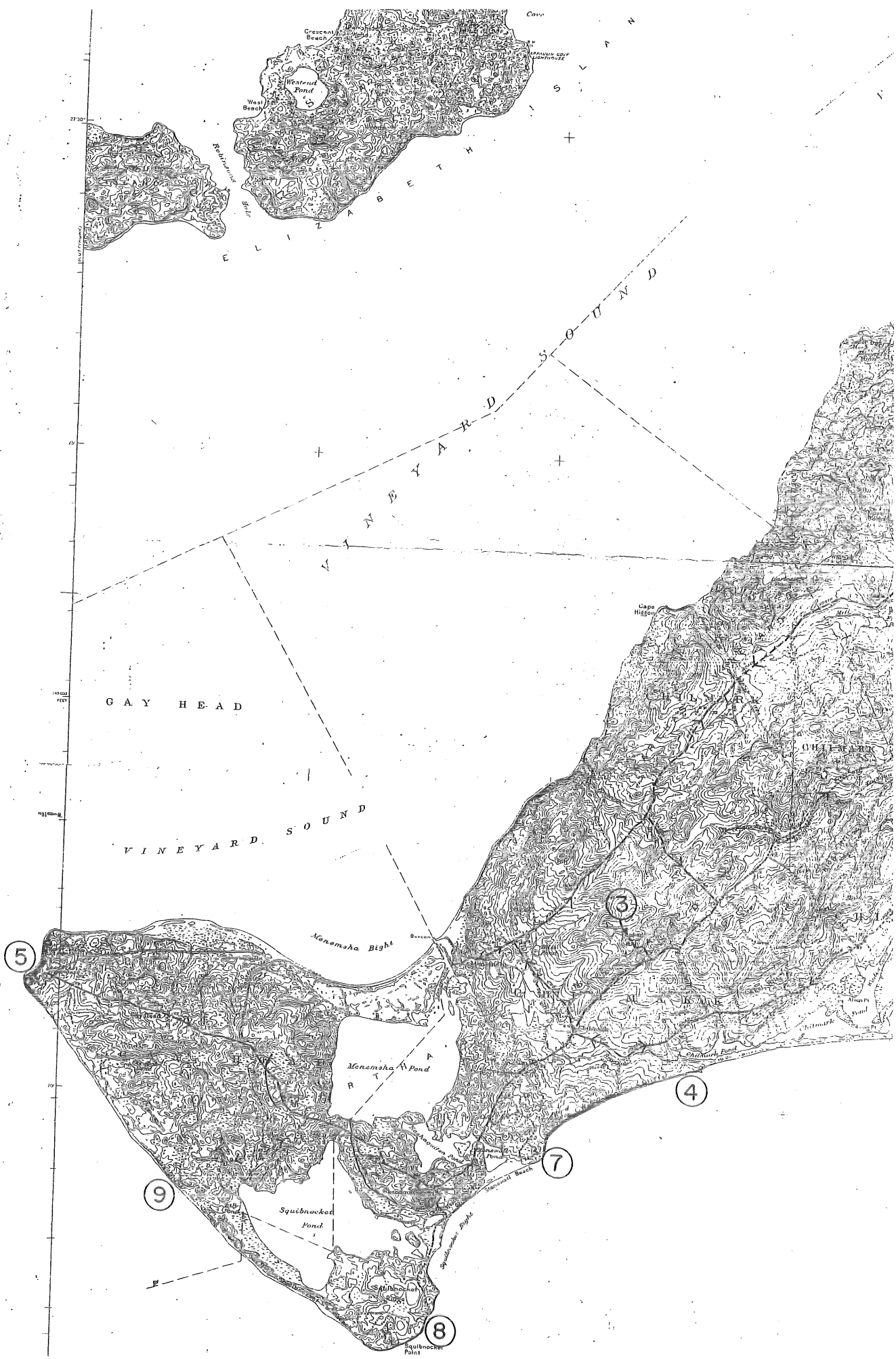




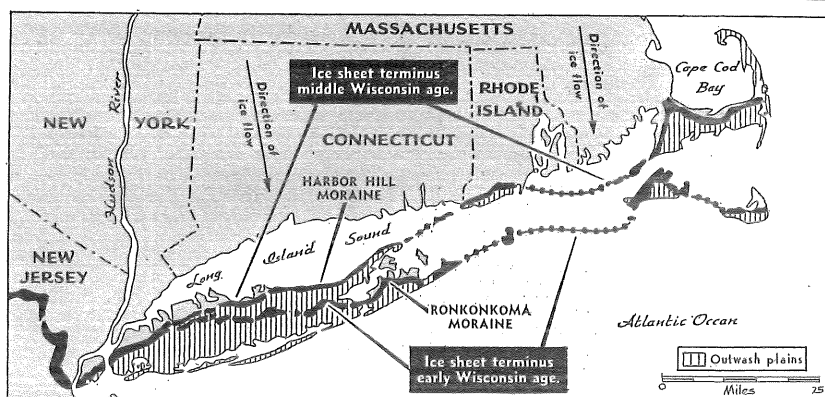
UNITED STATES  
DEPARTMENT OF THE INTERIOR  
GEOLOGICAL SURVEY

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## HOW GLACIERS FORMED FEATURES OF COASTLINE



During the most recent, or "Wisconsin," ice age, sheets of ice twice forced their way south until halted by warm sea air. When they melted, each time, they left ridges, or moraines, of crumpled ocean sediment and glacier-borne rock. Water from the melting ice spread sand and gravel, forming broad plains in front of the ice cliffs. The map, based on one prepared by the Geological Society of America, shows ice-created features such as Long Island and Cape Cod. In photograph members of Friends of the Pleistocene view one of the ice relics: Gay Head on Martha's Vineyard.

## SCIENCE

## ICE AGE RESTUDIED

## New Light Is Shed on Pleistocene By Radioactive Carbon 'Clock'

By WALTER SULLIVAN

Few residents of Long Island, Cape Cod and the nearby islands realize that the land on which they live was created by events so recent that they were incomplete when civilizations were evolving elsewhere.

The events were the four ice ages that, with the temperate intermissions separating them, are known as the Pleistocene, from the Greek meaning "most recent". Only with the dating method that uses radioactive carbon as a slow-ticking stopwatch has the timetable of the last of these ages been reconstructed.

Yet the most basic questions remain unanswered: What caused the ice ages? When did they begin? Are they over? It is quite possible that we are, in effect, still in the Pleistocene.

## Specialists Meet

Once a year a group of American and Canadian specialists, known as the Friends of the Pleistocene, meets somewhere to contemplate such problems. Last weekend they assembled on the island of Martha's Vineyard, one of the most puzzling children of the ice ages. Their host was Clifford A. Kaye of the United States Geological Survey, whose studies of the island have convinced him that, "by some curious coincidence," three great ice advances from the distant Arctic came to a halt on the island.

Two of these advances occurred during the Illinoian ice age and one during the Wisconsin ice age. The ages of the Pleistocene are named, consecutively, Nebraskan, Kansan, Illinoian, and Wisconsin for states where their debris was first recognized.

While the ice may have vanished entirely during the long intervals between these ages, during any one age it advanced and retreated several times. It was the great advances of the Early and Middle Wisconsin that finally shaped the island from Cape Cod to Long Island.

Each time the glacier stopped and melted, it left a ridge, or "terminal moraine," of sediment gravel and boulders that had been pushed before it or heaped on its forward slope. The moraine systems left by the Early and Middle Wisconsin ice sheets are strikingly parallel.

## Farthest Advance

The Early Wisconsin moraine represents the farthest advance and accounts for ridges on Nantucket, Martha's Vineyard, Block Island and down the center of Long Island from Montauk Point.

The Middle Wisconsin system extends from Cape Cod along the Elizabeth Islands to Point Judith, in Rhode Island, and along the coast of that state to Watch Hill. It then crosses Long Island Sound, rising briefly above the water as Fishers Island and then as Orient Point, on Long Island.

As the Harbor Hill Moraine, it flanks the entire North Shore of Long Island, crossing Queens, Brooklyn, Staten Island and New Jersey.

Thus there are no true hills, with bedrock cores, on Long Island. What appear to be ledges are, in fact, giant boulders almost buried in the moraine.

Southeast of the moraines on Cape Cod and the islands are broad "outwash plains" as flat as a Western prairie. Most of the post-World War II housing on Long Island has sprouted on such plains.

Both on Long Island and Martha's Vineyard these plains rise higher than the moraines.

At first it would seem highly improbable that three great ice advances would end at the same spot, as noted by Mr. Kaye. However, last weekend Dr. Richard P. Flint, professor of geology at Yale University, noted that the same thing apparently stopped the ice each time at the same place.

The chief factor, in this respect, was probably the climate-tempering influence of the ocean. The coastal terrain must also have played a role, although it varied slightly from one age to the next, since the ice itself changed the landscape. In the Middle West, where the land is flat and there is no sharp transition in climate, the ice advances were considerably more variable.

The timetable has been pinned down by measuring the extent of radioactive decay in carbon absorbed by biological specimens when they were still alive. The dates of trees crushed by the southward-flowing ice have been compared with the ages of specimens on top of the glacial debris.

It has been shown that the



last advance took some 6,000 years to cross Ohio, remaining thus extended only briefly. Some 14,000 years ago the ice had again withdrawn to the Great Lakes and from the mouth of the Connecticut River.

The schedule is less well known in the East because the ice pushed to the sea and specimens of wood are rare in the moraines. At the end of the Wisconsin there was a final advance that reached Fort Huron, north of Detroit. Mr. Kaye believes at that time, 12 to 13 thousand years ago, there may have been a similar advance to Martha's Vineyard, but his proposal has been met with some skepticism.

## Last Retreat

Dr. Flint, on the other hand, suspects that a vestigial ice sheet may have lingered in the White Mountains until comparatively recently, sending ice into neighboring areas perhaps less than 10,000 years ago.

The carbon dating method cannot reach back much further than the start of the last, or Wisconsin, ice age, some 70,000 years ago. Other dating methods, such as that dependent on the radioactive decay of potassium into argon, is good only for periods of much greater antiquity. For this reason the start of the Pleistocene, while popularly given as one million years ago, is still unknown.